Oscillographs for Recording Transient Phenomena [1]

By W. A. MARRISON

In this paper, oscillographs developed for recording transient phenomena are described which obtain automatically records of amplitude, wave form, frequency, duration, and time of any electrical disturbance for which they are adapted. Two instruments are described for recording very short or very long transients: these may be used in combination. At power frequencies satisfactory records may be made on film or sensitized paper with a two-watt lamp. The instruments and their performance are illustrated by photographs and oscillograms.

OSCILLOGRAPHS are described which were developed primarily for recording transient phenomena of which the time of occurrence is neither known nor subject to control. The specific apparatus described was designed primarily for recording transient inductive disturbances in communication lines from neighboring power circuits. When the design of this apparatus was begun, there was no satisfactory way for determining the duration, frequency or wave form of such disturbances, although apparatus was available by means of which the approximate magnitude of such transients could be determined, and, by constant supervision, the time of their occurrence. It was with the idea of determining part or all of these factors automatically in a single record that the oscillographs to be described were developed.

Transients in general may be of various types. They may have components in a large range of frequencies, they may occur in a large range of amplitudes and may be very long or very short or intermittent. Attention was directed toward recording devices which would obtain records of any disturbances in excess of a predetermined magnitude regardless of the time of occurrence. For practical reasons it was necessary also to give attention to the cost of operation, the power consumed, and the amount of servicing in operation.

To meet these requirements two somewhat different types of oscillograph were developed. One is capable of making records of short duration having uniform resolution throughout. By its use the wave shape of the first half cycle of a transient is recorded as clearly as that of any subsequent wave. The other instrument makes long continuous records and may be arranged to record a disturbance of any reasonable duration. The former instrument makes records in polar coordinates on a sheet of film rotating in its plane and will be called a "polar oscillograph." The latter records in rectangular coordinates

[1] Presented at the Regional Meeting of the Middle Eastern District of the A. I. E. E. at Cincinnati, Ohio, March 20–22, 1929.

on long strips such as motion picture film and will be called a "continuous-film oscillograph." [2]

Features Common to Both Oscillographs

Since both of these oscillographs were designed for recording the same sort of phenomena and for operating under somewhat similar conditions, they have a number of features in common.

As in most oscillographs the optical system consists of a light source, a mirror capable of being vibrated about an axis in its plane with an amplitude proportional to the signal to be recorded, and a lens system, including the mirror, to form an image of the light source on light sensitive film moved in a direction perpendicular to the plane of vibration of the mirror.

The light source consists of a concentrated filament flashlight lamp placed as close as possible to a pinhole aperture in such a way that the aperture, as viewed from the vibrator side, appears to be completely

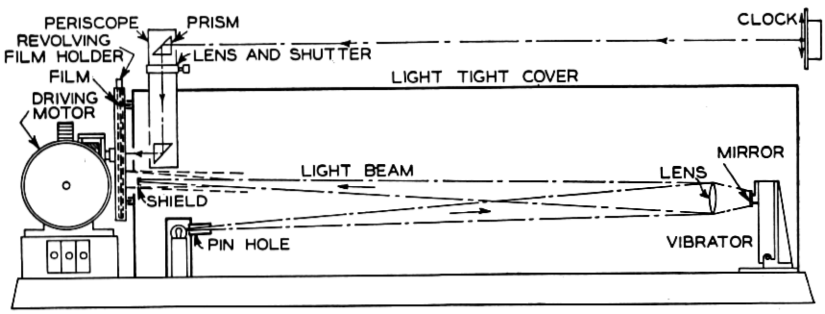

Fig. 1—Essential elements of polar oscillograph.

filled by the lighted filament. No condensing lens is used because of the small size of the bulb which permits the filament to be brought close to the aperture. The filament is brighter than its image and the use of a condensing lens in this instance would waste light unnecessarily by reflection and absorption, and would make the optical system larger.

The vibrator is of the moving-iron balanced armature type similar to a driving element frequently used in loud speakers. The armature is attached by means of a stiff rod to a mirror free to vibrate about an axis in its plane in such a way that, as the armature of the element vibrates, the mirror vibrates at a relatively large angular amplitude. With this type of vibrator it has been possible to employ a mirror half an inch in diameter and still retain a satisfactory frequency range and

[2] This instrument is frequently called a "Movie Oscillograph."

sensitivity. The use of a large mirror makes it possible to use either less sensitive film or a less intense light source than ordinarily would be required for a given recording frequency and film speed. With a half inch mirror it has been found practicable to use a lamp requiring only about two watts for recording on par-speed film.

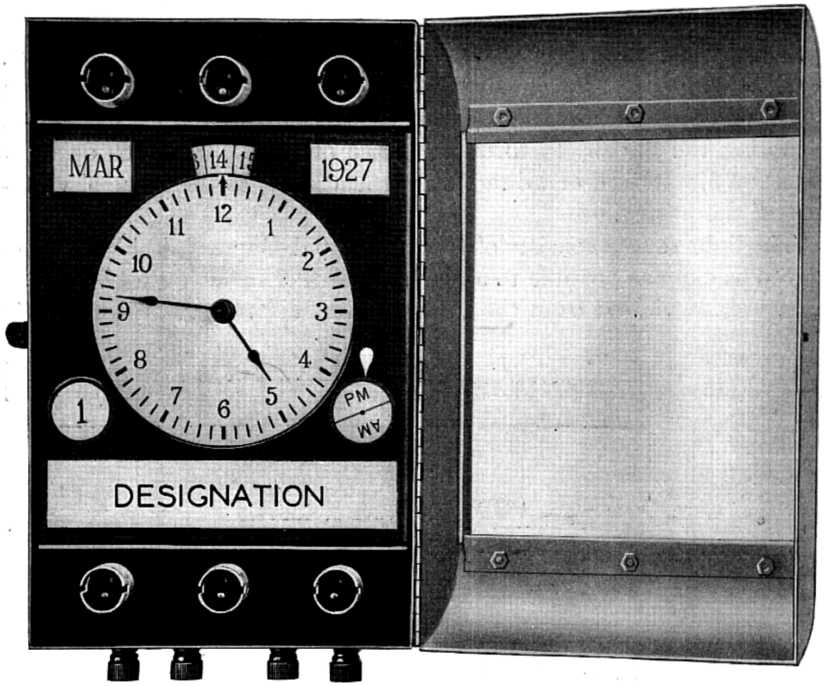

Fig. 2—Calendar clock used with oscillographs. Door is open to show lamp sockets.

A plane mirror is used on the vibrator, and a single meniscus lens mounted in front of it serves, in virtue of the reflection, as a symmetrical lens in forming an image of the pinhole on the film. When greater resolution along the time axis is required than can be obtained with this simple system, a cylindrical lens with short focus is placed in the light path just in front of the film.

