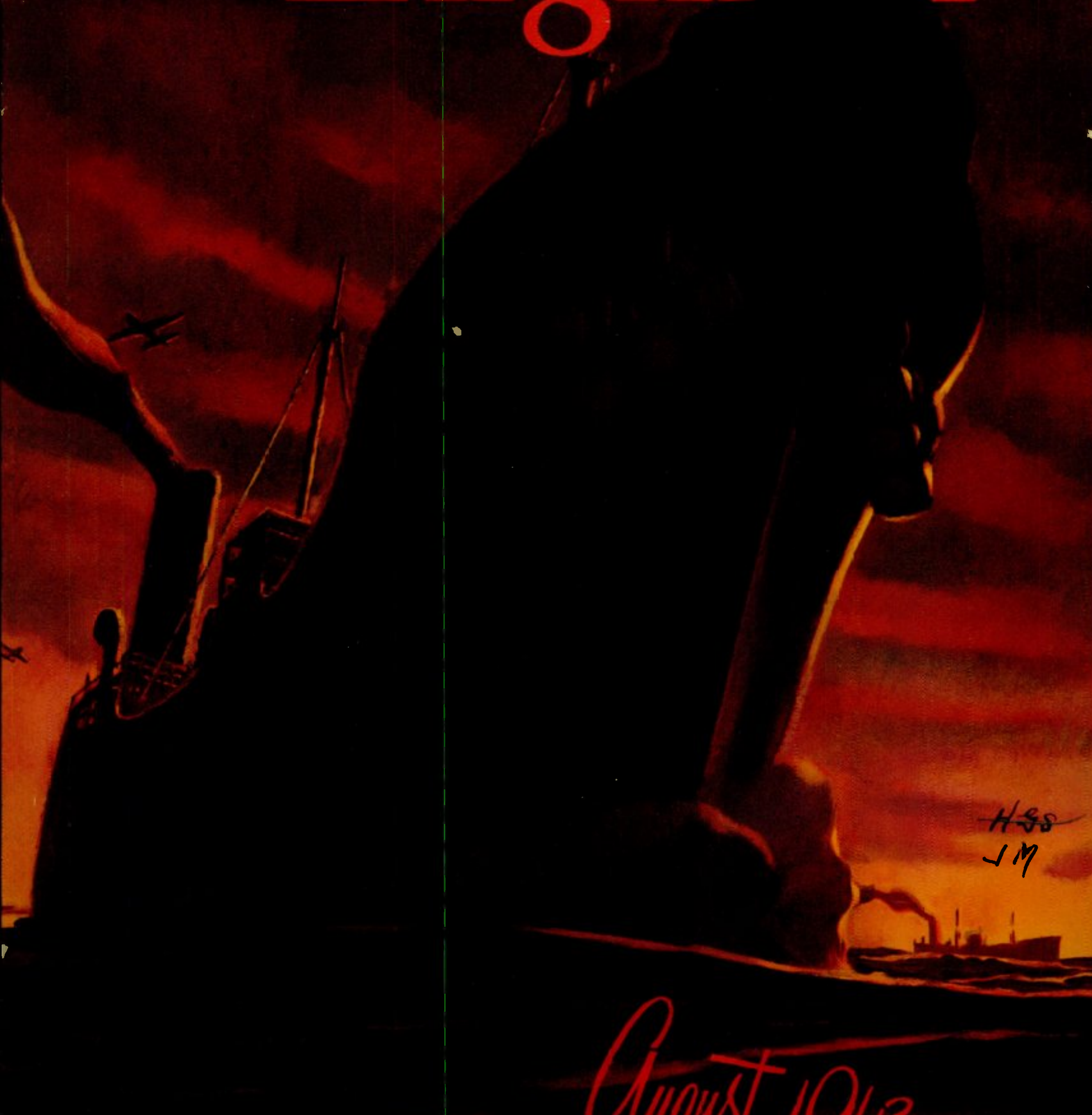
WESTINGHOUSE

Engineer



August 1943

Air Conditioning for Discomfort

OF THE AXIS

A perpetual surprise of this war is the number and kinds of things that are its essential weapons. Many things, even some considered in the luxury class, that apparently could be laid aside for the duration, are found upon close inspection to have places as indispensable in the war as bullets and tanks. Air conditioning is one of these. Refrigeration engineering did the Houdini act from air conditioning for comfort to air conditioning for victory—with suddenness—and to such an extent that factories building temperature-control apparatus are busier than in any peacetime boom.

