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The realm of high speed still photography is generally determined by the exposure times used or the picture repetition rate. Exposure times of leaf or diaphragm mechanical shutters in still cameras generally have a minimum time limit of around 1/500 second while modern focal plane shutters have achieved exposure times as short as 1/8,000 second. Generally, when photography with exposure times shorter than about 1/1000 second is contemplated it is classed as high speed work, and nearly always requires special techniques.

To arrest motion in a picture, either the shortest exposure possible is used or the camera is moved in synchronism with the subject (permitting the background to blur).

A formula for the maximun permissible exposure time is:

T = L/500 x V seconds

where L is the largest subject dimension to be recorded and V is the subject speed in the same units as L per second. For example, for a car moving at 68 m.p.h. (100 feet per second) the longest frame dimension, L, might be 50 feet. Thus

T = 50/500 x 100 or T = 1/1000 second - just on the limit for a normal shutter and no camera motion.

It should be noted that both V and L determine the exposure time - increasing V or decreasing L both demand shorter exposures. Many research subjects are both faster and smaller than a car.

Another method for determining exposure time is based on the concept of maximum allowable blur based on subject dimensions. A decision on what this dimension is at the subject may be influenced by several factors, each depending on user-defined criteria. These may include such items as total absence of blur at a given degree of magnification of the reproduction, size of smallest object within the subject of which useful detail needs to be recorded, etc. The formula, which also takes into account the diraction of subject motion is:

$$T = \frac{\text{size of smallest detail within subject}}{K \times \text{velocity of subject} \times \cos A}$$

where:
K is a quality constant, generally a number from 2-4.
A is angle between film plane and subject direction

Even an air rifle dart with a relatively slow speed (100 f.p.s.) but only an inch or so long within which it is desired to perceive detail as small as 1/200 inch, according to formula and practice, requires an exposure as short as 4 microseconds (1/250,000 second).

The two main methods of taking high speed still photographs are the use of a suitable high speed shutter system, and the use of a short duration flash while the shutter is open.

High speed shutter systems may be magneto-optical, electro- optical, or electronic units using image converter tubes.

High speed flash systems may utilize electronic flash discharges or sparks, or special discharges such as X-ray flashes for high speed radiography.

Magneto-optical Shutter

This utilizes the Faraday effect, i.e., the rotation of the plane of polarization of light passing through a transparent medium in a magnetic field.

To use the Faraday effect, a suitable medium in a magnetic coil is placed between crossed polarizers. Dense flint glass is generally used, since it shows considerable rotation of the plane of polarization for a given magnetic field and is convenient to handle. With no current in the coil, there is no magnetic field, no rotation of the plane of polarization occurs, and therefore no light is transmitted. When a suitable current is applied (often 1,000 amperes needing 10,000 volts) the plane of polarization is rotated until it agrees with the second polarizer, and the maximum light is transmitted. This current can be supplied by discharging a capacitor through the coil using a spark gap as a switch. The time of the discharge depends on the capacitor size, the voltage, and the number of turns in the coil. Exposure times down to 1 microsecond have been achieved.

Fig. 1
Fig. 2

In practice, a cylinder of the glass is placed in front of the lens and co-axially with it, together with the crossed polarizers, while the coil surrounds the cylinder.

The capacitor discharge may be controlled by a spark gap, the spark in turn is actuated by the subject itself (i.e., the shock wave or the flash from an explosion under examination).

Electro-Optical Shutter (Kerr Cell Shutter)

Kerr discovered that certain mediums in the presence of an electric field become bi-refringent, that is, light polarized in one plane has a different velocity in the medium to light polarized in a plane at right angles.

The usual Kerr cell shutter consists of a glass cell fitted with electrodes and filled with nitrobenzene, and placed between two polarizers. The whole assembly may be mounted in front of the camera lens or within the optical system. The first polarizer is set such that its polarizing plane is at 45 degrees to the cell plates and the electric field. Plane-polarized light entering the cell becomes circularly polarized, i.e. has two equal components each at 45 degrees to the original plane of polarization, 90 degrees to each other.

If a suitable voltage is applied to the plates (commonly near 20,000 volts), the phase difference produced by the differing velocities is such that on recombining at the second polarizer, the resultant plane-polarized beam is in agreement with this polarizer. With no voltage applied, no phase change occurs and the resultant beam is polarized such that no light is transmitted. Thus by switching the voltage on and off, a shutter is produced and exposure times down to a few thousandths of a microsecond (1/200,000,000 second) are possible.

