Motion Picture Photomicrography with Electronic Flash

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Motion picture photography of very small objects by reflected light at high speed requires a large amount of radiant light flux per unit area. Difficulties are often experienced with temperature-sensitive subjects, such as biological specimens. The required light and heat, besides causing evaporation of liquid, can raise the temperature so that abnormal, unwanted conditions are present. The purpose of this paper is to point out several advantages of the xenon electronic flash system for closeup photography. The heating produced on the subject with xenon flash lamps is less than with continuous lamps for the same photographic result. The advantages of xenon strobe lighting are (1) there is no light on the subject when the motion picture shutter is closed between frames since the lamp is not on; (2) the electronic flash lamp need not operate before the camera is up to speed or after a specified time of operation; (3) the color temperature of a typical xenon lamp is 7000° K resulting in a greater blue-to-red ratio than with tungsten light.

Xenon Flash Lamps

Several small xenon-filled flash lamps can be used, such as, the FX-11 flash lamp (3.2-mm xenon gap at 1-atm pressure in 4-mm i.d. quartz tube) as shown in Fig. 1. The xenon lamp can serve as a small intense source of high-frequency pulse light for special projects, for example, direct-lighted microscopy. The lamp is flashed in synchronism with a motion picture camera by the use of a small reluctance generator which creates a small synchronizing voltage pulse when the camera sprocket teeth pass a permanent magnet. Exposure on each frame will be constant, regardless of the speed, if the energy per flash and lamp efficiency are constant.

A special circuit (Fig. 2), including a coupling transformer, is required to couple the FX-11 flash lamp to the EG&G Type 501 high-speed stroboscope. This transformer has a 5 to 1 stepdown ratio with the lamp on the *low-voltage* side. The normal output of the Type 501 unit is 8 kV which produces about 2000 V on the FX-11. Since this is insufficient to start the lamp, a starting pulse is obtained from the 8-kV terminal as shown in the attached wiring diagram. The transformer also serves to reduce the peak load current in the hydrogen thyratron.

The FX-11 has a practical limit of operation at 500 cps with a 1.0-sec operation time using a 0.01 μF capacitor as shown in Table I.

With greater energy than above, the lamp will be overheated and the electrodes may partially melt.

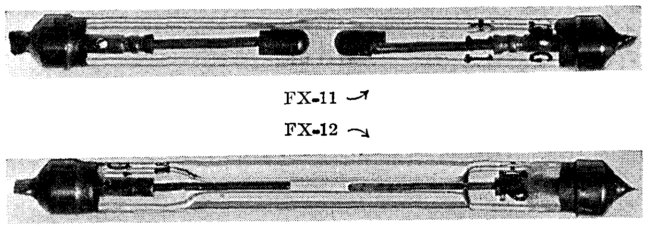

Fig. 1. Xenon flash lamps of small volume as used for high-speed motion picture photography. Over-all length about 7.5 cm (3 in.).

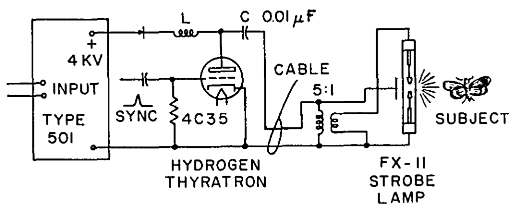

Fig. 2. EG&G Type 501 high-speed stroboscope circuit modified by an output transformer to drive a small volume flash lamp, such as the FX-11, FX-12, FX-33, etc.

Other flash lamps, for example, the FX-12, can be driven by the Type 501 using the circuit shown. The FX-12 has a 0.127-mm bore of 6.35-mm length which restrains the arc into a line shape that is particularly useful for optical systems involving a knife edge, such as schlieren. However, the FX-12 is *limited in operation by the intense heat from the arc*, which melts the small tungsten electrodes and vaporizes the quartz capillary walls if the operation is too long. It has been found that operation at 1000 flashes/sec with a capacitance of 0.01 μF is limited to a burst of about 0.1 of a second.