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Some air-conditioning equipment gets very close to the battle lines. Last summer, when Uncle Sam was planning to dispossess the Afrika Korps, he gave precious space aboard a ship to several self-contained air-conditioning units. These were installed as an essential part of an instrument-repair shop set up in a close-to-the-battle area where temperatures rise to suffocating limits. Here the delicate repair and testing of such indispensable tools of war as the famous bomb sight, rifle telescopes, radio instruments, etc., would have been impossible had not some control of temperature been provided. High temperatures themselves would have caused testing errors, while perspiration would have caused ruinous corrosion.

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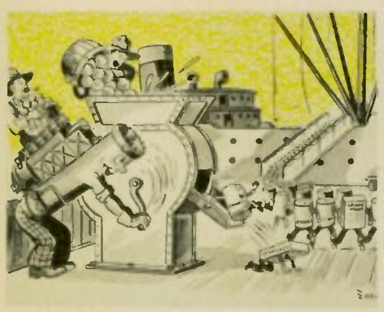

Transportation has long been at the head of the list of obstacles to Allied victory. Yet our fighting men, be they in Attu or Africa, must be well nourished—and every ton of food shipped to them means just that much less fighting materials can be sent. Service men need the vitamins of oranges and grapefruit—and they are getting them, but not in the form of whole fruit. New methods of preparing fruit concentrates have been devised that strip the fruit of its greatest bulk—water—leaving a marmalade-like substance that retains all the flavor, vitamins, and food value of the original fruit. This concentrate can be reconverted to a very satisfactory fruit juice by the simple addition of water. In this way, about nine-tenths of the weight and volume of fresh fruit are saved. But the preparation of the concentrate calls for closely controlled temperatures. An essential part of the procedure requires holding the freshly made concentrate in a temperature of 35 degrees F for 48 to 60 hours.

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On the list of enemies, along with Japs and Germans, the Air Corps includes moths. The fur and wool flying suits of high-altitude pilots are just their dish. Or would be if moth larvae were left undisturbed. But the Air Corps has devised a shock treatment that effectively disposes of them before their feasting day. The flying suits are first hung in a chamber where the temperature is about 35 degrees F. This kills nearly all adult moths, but unhatched eggs or larvae buried deep in the wool or fur may survive the cold wave. So the suits are brought out into a warm room for a day or two. The eggs hatch, and larvae, thinking spring has come, rapidly develop. Ere this proceeds too far, the suits are returned to the cold room, so that the creatures quickly depart from this life.

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Armor-piercing shot must not possess unrelieved strains or invisible cracks. Such a flaw might result in the shot breaking up in flight—or possibly damaging the gun or injuring the gun crew—in any case, flunking out on its job of dealing distress to the enemy. How to test a shot without destroying it was something of a problem, but Army ordnance engineers devised a simple method that might be called an ordeal-by-water or ducking-stool test. The shot are first dunked in boiling water until they get thoroughly hot. Then they are plunged into a tank of cold water. Defective shot simply go to pieces under such an ordeal. For consistent results, the temperature of the cold-water bath must be held constant, a job for refrigeration equipment—of the same type that once provided chilled water to keep a theatre audience comfortable.

