EYES FOR INDUSTRY

...STROBOSCOPIC TECHNIQUES...

GENERAL RADIO COMPANY
Cambridge, Massachusetts

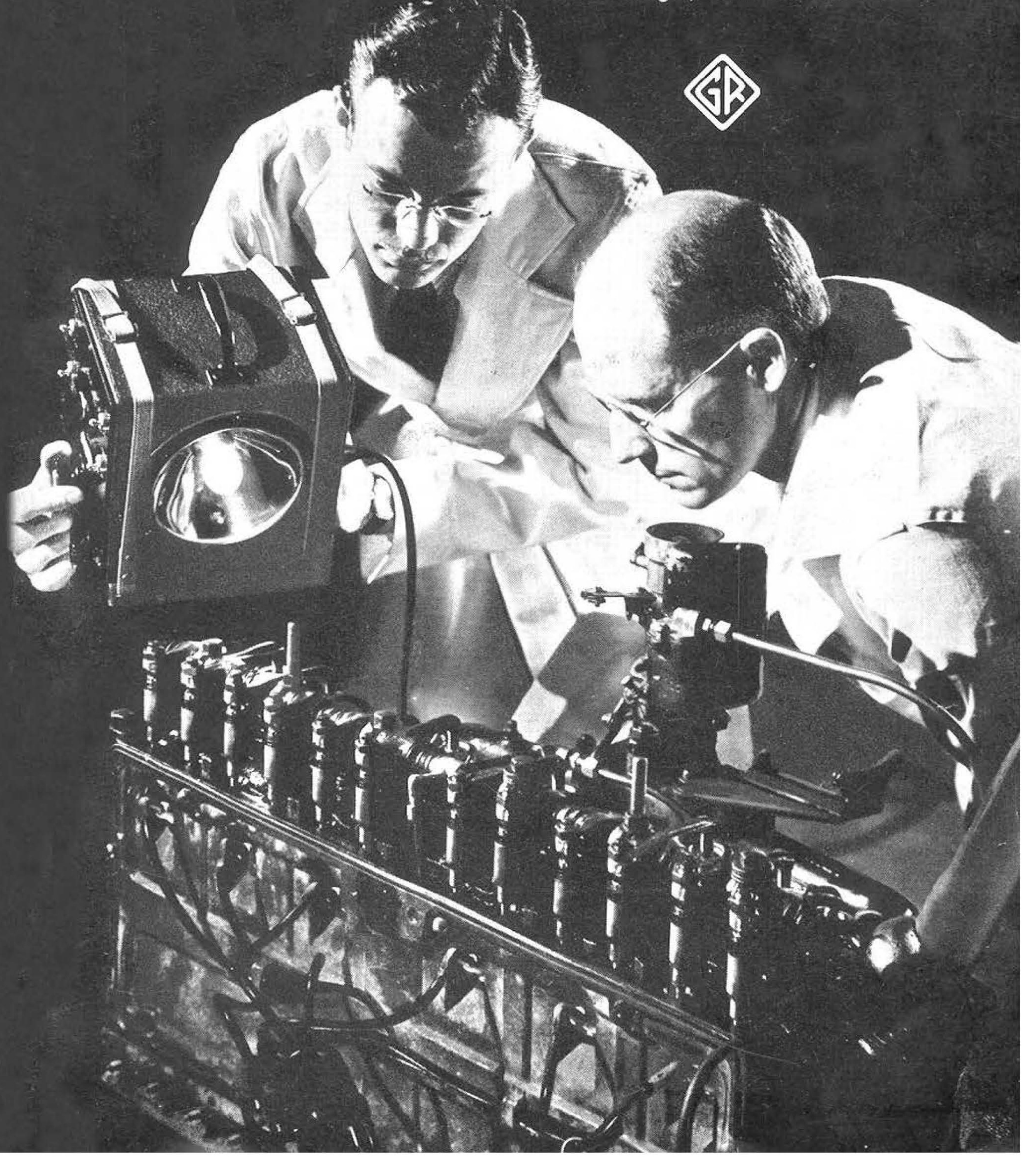


TABLE OF CONTENTS

Cover photo courtesy Wilcox Rich Division, Eaton Manufacturing Company, Detroit, Mich.

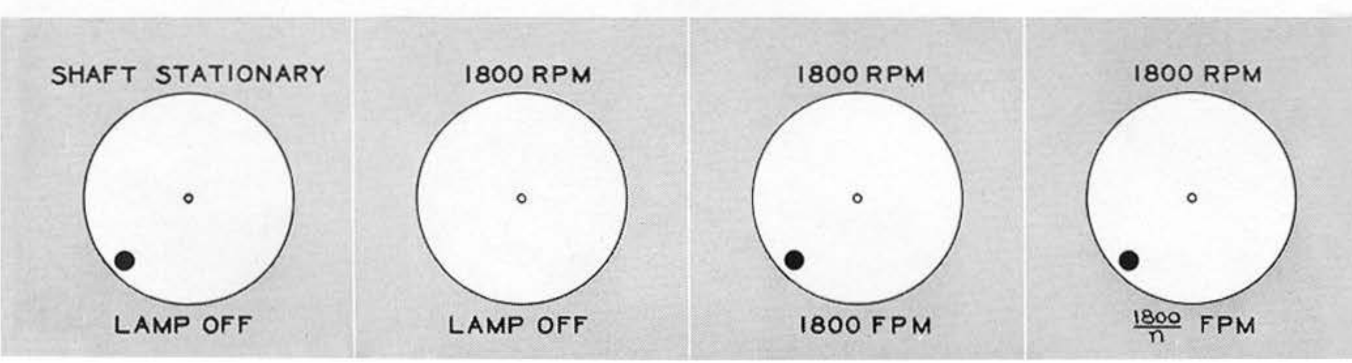
FIGURE 1:

(a) These diagrams explain the operation of the stroboscope. Here is shown a flywheel on the end of a shaft with a spot painted on it for an index.

(b) The wheel rotates uniformly at 1800 rpm. In ordinary light, the spot is invisible because the wheel moves too fast for the eye to follow it.

(c) The wheel is periodically illuminated by a light which flashes once in each revolution. Since the spot is always at the same position when illuminated, the wheel appears stationary.

(d) When the light is flashed every second, third, fourth, or *n*th revolution, disc appears stationary.



EYES FOR INDUSTRY

...STROBOSCOPIC TECHNIQUES...

THE STROBOSCOPE, in the last ten years, has exerted more influence on the mechanical and electrical industries than has any other single instrument. In the design, production, test, and application of moving mechanisms, the Edgerton-type stroboscope is rapidly becoming indispensable.

What is a stroboscope? The dictionary gives the following definition:

> "Stroboscope, n. (Gr. στροβος, *a whirling* + σκοπός, *watcher.*) An instrument for studying or observing a periodic or varying motion by means of light periodically interrupted."

In terms of what it can do for the engineer, the viewing of moving objects by periodically interrupted light implies practical uses almost without limit. Intermittent viewing makes possible the optical illusion of slowing down or stopping the motion being viewed, although retaining all the characteristics of the original motion, so that irregularities occurring at high speeds can be studied as if the object under observation were stationary, or barely moving.

The operation of a stroboscope can be understood by reference to the diagrams of FIGURE 1. Consider the white disc shown here to be a flywheel on the end of a shaft rotating at a rate of 1800 rpm. Near the rim is painted a black spot. Let us view this flywheel in a darkened room, by means of light which is flashed periodically 1800 times per minute (once each revolution of the flywheel). Under this condition the flywheel will appear to be stationary, because it is always in the same position when we see it. Since the retina of the eye retains each image for an appreciable fraction of a second (the so-called persistence of vision) no flicker is seen, except at very low speeds.

This property of apparently stopping motion has many important applications, chief among which is the measurement of speed. The rate of flashing is equal to the speed of the flywheel. Consequently, if the flashing rate is adjustable and if the flashing rate control is calibrated, the stroboscope becomes a tachometer.

A further property of the stroboscope

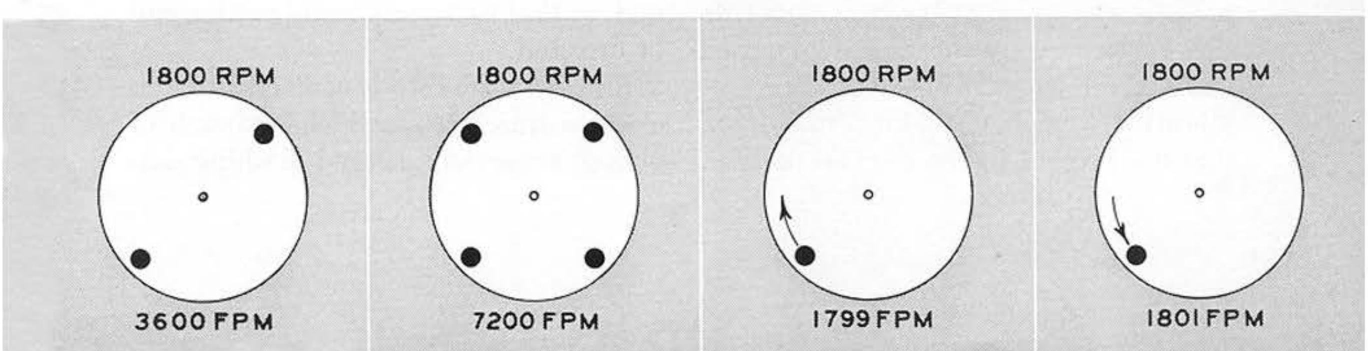
FIGURE 1 (*cont.*):

(e) If the disc is periodically illuminated by a light which flashes twice in each revolution, two diametrically opposite spots are seen, because between flashes the disc moves one-half revolution.

(f) Four evenly-spaced flashes per revolution make four spots visible. Similarly, if the flashing rate is n times the rotational rate, n spots will be seen.

(g) If the flashing rate is slightly less than the rotational rate, the spot appears to progress around the circumference at a speed equal to their difference, giving the illusion of slow motion.

(h) If the flashing rate is slightly greater than the rotational rate, the slow-motion rotation is backward.