Each oscillograph is equipped with a camera for the purpose of photographing a clock on the oscillogram to indicate the exact time of occurrence of the disturbance recorded. Any other information it is desired to associate with the records made by a particular oscillograph may be recorded photographically along with the clock. In several cases calendar clocks have been employed indicating the day and the month, and indicating whether the time is A.M. or P.M.

A schematic diagram of the optical system of the recorder and of the camera, as used in the polar oscillograph, is shown in Fig. 1. Some of the mechanism essential for operation is omitted for the sake of clearness.

One of the calendar clocks used in conjunction with these oscillographs is shown with cover open in Fig. 2. A space is left below the clock face for a card on which may be written identifying or other information relative to records that may be obtained. Lamps are mounted within the cover to illuminate the clock when necessary.

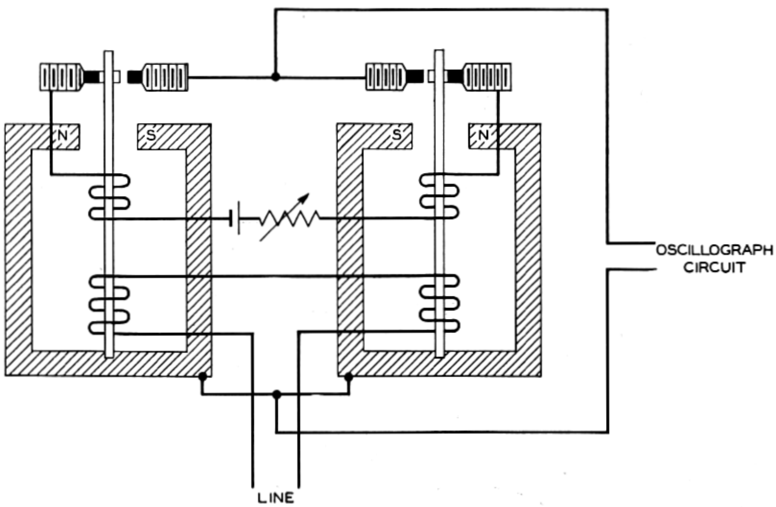

Fig. 3—Circuit of high-speed line-relay.

Both oscillographs are equipped with automatic devices which enable them to make records of transients for which they are intended without the attention of an operator. These automatic features will be described in some detail in the following discussion of the individual oscillographs.

One part, however, a high-speed "line-relay" is common to both. It consists of a pair of high-speed polar relays, the windings of which may be connected into a line in such a way that, depending on the polarity, one or the other will be operated by any pulse of sufficient magnitude. The relays may be so biased that they operate only on pulses in excess of any given magnitude. They are connected so that when they do operate they remain operated until reset by some external means. Contacts on the relays are connected to the apparatus to be controlled so that a single positive or negative pulse will put that

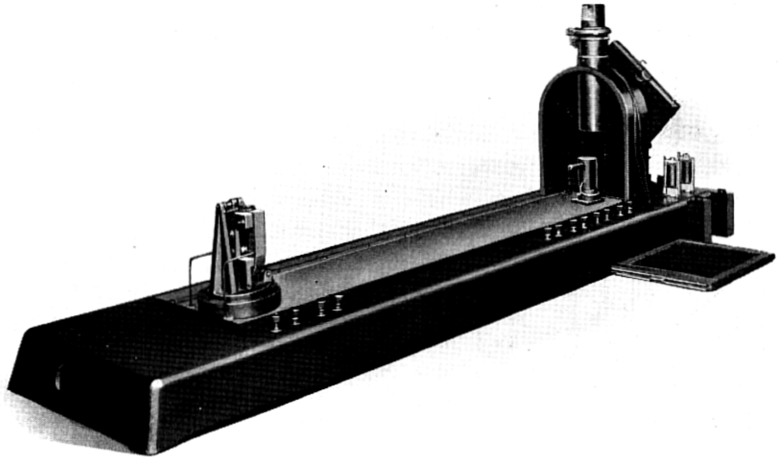

Fig. 4—Polar oscillograph, showing film rotor, periscope, lamp housing, and vibrator.

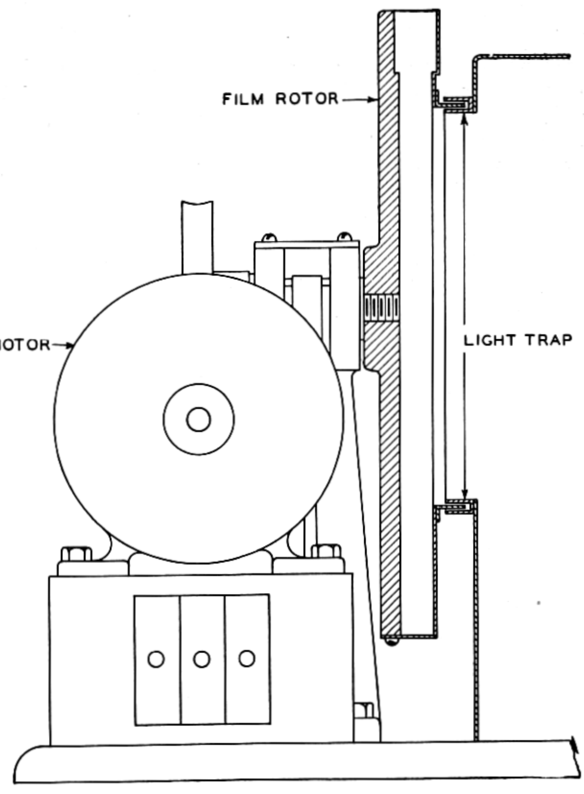

Fig. 5—Scale drawing of rotating light trap.

apparatus in operation. The time elapsed between the arrival of a pulse and the closing of the operating contact is less than 0.01 second. A schematic diagram of the line relay is shown in Fig. 3.

A polar oscillograph is shown in Fig. 4 with the light-tight cover removed to show the optical system. The film is held in a standard film holder in a rotating member at the extreme right of the picture. The use of standard film holders facilitates loading in daylight as in an ordinary camera. The film is rotated by a small motor geared to the rotating member. The rotating member is separated from the remainder of the oscillograph by a circular light trap which permits free rotation while shielding the film from external light. The circular light trap used is illustrated in Fig. 1 and in Fig. 5. With this arrangement films may be exposed for days at a time under ordinary light conditions without appreciable fogging.

A B

Fig. 6—Oscillograms illustrating the use and omission of a light shield over the zero line.

The flashlight lamp is housed in the small light-tight box on the base near the film rotor. Excessive scattering of the light is prevented by a small tube, with a diaphragm near the end, directed toward the vibrator mirror. The vibrator and mirror and the lens of the optical system are mounted on the base near the other end.