Image Tubes

A variety of image tubes exist including image converters, orthicons, image-orthicons and image-intensifiers. Some of these can act as high speed shutters. Metals, particularly caesium, have the property that, in a suitable electric field, they emit electrons when irradiated with light. Also certain materials exist which emit light when bombarded by electrons (e.g. a television screen).

Fig. 3

A combination of these into one evacuated tube can produce an image converter. The light receiver is called a photo-cathode, and the light emitter is the screen. An image is focused on the photo-cathode by a lens. By applying suitable electric and magnetic fields the image can be faithfully reproduced on the screen, which in turn can be photographed by a recording camera. With no voltage applied to the tube, no picture is produced. Thus by turning the electric field on and off, the tube acts as a shutter. The voltages employed are usually between 6,000 and 25,000 volts. In some tubes, other electrodes (grid electrodes) are inserted that can control the tube with lower voltages (e.g. about 300 volts). Additionally, by suitable electrodes or magnetic coils, the image on the screen can be deflected, permitting other techniques.

The orthicon or iconoscope uses as the light receiving element a mosaic of photo-emissive elements. These store an image that is later scanned off by an electron beam. The image-orthicon has a photo-cathode, similar to the image converter. The electrons from the cathode strike a storage plate, which is again scanned later. An image-intensifier has a photo-cathode and a number of secondary-emissive surfaces, the electron beam passing from one to another in turn and being amplified before reaching either a screen or a storage plate. The gains possible to intensifiers, to date, are several thousandfold. An image converter can give some light intensification, e.g. at 25,000 volts, the light gain in a simple tube can be ten times.

Using image converters, exposures as short as fractions of 1 nanosecond have been achieved, and it is in these devices, particularly, that further advances will be made.

Fig 4.

Flash Photography

Electronic flash is now standard photographic equipment and is used not only when the available light is too weak but, with an open shutter, to arrest motion due to the shortness of the flash. Normal photographic electronic flashes have durations in the region of 100 to 1,000 microseconds (1/1000 to 1/10,000 second), which is too long for most high-speed subjects. But with special control circuits and capacitors, durations of a few microseconds or so are possible at photographically practical intensities.

As the exposure time gets shorter, the intensity of the light source must increase. The threshold of fast films has been measured at very short exposures to be 10 -3 (1/1000) meter- candle-second. This means, allowing for all the likely losses, that the subject illumination needs about 1 meter-candle-second or 1,000,000 lumens per square meter if it is to last for 1 microsecond. This would be the equivalent to a source of 1,000,000 candles at a distance of 1 meter.

The light sources capable of producing the high levels normally used in high speed photography include special electronic flash tubes, sparks and flash bombs. Sparks are produced by capacitor discharges across tungsten, steel or copper electrodes. They have been made with durations as short as a few nanoseconds. In the microsecond region, an improved spark gap has argon gas blown into it via a hole drilled along the axis of one electrode giving a longer gap for the same voltage, and thus more light output and a repeatable line source particularly suitable for schlieren photography.

A special type of spark is obtained by the explosion of thin metal wires. The wire is connected in series with a spark gap, wired in parallel with a bank of capacitors. These are charged to 15,000 to 60,000 volts. As the voltage rises, the spark gap breaks down, and the wire explosively vaporizes with a brilliant flash. Generally, however, explosions are more likely to be the events studied by high speed photography rather than light sources for other subjects.

High speed radiography units capable of submicrosecond exposure times are also available. A high vacuum X-ray tube is used for the purpose and is fed by 500,000 - 2,000,000 volt pulses at several thousand amps.

Flash bombs are tubes containing argon with a transparent end window and a small explosive charge at the opposite end. The explosive, when detonated, produces a luminous shock-wave in the gas, which produces a very high light level for periods from fractions of a microsecond up to many microseconds, depending on the geometrical structure.

The latest light source is the giant pulsed laser, giving extremely energetic flashes as short as 30 nanoseconds, concentrated in a very narrow spectral band and in a very parallel beam. It allows photography of the surfaces of other highly luminous surfaces as the subject light can be ignored by a narrow-band filter set to accept the laser light only.

With these various devices, high speed still pictures can be taken, using normal cameras with open shutters, always assuming that the background light level is not excessive.

Stroboscopic Operation

Using a still camera and a flashing light source (stroboscope) a subject can be photographed in a series of positions in one picture. Alternatively, by synchronizing the flashes with a subject with a repetitive motion, a succession of exposures can be superimposed of the subject in the same position.