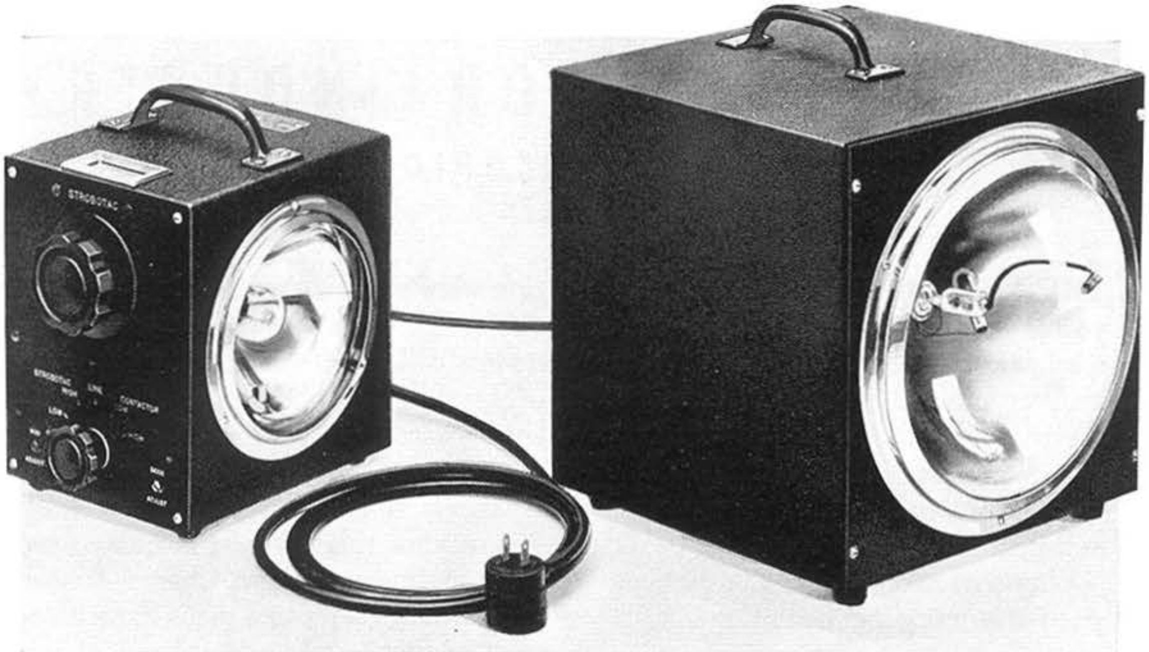


FIGURE 2: TYPE 631-B Strobotac with TYPE 648-A Strobolux.

is its ability to show rapidly moving objects in slow motion. If the frequency of light flashing is made slightly less than the shaft speed, say 1799 flashes per minute, the flywheel will appear to rotate at one rpm because, each time it is illuminated, the reference spot has moved 1/1800th of a revolution. This is shown in FIGURE 1 (g). Consequently, the spot progresses around the circumference at a rate of one rpm. If the difference between rate of light flashing and rate of rotation is made greater, the flywheel will appear to revolve more rapidly, the apparent rate of rotation being equal to the difference between rate of viewing and rate of rotation. If the rate of viewing is greater than the rate of rotation, the flywheel will appear to revolve backwards, as in FIGURE 1 (h).

The practical significance of the slow-motion effect is that, since it is a true slow-motion copy of the high-speed motion, all irregularities can be seen: vibration, torsion, chattering, whip, etc., that are present in the original motion.

TYPES OF STROBOSCOPES

Early stroboscopes, instead of intermittently illuminating the subject, used a spring-motor-operated shutter to interrupt the vision of the observer. This type of instrument cuts down the average illumination of the subject and, unless of very expensive construction, is not uniform in speed and timing. The Edgerton stroboscope, developed by Edgerton, Germeshausen and Grier, of the Massachusetts Institute of Technology, consists of a light source which can be turned on and off at accurately spaced intervals by an electronic switch. The Edgerton system has many advantages. Among them are:

(1) The average illumination on the viewed object is increased.

(2) The flash is extremely short, lasting only a few one-millionths of a second, so that extremely rapid motion can be arrested.

(3) The flash rate is controlled by an electron-tube circuit, which is capable of giving accurately spaced flashing im-

pulses. Flashing rates can be standardized from external sources for accurate measurements of speed.

(4) Since the object itself is illuminated intermittently, several observers can view it simultaneously. A shutter-type stroboscope is limited to one observer at a time.

The General Radio Company manufactures several stroboscopes based on the designs of Edgerton, Germeshausen and Grier. Three stock models are sold under the trade names, *Strobotac*, a stroboscopic tachometer, *Strobolux*, a high-intensity light source operated from the Strobotac, and *Strobolume*, a high-intensity light source for slow-speed observations. It is not necessary that the room be darkened when using these instruments, since all models provide enough light to override considerable steady background illumination. Descriptions and specifications are given on pages 19, 20 and 21 of this booklet.

QUALITATIVE MEASUREMENTS

An important use of the Edgerton stroboscope is the observation, by stroboscopic light, of moving elements of machines. Motion, to be observed by periodic light flashes, must itself be periodic, either rotating or reciprocating.

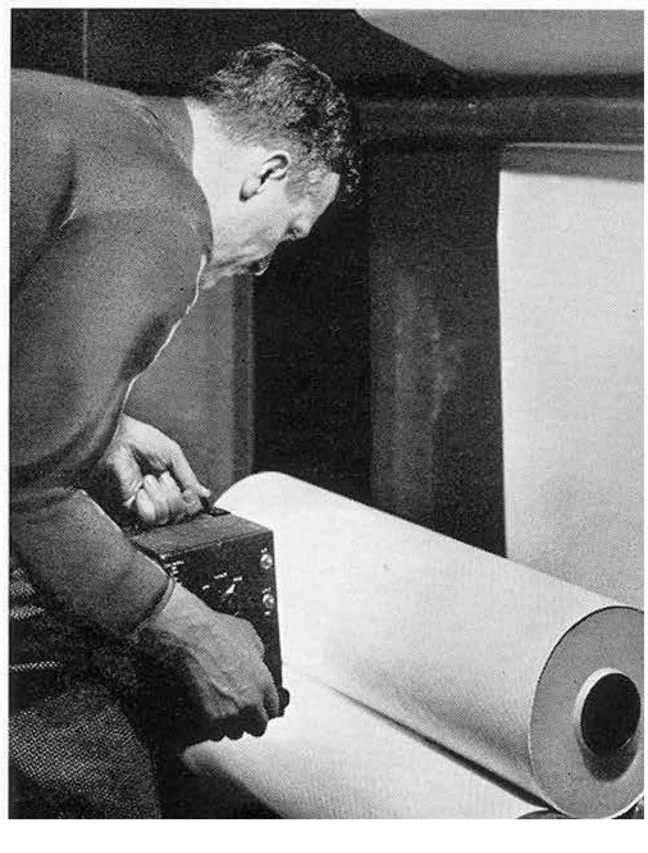
SLOW-MOTION STUDIES

When the flashing rate of the stroboscopic lamp is equal to, or differs only slightly from, the speed of the object under observation, transient motions, vibration, chattering, and other defects of operation can be clearly seen, although the fundamental motion of the object appears to be either completely stopped or very slow. Usually these phenomena do not occur when the machine is operated at slow speeds; they appear only at speeds too high for normal visual observation. Consequently, they can be identified and studied only through the use of the stroboscope. They may be defects in design, the result of faulty construction, or peculiar to the way the machine is operated. Often they can be easily corrected, once their nature is known.

EXTERNAL CONTACTOR

The use of an external make-or-break contactor for controlling the flashing rate of the Strobotac has advantages for some kinds of work. If the contactor is mounted or held on the shaft under observation, the rotational motion will, of course, appear to be stopped. By adjusting the angular position of the contact during revolution of the shaft, i.e.,

FIGURE 3: Photograph courtesy Strathmore Paper Company. With the Strobotac, the repetitive design on this sheet of paper moving at 300 feet per minute can be made to stand still for the inspection of the printed pattern. Inspection is made every three or four minutes without stopping the machine.



by "phasing" the flash, it can be stopped in any position desired, so that phenomena peculiar to any angular shaft position can be studied.

When the rotational shaft motion is stopped by a synchronized contact, transients and harmonics not integrally related to the fundamental speed can be observed. Torsion, whip, secondary oscillations, etc., stand out clearly.

A motor-driven contactor is also useful for slow flashing rates, and for phasing the flash, i.e., adjusting its time within the operating cycle.

QUANTITATIVE MEASUREMENTS

The flashing rate control of the Edgerton stroboscope can be provided with a scale reading directly in flashes per minute, and, when this is done, the instrument becomes a tachometer, whose accuracy depends primarily upon the accuracy and stability of the flashing means.

FIGURE 4: When the Strobotac is held in operating position, the speed scale (shown in inset) is at the top where it can be easily seen by the operator.

The Strobotac, whose scale, for convenience, is calibrated directly in rpm, has a usable accuracy considerably in excess of that of many ordinary tachometers, being better than 1% when locally standardized. The method of standardization is discussed on the next page.

The outstanding advantages, other than accuracy, of the Strobotac for speed measurement are:

(1) that it absorbs no power from the mechanism whose speed is being measured, so that it can be used on low power devices where conventional tachometers would impair operation;

(2) that it can be used to measure the speed of machine elements inaccessible to ordinary tachometers; and

(3) that, because the light flash is very short, extremely fast motion can be arrested without blurring.

These three factors alone open up fields of usefulness for the Strobotac that other types of speed-measuring devices have left untouched.

Small electric motors, delicate mechanisms, and precision devices that slow down or stop when even minute amounts of power are drawn from them operate unimpaired when their speed is measured with the Strobotac. Thus, accurate measurements of speed can be made under normal operating conditions, which are usually the only conditions under which the results have any significance.

In complicated machines, where the

FIGURE 5: Photograph courtesy Continental Machines, Inc. Continental Machines and its associated DoAll Company use the Strobotac in the design of band saws, contour saws, and band filing machines. This photograph shows the Strobotac used in watching the action of a DoAll band saw cutting a slab of transparent plastic to see the cutting action of the saw teeth and to isolate and to analyze vibration.

FIGURE 6: Photograph courtesy Continental Machines, Inc. All DoAll machines are equipped with a Speedmaster Variable Speed Pulley. The Strobotac is used to study the mechanics of the Speedmaster, particularly the effect of various torques in order to detect and to correct excessive slippage and vibration.

part to be measured is in a position completely inaccessible to mechanical contact, a beam of light from the Strobotac can usually be made to reach it, and accurate speed measurements made.

Where the light from the Strobotac is insufficient to overcome background illumination, or where large areas are to be illuminated, the Strobolux can be used.

STANDARDIZATION

The Strobotac operates from a 60-cycle,* a-c power line, and this offers a convenient and reliable means of standardizing the scale. Below the stroboscopic lamp is mounted a small metal reed, which is driven electromagnetically from the power line. This reed vibrates at a frequency of 120 cycles per second, one vibration for each half cycle of supply voltage. Since the stroboscopic light from the lamp shines directly on the reed, a stationary image of the reed is obtained when the reed frequency is equal to, or an integral multiple of, the flashing speed of the lamp. To standardize the Strobotac, the scale is set at 3600 rpm and a trimmer is adjusted until the reed appears to stand still. This is repeated at 900 rpm using another trimmer adjustment. Additional checks at intermediate points can also be made. Usually only an adjustment at the start of a set of measurements and a check at the end are required.