The chief value of this oscillograph lies in its ability to record with good resolution from the very beginning of a transient, regardless of the time at which it occurs, and regardless of the angular position of the film at which it begins. To accomplish this, the lamp is lighted continuously during the time a transient is expected and a narrow shield is placed in the light path of just sufficient width to prevent light from reaching the film when the vibrator is at rest. In this way fogging of the film is prevented during the time when no current is flowing into the vibrator but a record is made of any disturbance of sufficient magnitude to move the spot off the shield. A record made in this way appears like an ordinary oscillogram except that a narrow,

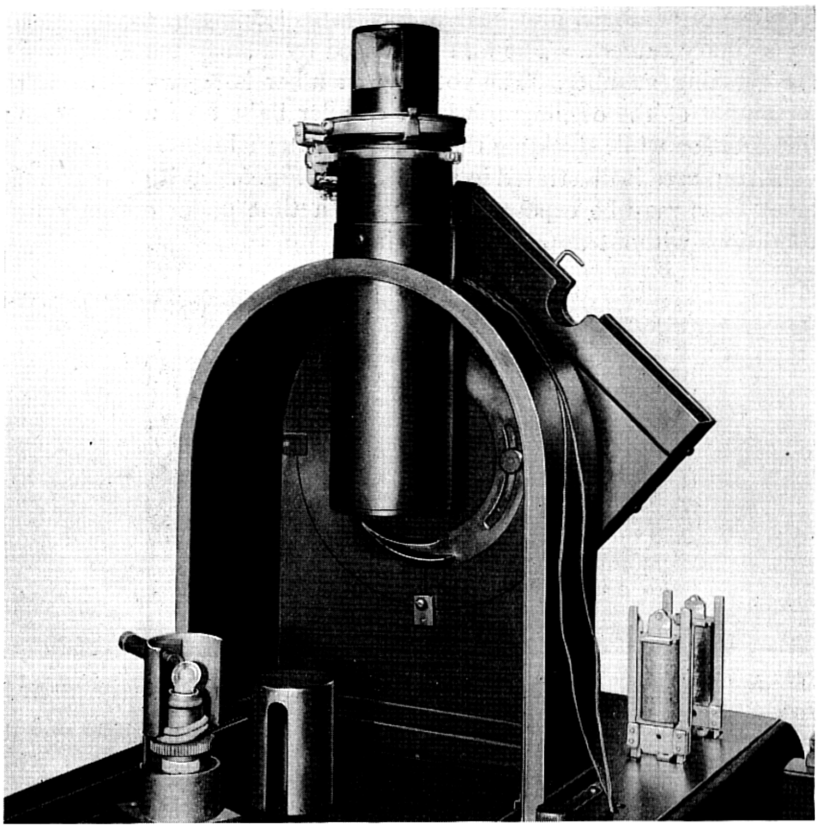

Fig. 7—Shields to prevent fogging on polar oscillograph.

clear space is left where a zero line is usually obtained. This is illustrated in Fig. 6-A.

In the absence of a shield the film soon becomes so badly fogged that an oscillogram made upon it is useless. Fig. 6-B shows the fogging obtained with an exposure of one minute on the zero line without a shield.

If it is desired to record only disturbances in excess of a certain magnitude, the width of the shield may be increased so that no exposure occurs until the vibrator moves at more than a predetermined amplitude. In Fig. 7 a shield for this purpose is shown which may be adjusted to cover a portion in the center of the record from the width of the spot to about half an inch, or removed from the field entirely. As may be seen from the illustration, this is accomplished by moving the shield in guides about the axis of film rotation.

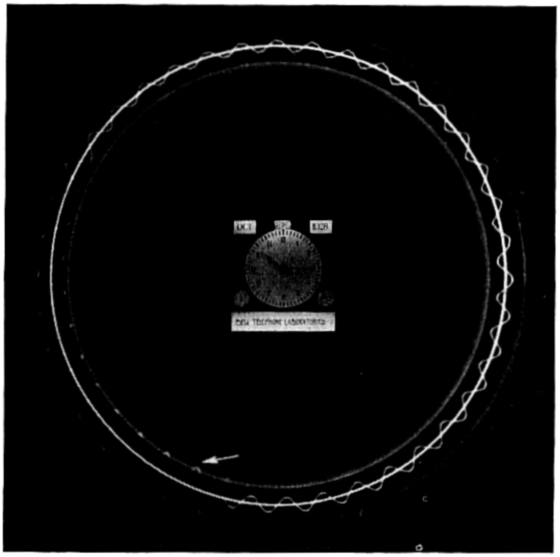

Fig. 8—Oscillogram illustrating the use of removable shield.

There is a disadvantage in using a very wide shield of the type described. If, for example, a disturbance occurs which is just great enough to be recorded, the major portion of the wave is hidden by the shield and all that can be deduced from the record are the peak amplitude, frequency and time. This difficulty can be avoided readily, however, by attaching a shield to the armature of an electromagnet so that it can be removed from the light path when the magnet is energized. The magnet may be operated by the high-speed line-relay, which is adjusted to operate when the disturbance exceeds a certain amount, in this case the same amount that moves the light spot at an amplitude greater than the width of the shield. The oscillogram shown in Fig. 8 was made with a removable shield of this type. The shadow of the shield is indicated in the first four cycles but does not appear during the remainder of the oscillogram. For convenience in interpreting the results, a zero line is automatically recorded immediately after the recording of the oscillogram.

In order to reduce fogging due to stray light a large shield is placed between the film and the light source, having a vertical slit just large