The first method, with the flashes at regular intervals, is useful in studying movement sequences (e.g. athletes, dancers, etc.). The second method serves to study mechanical motion when it is not possible to produce enough light to take a single short-duration exposure or when it is desirable to check that the subject is truly repetitive. Stroboscopic flash units are available that operate at speeds up to many thousand flashes per second in some special cases, but more commonly operate at around 100 per second.

Lighting Technique

High speed photographs taken with electronic or optical shutters need a high level of illumination. Self-luminous subjects, such as flash discharges, explosions, etc., usually themselves provide sufficient illumination for high speed photographs. Non-luminous subjects, as well as those where the self-illumination is not to be recorded, must be lit separately. There the light source may be either a constant-intensity lamp, or a flash unit synchronized with the shutter.

Suitable constant-intensity sources are high pressure mercury vapor lamps. They are available in units up to 1,000 watts, with an arc length of about 1/2 inch. With an appropriate reflector, lighting levels up to 50,000 foot-candles can be achieved over an area 5 inches in diameter, 8 inches from the lamp.

Pulsed xenon arc lamps can reach light intensities ten times as high. The lamp usually burns at 50 watts, and is pulsed up to 10,000 watts for periods of 2-3 seconds.

In many cases the high instantaneous intensity of electronic flash or spark units makes them more suitable as high-speed light sources, even when an electronic or optical shutter is used. The light usually still lasts longer than the effective shutter opening, so that the latter controls the exposure time.

The light may be synchronized so as to provide the whole of the illumination, or merely the shadow illumination for self-luminous phenomena such as explosions. Alternatively, the synchronization may be timed in such a way as to exclude the light generated by the subject itself (e.g. explosion flash) and record only the movement of, for instance, the shock wave. This procedure is possible only with the aid of a high speed shutter. Such a shutter is also useful for eliminating other extraneous light. This may include the "tail" or "afterglow" of the high speed flash discharge itself; even a 2-microsecond discharge may take about 10 or more microseconds to die away completely. Such a comparatively low intensity light may, without a Kerr cell or similar shutter, record on the film owing to its duration, and blur or obscure the main subject.

Under certain conditions, quenching circuits may be used to shorten the duration of otherwise conventional flashes to generate durations as short as 20 microseconds (1/50,000 second) or less.

Synchronization

It is equally important not only to select the correct exposure time but also the correct exposure instant. Various techniques are possible and each new experiment may suggest or demand a new method.

When the event is self-luminous, a photo-electric trigger is most commonly used. It has the particular advantage that the trigger sensitivity level can be so adjusted that the exposure is not made until the subject is sufficiently bright to be recordable. For exposures at later instants, the same trigger may be used and electronic delay circuits inserted before a start signal is passed to the shutter.

Should the event and the camera both be capable of precise triggering, suitable signals can be generated from a common source, thus allowing any possible time arrangement to be selected. An important factor is to know the response time of all components. This becomes increasingly important as time intervals get shorter, reaching, eventually, conditions in which it is essential to make due allowance for the transit time of light. In one nanosecond (1/1,000,000,000 second) light only travels approximately one foot.

When the event is non-luminous, some light source is necessary. Especially at the shorter exposure times, this is some form of electrical discharge started by an electrical signal. The event must then be made to activate some electrical circuit and in a sense be made to take its own picture. For example, it can be arranged that a light beam to a photocell is interrupted or a projectile can break a wire or pierce a screen to give a signal. At lower speeds, relays can be used. Each subject usually suggests its own solution.

On supersonic projectiles or events initiated with a bang, an acoustic pick-up can be a very elegant device. For example, when photographing the action of guns and their projectiles, a pick-up to detect the initiating explosion or the projectile's shock wave can be used to trigger or start the light source and, when necessary, the shutter. Merely moving the pick-up along and below the line of flight can trigger exposures at different instants, by knowing the distance the pick-up was moved and comparing it with the change in the projectile's position in the pictures, the projectile's velocity can be readily given as a multiple of the speed of sound.

More elaborate arrangements are sometimes required, including, for example, coincidence circuits when two parts of an experiment are not precisely controllable. Normally, however, relatively straightforward optical, acoustic or mechanical synchronization devices will most often suffice.

Applications

High speed still cameras have been used in almost every field of scientific and industrial research, permitting the study of subjects whose changes are far too rapid for the unaided human eye to perceive. It is true that it is in weapon research that most advances have been made, but it is one of the bonuses of warlike activities that high speed photography has been developed to its currently very high capability and that it is now available for more peaceful applications.