Obviously, the accuracy of the scale when standardized in this way can be no better than that of the power-line frequency but, since the advent of synchronous electric clocks for home use, nearly all power companies hold their line frequencies within very narrow limits, and their accuracy is more than

*Strobotacs for operation at other frequencies can be obtained on special order.

FIGURE 7: Photograph courtesy Remington-Rand, Inc. An application of the Strobotac in modern production testing. Adjusting the cutters of electric shavers for optimum operation.

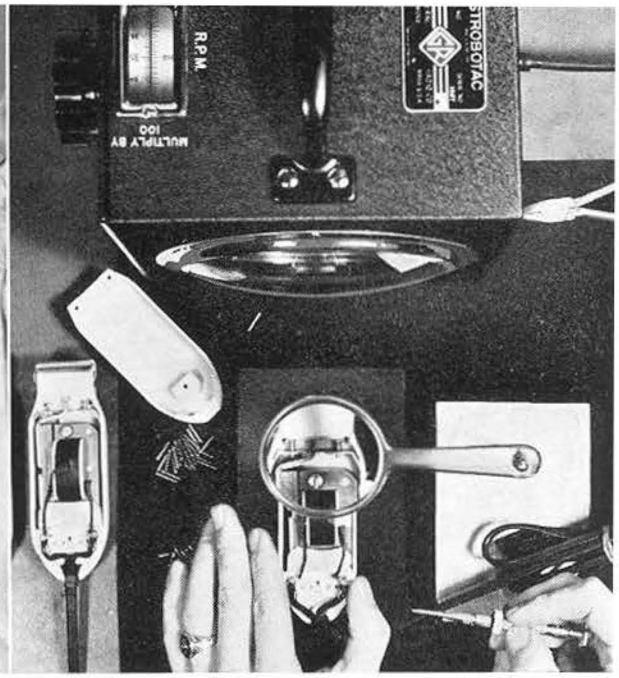


FIGURE 8: Photograph courtesy Remington-Rand, Inc. Looking down on the test set-up of FIGURE 7. The use of the Strobotac facilitates the final adjustment and insures its accuracy.

adequate for speed measurements. The over-all rated accuracy of the Strobotac is 1%, or better, when the scale is standardized in terms of a frequency-controlled power line. Greater accuracy can be obtained over short-scale intervals if more standardization adjustments are made (see page 10).

TYPICAL USES

America's leading manufacturers and users of machines have applied the stroboscope to the solution of hundreds of mechanical problems. Examples taken from their experience are excellent illustrations of the stroboscope's utility.

In the design and manufacture of small motors, for instance, there are many uses for the Strobotac. These fractional horse power motors are used to drive fans, electric mixers, refrigerators, automobile heaters, phonographs, centrifuges, vacuum cleaners, and other low-power mechanisms. Speeds cannot be measured by ordinary means, because the load of a conventional tachometer would alter operating conditions. The Strobotac, because it requires no mechanical or electrical connection to the motor, is the ideal tachometer for this use. Speed can be measured under any driving or load conditions. Speed measurements are made to determine:

(1) Normal operating speed.

(2) Undervoltage and overvoltage characteristics.

(3) Speeds at various conditions of overload and underload.

(4) Torque vs. speed characteristics.

(5) Ratings of speed, torque, input, and load.

(6) Critical speeds where vibration occurs.

By observing the operation of the motor in slow motion, brush action can be studied, and chattering caused by commutator eccentricity as well as vibration of frame and parts can often be detected.

The Strobotac is also used to study the

operation of electric fans. Vibration can be located, and the air currents around the blades can be seen through the use of chemical "smokes" introduced into the air stream. This technique has led to a considerable improvement in fan design. Single-flash photographs are also helpful (see page 15).

Vacuum cleaner design has been another field prolific in uses. Not only the motor, but all moving parts are studied; life tests are made with stroboscopic studies to determine wear, etc. When the cleaner vibrates the carpet, the vibration pattern can be observed.

In industrial maintenance work, the operation of gears, cams, drills, saws, and cutting tools is watched with the Strobotac. Misadjustments, misalignment, wear, sources of noise and vibration, etc., are easily detected before failure of the machines occurs. Governor action, belt slip, lubrication, clearances, and the action of springs can be checked and measured.

Designers of mechanisms find innumerable uses for the stroboscope. A manufacturer of centrifugal clutches determines the precise rotational speed at which the jaws start to open. A maker of pneumatic grinders was able to determine the speed at which the optimum grinding qualities occur. Another interesting application is the study of slip between friction-driven members.

Uses in the automotive industry include studies of spring surge, vibration studies to determine where dampers should be applied, valve spring operation, determination of the effect of flywheel mass on speed variations, studies of piston ring action, and the operation of V-belt drives for generators. The vari-

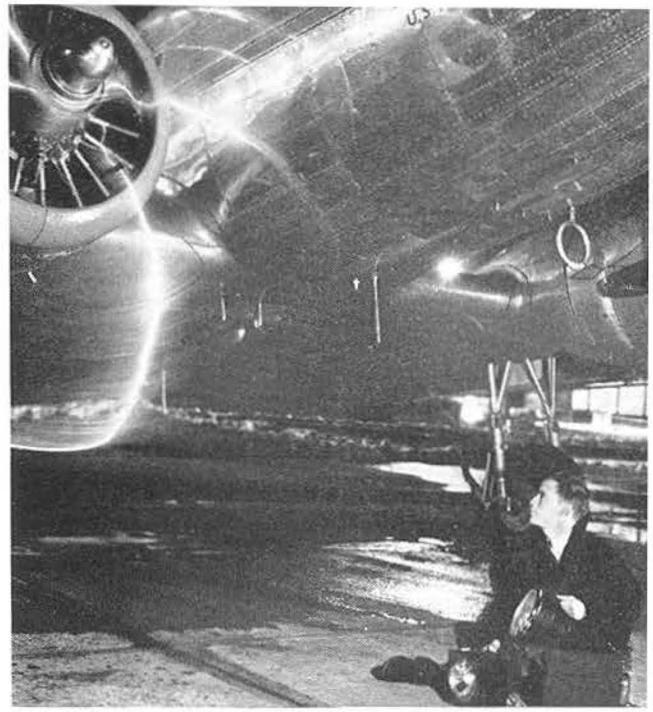


FIGURE 9 (*above*): Photograph courtesy American Airlines. The Strobotac and Strobolux aid the design of propeller counterweights by showing the performance at high speeds by means of the slow-motion effect.

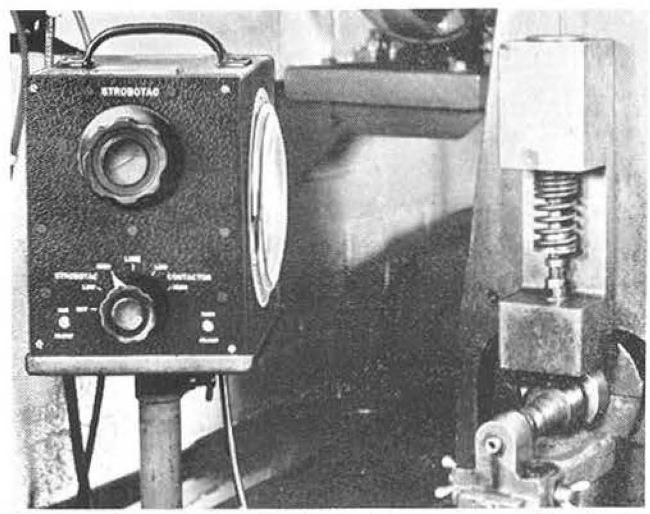


FIGURE 10 (*above*): Photograph courtesy Cleveland Wire Spring Company. Valve spring operation is studied in slow motion with the Strobotac.

FIGURE 11 (*right*): The Strobotac enables the Diesel engineer to study fuel spray from the start to the "full-blown" jet. Defective orifices produce irregular fuel spray, leading to inferior combustion.

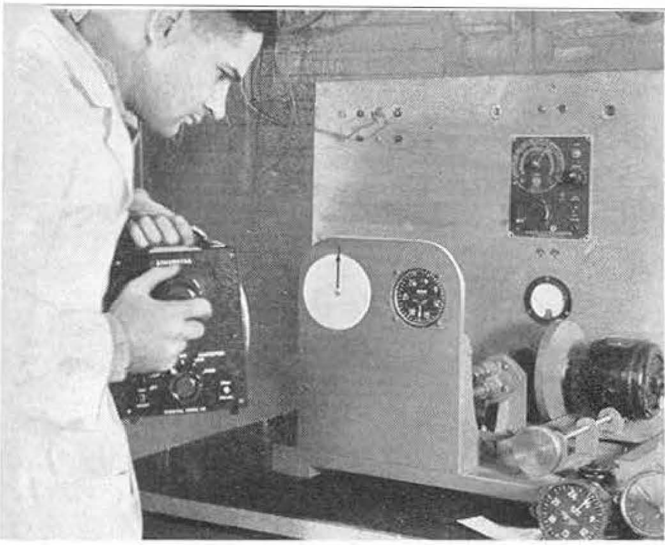


FIGURE 12: Photograph courtesy Intercity Air Lines. Checking an aircraft tachometer with the Strobotac, a simple and accurate method of making an important test.

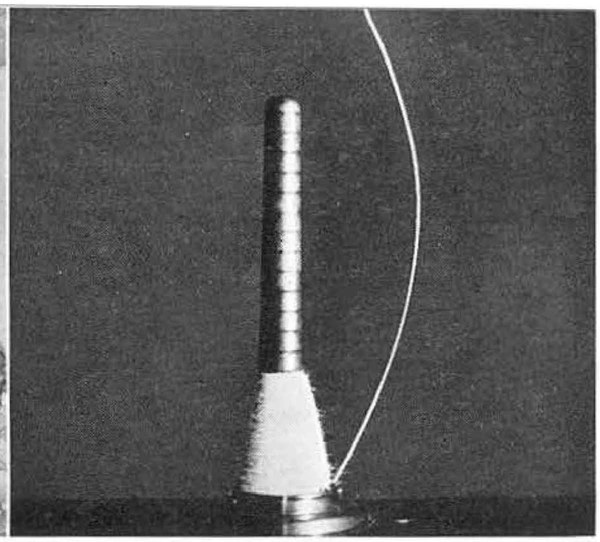


FIGURE 13: Photograph courtesy H. E. Edgerton. When a cotton yarn spindle is viewed with the stroboscope, the "balloon" stands out clearly so that its exact shape can be seen. A single-flash photograph.

ous reciprocating parts of an internal combustion engine can be illuminated for study when the stroboscope is flashed from a contactor on the crankshaft. For studying the action of pistons and other enclosed parts, a window in the side of an experimental engine is ordinarily used.