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Table I. Permissible Operating Time of the FX-11 Flash Lamp as a Function of Capacity and Frequency

Frequency (cps)	Cap. (μF)	Allowable operation, time (sec)
500	0.01	1.0
1000	0.01	0.5
2000	0.01	0.25
4000	0.01	0.12

Table II. Typical Light Output of Xenon Flash Lamps Operated from the EG&G High-Speed Stroboscope, Model 501, at 1000 Flashes Per Second[a]

Flash lamp type	Arc length (mm)	Arc diam (mm)	Light output in horizontal (cp-sec)		
			0.01 μF	0.02 μF	0.04 μF
FX-11[b]	3	4	0.22	0.48	1.4
FX-12[b]	6	1	0.48	0.78	2.25
FX-21[b]	13	4	0.14	0.4	1.1
FX-2	92[c]	1	0.12	0.28	0.57
FX-3 line source	92	1	0.12	0.28	0.57

[a] Horizontal lamp output measure perpendicular to long axis of lamp. Measured with a 935 phototube, 1.5-kV anode voltage, 400-Ω load resistor, with a window of 1.27-mm thick lantern slide glass. Flashtube to phototube distance 96.5 cm, calibrated with a standard xenon flashtube, General Electric Type FT-214.

[b] Requires a matching transformer, 5:1 voltage stepdown with half-cylindrical reflector, 6 mm × 6 mm, used as trigger electrode.

[c] Coiled into helix, 13 mm × 13 mm. Duration (1/3 peak) of lamps is about 1.5 μsec.

The lamp life will be shorter as the loading is increased, due to wall damage and electrode melting.

Xenon-filled gas lamps, with effective lengths of 13-mm, 25-mm, and 38-mm in Vycor or quartz of 4-mm i.d. (otherwise the same as the FX-11), can be operated from the EG&G Type 501 driver and transformer described above. Table II shows the average observed output for some of these lamps when operated with 1000-cycle bursts of 0.1-sec duration. The larger lamps can be loaded with more energy than the FX-11 or FX-12.

There are two xenon flash lamps that were designed to have a high electrical resistance. Therefore, these do not require the coupling transformer described before. These are the FX-2 (spiral lamp) and FX-3 (linear lamp) as shown in Fig. 3. Light output information is given in Table II for these lamps.

Closeup Photography; Light Requirements

A camera focused on a close subject must have its lens adjusted to a greater distance from the film than the focal length of the lens, F (see Fig. 4).

The relationship between the distance from the subject to the lens, f_1, and the distance from the lens to the image plane, f_2, from the simple-lens theory of optics is

$$\frac{1}{f_1} + \frac{1}{f_2} = \frac{1}{F}; \text{ and } M = \text{magnification} = f_2/f_1.$$

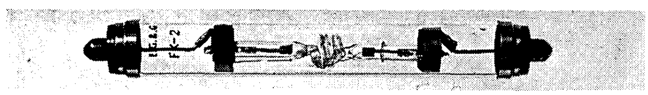
Notice that less light per unit area will arrive at the image plane when the camera is focused on a close object, since the effective aperture is smaller than when focused at infinity. This decrease of illumination is a function of magnification. The illumination will decrease by the factor $[(M + 1)^{-1}]^2$, where M is the linear magnification f_2/f_1. For example, should the magnification be 1 to 1, then the illumination at the emulsion will be 25% of the illumination of a distant subject if the illumination incident on the subject is the same in both cases. In other words, four times the exposure is required. The increase in exposure for the general case is equal to $(M + 1)^2$.

Thus, to obtain the same exposure on the film, regardless of distance from the lens to the subject, the radiation incident on the subject must be increased by the factor $(M + 1)^2$. As an example, let $M = 4$, then 25 times the illumination is required on the subject as compared to distant photography. Note that this factor increases very fast as the magnification is increased.