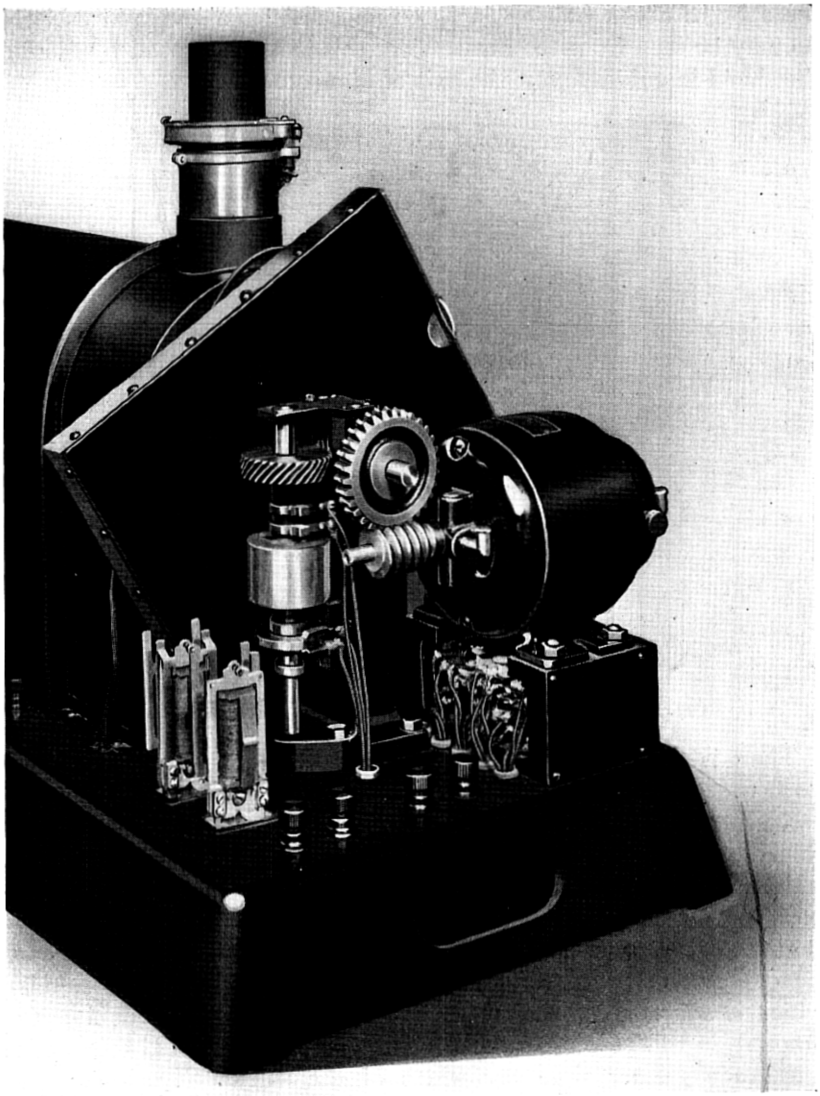

Fig. 9—Device on polar oscillograph to limit recording time.

enough to allow the vibrating beam of light from the mirror to pass through to the film. This device reduces the fogging due to stray light to a small fraction of what otherwise would be obtained. The vertical slit can be seen in Fig. 7 behind the variable shield. A slight corona-like fogging on either side of the circular shadow of the shield, as shown in Fig. 8, is obtained after a few hours of exposure. In practice a film may be exposed for twenty-four hours or more without the fogging becoming so serious as to obscure a record.

To avoid confusion due to overlapping records a device is used to stop recording after one complete revolution of the film. It is put in operation at the beginning of a transient by the high-speed line-relay and allows recording to continue for one complete revolution, regardless of the angular position of the film at which it begins.

This device is shown on the oscillograph in Fig. 9. A vertical shaft driven at half the speed of the film carries a magnetic clutch fastened rigidly to it and a commutator which idles on the shaft except when engaged by the clutch. This commutator has one insulating segment and one conducting segment, each of angle about 180 degrees. Contacts, controlling the current to a relay winding, are normally on the insulating segment of this commutator, but when the high-speed line-relay operates, the magnetic clutch is energized and the commutator is rotated until the contacts touch the conducting segment, thus operating the relay. One contact on the relay automatically releases the magnetic clutch, preventing further rotation of the commutator. Another contact interrupts the current going to the light source. Since the filament of the lamp is small the light is extinguished in a very short time and, of course, recording is stopped immediately.

After the exposed film has been replaced, and it is desired to put the oscillograph in operation again, the clutch and commutator are restored to their original condition by operating a key which energizes the clutch magnet and releases it again automatically after one-half revolution of the vertical shaft.

If it is desired to make a record covering more or less than one revolution it can be arranged simply by changing the gear ratio between the film shaft and the vertical commutator shaft. The film speed may be changed either by changing the gear ratio between the motor and the film driving shaft or by varying the speed of the motor.

The camera for photographing a clock is shown in Fig. 4. It consists of a lens and shutter, shown at the top, and a periscope consisting of two right-angled glass prisms mounted in the vertical tube. The periscope places the image in the center of the film and since there are two reflections the image will be the same as if none were used. The shutter is equipped with an automatic release which is operated a definite time interval after the beginning of an oscillogram, the time being determined by means of a slow acting relay or by a sequence switch. It is desirable to stop the film from rotating before photographing the clock which may be done by means of the same relay that turns off the lamp, or by means of a sequence switch.

Main Features of Continuous-Film Oscillograph

A picture of the continuous-film oscillograph is shown in Fig. 10. It differs from the polar oscillograph mainly in the form in which records are obtained. As previously stated, records are made in

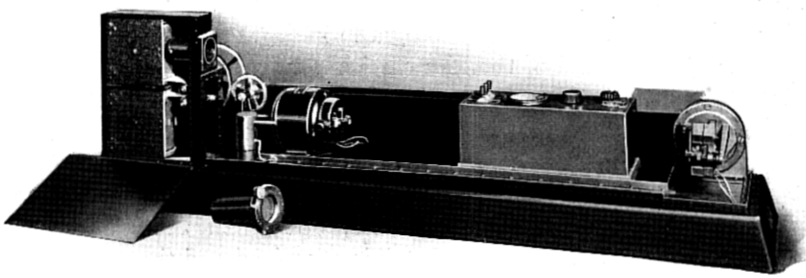

Fig. 10—Continuous-film oscillograph with covers removed.

rectangular coordinates on a strip of film and may, therefore, be of any length depending only on the length of film available and on the size of the storage magazines. The oscillograph shown makes records on motion picture film or sensitized paper of the same width. The film is

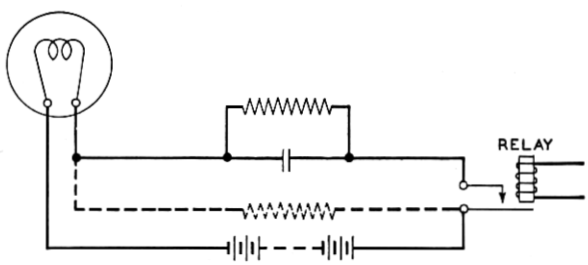

Fig. 11—Circuit for lighting lamp quickly.

stored in standard magazines for motion picture film holding up to 200 feet. It is advanced by means of a motion picture sprocket driven through gears and a magnetic clutch from a variable speed motor. The optical system is practically identical with that used on the polar oscillograph.

