REPRINTED FROM
The GENERAL RADIO
EXPERIMENTER

VOL. VII. No. 7 DECEMBER, 1932

ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

THE STROBOSCOPE

THE stroboscope consists fundamentally of a device which permits intermittent observations, either visual or photographic, of a moving object in such a manner as to reduce the speed of, or stop, the motion.

THE quickness of the hand deceives the eye. But the eye knows a trick or two, and, aided by ingenious mechanisms, it is not deceived by the gyrations of machinery at far higher speeds than the trickster's hand achieves. Hence the stroboscope, which is not new, and the Edgerton* stroboscope, which is.

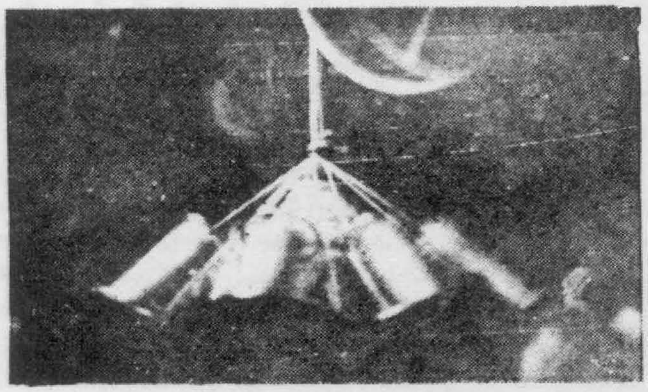
Stroboscopes and their applications are described herewith. The Edgerton stroboscope on page 5.

The slow-motion picture is a familiar example of the interesting and profitable information which may be derived from a leisurely study of events which necessarily take place at a high rate of speed. The tennis player cannot slow the championship stroke to accommodate the laggard eye of the novice, but the camera can, and the motion picture camera is a stroboscope, but not all stroboscopes are cameras.

The camera shutter, operating at high speed, chops up the action into a number of small elements, so short that movement is not apparent in any one. The film can then be projected at normal speed with results that are instructive, or even backward with results that may be amusing. The function of the shutter is to exclude light from the film except for brief flashes. It seems reasonable that the same result can be obtained by shutting off the light from the object, except for brief flashes. This is the nature of the second style of stroboscope, of which the Edgerton type is the outstanding example. Obviously this type of stroboscope is well adapted for visual observations. Photography must still be used, if a non-repeated event is viewed, to store the elementary views and to release them later at a rate that the eye and mind can follow.

Consider, however, an indefatigable tennis player who repeats his stroke,

*The Edgerton Stroboscope is a development of Prof. Harold E. Edgerton, Massachusetts Institute of Technology.



Courtesy of Simplex Wire and Cable Co.

THE STROBOSCOPE STOPS MOTION

An insulation winder operating at normal speed. The carriage carrying the spools was revolving 180 r.p.m., the spools were also turning. A lower carriage turns in the opposite direction. The picture conveys an imperfect idea of the distinctness with which the operation of such machines can be observed visually. The threads and feeding mechanisms can be followed perfectly. The exposure lasted about one second, yet there is no blurring, testifying to the accuracy of flashing (unretouched)

identically, one thousand times a minute in a darkened room. If the light be flashed on him at a constant rate, exactly equal to his stroking rate, he will appear as though motionless under continuous illumination. If the flash speed be slightly slower than his stroking rate, his arm will be illuminated a little farther along in the stroke each time the light flashes and, as the eye retains the image between flashes, the madly stroking player will seem leisurely, and a single stroke can be spread over a minute if desired.

Humans, tennis playing or otherwise, cannot repeat uniform cycles at any such speed. Machines can, and wherever complicated machines are designed, built, or used, the ability to watch their operation in slow motion without photography is a boon.

The stroboscope permits stopping the motion of the machine (visually) for examination of machine or product at any part of its operating cycle while the grommets flow into the hoppers at undiminished speed. Or, perhaps, a squeaking clutch, a vibrating shaft, or a chattering valve spring stands between a new model and a waiting public—which will not wait long. A slow motion study will show the trouble, or the primary motion may be stopped and the vibrating member made as conspicuous as a mosquito-brushing hand at formal guard mount.