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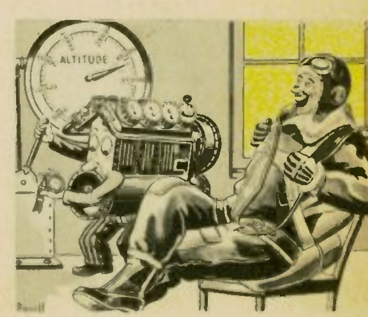
How a would-be pilot will react to the rigors of high altitude no one can tell, least of all the pilot himself, regardless of his personal desires or native courage. Only a trial under high-altitude conditions will disclose a person's fitness to pilot a ship in the substratosphere. The Air Corps has arranged to do this finding out on the ground, where it is safer for all concerned, much less expensive, and much more informative. This not only discloses to the intructor the inherent reactions of the individual to rarefied air conditions, but also enables the student to become accustomed to this part of his "high-ceiling" work as a lesson by itself. The student flier takes his place in an altitude chamber, where both the temperature and pressure are decreased at the same rate experienced in a fast-climbing airplane. The vacuum pumps and refrigeration equipment change the equivalent "altitude" in the chamber at a rate of about 1000 feet per minute. (Incidentally, the fastest building elevator rises only 1500 feet per minute.)



VOLUME THREE · AUGUST, 1943 · NUMBER THREE

WESTINGHOUSE Engineer

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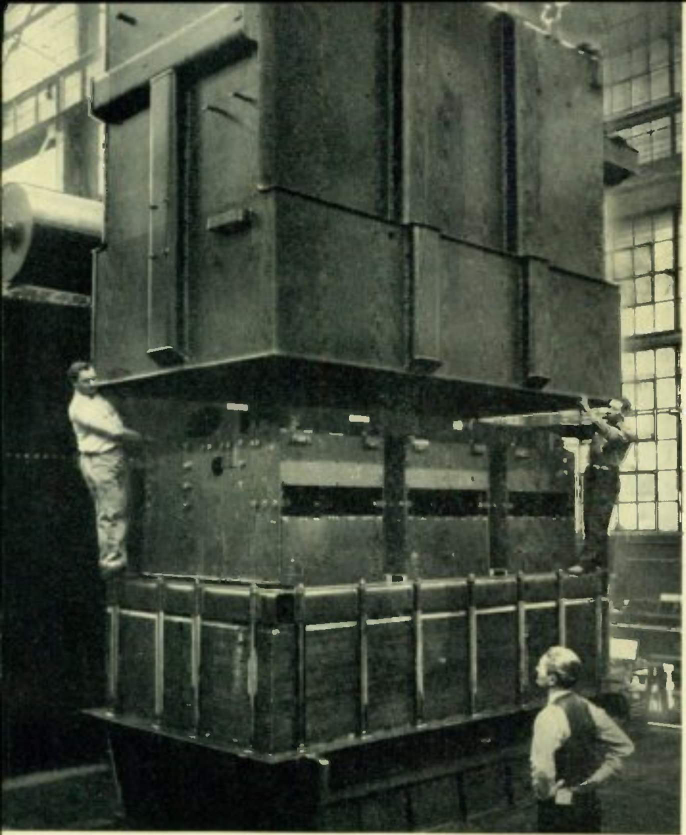
COVER: *The war against the submarine is being won, slowly but surely. Its winning will be one of the greatest stories of the sea of all time. It is being written not alone by the heroes of naval and cargo ships, but also by engineers at home who have created faster ships, better ships, and for them improved turbines, generators, motors, gears, instruments, controls, signaling and detecting devices, and scores of other mechanisms. We must wait awhile to set down in these pages the account of this engineering; meanwhile, with the help of our artist, F. G. Ackerson, we pay tribute to those contributing to this victory.*

Editor—CHARLES A. SCARLOTT · *Editorial Advisors*—R. C. BERGVALL · T. FORT · R. E. WILLIAMS

PUBLISHED QUARTERLY BY WESTINGHOUSE ELECTRIC & MFG. CO. ANNUAL SUBSCRIPTION PRICE: U.S.A., $2.00; CANADA, $2.50; OTHER $2.25. SINGLE COPIES, 50c. ADDRESS, WESTINGHOUSE ENGINEER, EAST PITTSBURGH, PA.