With an oscillograph of this type it is not practicable to allow the film to be moving all the time on account of waste of film and the maintenance difficulties. In order to avoid this and still make it possible to begin recording soon after the beginning of a disturbance,

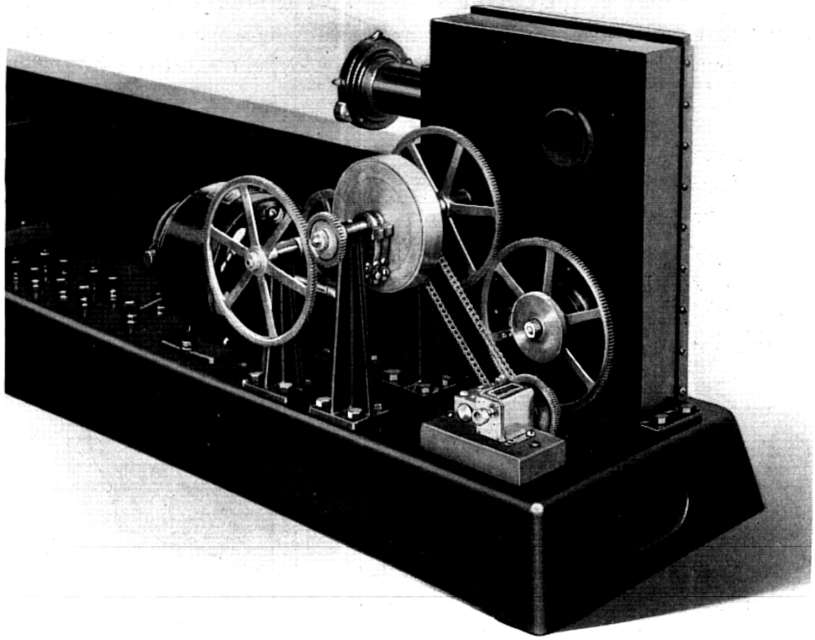

Fig. 12—Quick acting magnetic clutch on continuous-film oscillograph.

the motor and associated gears are left running the whole time during which a transient may be expected, and, when a disturbance occurs, a quick acting magnetic clutch engages the film driving shaft with the motor which puts the film in motion very quickly. The line relay lights the oscillograph lamp at the same time. The whole recording mechanism may be put in operation within 0.02 second, thus insuring a good record of any but a very short transient.

Normally the lamp would require several hundredths of a second to become lighted to full brilliancy if operated at normal voltage. However, with a voltage several times normal and by the use of the circuit shown in Fig. 11, it is possible to bring it to full brilliancy within 0.01 of a second without danger to the lamp. When the circuit is closed by the relay the condenser is charged suddenly to the applied voltage, the charging current passing through the lamp filament. This current, at the outset, is several times the normal current for the lamp and brings it to full brilliancy quickly. The resistance shunting the condenser has such a value that normal current flows through the lamp filament in the steady state, so, once lighted, the lamp remains at normal brilliancy as long as the circuit is closed. The lamp may be lighted in even less time if a small current is left flowing through the filament continuously in order to keep it hot but not hot enough to be luminous.

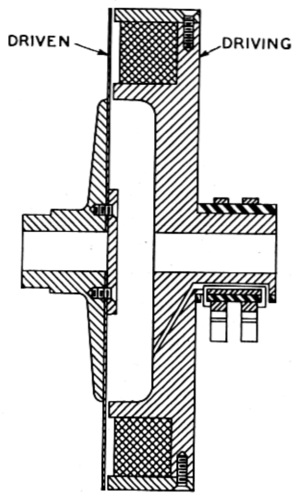

Fig. 13—Sectional scale drawing of magnetic clutch.

A resistance of suitable value connected as indicated by dotted lines in Fig. 11 will accomplish this result.

The magnetic clutch, while especially designed to operate quickly, accelerates the sprocket and film without shock in order to avoid danger of tearing the film and to reduce wear and tear on the mechanism. The clutch is shown mounted on the oscillograph in Fig. 12. It is also shown diagrammatically in Fig. 13 to illustrate its construction and operation. The annular coil in the driving member is connected, through slip-rings and contacts on the high-speed relay, to a battery. When current flows in this coil a steel diaphragm on the driven member is drawn against the annular electromagnet, traction being obtained at the outer edge of the diaphragm. Due to the small clearance between the diaphragm and the electromagnet the diaphragm is drawn into contact very quickly, and due to the small moment of inertia of the driven member it is rapidly accelerated to maximum speed. Since this is a friction type of clutch, the acceleration is gradual and does not submit the sprocket and film to shock as would a toothed clutch.

The delay in recording after the beginning of a disturbance depends on the time of operation of the high-speed relay plus that of either the clutch or the lamp, whichever is the longer. The relay requires only a few thousandths of a second to operate and both the clutch and the lamp may be adjusted to operate in less than one hundredth of a second. With this apparatus, therefore, it is possible to record all of a disturbance except that part which occurs during about the first 0.02 of a second. If desired, the lamp can be arranged to operate in considerably less time than the clutch, in which case the first part of the record will not be resolved but will indicate the amplitude of the disturbance which is frequently the most desired information. In the case of 25-cycle or 60-cycle disturbances the maximum of even the first half cycle may be recorded in this manner.

The film driving mechanism is arranged so that the film may be advanced at any speed in a wide range, from a few inches per minute to about a foot per second. This is accomplished by means of a set of change gears and by changing the speed of the driving motor, or by both in combination.

As with the polar oscillograph, a camera is included for the purpose of recording the time automatically on the oscillograph film. This camera may be seen in Fig. 10. It is similar to that on the polar oscillograph with the difference that only one prism is used. This has the advantage, when recording is done on paper, that the image obtained through a lens and a single reflection is not reversed. The shutter is equipped with an automatic release that can be associated with slow acting relays or a sequence switch to take care of photographing the clock on the right portion of the film.

Operation

There are a great many ways in which the oscillographs, described above, may be used. An arrangement is described in which two polar oscillographs and one continuous-film oscillograph have been used in conjunction for studying transients which are likely to occur at any time during long continuous periods. It was desired to determine the magnitude with considerable accuracy and at the same time to determine the time of occurrence, duration, frequency and wave form.

The arrangement of oscillographs is shown diagrammatically in

Fig. 14. One of two polar oscillographs is connected in the circuit being investigated so that it is in condition to record the first part of any transient that should occur. A high-speed line-relay associated with it is arranged to put in motion the sequence switch which takes care of a number of operations consisting chiefly in starting the continuous-film oscillograph, in substituting the second polar oscillograph for the first after a certain small time interval, and in operating the camera shutters at the proper times.