Sometimes the transient movement or vibration takes place at too high a speed for the eye even with the primary motion stopped. Here photography is resorted to for a second slowing down of the transient.

A little consideration of what is being done by the stroboscope is sufficient to set up the requirements of a satisfactory one.

An accurate means of timing the flash and a prompt and accurate response to the flash control are essential, otherwise the object will be viewed at irregular intervals, and vibrations not present in the object viewed will be introduced.

The flash must be of extremely short duration. Otherwise appreciable motion will take place during illumination, and blurring of detail will result.

The light must be brilliant. Otherwise the room must be made entirely dark, and details will not be seen clearly.

Stroboscope Arithmetic

Suppose that the object to be observed is executing uniformly R complete cycles of motion in unit time. Suppose further that the object is either viewed through a shutter opening for F brief, uniformly timed intervals, or is illuminated by F uniform instantaneous flashes of light in unit time. Then, if

$$R = nF \qquad (1)$$

where n is an integral number, it will be evident that each point of the object will be in exactly the same position in its cycle of motion at each observation, resulting in what we shall designate as a condition of "perfect" synchronism. Accordingly, all apparent motion of the body will be arrested, so that it will appear to be stationary at some particular phase in its cycle of motion, provided that the opening of the shutter or the flash of the lamp is of extremely short duration. If this interval of observation is of sufficient duration, the moving object, even when viewed stroboscopically, will appear blurred in outline, since each point of the body executes a perceptible amount of motion during the interval of observation.

It is further evident that the phase of the observed position of the object in its cycle of motion may be controlled at will merely by shifting the phase of the synchronous shutter or light flash with respect to the motion.

The special case of perfect synchronism, in which the frequency of motion and of observation are identical, is known as "fundamental" synchronism.

If n is greater than 1, the object will be observed only at every nth cycle of motion, so that the integrated illumination is reduced to the fractional amount $1/n$ times the illumination at fundamental synchronism.

Although any condition of perfect synchronism will completely arrest the motion, it is obviously desirable to work at the condition of fundamental synchronism.

If, on the other hand,

$$F = kR \qquad (2)$$

where k is any integral number greater than 1, then each point of the object will be visible k times per cycle of motion and will, accordingly, be observed successively at k points equally spaced, in time, throughout the cycle of motion. Such a condition, which is known as "partial" synchronism, while apparently arresting the motion of the object, is not, in general, satisfactory for visual stroboscopic observations. For example, a rotating disc having one radial line is seen as a disc with k radial lines.

A more distinct image is obtained at partial synchronism if the body is composed of mk identical parts equally spaced, in time, throughout the cycle of motion, *e.g.*, by a wheel having $P = mk$ spokes. Further, it can readily be shown that such a wheel will appear as a stationary wheel having P spokes whenever

$$PR = nF \qquad (3)$$

On the other hand, the wheel having P spokes will appear as a stationary wheel having nP spokes whenever

$$nPR = F \qquad (4)$$

Reference to equation (3) shows that there are, theoretically, an infinite number of values of R or of F for which a wheel of P spokes will be seen as a stationary wheel of P spokes. The larger the value of P, the greater will be the number of these partial synchronisms which occur within a given range of values of R or F. These facts are of importance in using the stroboscope to determine the frequency or speed of cyclic motions.

We have so far analyzed the fundamental laws of the stroboscope for conditions of exact synchronism, either partial or perfect. Consider now the case where the cyclic frequency of motion is slightly greater than an integral multiple of the frequency of observation—

$$R = nF + S \qquad (5)$$

where S is small compared to R. This means that the moving object will execute slightly more than n cycles of motion during the interval between observations so that the phase at which it is seen stroboscopically will continually advance. The object will therefore appear to move at a slow cyclic frequency of

$$S = R - nF \qquad (5a)$$

cycles in unit time and to travel in the same direction as the object is actually moving.