It has been a valuable tool in the studies of motors, complex mechanical processes, medicine and the peaceful uses of atomic energy.

Exposure Effects

Exposures of short duration at high light intensities are subject to reciprocity failure. The effective sensitivity and contrast of most materials reaches a minimum with exposure times of about 10 microseconds. Below that the reciprocity law is usually valid, and the sensitivity of blue-sensitive emulsions remains independent of the exposure time. With optically (dye-) sensitized emulsions, a further loss of speed occurs around 1 microsecond exposure, and is believed to be due to the sensitizing dyes. Above 10 microseconds the speed and contrast increase, showing a maximum at 10,000 microseconds (1/100 second). This is generally the optimum exposure time from the point of view of speed for most materials.

With all short duration exposures the photographer must consider the effects of such short exposures particularly with respect to proper color reproduction when using color films. Incorrect color reproduction may be caused by differences in the reciprocity characteristics of the color layers or a change in the overall color output of the flash tube at different durations and/or illumination intensities.

Stroboscopic Flash

Electronic flashes can be fired repeatedly at high frequencies of hundreds to thousands of flashes per second. This method has various applications in high speed photography and motion study.

Technically a stroboscopic flash unit is based on an electronic flash discharge circuit, with certain modifications to permit a high flashing rate.

Historically, electronic flash lighting is almost as old as the negative-positive photographic process, since W.H. Fox Talbot used both about one hundred and fifty years ago. True, he covered only a small subject with his flash, but his writings prophetically describe the modern electrical equipment, as used in photography today.

Theory of the Single Flash

Light is produced when electrical energy stored in a charged condenser is discharged into the flash tube. During the discharge, the instantaneous power is very large (it may be as much as several million watts). However, the practical criterion is the light energy or exposure - i.e., the integral of the candlepower in candlas during the flash time in seconds.

Possibly the most important component in a flash unit, other than the flash lamp, is the condenser (or capacitor). This accounts for most of the weight, volume and cost, of the typical flash equipment. The capacitor is the energy storage component of the circuit. It can take in energy at a slow rate over a period of seconds or even minutes and then discharge it into the lamp in a fraction of a second at the required megawatt rate. Many of the advances in modern electronic flash equipment design have been concerned with improved capacitors, and further improvements are expected.

Electronic flash tubes are made in many sizes and forms, such as straight, U, or spiral shapes, as required for different applications. The gas pressure and electrode spacing are arranged so that the tube will not flash by itself in most applications. But when a triggering pulse is applied to an external electrode, internal ionization results, and the tube flashes.

Most of the flash tubes used today are filled with Xenon gas at a pressure of a fraction of an atmosphere. A series of 1 microsecond exposures of the arc in a typical tube made with a magneto-optic shutter shows that the arc starts as a narrow filament adjacent to the flash-tube wall on the side of the external triggering electrode. Soon, if the energy is sufficiently large, the arc filament enlarges to fill the entire flash tube.

Flash duration for a specific flash tube and circuit is best defined by plotting the light as a function of time. This shows the initial delay, the initial rise, the peak, and the decay of the light. From a practical standpoint, the actual duration is negligible, if the motion of the subject is effectively stopped. One common way to indicate duration is to define it as the time between the initial and final instants when the light is 1/2 of the peak intensity. This is the method in widest use but it also may be misleading in terms of actual action stopping ability of the flash. This is due to the fact that the light emitted by the flash at intensities below the 1/2 peak intensity actually is image forming light being only one stop away maximum exposure. A duration criterion based on of 1/8 peak to peak intensity would be more appropriate for high speed photography, but is not generally industrially accepted.

The output of a flash tube is the integral of the light against time. An approximate value can be obtained by taking the product of duration and peak light. If the candlepower of peak light is measured in candlas, and time in seconds, then the output will be in units of candle-power-seconds. The lumen-second output is greater by a factor of 4 pi or about 2.5, when the angular asymmetries of the flash tube are considered.

The electronic flash tube has a most unusual volt-ampere characteristic. At the start of the discharge, the resistance is infinite, since no current is flowing. Then, as current starts to flow, the resistance drops rapidly to a value of a few ohms for the main portion of the discharge. Finally the current again becomes zero, and the resistance infinite. During most of the flash, the volt-ampere curve is similar to that of a resistor and the circuit transients can be calculated approximately. Extrapolations to other lengths and diameters of flash tubes can be made as though the tube were a resistor of uniform conductivity. Then flash duration can be estimated from the equation:

Flash duration = RC/2 seconds

where:
C = capacitance in farads.
R = resistance in ohms

There is a large variety of electronic flash tubes available for the equipment designer to consider. For any specific case important factors are:

1) The shape of the tube - linear, spiral, U-shaped, etc. A concentrated lamp is more effective in a reflector, where control of the light is required.