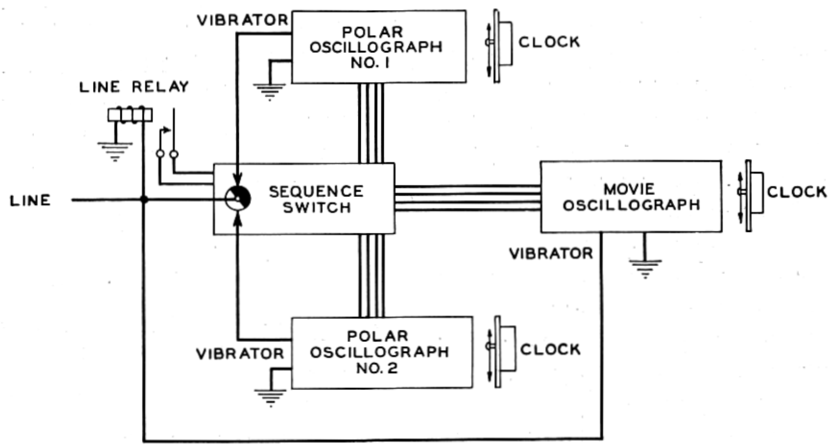

Fig. 14—Arrangement of oscillographs for recording any transient in a line. Two polar oscillographs and one continuous-film oscillograph with control equipment and clocks are arranged so that a transient of any duration occurring at any time will be recorded with a record of the time of occurrence.

Used in this way the first polar oscillograph obtains a record, having considerable resolution, of the first part of a transient while the other oscillograph obtains a record of the complete transient with the exception of the first few cycles which are, however, obtained on the polar machine. The sequence switch is adjusted so that the continuous oscillograph is put in operation before the polar machine stops recording so that, with the two records, complete information of the disturbance may be obtained. Two polar oscillographs are used in this way so that, in case two transients occur close together, a record of one of them will not be lost during the time required for reloading. The sequence switch connects the line to the spare polar oscillograph automatically and gives the operator ample time to make any necessary adjustments on the remaining machine. The arrangement is symmetrical and either polar oscillograph may become the spare.

An example of the record of a transient obtained with a polar and a continuous-film oscillograph used together is shown in Fig. 18. The polar oscillogram is similar to that shown in Fig. 8. It is obvious that the continuous oscillograph began recording about five cycles after the beginning of the transient while, of course, the polar oscillograph began recording immediately. The long record, however, continues twenty-five or thirty cycles beyond the end of the polar record and shows the manner in which the transient ended. Space does not permit of showing the clock that was photographed on the strip record.

When certain factors are known about the disturbances to be recorded the arrangement may be somewhat simplified. If, for example, it is known that any transient to be recorded will be of very short duration, the continuous oscillograph need not be used. If, on the other hand, it is known that the first cycle or two of the disturbance will be of no importance in the record, the polar oscillograph may be dispensed with.

The continuous film type of oscillograph offers some decided advantages over the polar type in that a large number of records can be made at one loading. Largely because of this it is possible to make the oscillograph entirely automatic in operation, causing it to record, without any attention whatever, all the transients in a circuit as they occur, until the supply of film is exhausted. Such an oscillograph may be left permanently connected into a circuit in which transients are expected, and at the end of any period the film that has been advanced into the "exposed" magazine will show on development records of the magnitude, frequency, and wave form of the disturbances and of the time of occurrence of each.

For automatic operation of the oscillograph a sequence switch of some sort must be used to insure that the various automatic operations are performed in the proper sequence. In Fig. 15 a schematic drawing illustrates the essential elements of such an arrangement. When standing by, ready to record a transient, the motor on the oscillograph is running but does not engage the film advancing mechanism because the magnetic clutch is normally deenergized. On the arrival of a transient the sequence of operation is as follows:

The line-relay operates, and locks in operated position in virtue of the bias current through the outer winding being removed by the opening of the back contact. The lamp is lighted through the resistance and condenser combination RC, and, at the same time, the motor is engaged with the film driving mechanism through the magnetic clutch. Since the vibrator is connected continuously to the line, recording begins immediately. Relay SR operates at the same time that the clutch is energized and starts the motor of the sequence switch which rotates the cams in the direction of the arrow. After a predetermined amount of film has been advanced, cam 3 rebiases the line relay and restores it to the original non-operated condition (unless the disturbances on the line continue beyond this time). This releases relay SR but the cams continue to turn because the contact operated by cam 1 is in parallel with that on the relay, which allows the motor

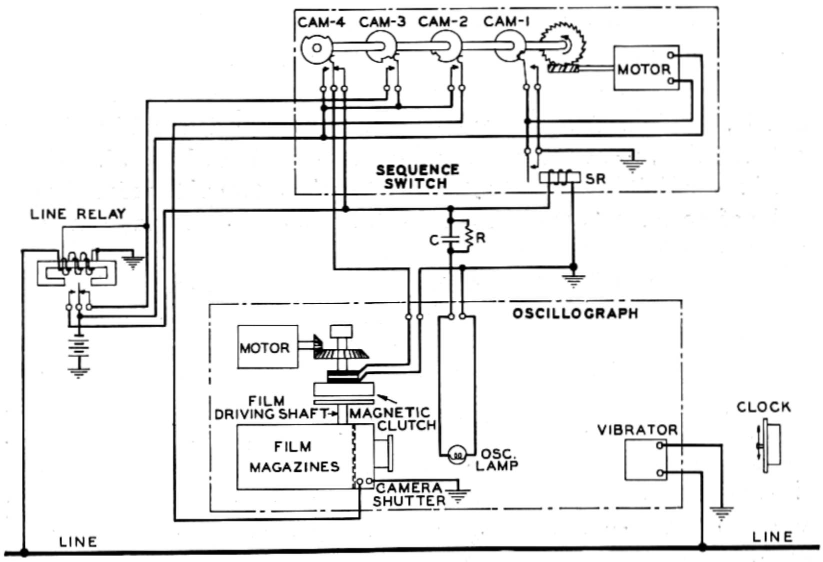

Fig. 15—Schematic arrangement of continuous-film oscillograph with sequence switch, line-relay, and clock, arranged for automatic operation.

to run during one complete revolution of that cam. When the line-relay is restored the film stops and the lamp circuit is opened. After cam 3 stops the recording and resets the line-relay, cam 2 operates the camera shutter which photographs the clock on the film at the end of the oscillograms. As the cam shaft continues to revolve, cam 4 operates the magnetic clutch for a short time without lighting the lamp. This advances the film far enough so that the beginning of the next record will not be superposed on the image of the clock. When the cam shaft has completed one revolution, cam 1 stops the sequence switch motor by opening the contact associated with it.

After this sequence of operations everything is exactly the same as before except that a certain length of film has been advanced into the used-film magazine and a complete record made up on it. The length of the record may be adjusted by an adjustment of cam 3.

In case the disturbance lasts until after the amount of film allotted to each record has been used, the line-relay will remain operated and the film will continue to be exposed during one whole cycle of the sequence switch. Thus a continuous record can be made of any disturbance, however long, provided there is sufficient film.