Conversely, if the cyclic frequency is slightly less than an integral multiple of the frequency of observation the phase at which the object is seen stroboscopically will continually recede so that the object will appear to move at a slow cyclic frequency in a direction opposite to the true motion:

$$S = nF - R \qquad (6)$$

The slow stroboscopic motion which can be obtained in this manner, and which can be adjusted to become a very small fraction of the true speed, makes the stroboscope extremely valuable in watching the cycle of motion of machinery running at speeds too high to be followed with the unaided eye.

The frequency of stroboscopic motion, S, may be made as slow as desired. On the other hand if S is increased above a certain limit the observed motion becomes intermittent and less satisfactory for purposes of visual study.

SOME STROBOSCOPE APPLICATIONS

DEVELOPMENT

An automobile manufacturer was troubled by a slight crank-shaft vibration in a new model, far too small to be observed in the rapidly revolving shaft. The stroboscope stopped the shaft motion and left the vibration which was seen and measured, although amounting to but 0.001 inch.

Automobile radio installations use a vibrating reed interruptor to obtain high voltage from the storage battery. The efficiency of these devices has been greatly increased by stroboscopic studies, revealing bending of the reed, chattering of the contacts, etc.

Other development applications: study of hunting in machinery, torsion in shafts, shaft whip, clutch slip, engagement of sprockets, cam action, behavior of loudspeakers.

PRODUCT CONTROL

The artistic effect of Andy Gump may be seriously impaired if Uncle Bim's necktie trespasses on his collar or on his chin. The proper color register with high-speed presses—for in modern plants the paper speed may approach a mile a minute—is a troublesome task. At present the register cannot be examined until the paper comes off the press, and much paper is wasted in the process of correcting the register. With the stroboscope, the sheet may be examined as though stationary while the paper rushes past. When the operator adjusts his register Uncle Bim's necktie slides gently into place and much paper and time are saved. Similarly the product of other high-speed machines can be examined and imperfections quickly spotted, and perhaps corrected, without stopping the machine.

PLANT MAINTENANCE

When machinery fails, operatives are thrown out of employment, customers wait, or trade elsewhere. Observed with the stroboscope, the machine can be followed through its cycle and the faltering element quickly spotted. Typical applications: slipping belt drives, clutches, chattering gears, hunting motors, chattering relays.

SALES

Vacuum cleaners, automobile tires, sewing machines—many consumer and industrial products operate at too high speeds for the unaided eye to judge their performance. The stroboscope is an impressive sales tool. Used at shows, exhibitions, salesmen's meetings it commands attention — drives home sales points dramatically.

POWER ENGINEERING

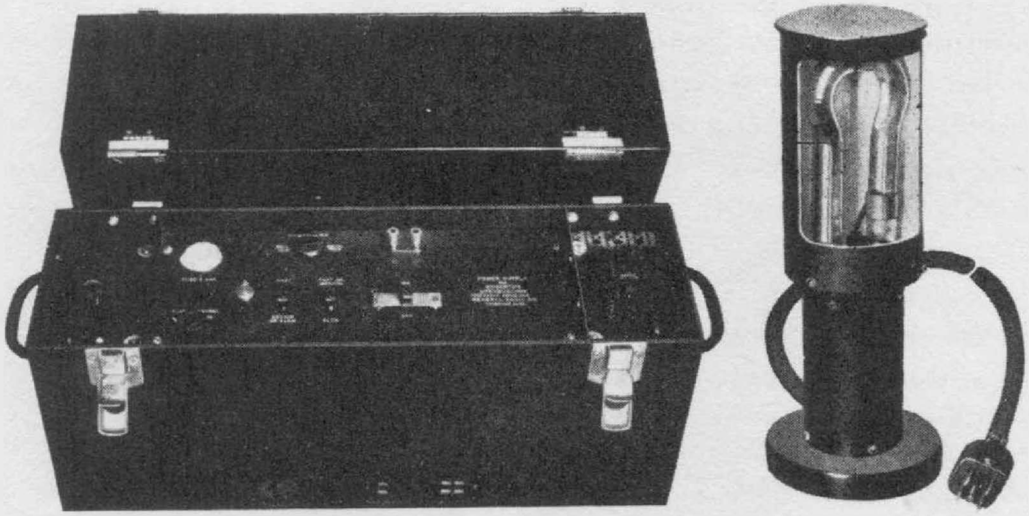
The behavior of machines and governors under sudden fluctuations in load can be observed. The stroboscope yields information as to hunting, speed of governor response, vibration, and starting characteristics. The phase of the light does not shift even with wide changes in frequency or voltage, and the supply line voltage can be used as a phase reference in making such studies on alternating-current machines.