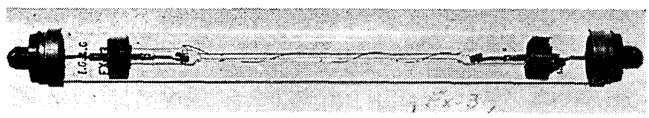
Guide Factor

The "guide factor" concept can be used for closeup photography, if the lamp and reflector are small compared to the dimensions of the system. For example, the FX-11 has a light emitting area of 3 mm × 4 mm, and its reflector can be a wrap-around aluminum sheet which allows the light to go in the desired direction. With such a combination, the square law is approximately applicable down to 1 cm or 2 cm from the lamp.

The time integral of the illumination at the subject, for a lamp with an output of Q beam-cp-sec, at a distance D from the lamp is $(IT) = (Q)/D^2$ ft-cp-sec.



FX-2



FX-3

Fig. 3. High resistance xenon flash lamps as used with the EG&G Type 501 high-speed stroboscope. Over-all length of FX-2, 16.5 cm (6.5 in.); of FX-3, 22 cm (8.75 in.).

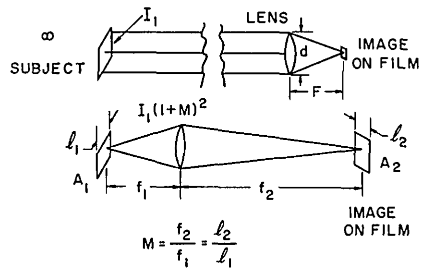


Fig. 4. Optical focus requirements for closeup photography.

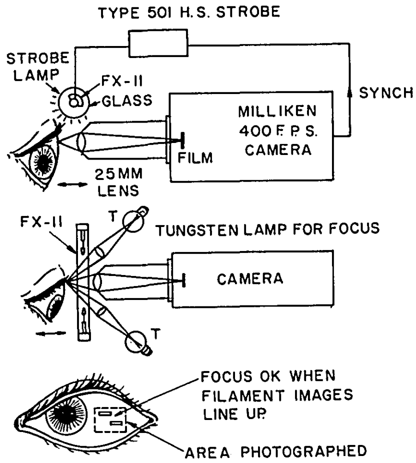


Fig. 5. Arrangement used to photograph the blood circulation in the human eye.

For adequate exposure of a film it must, therefore, satisfy a relation of the form

$$IT = \frac{A^2C}{S}(M+1)^2,$$

where

A = numerical aperture of the lens,
S = film speed, ASA,
C = a constant, 15–25 if D is in feet,
M = magnification.

Then the guide factor is

$$DA = \frac{1}{(M+1)}\sqrt{\frac{QS}{C}}.$$

Thus, the normal guide factor for large distances will be altered by the factor $(M+1)^{-1}$ if the image is magnified by the factor M.

Example

Light output from the FX-11 xenon flash lamp with a small wrap-around aluminum reflector and excited from 0.02 μF charged to 8 kV is,

Q = 0.50 beam-cp-sec (see Table II),
Let A = 5.6 and M = 4,
S = 100 ASA (Plus-X),
C = 15 (when D is in feet).

Then the guide factor DA = 0.37 aperture × feet or 4.5 aperture × inches or 9.4 aperture × cm and, therefore, D = 0.8 in. = 2 cm.

It was found that this resulted in a suitable negative.