PRINTED IN U. S. A.



The core and coil assembly of a form-fit transformer can be exposed readily without lifting it out of a full-depth tank. Instead, only the upper section of the form-fit tank, which is comparatively light, is removed from the assembly.

Fitted Tanks for Transformers

Generally, war-inspired devices follow the classical example of swords being beaten into pruning hooks and need adapting to peacetime use. Not so with the form-fit transformer tank. Already this development, lifted bodily from a war application, has found important use in industry. The saving of material, decreasing size, simplifying maintenance and shipping, without any sacrifice of performance, is ever an engineer's peacetime goal as well as a wartime must.

The war will leave its mark on many things, the marks for the most part being horrible, ugly scars. Already it has left its mark on power transformer design, but happily the mark is a beneficial one. Transformers have undergone a radical change as to appearance through a fundamental change in the shape of the tank. This design change has effected a saving of 33 per cent in oil and a total weight saving of 20 per cent.

The core and coil assembly of a power transformer can be thought of as roughly a vertical rectangle crossed at its middle by a horizontal rectangle. Common practice throughout the years has been to set this resulting irregular shaped object down into a straight-walled steel tank with a cover at the top. Tanks have been circular, oval, square, or octagonal, as dictated by specific requirements of strength, cooling, and space required for exterior-mounted auxiliaries, but in any event the tank's vertical surfaces did not conform to the shape of the assembled core and coils. The intervening space between assembly and tank was filled with oil.

The new concept is to shape the tank to follow closely the contour of the core and coils. The tank is built in two sections, the bottom portion serving both as part of the transformer foundation support and to enclose the portion of the winding below the core. The upper section of the tank is made wide at its base to enclose the transformer core, which is the widest part of the assembly, and narrower at the top to accommodate the coils that extend above the cores. This upper part of the tank is welded to the lower section that extends just above the lower edge of the core. The space between tank wall and core and coil assembly, obviously much less than with straight-walled tanks, is filled with oil.

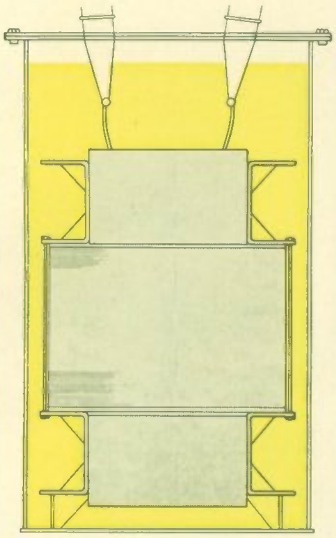
To inspect or repair the transformer it is necessary only to cut this weld and lift off the comparatively light upper section of the tank. The core, coils, and connections are then fully exposed without the necessity of lifting them entirely out of the enveloping tank.

Welded construction is also used on the tops of tanks of conventional design. This weld, however, is at the top of the tank which makes it more difficult to cut open when the cover is to be removed. In the form-fit construction the weld is near the bottom of the tank and can be easily reached by workmen.

The first application of this oil, steel, weight, and space-saving idea was to a war problem. In fact, the whole idea grew out of a war need. Several floating, power-supply barges were required. Obviously space aboard was at a premium. Weight must be limited. The transformers, as well as the other power equipment, must be adequate in capacity, yet small enough to lower into the restricted spaces available. Furthermore, means had to be provided for inspection, overhaul, and repair in the crowded cubicle in which they were to be installed, and with the small-capacity cranes that might be available. Thus the new type of transformer tank not only simplified the space, weight, and inspection problem on the barge, but also made important savings in oil and steel, both on the list of scarce materials.