The textile industry has found uses for the Strobotac that lead to direct savings in production costs and a definite decrease in rejected product. Cards, pickers, spinning frames, looms, ring travelers, and rayon buckets can be adjusted for more efficient operation by means of the stroboscope. Keeping spindles at uniform and at correct operating speed assures maximum production and uniform product. The Strobotac has been widely used in mills for this purpose.*

Designers and manufacturers of textile machinery use stroboscopes as an aid to design.

Radio manufacturers have found the stroboscope valuable in adjusting power-supply vibrators. Both frequency and amplitude of vibration can be measured. Another application is found in the design of loudspeakers. Voice coil clearance, spider flexing, and cone performance are all susceptible to stroboscopic measurement. Vibration tests on aircraft receivers are facilitated. The vibration table is made to stand still under the stroboscopic light, and unwanted vibration can then be observed. Manufacturers of relays and other aircraft instruments and parts also use the Strobotac for vibration tests.

One public utility company found that the progress of grinding commutators on electrical machines could be watched by means of the Strobotac without shutting down the machine. Commutator and brush action studies in generators have been made. Several utilities have found that the Strobotac is useful for reading numbers or other identification marks on rotating machine parts without shutting down the machine.

Measurements of the power angle and the torque angle of synchronous electrical machines are made by stopping the rotor motion stroboscopically and observing the displacement of the rotor as the load is applied.

A number of uses have been found in the printing industry, including the checking of register and the accuracy of cutting and punching.

*For a complete discussion of the uses of the Strobotac in the cotton textile industry, see "Intelligent Use of the Strobotac," by Raymond W. Mitchem, *Textile World*, October, 1942.

EXTENSION OF RANGE

High Speeds

Although the fundamental speed range of the Strobotac (600 to 14,400 rpm) covers the majority of speed-measuring problems, speeds above and below this range can be measured through the use of multiple relationships, as shown in FIGURE 1 (d).

Measurement of speed above 14,400 is simple. If the speed to be measured is, say, 50,000 rpm, the Strobotac can be set at any integral submultiple of 50,000, that is, at 50,000 ÷ 4, 50,000 ÷ 3, or 50,000 ÷ 2 rpm, and a single image will be seen. The illumination of the subject will, of course, be reduced, because, at 50,000 ÷ 4 or 12,500 rpm, the subject is illuminated only once in 4 revolutions, and consequently the average illumination is only one-fourth that obtained when the subject speed and the lamp speed are equal.

The calculation of the speed from submultiple scale settings is not difficult. Let R be the speed of the shaft or other element to be measured. Let F_1 be the highest Strobotac reading at which a standstill single pattern is obtained. Let F_2 be the next lower setting for a similar pattern. Then

$$R = nF_1 = (n+1)F_2$$

where n is the harmonic number for the first setting.

$$\text{Then } n = \frac{F_2}{F_1 - F_2}$$

$$\text{and } R = nF_1$$

In making the measurement, F_1 need not necessarily be the highest setting at which a stationary pattern can be obtained, but the higher F_1, the greater the difference $F_1 - F_2$, and consequently the more accurately it can be determined.

Speeds up to 100,000 rpm can be measured easily by this method, if care is taken. Higher speeds are possible and the upper limit is determined usually by the local conditions.

Low Speeds—the *Strobolume*

The measurement of speeds below 600 rpm is a more difficult problem. The limitations are not so much in the Strobotac as in the human eye. That property of the eye known as persistence of vision results in the retention of images on the retina for an appreciable fraction of a second. When the rate of repetition of successive images is above about 15 per second, the eye creates the illusion of continuous motion. This phenomenon is the basis of not only stroboscopic work, but also ordinary motion pictures.

The lower speed limit of the Strobotac, 600 rpm, is somewhat below the speed at which flicker is observed. At 600 rpm, and below, flicker is readily observable, and a darkened room is usually necessary so that the eye will not follow the motion of the subject between flashes. A special model of the Strobotac, TYPE 631-BL, is available for this application and has an extra low-speed range of 60 to 1440 rpm.

For best results under general lighting conditions, however, the TYPE 1532-A Strobolume should be used. This powerful low-speed light source gives a brilliant, intense light flash that overrides background lighting and impresses a sharp image on the eye. With the Strobolume, such relatively low-speed mechanisms as printing presses, loom shuttles, packaging machines, and heavy grinding and crushing machinery can be successfully watched in slow motion.

The Strobolume is flashed from the Type 631-BL Strobotac or from a contactor.

For many applications, a contactor is desirable as a flashing source. In observing the motion of loom shuttles, for instance, the contactor, closing an electrical circuit once per revolution, can be attached to the main drive shaft of the loom. By means of a control mounted on the contactor head, the time of flash can be set at any angular position and the position of the shuttle with respect to the angular position of the shaft can be determined.

The General Radio Type 1535-A Contactor is designed for this purpose and for easy and convenient attachment to the shaft.

ADDITIONAL SCALE STANDARDIZATION

As previously mentioned, the scale of the Strobotac can be standardized at a number of points besides 900 and 3600, and, when greater accuracy than 1% is required over narrow ranges, a few points in the vicinity of the desired speed can be spotted by means of the reed and a scale correction applied. When this is done, the accuracy over a small range is essentially that with which the scale can be read. Multiple reed images are obtained at many points but, because of the difficulty of interpreting complicated patterns directly, it is recommended that only single- and double-image patterns be used. Single-image points are obtained at scale readings of $\frac{7200}{n}$, where n is an integer. Double-image points are seen at speeds of $\frac{7200 \times 2}{n}$, where n is an odd integer. A table in the instruction book supplied with the Strobotac lists the single- and double-image points between 600 and 3600 rpm.

USE OF STANDARD SPEED DISC

Another convenient method of speed standardization uses a synchronous motor, on whose shaft is mounted a disc carrying a spot near its edge. For best results, a black spot on a white disc, or white on black, should be used. A table of patterns and corresponding speed ratios is given in the instruction book for the Strobotac for a motor speed of 1800 rpm. This method, like the reed method, is accurate to the limits with which the scale can be read, if the power-line frequency applied to the synchronous motor is controlled.

Precise speed measurements involving the use of several standardization points over a small speed range are often required in calibrating or testing instruments. Among these uses is the calibration of aircraft tachometers under CAA Specifications.

SPECIALIZED TECHNIQUES

Special techniques are often helpful in stroboscopic work. An example is the use of a window set in the enclosure housing a fan, engine, pump, compressor, turbine, or other enclosed mechanism. Manufacturers of air conditioning equipment have used this technique to measure the speed and to observe the characteristics of fans in ventilating ducts, where opening the duct would alter the operating conditions. The study of piston ring performance is also carried out by means of a window. An interesting

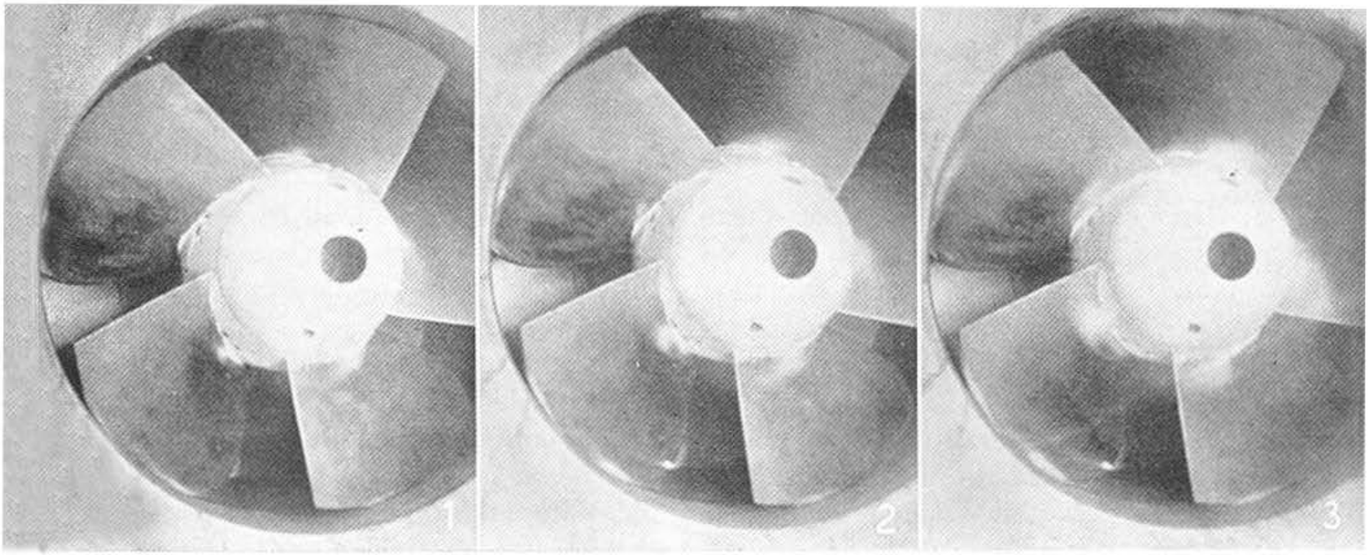


FIGURE 14: Photograph courtesy Baldwin Southwark Division, Baldwin Locomotive Works. Stroboscopic photographs of cavitation in hydraulic turbine runners. Cavitation, shown by the cloudy areas, indicates eventual pitting of the blades and decreases over-all efficiency.

example of the window technique is provided by the work on cavitation of turbine wheel blades carried out at the I. P. Morris Department, Baldwin Southwark Division, The Baldwin Locomotive Works. Cavitation results not only in a loss of efficiency, but also in serious pitting of the metal blades. In the past, cut-and-try methods have been used to eliminate or reduce cavitation, but stroboscopic methods have now provided a quantitative solution to the problem.

A sketch of the apparatus is shown in FIGURE 15 and a photograph showing the cavitation areas is reproduced in FIGURE 14. Photographs were taken by firing the Strobolux from a contactor mounted on the turbine shaft.*

When parts are so inaccessible as to require the Strobotac to be placed some distance from the object, thereby greatly diminishing the available light, painting the parts to give black-and-white contrast is sometimes helpful, as is reducing the background lighting.