EDUCATION

Modern education, particularly modern engineering education, explores in some degree all of the applications mentioned above, but the application of the stroboscope in the educational field only begins with them. Principles can be illustrated, phenomena observed, in the fields of mechanics, electricity, sound, and light.

THE EDGERTON STROBOSCOPE

(GENERAL RADIO TYPE 548-A)



THE EDGERTON STROBOSCOPE
Space is provided in the cover for the lamp

THE essential stroboscope requirement of a short and brilliant light flash is met in the Edgerton stroboscope by a high-intensity mercury arc lasting but five microseconds—sufficient time for an object traveling a mile per minute to move only 0.005 inch. The flash speed can be controlled accurately over the entire range ordinarily required and fundamental synchronism can be obtained up to speeds of 10,000 r.p.m.

This short, brilliant flash is obtained by discharging a capacitor across a mercury-arc tube which has the form of an inverted "U" with internal electrodes of mercury, anode and cathode, at its lower extremities.

Provision is made in the Edgerton stroboscope for flashing the light in exact synchronism with the closing of a pair of electrical contacts, by the 60-cycle supply mains (60 flashes per second), or by any external source of alternating current. The maximum speed of operation of the present equipment, which is limited by the regulation of the rectifier unit, is in excess of 150 flashes per second, so that fundamental synchronism may be obtained at all speeds from zero up to at least 10,000 r.p.m., while perfect synchronism of the second or third order will double or treble this limit.

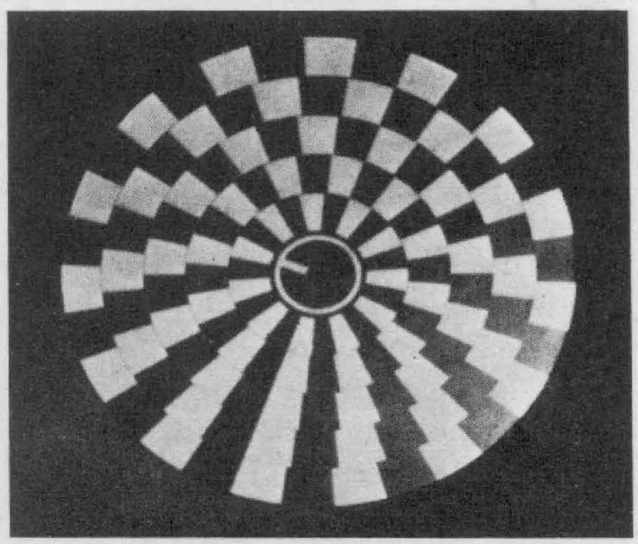
All parts of the stroboscope equipment, except the lamp and the tripping contacts, are built into a metal cabinet which constitutes the TYPE 548-A Power Supply. This is energized directly from 110-volt, 60-cycle mains and consumes a maximum power of about 0.25 kilowatt. Only three adjustable controls are required: the size of the lamp capacitor, a rheostat for controlling the intensity of the flashing voltage, and an adjustable speed contactor (if used). The cover of the cabinet is designed to store the detachable mercury-arc lamp, which is mounted in a suitable bakelite housing, and a synchronous-motor friction-driven vari-

TIMING THE FLASH

Precise and controllable timing of the flash is the essence of the stroboscope. The contactor seen consists of a constant speed synchronous motor driving a revolving commutator which makes a contact once each revolution. The flash speed is varied by sliding the driven wheel along the rack. This timer is generally used for viewing machinery in slow moton, studying vibration, hunting, relay action, etc. The position in the cycle of motion at which the flash occurs is adjusted by revolving the contactor head. Effective demonstration — a newspaper clipping on the end of a shaft can be stopped by the light and turned to the proper position for reading by the phaser. Newsprint is easily read while revolving 1800 turns a minute