In the transformer for the barges a water-cooled heat exchanger was used to extract the heat from the oil in which the windings were immersed. This was necessary because the limited size of the cubicle in which it was installed precluded natural ventilation. The form-fit tank has, however, proved its versatility and is being used extensively in the more usual applications. A variety of cooling methods have been applied—forced-cooled with heat exchanger, forced-cooled with fin-type air-blast radiators, forced-cooled for triple-rated transformer, and conventional self-cooled by convection. This is despite the fact that by following closely the outline of the transformer it encloses, the waste spaces normally filled with oil have been eliminated, and the amount of coolant oil has been reduced one third. Aside from the substantial monetary savings achieved, both from the reduced cost of the oil itself, and the reduced cost of handling because of the greatly lessened weight, this reduction in the amount of oil used has another important aspect. When inspecting, servicing, or repairing the transformer, it means that the handling and storing of the oil while the tank is disassembled has also been reduced by one third.

The form-fit transformer tank has several points of merit. For one, it simplifies the shipping problem. Some transformers that were previously so large they had to be shipped in



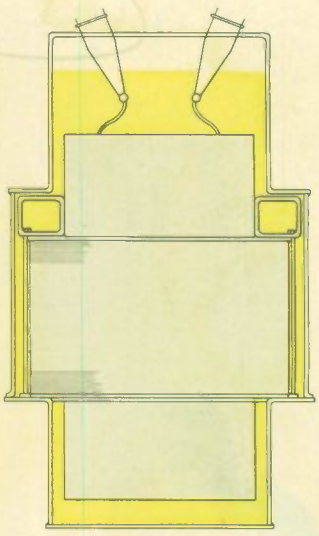
Transformer in conventional tank.

two sections can now be shipped as one assembled unit. This is because usually the shipping limitation for a given height is the width at the top. The form-fit tank is much narrower at the top than the standard tank.

Another innovation made possible by this design and which also permits the shipping of a larger unit, completely tanked, is that of shipping the transformer lying down. Wooden blocks interposed between the core and coils and the closely fitting steel tank prevent any relative movement. International shipments of a number of 10 500-kva transformers have been successfully accomplished in this manner.

This tank has received rapid industrial acceptance because it fills many long-felt needs. In addition to requiring less equipment capacity for installation and less crane capacity for servicing, less head room is required for dismantling and assembling. In the form-fit equipped transformer it is necessary to lift only the upper portion of the tank clear of the transformer to gain access to it, whereas in the conventional style it is necessary to lift the whole core and coil assembly clear of the tank itself.

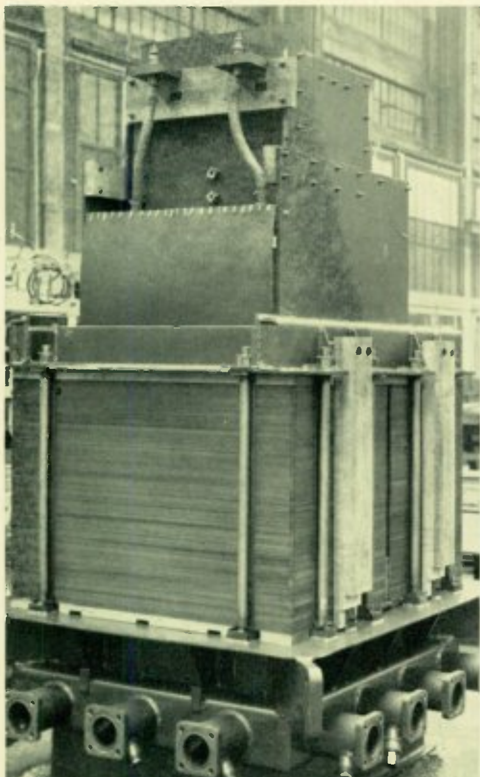
Of the total 20 per cent weight saved, 10 per cent represents the weight of metal and 10 per cent the weight of oil conserved. These weight reductions have a proportional counterpart in space reduction. The saving of floor space is an important item in station installations, particularly those stations where expansion was necessary without adequate space facilities. Physical conditions at one particular installation made the use of the form-fit tank mandatory. War needs precluded any service interruptions so existing equipment could not be moved to admit the usual size additional transformer capacity vitally needed. In addition the crane capacity at the place of installation was limited. Both limiting stipulations were met with the new tank design, which permitted the transformer to be maneuvered between installed apparatus and to be placed in position by the existing crane.