Displacements in vibrating parts can often be measured accurately with the aid of a microscope and cross hairs. This technique has been used by auto-

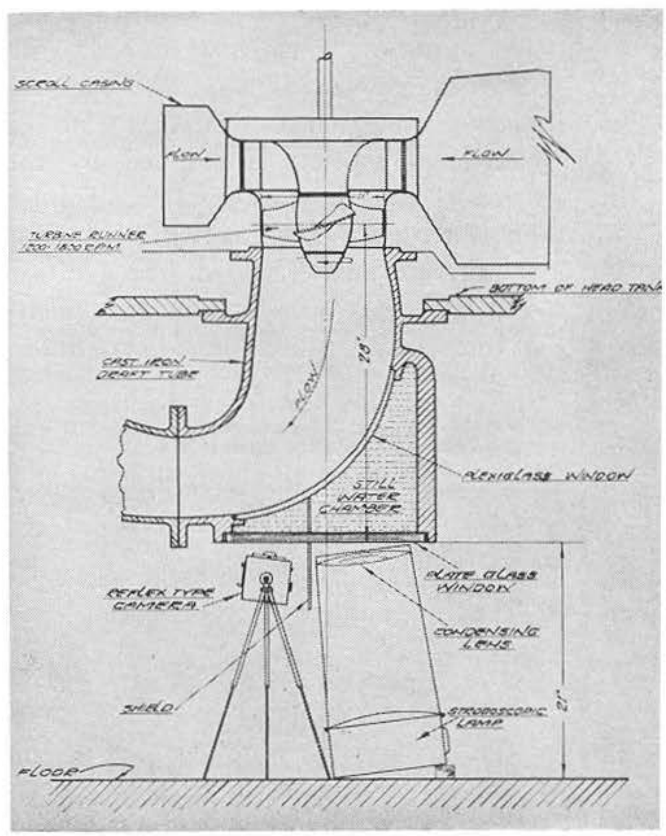


FIGURE 15: Courtesy Baldwin Southwark Division, Baldwin Locomotive Works. Sketch of the apparatus used to obtain the cavitation pictures of FIGURE 14. The still-water chamber is used to avoid severe distortion of the image.

*For a complete discussion of the measurements, see R. E. B. Sharp, "Cavitation of Hydraulic Turbines," *A.S.M.E. Transactions*, October, 1940, and K. W. Beattie, "Cavitation Study," *Baldwin Southwark*, September, 1940.

motive engineers in measuring crankshaft whip and vibration.*

In addition to the more obvious uses of the stroboscope involving either speed measurements or simple slow-motion observation, extensions of the fundamental technique will occur to the experienced user.

Among these is the measurement or study of what might be termed secondary motions. An example of this is transient or vibrating motions in springs, unrelated to the fundamental motion. If a coiled spring vibrating in simple harmonic motion is "stopped" stroboscopically, parasitic motions can then be seen.

Another arrangement provides a simple torque meter. If two shafts are connected by an elastic coupling and the rotational motion is stopped by the stroboscope, the position of a pointer on the spring coupling will change as the driven shaft is loaded. The addition of a scale makes possible measurements of torque. Other measurements of differential displacement can be made by a similar procedure.

*M. M. Roensch, "Measurements of Crankshaft Whip and Vibration," *Instruments*, April, 1933.

This principle was used by a manufacturer of tachometers to measure the power dissipated in the tachometer gears.

FIGURE 16 shows a brass tube about 15 inches long, coupled to the motor shaft at one end while the other end runs in a bearing and carries a drum-type dial. Within this tube is a straight length of 0.037-inch steel piano wire, rigidly attached at the motor end and fixed at the other end to a small shaft that turns freely in a bearing within the end of the tube. This shaft carries a small drum with an index mark on its periphery which indicates the angular displacement against the scale on the adjacent dial attached to the brass tube. The short shaft then passes through the outer bearing and a coupling to the rotating member on which the power loss is to be measured. Thus it is seen that when the motor is stationary, manual rotation of the output coupling shaft results in rotation of the index dial as the piano wire is twisted against its restoring torque.

When the motor is started, the acceleration puts a high torque on the wire, which might be broken except that the index dial has its motion with respect to the other dial limited to 180° by means of stop pins. The load is driven directly, therefore, when starting or stopping. Under running conditions, however, the Strobotac is adjusted to give a stationary image of the dials, and the position of the index with respect to the dial marked in degrees of arc is readily observed.

FIGURE 16. Close-up of the torque meter. The two drum dials, one carrying an index, the other a scale, are shown between the two vertical supports. Photograph courtesy Barbour Stockwell Company.

The torsion meter is easily calibrated in a stationary condition by comparing applied torques on the output shaft to resulting dial readings. The results should give a linear curve. Power measurements are then made by observing, with the Strobotac, the reading of the torsion dial and the speed of rotation. Calculation of power from the product of torque and speed is then a simple matter.

The equipment illustrated has been used to measure power losses as small as 0.003 horsepower at speeds of 600 rpm, with an accuracy of $\pm 5\%$. With smaller equipment using a finer wire, there seems to be no reason why this arrangement cannot be used for measuring very much smaller amounts of power.

An ingenious application of the Strobolux has been made in conjunction with a shadow projector type of contour comparator. Small irregularities in the moving parts of a flyball tachometer were being measured under static conditions with the comparator, when it occurred to the engineers working on the project that an investigation under dynamic conditions could be made with stroboscopic light. To accomplish this, the incandescent lamp in the comparator was replaced by the Strobolux,

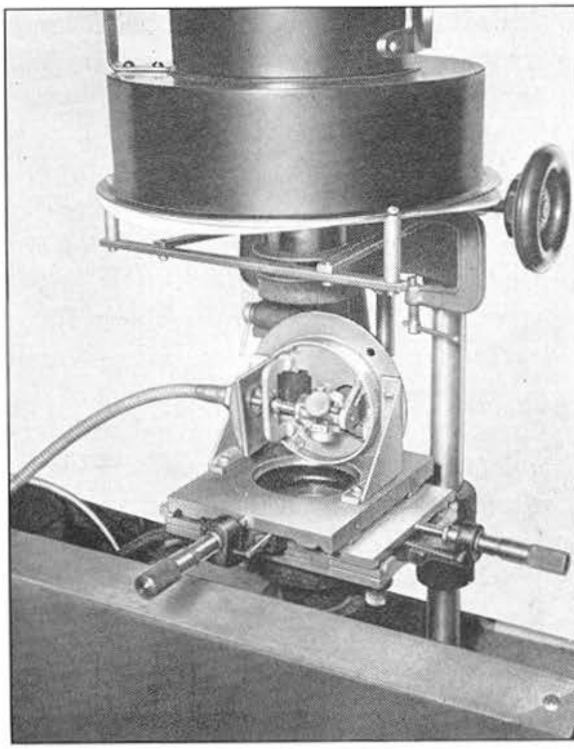


FIGURE 17. View of the tachometer mounted in the contour comparator with Strobolux lamp above. Photograph courtesy Barbour Stockwell Company.

which was flashed at a rate slightly slower than the rotational speed of the tachometer. The irregularities at normal operating speeds proved to be somewhat different from those at slow speeds.

It was found possible to measure the unwanted motions and to improve the performance of the tachometer by setting proper production tolerances.

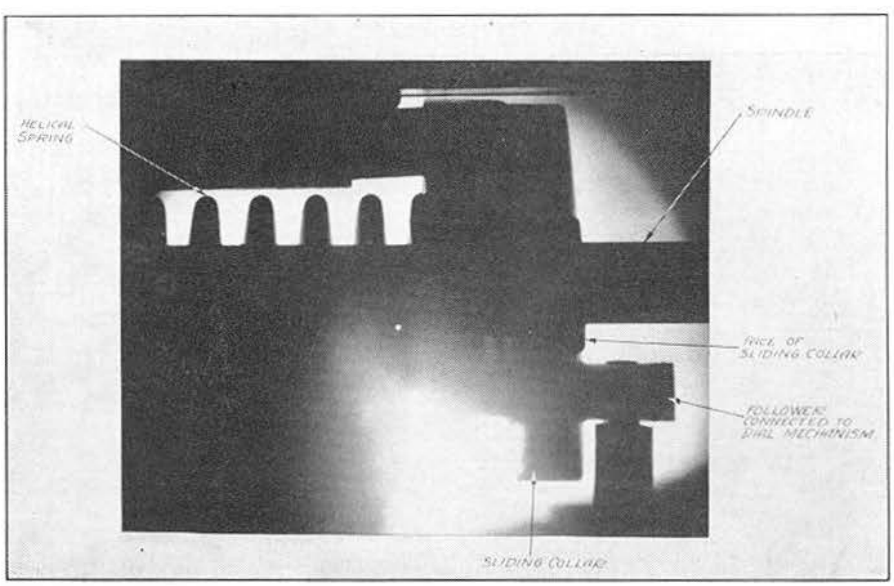


FIGURE 18. View of the image appearing in the ground glass screen of the comparator.

FIGURE 17 shows the Strobolux lamp installed in the shadow comparator, and the image seen on the ground-glass screen is reproduced in FIGURE 18.

An interesting example of the application of this technique is provided by the time-signal recorder in the General Radio laboratories. Here, a primary standard of frequency operating a 1000-cycle synchronous clock is operated continuously. To provide a check of the operating frequency at convenient intervals, the clock reading is compared with standard time as transmitted by radio from the U. S. Naval Observatory in Washington. The clock, in addition to the conventional dial reading in hours, minutes and seconds, is provided with a second dial carrying two hands, one of which rotates once a second, and the other ten times a second. The clock faces are shown in FIGURE 19. To read these two rapidly-moving hands, a stroboscopic lamp is flashed by a pulse from the received time signal. Since the time signal pulses come at one-second intervals, only a few pulses are necessary to register the reading on the eye. A precision of reading of two ten-thousandths of a second (0.0002 second) is possible by this method.

The same principles could obviously be applied to timing falling bodies, projectiles, and other moving objects.

Ingenious methods have been devised by a number of investigators to suit their own particular problems. Among these applications are the dynamic balancing of rotors, the rating of clocks and watches, and the calibration of watt-hour meters. One of the most interesting is that used by Professor Philip Bucky of the School of Mines, Columbia University, for problems in structure by means of small scalar models. By increasing the pull of gravity on the model in the same proportion as the linear dimensions have been decreased, unit stresses in the model and the structure are made identical and the displacement at any point on the model represents to scale the displacement of a corresponding point on the prototype. To simulate the increased pull of gravity, the model is spun in a centrifuge so that the centrifugal field is substituted for the gravitational field. To observe and to photograph displacements a stroboscope is used, flashing once each revolution of the centrifuge.

The stresses in transparent plastic models have also been studied in the centrifuge by means of polarized stroboscopic light.

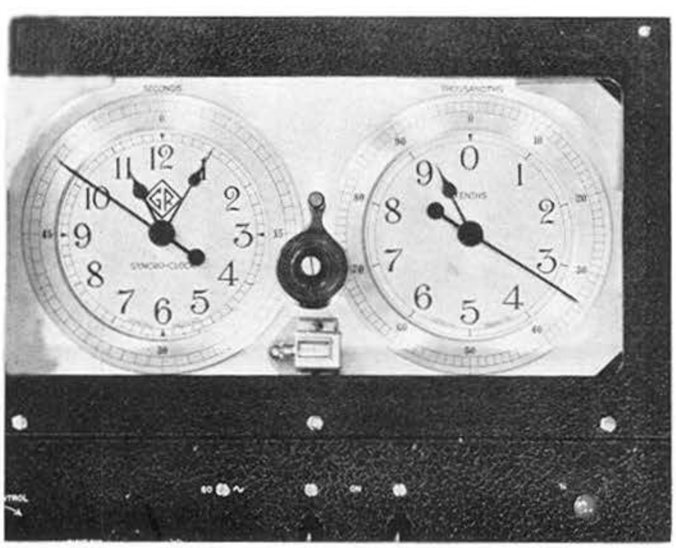


FIGURE 19: Photograph of the dials of the five-handed clock on which readings are taken by stroboscopic flashes in the General Radio laboratories.