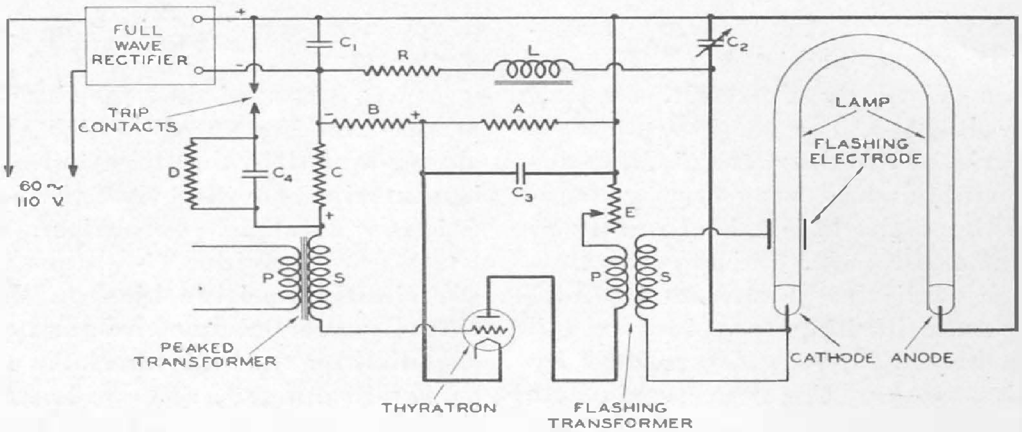
able-speed contactor, TYPE 549-A, which is optional and sold separately. This contactor has a continuously adjustable range of operation from 5 to 30 flashes per second. While this gives fundamental synchronism for 300 to 1800 r.p.m., it may, of course, be used at perfect synchronisms for higher speeds. For any adjustment, the timing of this contactor is very precise and dependent only upon the frequency precision of the supply mains. The phase of the contacts may be adjusted at will by rotating the head of the contactor. If desired, the contactor mechanism may be detached from the motor drive and used, in the manner of a tachometer, against any centered, rotating shaft. This insures, of course, that the contacts will be operated in exact synchronism with the rotation of the shaft.

The method by which the short, brilliant flash is obtained in the Edgerton stroboscope may be analyzed with reference to the schematic wiring diagram.



FOR SPEED MEASUREMENT

The disc was photographed under stroboscopic light at 1800 r.p.m. (fundamental synchronism). At this speed, all of the rings of squares are stopped. It will be observed that each ring has a different number of squares. As the motor speed changes (flash speed constant) different rows of squares will be stopped. A relation exists between the flash speed and motor speed which is signified by the number of squares in the stationary row (see stroboscope arithmetic, page 3)



Wiring diagram of TYPE 548-A Edgerton Stroboscope

A full-wave thermionic rectifier containing the customary elements is used to feed energy into a reservoir capacitor C_1. The energy in the reservoir capacitor is subsequently fed into the lamp capacitor C_2 which, in turn, discharges directly through the mercury-arc lamp whenever the latter is flashed. The resistor R and the choke L permit the capacitor C_2 to be instantaneously discharged completely through the lamp so that the voltage on C_2 may be reduced momentarily to zero or slightly reversed, irrespective of the voltage which may exist upon the reservoir capacitor C_1. This feature permits the lamp to become extinguished immediately after it is flashed. The time constant of the discharge circuit of C_2 across the anode and cathode of the lamp (shown in heavy lines) is what determines, primarily, the duration of the light impulse, that is, the exposure of the lamp. If the lamp becomes overheated, however, the exposure increases somewhat.

The lamp capacitor is charged to a peak potential of about 800 volts so that the discharge current, if it were uniform throughout the interval of exposure, would approximate 300 amperes. This current is not uniform, however, but reaches a peak value in excess of 1000 amperes. Due to the regulation of the rectifier, this lamp capacitor must be reduced in capacity as the frequency of flashing is increased.