Fig. 5

2) The efficiency at the required energy input. Each lamp has its maximum efficiency for a particular input. The designer should attempt to use the lamp at or near this maximum efficiency point, although in practice it is generally necessary to work at a lower value of efficiency to prevent the tube from overheating and to prolong its life.

3) The flash duration is a function of the tube and the circuit. If a specific duration is required, the design is usually fixed.

4) The voltage at which the flash is desired. Item (2) above needs to be reconsidered in terms of voltage, since the efficiency usually drops when the tube is used at low voltage.

There are many times when the most efficient flash tube cannot be used - particularly in stroboscopic work, at high frequency and high power - because of heat storage and heat conductivity problems.

Stroboscopic Photography

The name "stroboscopic" photography has come to mean multiple- flash exposed photographs. Some of the earliest exploiters of this general system are Muybridge, Marey, Cranz, Bull, etc., whose excellent pictures of horses, people, and bullets are still used as examples today. The first multi-exposure photographs were made on a single, moving plate using a slotted disc as a shutter or on separate plates with a series of cameras. The modern method is to use a succession of electronically produced flashes of light separated by accurately controlled intervals of time.

Two practical problems arise when an electronic flash tube is required to run as a stroboscopic source:

1) The flash tube becomes so hot that it does not function properly - e.g., it may miss occasional flashes, due to not starting properly.

2) The flash tube fails to de-ionize, thus preventing the capacitor from building up a charge for the subsequent flash. A low value continuous current flows in the flash tube. This condition is called "hold-over".

A hot tube may fail for several reasons: such as, puncture of the glass by the external sparking circuit, short circuiting of the triggering spark by the conduction of the hot glass, or actual collapse of the glass wall of the tube. Failure of a tube to de- ionize results in the continuous arc hold-over condition, where the capacitor charging current flows continuously into the lamp. A further difficulty may result when the tube self-flashes, as the capacitor recharges, due to the lowering of the hold-off voltage by residual ionization or temperature.

Any or several of the difficulties mentioned above are soon experienced when a flash tube is operated at a fast rate of flashing with high energy per flash.

Tubes of quartz are better than glass tubes at high power rate, since quartz has a higher melting temperature.

Several special circuits have been used to operate flash tubes at high rates. Examples are the series mercury-arc rectifier of the pool type, and the hydrogen thyratron, as used in radar modulators.

Mercury-pool Control Tube Circuit

The only new element added to the conventional electronic flash operating circuit is the mercury tube. This mercury tube is connected directly in series with the main discharge current path of the capacitor to the flash tube. Thus the mercury tube must be designed to handle adequately these high-valued peak currents. Immediately after a discharge, the mercury tube de-ionizes quickly, due to its low-pressure, and thereby prevents the previously mentioned hold-over current from flowing in the flash tube.

The mercury tube connected in series is also beneficial in starting a flash tube, because the igniting spark circuit from the mercury cathode goes directly between the two main electrodes. This circuit makes it possible to start flash tubes at very low voltages on the flash capacitor.

Operation at several thousand flashes per second with an input of 1 kilowatt are practical with the mercury-connectron tube.

Hydrogen-thyratron Tube

The thyratron serves as a switch to discharge the capacitor energy into the flash tube. This thyratron has a very quick de- ionization time, thus enabling the starting of the flash tube to be controlled at high frequency, far above rates where the frequency is limited by the slowly de-ionized high-pressure gas in the flash tube. High pressure (10 to 70 cm.) of xenon gas is required for efficient light production in the xenon flash tube.

Fig. 6

The circuit with the hydrogen thyratron is similar to that used in radar transmitters, except that the flash is replaced by a magnetron. In either application, the function is the same: namely, to pulse the lamp or magnetron with high-voltage and high-power energy. One of the properties of the hydrogen thyratron is the ability to supply large peak currents without change to the thyratron cathode.

A typical commercial high speed stroboscope using a hydrogen thyratron control tube operates at the following electrical conditions: lamp voltage, 8,000 volts; capacity, 0.01, 0.02 or 0.04 microfarads; frequency, 6,000 max. per second (0.01 microfarads); flash duration, 1 to 3 microseconds; energy per burst, 1,500 watt seconds (limit set by lamp heating).