PHOTOGRAPHY

Stroboscopic photography makes possible the recording of machine operations in slow motion for records or for detailed analysis. Movies of the apparent slow motion of rotating or reciprocating mechanisms can be made with a stroboscope (such as the Strobolux) and an ordinary movie camera. Similarly "still" photographs can be taken when the pattern or machine element appears to be stationary. Movies taken in this way are, as a rule, not particularly useful for engineering purposes, except as they may give a record of a condition which is temporary and difficult to reproduce, or is too unstable for direct visual analysis.

Still photographs made by the light from repeating flashes depend, of course, on the viewed object having no random variations in speed or configuration. An outstanding example of this type of photography was carried out by engineers of Baldwin Southwark, Inc., in connection with the studies of cavitations in hydraulic turbine runners, described on page 11. These photographs, taken under the most difficult of working conditions, show what can be accomplished by ingenuity and patience.

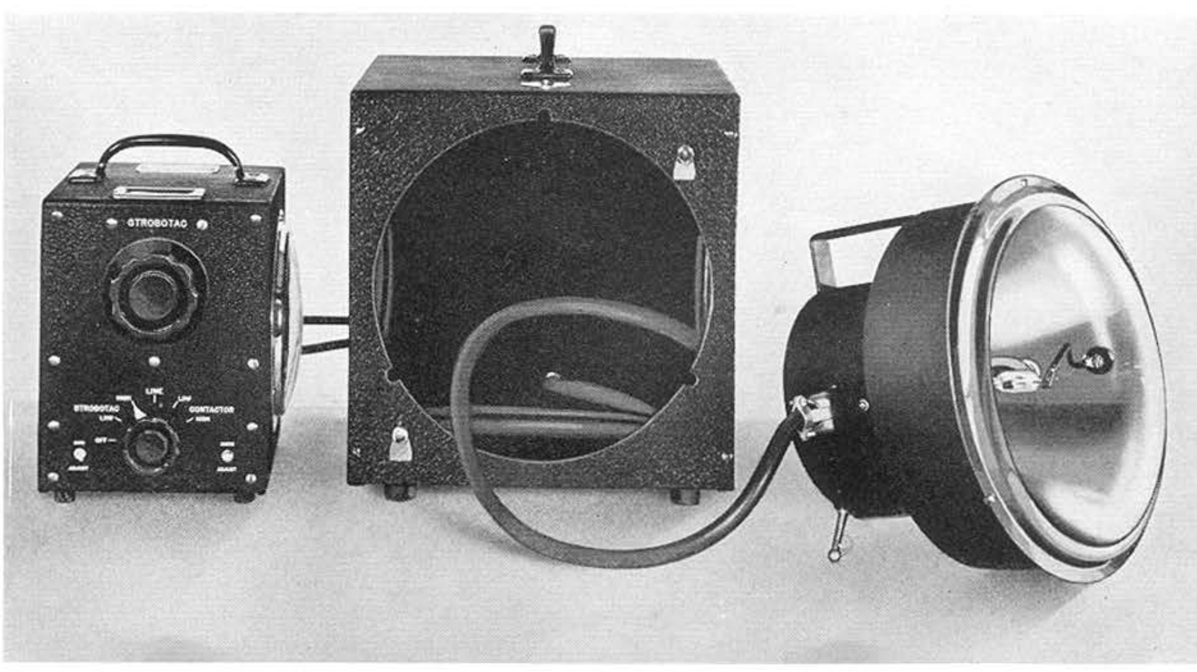
SINGLE-FLASH PHOTOGRAPHS

Single-flash photography by means of a stroboscopic lamp has many applications in engineering work. The yarn balloon of FIGURE 13, the loom shuttle of FIGURE 22 are both examples of this technique. They provide a record of the instantaneous position of machine elements that can be studied and analyzed at the engineer's convenience. Motion need not be repetitive for this type of photography, many examples of which have appeared in the press by Gjon Mili and others.*

While the Strobotac, Strobolux, and Strobolume are intended primarily for visual observation of mechanical phenomena, these instruments can be used quite successfully for taking single-flash pictures when the area to be illuminated is relatively small. The Strobolux when used for single-flash work supplies about ten times as much light as it does when flashed continuously from the Strobotac. The duration of a single flash from the Strobolux is about 1/30,000th second.

*See also the collection of striking single-flash photos taken by Edgerton, Germeshausen, and Grier in the book, *FLASH*, published by Hale, Cushman, and Flint.

FIGURE 20 (*below*): TYPE 631-B Strobotac and TYPE 648-A Strobolux. The Strobolux lamp is supplied with a 10-foot extension cable and can be removed easily from its case.



When single-flash pictures are to be taken over an area not exceeding approximately two feet square, and when the motion to be photographed can be stopped in not over 1/30,000th second, the Strobotac and the Strobolux can be used quite satisfactorily. Where more light is required, the xenon-lamp Strobolume, which furnishes 10 times as much light, should be used.

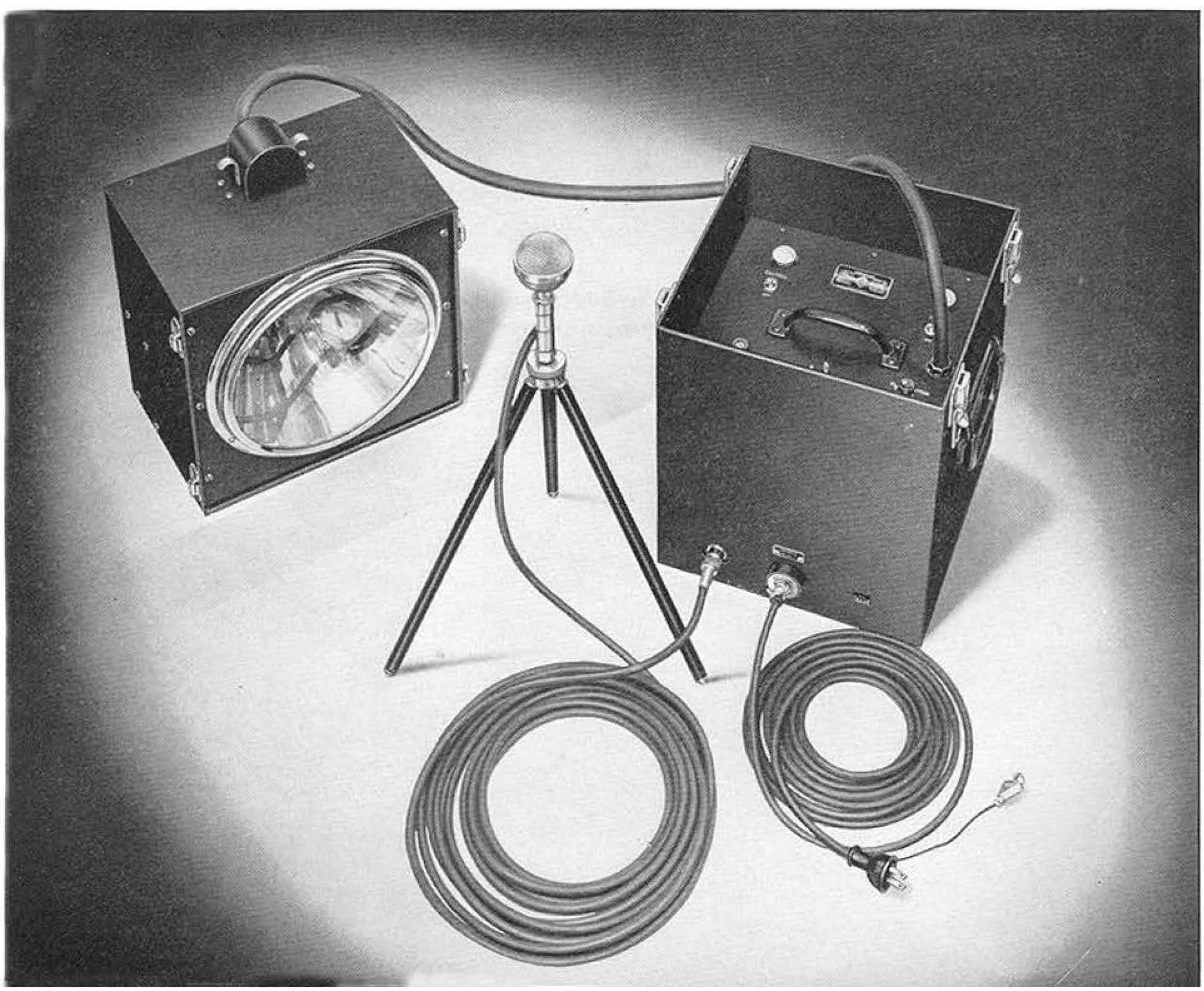
For applications where very short exposure is necessary in order to stop extremely fast motion, a specially designed light source, called the Microflash, is available. The flash duration of this lamp is of the order of one or two millionths of a second. It has been used successfully in photographing projectiles in flight and the propagation of fractures in materials.

The principal problem in high-speed, single-flash photography is the synchronization of the flash with the opening and closing of the camera shutter.

There are a number of satisfactory methods of tripping the flash. For the Strobolux, the tripping circuits are in the Strobotac, and the two instruments must be used in combination. A make-or-break contact is the simplest tripping mechanism, and several ways in which the contact can be synchronized are given in the captions to the photos. Since the Strobolume can be flashed directly by a single electrical contact, the Strobotac is not necessary. FIGURE 23 is an example of Strobolume photography.

The Microflash will trip satisfactorily with any of these methods and in addition it is equipped with a microphone and built-in amplifier for tripping

FIGURE 21: View of the Microflash set up and ready for operation.



by the sound associated with the phenomenon to be photographed, as, for instance, the explosion of the cartridge in bullet photography.

MULTIPLE-FLASH PHOTOGRAPHS

Often, rather than a single-flash photograph, several images of a nonrepeating sequence of operations is desired. For simple subjects, several flashes recording the scene on a single plate or film are satisfactory and may be better for the purpose than motion pictures. A familiar example is the golf club photograph of FIGURE 26, although there are many applications in engineering work.

The technique of multiple-flash photographs is similar to that for single flashes, except that the firing means is arranged to give a series of flashes. Means must also be arranged to initiate and to end the flashing sequence.

The moving object should preferably be white and the background black, in order that successive images of the object be registered on practically unexposed portions of the film. Each new image will then be registered as clearly as the preceding ones.