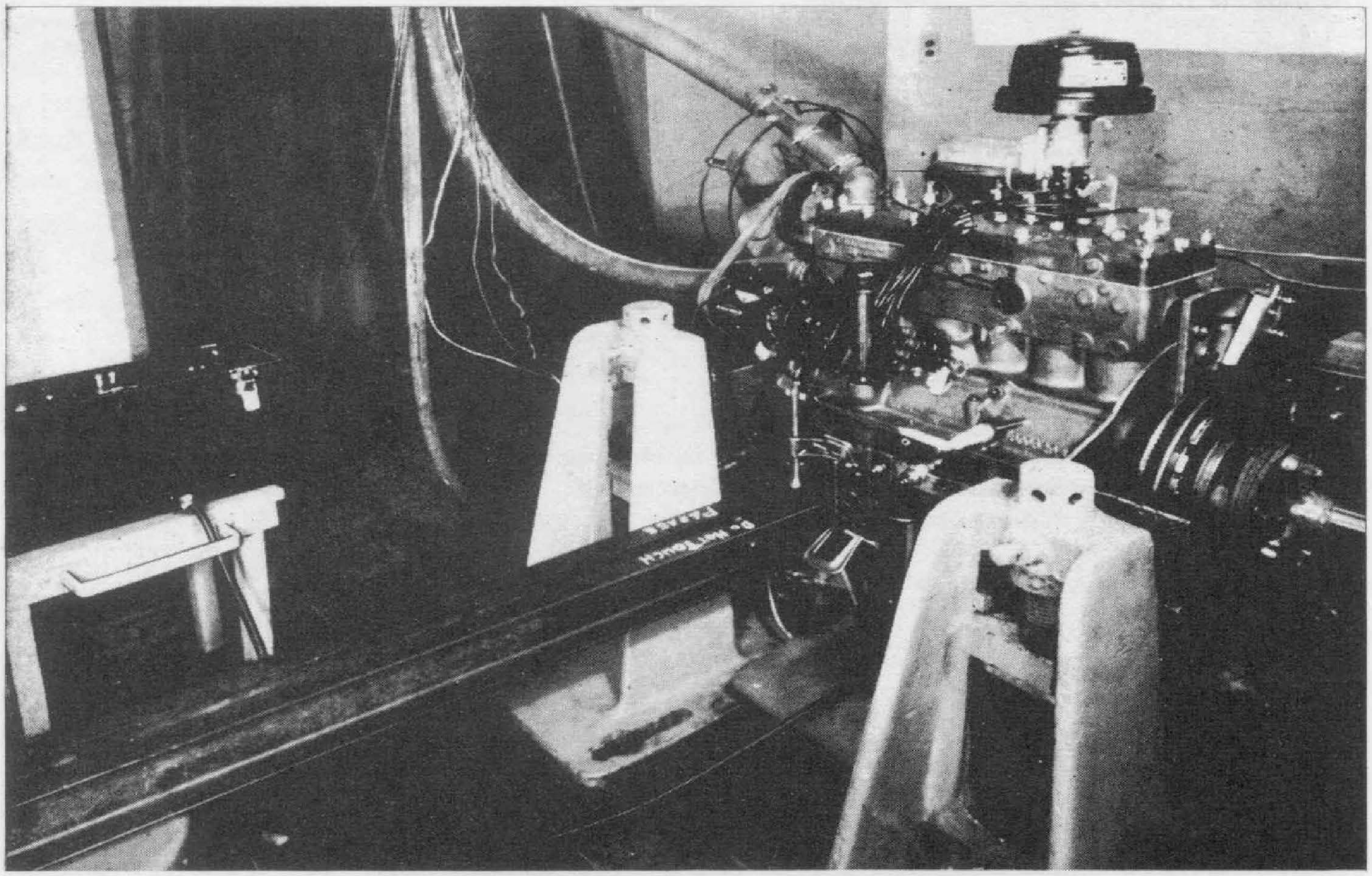
The voltage supplied across the anode and cathode of the lamp is not sufficient, of itself, to break down or flash the lamp. An auxiliary "flashing voltage" must be used for striking the arc. For this purpose a high-tension surge of several thousand volts is applied between the cathode and a flashing electrode which consists of an external band of metal around the tube in the vicinity of the cathode. The flashing potential, which is obtained through a high-ratio air-core transformer, mounted for convenience in the base of the lamp, creates an electrostatic field of sufficient intensity to ionize the gas in the vicinity of the cathode and thus aids in starting the arc between the anode and cathode of the lamp.