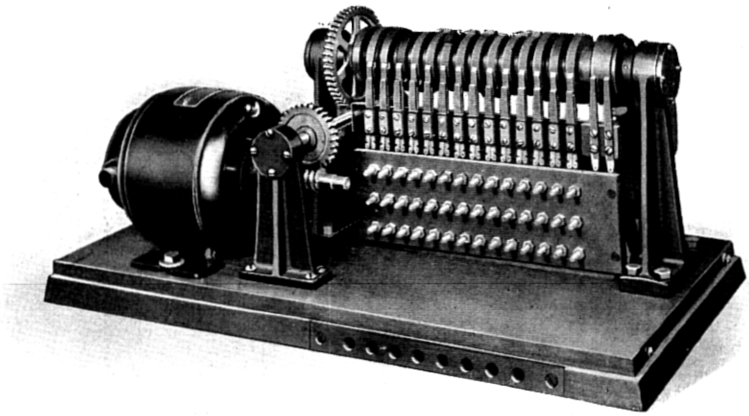

Fig. 16—Sequence switch.

Fig. 16 shows a sequence switch that has been used in the arrangements of both Fig. 14 and Fig. 15. With it a great many arrangements of automatically controlled equipment may be set up besides those described, permitting the oscillographs to be used in many different ways.

A modification of the continuous-film oscillograph which appears to have some novel and useful features is shown in Fig. 17. It is adapted

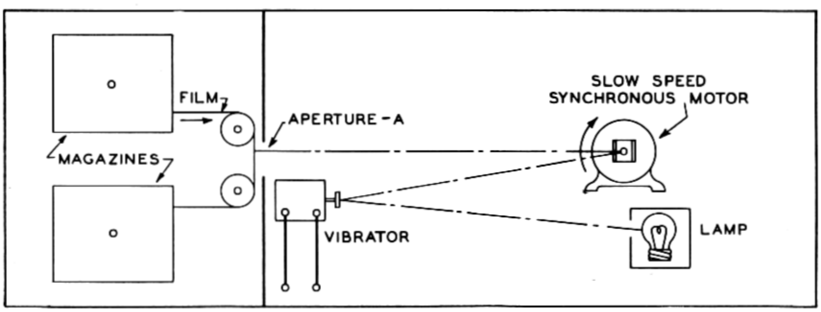

Fig. 17—Schematic drawing of sampling oscillograph. This oscillograph records one wave out of a number at regular intervals, say one cycle in sixty, with considerable resolution in order to record slow variations in wave form.

especially for sampling a wave at regular short intervals instead of making a continuous record or merely a record of unusual disturbances.

It involves, in addition to the usual optical system and means for advancing the film, an additional mirror in the light path between the vibrator and the film, rotating synchronously with the current or voltage to be recorded, about an axis perpendicular to both the direction of motion of the film and the axis of the vibrator mirror. The function of the rotating mirror is to sweep the light beam along the oscillograph film past an aperture A in such a way that the effective film speed during exposures is many times the actual film speed, and to permit of exposure during only a small part of the total time.

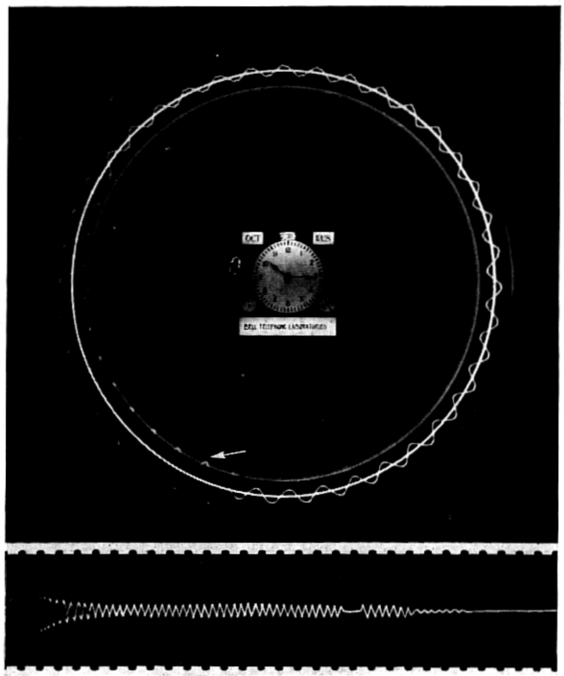

Fig. 18—Sample of records made by polar and continuous-film oscillographs used together.

As an example, suppose that the mirror makes one revolution in two seconds and that the wave to be recorded has a frequency of 60 cycles per second. If the distance of the rotating mirror from the film is 8.5 inches, one cycle of the wave recorded will be spread over approximately one inch of film. If a rotating mirror with a single facet is used, and if the aperture is just one inch wide, the actual film speed should be one inch in two seconds and every one hundred and twentieth wave will be recorded. If two facets 180 degrees apart are used on the

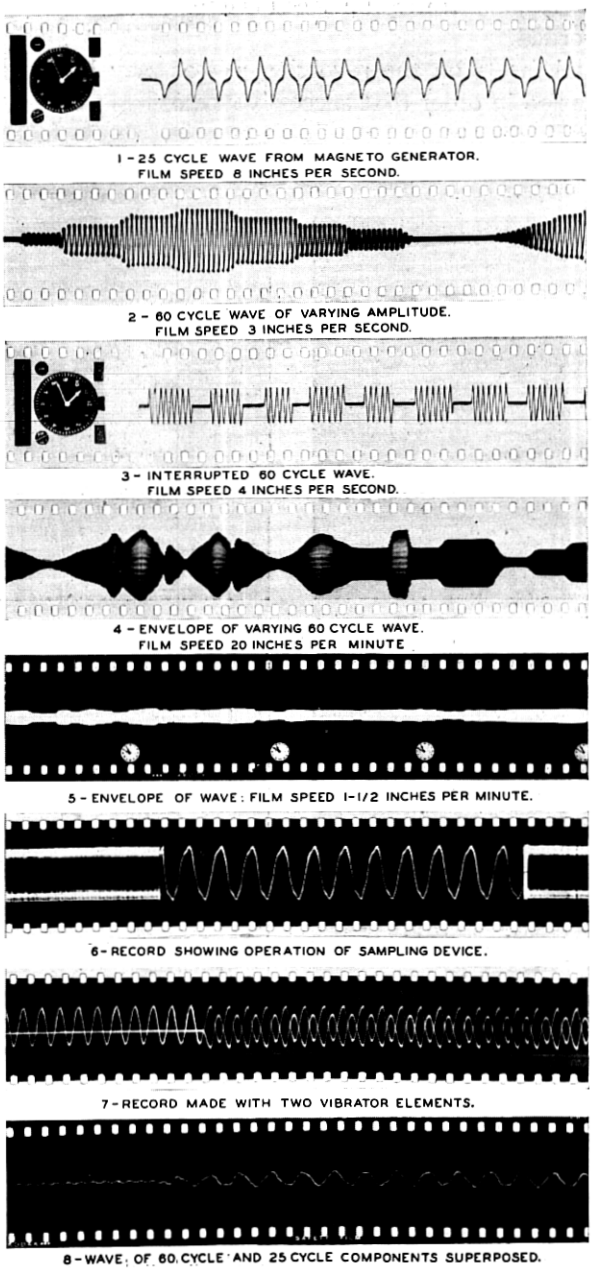

Fig. 19—Samples of continuous oscillograms.

rotating mirror, and if the film speed is doubled, one wave in every 60 will be recorded.