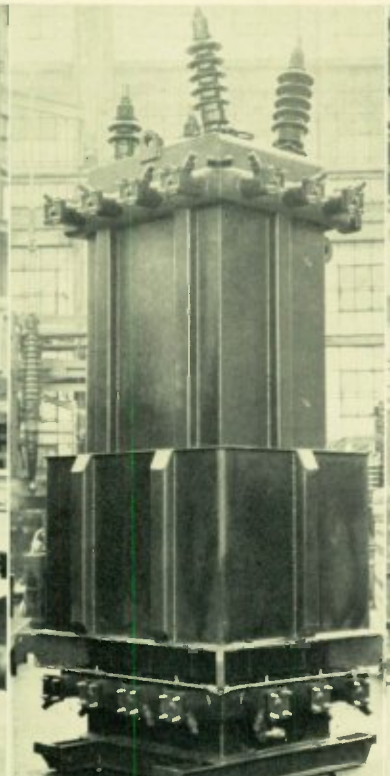


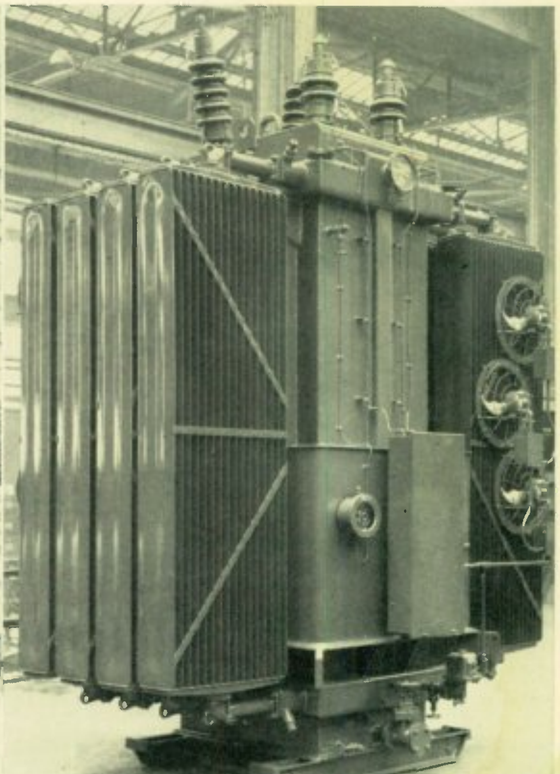
Transformer in form-fit tank.

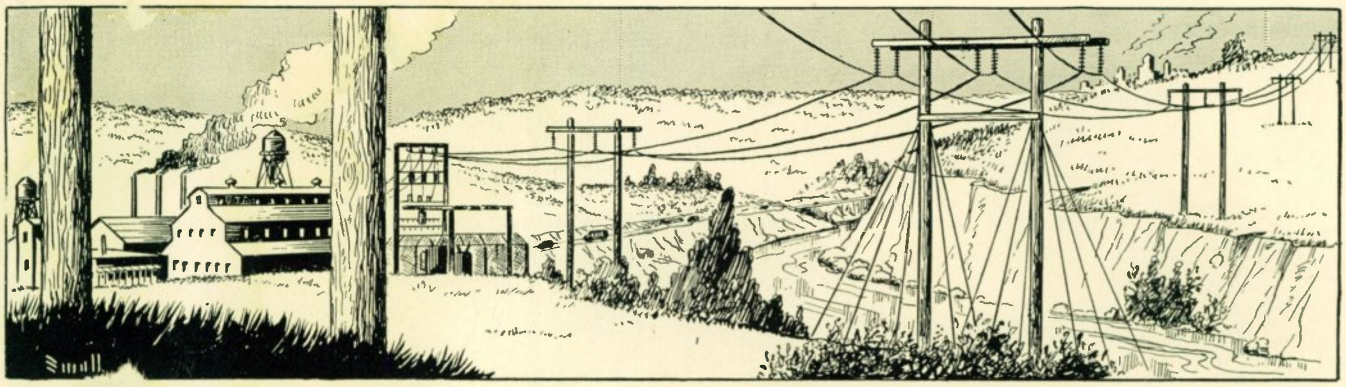
While primarily used for transformers of larger size, beginning at 5000 kva single phase and 10 000 kva three phase, this type of tank has been supplied for transformers as small as 500 kva. This new tank can be used for all sizes of shell-form transformers.