In order to obtain sudden surges of current through the primary of the flashing transformer, some form of timing relay must be used. A most satisfactory relay for this purpose is to be found in the mercury-vapor triode known as the TYPE FG-17 Thyratron in which the anode-cathode circuit, while normally open, becomes essentially short-circuited whenever the grid is subjected to a suitable stimulus. The timing mechanism to stimulate the grid so as to trip the thyratron, and hence flash the lamp, may consist of the closing of a pair of electrical contacts or be each positive peak of an alternating current of suitable frequency.

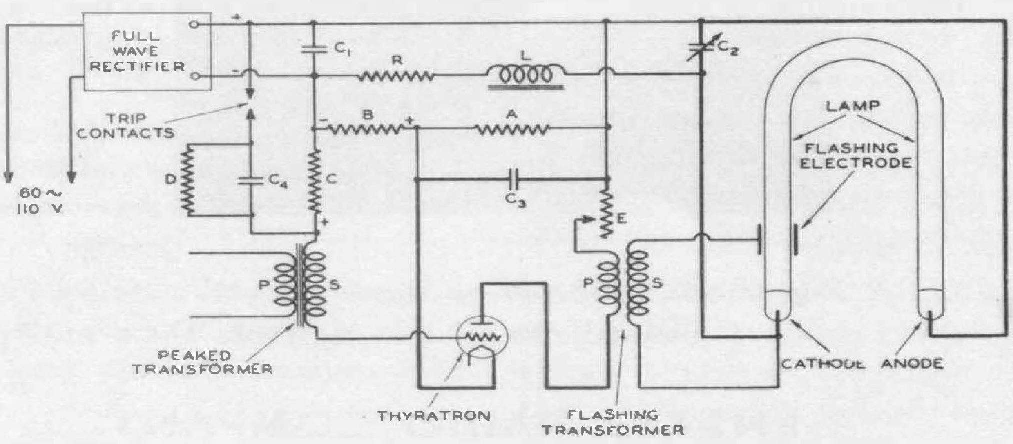
The two resistors A and B constitute a voltage divider across the high-voltage rectifier, A being several times larger than B. The grid of the thyratron is given a sufficient negative bias by means of the voltage drop across B to maintain the anode circuit open. At the same time, the condenser C_3 is normally charged to nearly the full potential of the rectifier.

Whenever the thyratron is tripped (see next page) the energy stored in C_3 discharges through the low-resistance circuit (shown in heavy lines) comprising the thyratron anode-cathode

USING THE EDGERTON STROBOSCOPE IN AUTOMOTIVE RESEARCH



Chrysler engineers measure crankshaft whip and vibration with the Edgerton Stroboscope. For an interesting description of the method, see page 75 of *Instruments* for April, 1933. Reprints can be had from General Radio Company without charge



Wiring diagram of TYPE 548-A Edgerton Stroboscope circuit, the primary of the flashing transformer, and the control resistor *E*. The resistor *A* is thus virtually short-circuited so that the full voltage of the rectifier appears across *B*. The grid of the thyratron is, accordingly, given a sudden and very strong negative bias since the cathode is raised nearly to the potential of the anode. This means that the sudden rush of discharge current from C_3 flowing through the flashing transformer will last only for a brief interval (determined by the de-ionization time of the thyratron). The very rapid rise of the primary flux in the air-core flashing transformer develops a sudden and intense potential which is supplied to the flashing electrode of the lamp and serves to strike the arc.