Multiple-flash photographs have the advantage of giving a complete record of a sequence of motion on a single film. From such a record motion analyses can be made, and plots of displacement, velocity, and acceleration can be drawn.

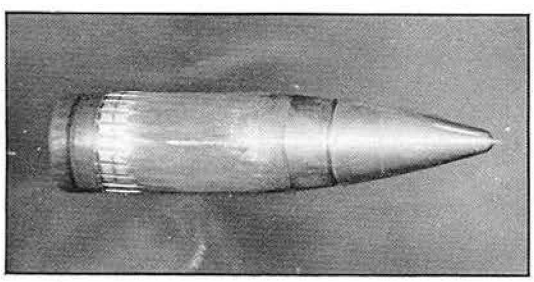


FIGURE 22 (*above*): Microflash photo of a projectile in flight. Courtesy Combined Inspection Board of the United Kingdom and Canada.

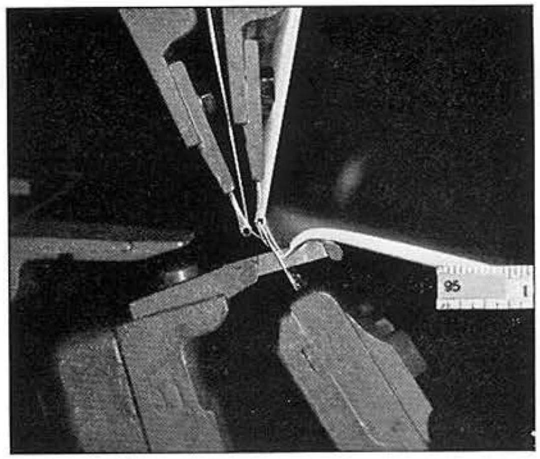


FIGURE 23: Strobolume photograph of a warp knitter in operation.

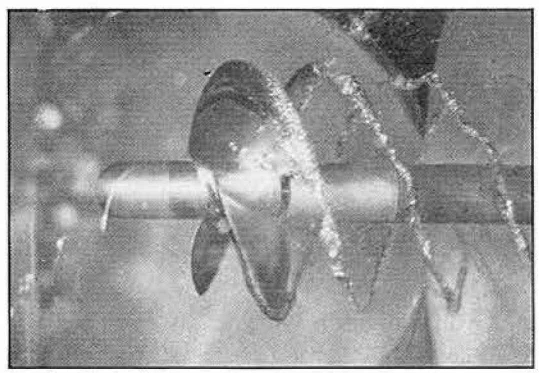
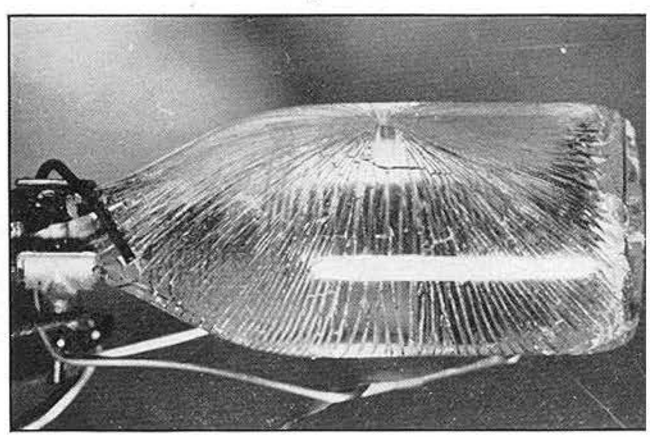


FIGURE 24: Microflash photo of a cavitating model propeller under test in a water tunnel. Courtesy David Taylor Model Basin, U.S. Navy.

FIGURE 25 (*below*): Fracture of an experimental bottle under a water pressure of 520 pounds per square inch. The fracture started at the center of the radiating pattern. The Microflash was tripped by a crystal phonograph pickup with needle bearing against the glass. Courtesy Hartford Empire Company and H. E. Edgerton.



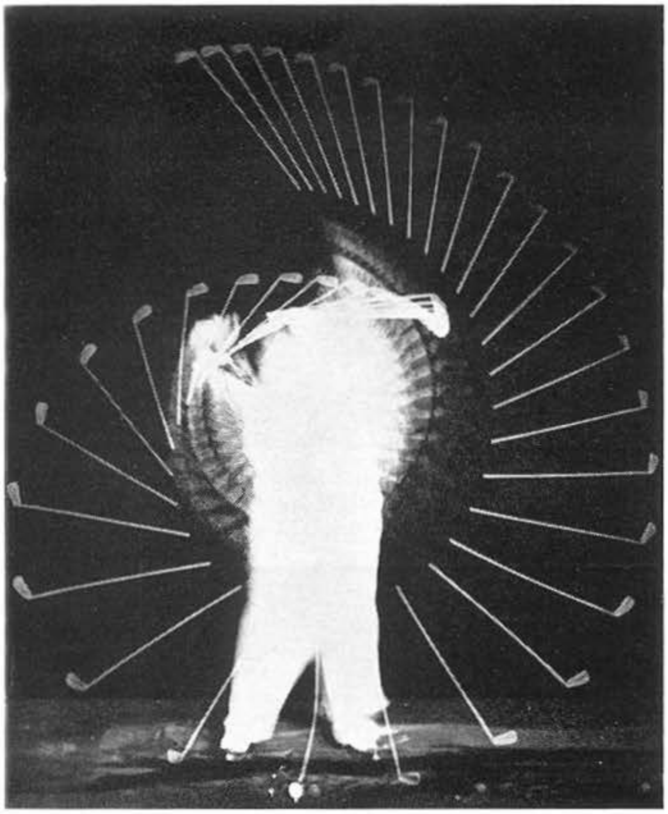


FIGURE 26: Photograph courtesy H. E. Edgerton. Multiple-flash photograph showing the pattern made by a golf club as it moves through the stroke.

ULTRA-HIGH-SPEED MOTION PICTURES

For the detailed analysis of non-cyclic motion, or motion in which the cycle is too long to be observed visually with the stroboscope, the continuous film camera in conjunction with the power stroboscope offers a ready solution.

The power stroboscope, as its name implies, is a high-power unit. It is capable of producing flashes at speeds up to 1500 *per second* or 90,000 per minute. Consequently, the energy per second, or power, that must be supplied to the lamp is many times greater than that of slower-speed units.

The camera used with this equipment has no shutter, the length of exposure being regulated entirely by the length of the stroboscopic flash. Framing the photographs for projection is accomplished by means of a commutator mounted on the sprocket which flashes the lamp once for each frame of travel of the film. Although the film is moving continuously, no blur results, because the film travel during the short flash is negligible.

Means are provided in the camera for focusing the lens on the object and producing a timing record on the film.

Motion pictures taken in this way at a speed of 1500 frames per second can be projected at the standard rate of 16 per second, giving a reduction in apparent speed of approximately 100:1, or they can be analyzed frame by frame and the results plotted as shown in FIGURE 27.

As with other types of stroboscopic photography, best results are obtained if the subject is prepared for maximum contrast and absence of mirror surfaces.

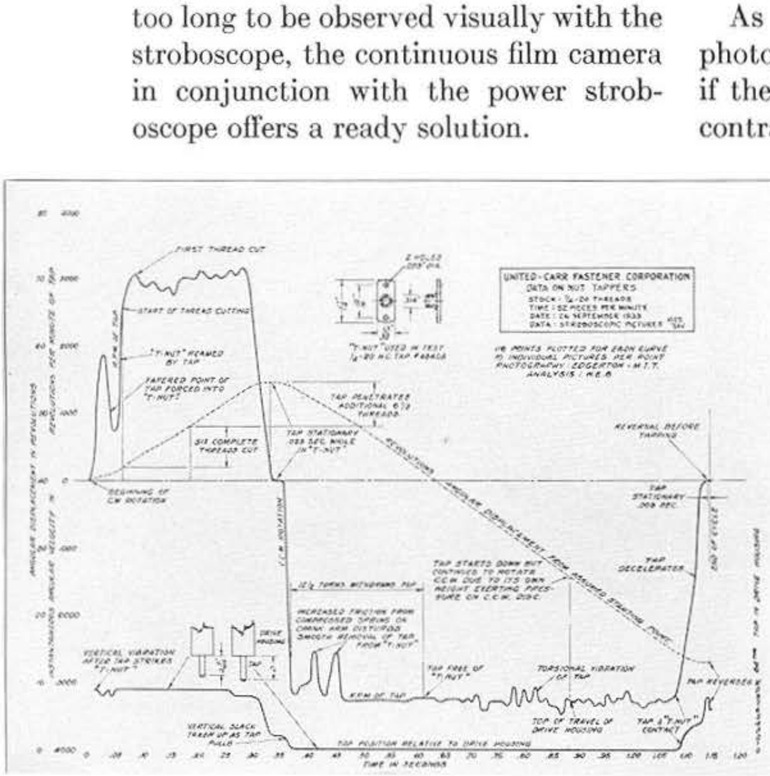


FIGURE 27: Courtesy United-Carr Fastener Corporation. Plot of the data obtained from a high-speed motion picture record of an automatic nut tapper. This type of analysis is usually more useful than are the actual photographs, since irregularities and defective operation are made evident at a glance.

TYPE 631-B STROBOTAC

Description: The Strobotac is a small, portable stroboscope. The light source is a Strobotron neon lamp mounted in a parabolic reflector. The frequency of a vacuum-tube relaxation oscillator determines the flashing speed which is varied manually and indicated on a direct-reading dial. The speed control is provided with a slow-motion drive to facilitate precise settings. If desired, the flashing speed can be controlled by an external contactor or by the a-c line frequency.

The Strobotac is small and light in weight. Controls are arranged so that the instrument can be held in the left hand, while the flashing speed control is varied with the right. Speed is read directly from a drum-type scale at the top of the instrument when held in the position of normal use.

When a larger area is to be illuminated, or sufficient light for some types of photography is required, the Strobotac can be used to control the flashing speed of the Type 648-A Strobolux.

Type 631-BL is a special model, which has an additional range of 60 to 1440 rpm, selected by throwing a switch. Calibration accuracy is not guaranteed for this model.

SPECIFICATIONS FOR TYPE 631-B

Range: The fundamental range of flashing speed is from 600 to 14,400 per minute. The speed is read directly from a scale graduated in rpm. By using multiples of the flashing speed, the range of measurement can be extended above 50,000 rpm and, by multiple images, speeds somewhat below 600 rpm can be measured.

Accuracy: $\pm 1\%$ of the dial reading above 900 rpm when the Strobotac is standardized in terms of a frequency-controlled power line. Controls for this standardization adjustment are included.

Duration of Flash: Between 5 and 10 microseconds.