Exigencies of shipping required that several 10 500-kva, single-phase transformers for service abroad be transported lying down. The form-fit tank made this innovation in transformer transportation possible. Below on the left, the core-coil assembly is shown exposed. In the center picture, the upper portion of the form-fit tank is welded into place. The transformer, complete with radiators and auxiliary equipment, is shown at the right.









Protection of Three-Terminal Lines

Where corn grew last year, factories are humming today. To supply power to these wartime plants the natural, logical thing to do is simply "plug in" to the nearest power line, with a **T** *tap and a single breaker. Desirable as this may be because of shortage of time and materials, it presents a problem in protective relaying that must receive careful attention.*

M. A. BOSTWICK
Relay Engineer

E. L. HARDER
Central Station Engineer,
Westinghouse Electric & Mfg. Co.

THE interconnection of power supply and load points by a multi-terminal, tapped transmission line instead of by a number of two-terminal lines has always presented first-cost advantages. Now other gains are most important with critical materials and man power limited by wartime shortages. However, construction of this kind may inherently impose operating handicaps on the associated protective relay circuits. These may increase the time required to clear faults or even cause some undesirable tripping of circuit breakers unless the correct relays are used on the circuit. In spite of this, many war plants have been supplied with power by tapping the nearest high-voltage line, bringing to the fore a relaying problem that has been relatively minor.

Problems that are encountered when applying protective relays to circuits of this kind and inherent system limitations will be discussed in three groups: 1—Directional overcurrent protection; 2—Impedance or distance-type protection; and 3—Pilot-wire and carrier-current protection.

The problem of coordinating a relay at one terminal with that at the next requires compromises when the coordination involves two other terminals. These problems become more involved if the three-terminal line is used to connect different power sources, as may be the case if the tap is to a plant that has its own power plant. If the terminals connected by the three-terminal line are also tied through other lines or "parallel ties" an additional problem is introduced. Power may then actually flow out of one terminal of a three-terminal line when a fault occurs near another terminal. This has an obvious detrimental effect on schemes which block tripping on the basis of "power flow out." It is apparent from the foregoing that from a relaying viewpoint, three-terminal circuits can be classified into:

a—Radial circuits with only one source of power and no paralleling ties.

b—Circuits connecting two or three sources of power, but with no parallel ties.

c—Circuits with paralleling ties between two or three terminals.

This classification applies similarly to ground-current circuits. However, power-transformer connections may limit the flow of ground current so that ground currents flow at only one or two terminals. Hence, the problem of applying ground relays to three-terminal circuits is frequently simplified.

Directional Overcurrent Protection

Three-terminal lines in radial circuits can be protected with standard, overcurrent, instantaneous, and time-delay relays, as indicated in Fig. 1. The addition of generators at one or two of the line terminals (indicated by the dotted construction in Fig. 1) requires the addition of directional elements in the relays. As the amount of power that must be transmitted over the circuit is increased, the problem of maintaining system stability becomes more difficult and may impose limitations on the time allowable for clearing faults. This frequently eliminates the use of timed overcurrent relays in the protective circuit. A high-speed relay scheme must then be used. These schemes include distance-type relays, such as the HZ type, or directional comparison pilot-wire or carrier-current circuits, and a-c pilot-wire circuits, such as the HCB. In most cases, except where the HCB relay is used, separate ground relays must be installed.