more

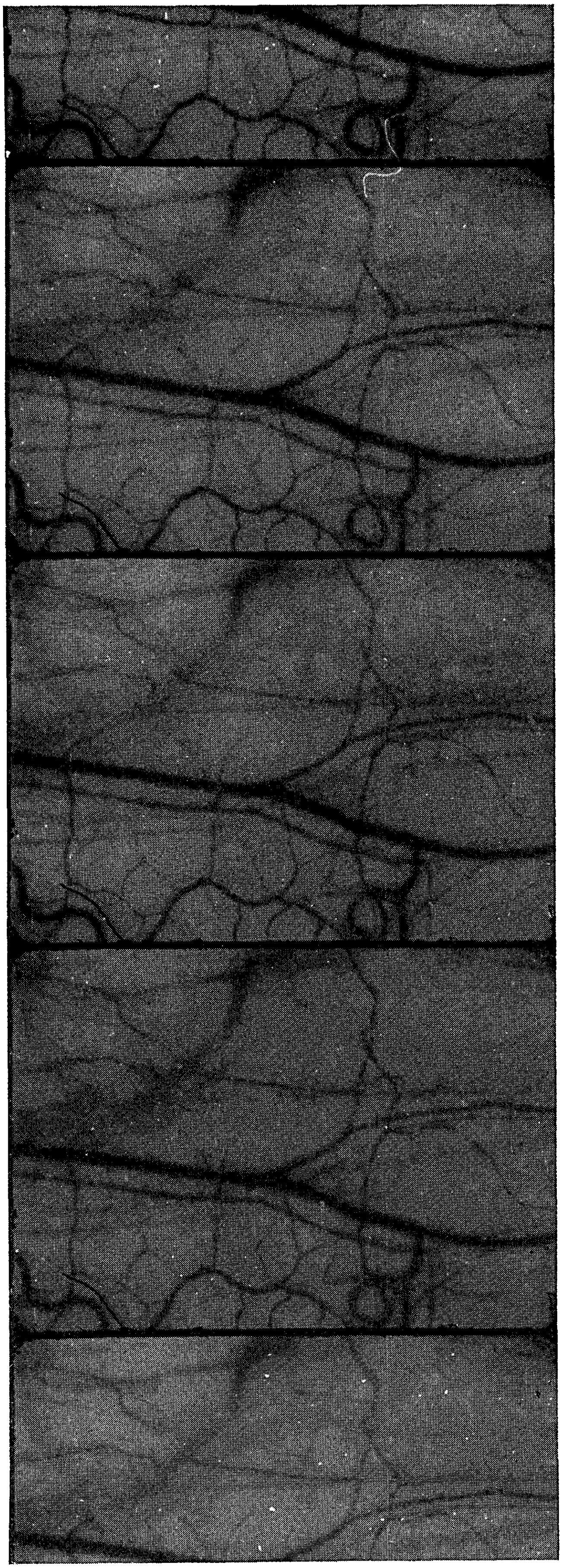


Fig. 6. Print from a 400 frames/sec negative of the blood circulation in a human eye.

Closeup Focus Adjustment

Anyone who has done closeup photography, even at 1 to 1, knows of the critical adjustment that must be held of the subject-to-lens distance. If a magnification of 10 is used, the problem becomes still more critical. Thus, in this range of $M = 1$ to $M = 10$, it is advisable to fix the lens-film distance at the value to produce an image at the desired magnification as calculated from the equation $f_2 = F(M + 1)$. Then the *entire camera with lens*, or the *subject*, is moved until the image is in focus. Here then is the problem—how to focus critically before making an exposure of a biological subject that cannot tolerate much light and which is always moving.

One method is illustrated in Fig. 5. Two small tungsten filaments at T are imaged on the subject so that the camera operator can tell when he is in focus. The small beams of light are at different angles, and it can be arranged that the spots will coincide when the distance is correct. It is necessary for the operator to adjust the two spots on a stationary subject, when the focus is accurately determined. Once he has made this adjustment then he will recognize the pattern, and when the two spots line up, the system is in focus.

The twin-light spot system resembles the system which was used for a camera range-setting device some years ago on the Kalart camera. David Donaldson of the Massachusetts General Hospital uses a similar system to focus a closeup stereo camera. In addition to focus adjustment, he also shows the size of the field covered by the camera.

For magnifications greater than 10, there is little space between the objective lens and the subject. Thus it is difficult to crowd in the lenses, and focus lamps as well as to observe the lighted spots on the subject. Special microscope objectives of small diameter may be helpful for such tasks.