Individual facets on the revolving mirror may be inclined to the axis of rotation in order that successive exposures may be made from different vibrator elements. For example, three facets suitably mounted could be employed to show in succession sample waves of

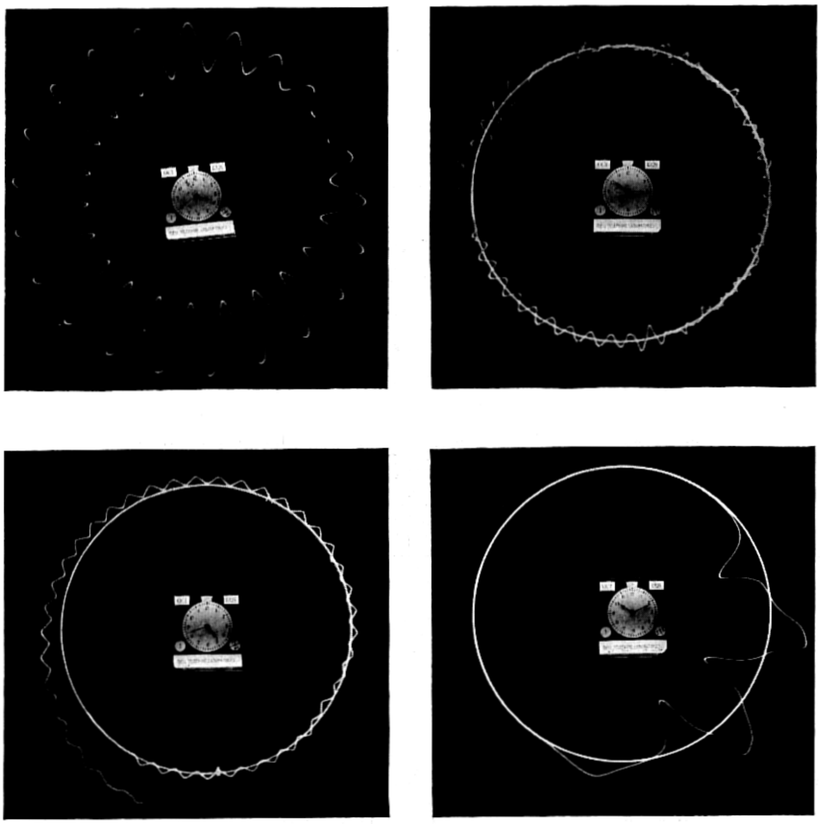

Fig. 20—Samples of polar oscillograms.

current from the three circuits in a three-phase line, the motor driving the mirror being operated synchronously in phase with the three-phase voltage.

The advantage in this recording method lies in the ability to obtain a good record of slow changes with good resolution and without the use of a large amount of film.

Another method of sampling which gives a somewhat different kind of information may be used with a continuous-film oscillograph with the usual form of optical system. The film is run at very slow speed in order to obtain normally an envelope of the wave. At intervals the speed of the film is increased to a value sufficient to resolve the wave and show the actual wave shape. A record of the time may be made on the film by photographing a clock at regular intervals, say once a minute. A record made in this way is shown in Fig. 19, No. 6.

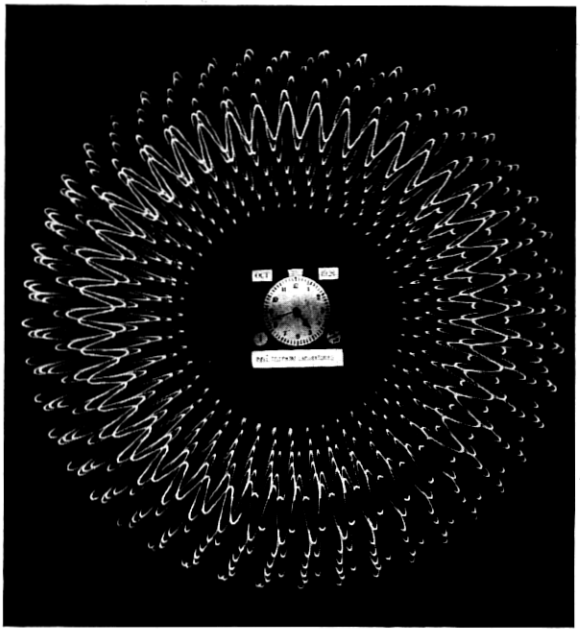

Fig. 21—Amplitude calibration of polar oscillograph.

Frequently there is an advantage in recording two or more variables simultaneously. A record obtained with two vibrators is shown in Fig. 19, No. 7.

PERFORMANCE

The limitations of an oscillograph lie mostly in the vibrator and, to a smaller degree, in the optical system and photographic emulsion used. The frequency characteristic of the vibrator up to 800 cycles is quite uniform, permitting records of disturbances having components in this range to be made with little distortion. This range includes the first 13 harmonics of 60 cycles and the first 32 harmonics of 25 cycles.

The vibrator may be wound to have any impedance in a wide range. If wound to have a high impedance it is especially suited for recording voltage waves, and if wound to have low impedance it is better suited for recording current waves. The sensitivity, as usually expressed, in millimeters deflection per milliampere of input, varies approximately as the square root of the impedance of the winding. The ratio of deflection to input is constant over a considerable range due to the balanced structure of the motor element.

As noted previously the oscillographs described are intended for recording in a comparatively low frequency range. In the range given there has been no difficulty in obtaining good records with a two-candle-power flashlight lamp. This of course, is principally due to the large size of the mirror on the vibrator.

Samples or records made with the oscillographs described are shown in Figs. 6, 8, 18, 19, 20 and 21. Those in Figs. 6, 8 and 18 have already been mentioned. Fig. 19 shows eight continuous oscillograms and Fig. 20 shows four polar oscillograms illustrating some of the possibilities of these instruments. Fig. 21 is a response calibration at constant frequency of a polar oscillograph.

A number of field applications of oscillographs of both types have been made with satisfactory results. In some cases where cooperative studies were being made, the oscillographs have been used for recording transient neutral currents in power systems as well as to record voltages induced in telephone circuits by power system transients. Experience with the oscillographs in these field installations has suggested a few improvements of a mechanical nature and certain rearrangements of parts to increase the convenience of operation. These changes are now being embodied in a new design. It is hoped that it will be possible in a later paper to describe these features and to give the results of field experience more fully than can be done at this time.