Tripping the thyratron is accomplished as follows: As stated above, the grid of the thyratron is sufficiently negative, due to the resistor *B*, to maintain the anode circuit normally open. If, now, the tripping contacts are closed, the sudden rush of charging current into the condenser C_4, passing through the resistor *C*, will develop across this resistor a momentary positive bias for the grid which may overbalance the negative bias, due to *B*, so as to trip the thyratron and produce the sequence of events described in the preceding paragraph.

It will be noted that the thyratron is tripped at the first instant at which the contacts are closed and that the duration of the contact is immaterial provided that the resistor *C* is sufficiently small in comparison with *D* so that the voltage divider *C-D* does not maintain a sufficiently positive bias on the grid to continually overbalance the normal negative bias supplied by the resistor *B*. As soon as the contacts are opened, the condenser C_4 discharges through *D* so that it will be ready to receive a new charging current when the tripping contacts are subsequently closed.

If the tripping contacts are left open and if an alternating current is applied through the primary of the peaked transformer, then at each alternate half cycle which swings the grid positive the thyratron will be tripped and the lamp flashed. The use of a saturated-core, peaked transformer improves the precision of timing, since a short, sudden pulse of secondary voltage occurs when the derivative of the primary current is a maximum, that is, when the primary current is passing through zero.

— Horatio W. Lamson

TYPE 548-A EDGERTON STROBOSCOPE

The main operating limits of the stroboscope and its accessories are summarized below.

Length of flash: 5-10 microseconds.

Maximum flashing speed: 180 flashes per second. (Permitting fundamental synchronism up to 10,000 r.p.m.). Maximum photographic speed, with Type 408 camera, 60 exposures per second.

Power supply required: 50-60 cycle, 110-115 volt, 250 watt.

Dimensions: 8½ x 15½ x 24 inches.

Weight: Without contactor—56 lbs.
With contactor —66 lbs.

Performance of Type 549-A Synchronous Motor Contactor:

Maximum flashing speed: 30 flashes per second. (Corresponding to fundamental synchronisms at 1800 r.p.m.).

Minimum flashing speed: 5 flashes per second.

Type		*Code Word*	*Price*
548-A	Edgerton Stroboscope (including lamp)	MAGIC	$290.00
549-A	Synchronous Motor Contactor	MACAW	55.00
549-PI	Contactor	MADAM	25.00

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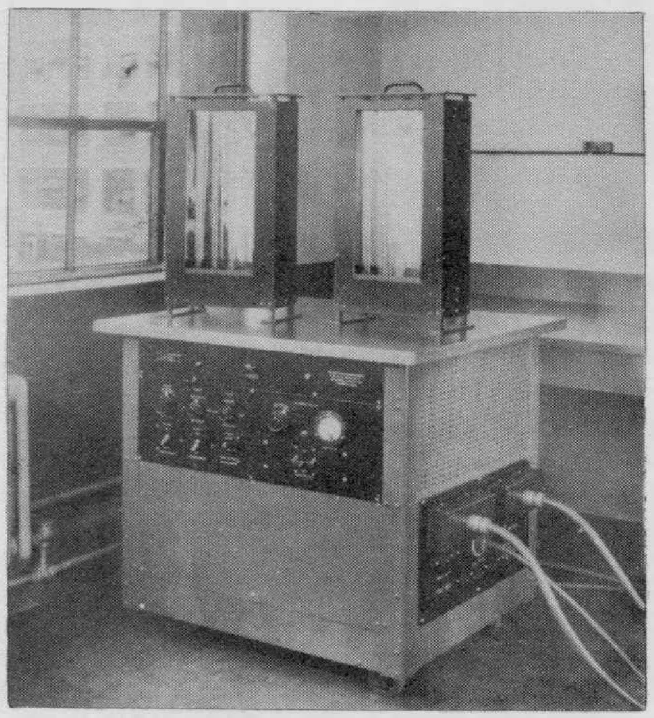
NEW LARGE SIZE STROBOSCOPE FOR GREATER ILLUMINATION



The Type 521-A Edgerton Stroboscope for service requiring greater illumination than the smaller standard model can deliver. Data and prices on request.

GENERAL RADIO COMPANY
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