One application of the spot-focus system has been made, as illustrated in Fig. 6 for Roe Wells of the Peter Bent Brigham Hospital, Boston. The object was to obtain information on the circulation of blood in a living human under normal conditions.

Two tungsten lamps, General Electric Type 43, were used as line sources. Two lenses of 2-cm focal length imaged the filaments of these two tungsten lamps in a single line, when the main 40-mm (or 25-mm) lens was accurately imaged on the film.

Figure 6 shows a sample of the photographs. On the motion picture screen, the motion of the blood in the large vein is just visible due to clumping of the red cells. The faster blood motion in the arteries is more difficult to see. There is some jitter in the motion picture which can be caused by camera motion, subject motion, or a combination of both. The results of the blood circulation shown are not of sufficient clarity in size or action. To answer all the questions that arise, more work needs to be done to improve the information content of the motion pictures.

Meeting Reports

SPIE 9th Annual Symposium, Miami Beach, 24–28 August 1964

Reported by I. J. Spiro, Aerospace Corporation

The cosponsor for the Society of Photo-optical Instrumentation Engineers' 9th Annual Symposium was the U. S. Air Force Eastern Test Range, therefore a number of papers dealt with missile and space photography.

TV vs Film for Data Acquisition. While many topics were covered, such as image intensification, automated data processing and reduction, satellite-borne photographic instrumentation, optical satellite tracking, and medical applications of photooptics, the one recurrent new concept considered was the marriage of optics and electronics in image recording. Many papers discussed the use of a vidicon or image orthicon as a sensor in a photographic system or on-board processing of film with subsequent telemetry readout to a ground station.

Because the angular coverage required is small (and small formats are used), long focal-length lenses are used conveniently. W. Manning *AFETR* described a system using a 2400-in. (61 m) focal length (including a Barlow lens) plus an 835-line image orthicon to obtain good photographs, from the ground, of missile stagings. In many instances, the choice of hardware was based not on the resolution capabilities of the lenses or films, but on those of the electronic imaging devices or the electromechanical readout units. When film is used, this often permits the use of slow film, such as S0243 (ASA 1.6), and longer exposure times, since the recording is not done necessarily in real time.

Several papers dealt with equipment proposed for photooptical recording of Mars during the forthcoming Mariner flights. Some of the interesting numbers quoted by Denton Allen *JPL* included: the expected coverage of the Mars surface will be 370 km^2 using a 30 cm. $f/8$ lens, and employing a vidicon with 200 TV scan lines and 200 bits/line. Since the telemetry rate is 8.33 bits/sec, it requires 8.33 h to send back a single frame. Allen also discussed the reliability aspects of the equipment. For example, since eight months are required for transit of the Mariner from Earth to Mars, 6,000 h will have elapsed before the TV system is commanded to function.

Subsequent papers described the electrophotooptical equipment used on the Tiros, Nimbus, Ranger, Apollo, Gemini, and the lunar orbiter satellites. Numerous questions and comments from the audience sought to bring out the facts about higher resolutions obtainable by using available optical systems and recording on film, but the discussion always returned to how data was to be returned to Earth. Thus, resolution was always limited by the electrooptical device, with the choice being between direct video (image orthicon or vidicon) transmission or on-board processing of film followed by telemetry readout, depending on the available time and bandwidth for transmission.

J. R. Brinkman *NASA* described the cameras, film, and TV to be used on Gemini and Apollo, and their design evolution. A list of experiments and test objectives was included.

Other TV Uses. The use of image orthicons in astronomy offers many advantages over telescopic observations, according to the paper by G. C. Barton *Dearborn Observatory*. Those who have spent cold hours in an astrodome could only envy his descriptions of "shirt sleeve" astronomical observations—watching the TV screen from a comfortable chair in a warm room. The resolutions obtainable are surprisingly good. The orthicon is particularly amenable to observations of variable stars. One

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