Lamp Life: The Type 631-P1 Strobotron Lamp is guaranteed for 250 hours of operation if used at flashing speeds below 5000 per minute, and for 100 hours if used at higher speeds, with both of these guarantees limited to 60 days after date of shipment from our plant. Replacement lamps can be supplied. See price list below.

Power Supply: 115 volts, 60 cycles. Prices for operation from lines of other voltages and frequencies will be quoted on request.

Power Input: 25 watts.

Vacuum Tubes: One Type 631-P1 Strobotron, one 6X5-type, and one 6N7-type are required. A complete set of tubes is furnished with the instrument.

Mounting: Aluminum case with carrying handle. Cord and plug for connection to the power line are included. Complete operating instructions are furnished.

Dimensions: $7\frac{1}{2}$ x $8\frac{3}{4}$ x $9\frac{7}{8}$ inches, overall.

Net Weight: 10 pounds.

Type		Code Word	Price
631-B	Strobotac	BRAVO	$125.00
631-P1	Replacement Lamp	SENNA	6.25
631-BL	Strobotac with extra low-speed range	BRUIN	155.00

TYPE 648-A STROBOLUX

AUXILIARY LIGHT SOURCE FOR USE WITH STROBOTAC

Description: The Strobolux extends the usefulness of the Strobotac to applications requiring considerably more light than the Strobotron lamp is capable of supplying. Specifically, it should be used where larger areas are to be illuminated, where photography is required, and on brightly lighted areas.

The Strobolux consists of a power supply and gas-filled lamp, capable of producing about 100 times as much light as the Strobotac. The flashing source is a Type 631-B Strobotac. The duration of flash is sufficiently short to permit single-flash photographs of small objects moving at extremely high speeds.

The entire assembly is housed in a metal cabinet, including the lamp and its 9-inch reflector. The lamp is removable and is furnished with a 10-foot extension cable.

SPECIFICATIONS

Range: Up to 100 flashes per second (6000 per minute). Single flashes for small area photography can also be obtained.

Accuracy: The accuracy is that of the source controlling the flashing speed. See specifications for Type 631-B Strobotac.

Duration of Flash: 10 to 15 microseconds at normal speeds; about 30 microseconds for single flashes and low speeds.

Lamp Life: The expected life of the Type 648-P1 Lamp is about 100 hours when operated intermittently at moderate flashing speeds. Replacement lamps can be supplied. See price list below.

Power Supply: 115 volts, 60 cycles. Prices for operation from lines of other voltages and frequencies will be quoted on request.

Power Input: 150 watts, maximum.

Vacuum Tube: One 5Z3-type vacuum tube and one 648-P1 lamp are required. Both are supplied with the instrument.

Accessories Required: Must be used with a Strobotac.

Mounting: The complete assembly is housed in a sheet metal case. The detachable lamp and its 9-inch reflector are mounted in one side, the power supply in the other. Cables for connection to the power line and to the Strobotac are supplied, together with an instruction book.

Dimensions: 13 x 11⅛ x 13⅛ inches, overall.

Net Weight: 25 pounds.

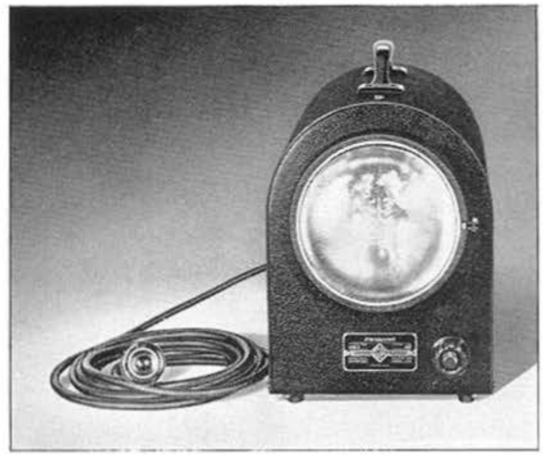
Type		Code Word	Price
648-A	Strobolux	SCALY	$205.00
648-P1	Replacement Lamp	SURLY	17.50

TYPE 1533-A HIGH-SPEED MOTION PICTURE EQUIPMENT

Space does not permit a description of this equipment here, but specifications and prices will be furnished on request.

General Radio Stroboscopes are licensed under designs, patents, and patent applications of Edgerton, Germeshausen, and Grier, including the following U. S. Patents: 2,185,189; 2,201,166; 2,302,690; 2,331,317; 2,201,167, and also under Patent No. 1,790,153 and other patents covering electrical discharge devices.

TYPE 1532-A STROBOLUME



Description: The Strobolume is a high-intensity light source for low-speed stroboscopic observations at relatively low speeds. Two important examples are the analysis and adjustment of shuttle motion in looms and of register in printing.

The Strobolume can be flashed from an external contactor, and hence is particularly useful where the motion to be examined is related to angular position of a shaft, such as a crankshaft, camshaft, or countershaft, on one end of which a contactor is held or clamped. It can also be flashed from a TYPE 631-BS18 Strobotac. The high intensity and short duration of the flash make the Strobolume adaptable as a light source for single-flash photography in research projects, where the motion of the subject is often too fast to be stopped by conventional "speedlights."

The elements of the Strobolume are a high-voltage transformer and rectifier; a capacitor, which is charged to about 2000 volts from the rectifier; and a lamp through which the capacitor is discharged to produce the flash. The discharge is initiated by a high-voltage Strobotron tripped from an external contactor.

The entire assembly is mounted in a small metal case with handle. Lamp and its housing are removable from power supply assembly for use at end of 10-foot cable.

Flashing rates up to 1200 per minute are possible for short periods. Overload breaker opens when maximum safe operating time has been reached at any speed.

SPECIFICATIONS

Duration of Flash: Approximately 10 microseconds.

Flashing Control: External contactor or low-speed Strobotac.

Tubes:

1	Rectifier	TYPE 816
1	Strobotron	TYPE OA5
1	Flash Lamp	TYPE 1532-P1 (GE Type FT-220)

Flashing Speed Range: Continuous, 45 flashes per minute, maximum; intermittent, or for short periods, up to 1200 flashes per minute. Maximum safe operating time is as follows:

TABLE I

Flashes per Minute	*Approximate Time for Breaker to Open*
60	—
300	1 min. 45 sec.
600	30 sec.
900	20 sec.
1200	15 sec.

Accessories Supplied: Instruction book; power cord with ground terminal; flash control cord for connection to contactor or push button; push button is furnished.

Other Accessories Required: None, if lamp is to be flashed manually by push button. For stroboscopic work, a contactor or a TYPE 631-BL Strobotac with TYPE 1532-P2 Cable is needed.

Mounting: Metal case with rounded top; lamp is removable; storage space for lamp cable is provided in case. Tripod mounting thread (1/4-20) is provided in lamp housing.

Power Supply: 105 to 125 (or 210 to 250) volts, 50 to 60 cycles.

Power Input: 70 watts at 60 flashes per minute; 500 watts at 1200 flashes per minute.

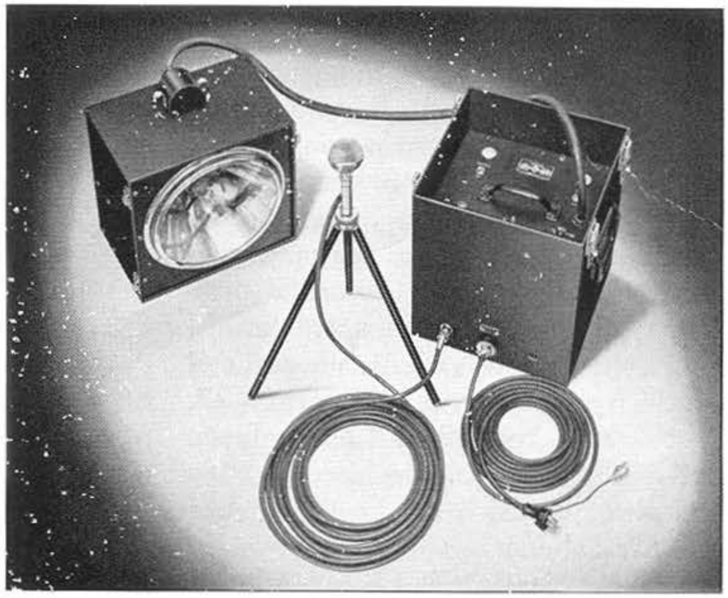
Dimensions: 13 x 7½ x 11 inches, overall.

Net Weight: 18½ pounds. Lamp only, 2 pounds.

Type		*Code Word*	*Price*
1532-A	Strobolume	TITLE	$225.00
1532-P1	Replacement Lamp	TOWEL	30.00
1532-P2	Cable (for connection to Strobotac)	TULIP	10.00

Licensed under designs, patents, and patent applications of Edgerton, Germeshausen and Grier.

TYPE 1530-A MICROFLASH
HIGH-SPEED LIGHT SOURCE FOR PHOTOGRAPHY



Designed specifically for ultra-high-speed photography, the Microflash is capable of stopping such high-speed motion as projectiles in flight and pressure waves in gases and fluids. The duration of the light flash is of the order of one or two microseconds (millionths of a second). The technique of microflash photography is not difficult with conventional camera equipment.

Used widely by the laboratories of the armed services, the Microflash can be applied to the investigation of many phenomena in pure and applied science, such as the mechanisms of wear or abrasion, of turbulence in liquids, of fractures in solids, of mechanical distortion at high rotational speeds, of atomization of fuel in nozzles, and many others.

The Microflash operates from an a-c power line and is portable.

SPECIFICATIONS

Duration of Flash: Approximately 2 microseconds.

Power Supply: 105 to 125, 210 to 250 volts, 50 to 60 cycles.

Power Input: 70 watts.

Tubes:
1 — 5T4 (RCA) 1 — FG-17 (GE)
1 — 2V3G (RCA) 1 — 6AC7 (1852) RCA
1 — 1530-P1 (General Radio)

Accessories Supplied: Microphone with cable; tripod; all tubes; spare pilot lamps and fuses; 2 spare flash lamps Type 1530-P1; plug for connection to contactor-trip jack; instruction book.

Mounting: The power supply and trigger circuits are assembled in one metal case, the lamp in another. The two cases lock together for transportation, completely protecting the lamp and controls.

Dimensions: 24⅛ x 13¼ x 11¾ inches, overall. ***Net Weight:*** 72 pounds.

Type		Code Word	Price
1530-A	Microflash	TAFFY	$600.00*
1530-P1	Replacement Flash Lamp	TONIC	22.00*

*Plus current Federal tax on photographic equipment.

GENERAL RADIO COMPANY

275 MASSACHUSETTS AVENUE CAMBRIDGE 39, MASSACHUSETTS

NEW YORK 6, NEW YORK
90 WEST STREET

CHICAGO 5, ILLINOIS
920 SOUTH MICHIGAN AVENUE

LOS ANGELES 38, CALIFORNIA
1000 NORTH SEWARD STREET

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