The flash tube in such equipment must be designed with high resistance to reduce the peak-current requirement of the hydrogen thyratron. This is accomplished by the use of a small diameter (of the order of 1 mm.) and a long arc length (up to 4 inches). A small percentage of hydrogen gas is mixed with the xenon to reduce the afterglow in the discharge.

The stroboscopic light can also be synchronized with the motion of the film to produce framed pictures for projection. This is commonly done with 16mm. high-speed cameras. Magnetic pickups are used to trigger the flash lamp at the correct instants of time.

Multi-capacitor Circuits

There is another general type of multiflash equipment that is capable of great speed and flexibility, and which has utility when a limited number of photographs can be used. Each flash for this method is powered by a separate capacitor into either separate lamps or a common lamp. This circuit becomes bulky when a large number of flashes are desired, since each flash requires a separate storage system, as contrasted with a single storage capacitor discussed in the previous method. There is a frequency limit set by trigger-tube de-ionization for these last two circuits, even if one operation is used. Control air-gaps with three electrodes triggered by a time-delay element can be used.

Fig. 7

Applications

Stroboscopic flash has two main applications: analyzing a rapid movement by photographing successive phases on one film or plate, and arresting a rapid cyclic or other periodic movement for visual observation and photography.

Examples of the first kind are multiple photographs of dancers, hurdlers, etc.; the classical one was a shot of a golfer driving off. For this two flash tubes were used, each driven by a mercury pool tube. Each flash tube was operated from a 10 watt- second charge at 100 flashes per second. The power into each lamp was about one kilowatt. Normally, such a lamp will soon overheat unless it is artificially cooled, but this tube did not overheat, since the operation time was only half a second.

A bullet in flight was taken by multiflash photography with a xenon tube operated at 6,000 flashes per second, with about half watt second per flash for a brief period. The bullet was photographed against a background of reflecting material to reflect the light of the lamp, which was mounted directly above the camera lens. A strip of 35mm film was used. The flashing frequency was controlled by an electronic oscillator. There was no blur on the continuously moving film, since the exposure was only about one microsecond in which time neither the bullet nor the film had moved appreciably. In this method there is no need for synchronization between the film motion and the frequency of flash, it is only necessary to move the film so fast that the photographs do not pile up on top of each other.

For the second type of application, the flashing frequency is matched to the frequency of the cycle of the movement. As a simple instance, a machine component rotating at 5000 revolutions per minute may be illuminated by one or more stroboscopic flashes flashing at 5000 flashes per minute. If both rates are accurately matched the flash will illuminate the same phase of the movement every time and the component will appear stationary. It can then be observed or photographed in that way - a useful procedure in industrial photography where it is not practicable to stop a machine for picture taking.

By slightly shifting the phase of the flash between successive exposures, a whole picture series of complicated movement cycles is obtained permitting the study of motion that would be impossible to observe in any other way.

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Fig. 1 Picture of ELECTRO-MAGNETIC (FARADAY) SHUTTER.
Fig. 2 Picture of ELECTRO-OPTICAL SHUTTER (KERR CELL).
Fig. 3 Picture of HOLST IMAGE CONVERTER. The main elements are: A, subject; B, lens; C, semi-transparent photo- cathode; D, electron stream; E, viewing screen observed by eye. As the image of the subject is formed on the photo-cathode the latter emits electrons. These travel through the evacuated tube and excite the fluorescent screen to produce an image there.
Fig. 4 Picture of IMAGE CONVERTER SET-UP. This system is used for single photographs of non-luminous objects that are illuminated by a flash tube. The image converter shutter is synchronized with the peak of the flash.
Fig. 5 Picture of MERCURY POOL CONTROL CIRCUIT. The mercury tube in series with the main flash tube sharply starts and interrupts the current for the flash, and handles high power rates. Permits several thousand flashes per second. C, main capacitor.
Fig. 6 Picture of HYDROGEN THYRATRON PULSING CIRCUIT. The quick deionization time of the thratron tube permits higher flashing frequencies, C, main capacitor, T, thyratron tube.
Fig. 7 Picture of MULTI-CAPACITOR CIRCUIT. A series of separate capacitors are discharged in turn into the same flash tube. Unit is flexible but bulky. C, power capacitors; G, control gaps; T, time delay units for triggering the successive flashes.