Impedance-Type Protection

Impedance relays, such as the HZ, can be used to protect a three-terminal line as indicated in Fig. 2. The first-zone impedance element of these relays should be set to trip phase

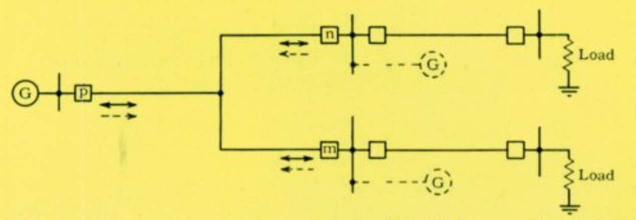


Fig. 1—*Overcurrent protection of a simplified three-terminal line.*

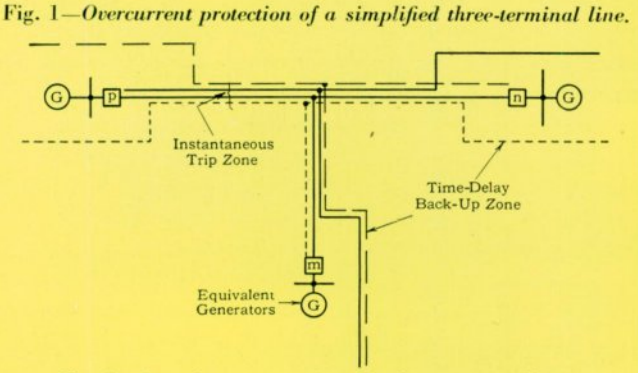


Fig. 2—*Impedance protection of a three-terminal line.*

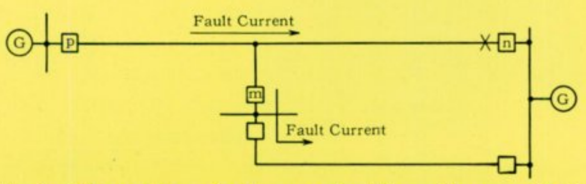


Fig. 3—*The problem of a three-terminal line with a parallel tie.*

faults that occur within 90 per cent of the impedance to the nearest terminal. Faults beyond this zone are tripped instantaneously by the relay nearest the fault, and after a time delay at other terminals.

Unfortunately the tripping zones do not include definite distances from the various line terminals because the voltage drop from the relay to the fault results not alone from the current through the relay, but also from the current entering at the tap from the other line terminal. The actual tripping zone of the relay is shortened by this mutual impedance effect, which increases the voltage at the relay for the same current value. This mutual effect is a variable depending on the amount of generating capacity at each terminal.

Frequently, settings can be found that will result in satisfactory protection. For a fault between *n*, Fig. 2, and the tap, the mutual action described above affects only the relays at *p* and *m*. Usually settings can be found such that one of these will trip immediately. The other trips as soon as the first has cleared and removed the mutual effect. That is, two breakers trip in normal time; the third trips immediately after the adjacent breaker has opened. Furthermore, time-delay tripping of the second- and third-zone elements of the relay provides back-up protection. Where the resulting operation is too slow for system stability, or where adequate selectivity cannot be obtained, a pilot wire or carrier-current channel must be used to obtain instantaneous tripping for faults at any point on the line.

Ground relays that are frequently used with HZ impedance relays include current or potential polarized power relays (CWC and CWP) or current or potential polarized directional overcurrent relays (CRC or CR) which may include instantaneous trip attachments. Coordination of these relays on three-terminal lines usually requires longer clearing time than on two-terminal lines, except where the ground currents are limited by power-transformer connections.

Pilot-Wire and Carrier-Current Circuits

Because of the difficulties outlined above, the protective scheme frequently must be expanded to compare conditions at each line terminal. This requires that a communication channel be used in conjunction with the relays. It can be either a metallic pilot-wire or a carrier-current channel.

Most carrier-current and some metallic [illegible]wire relay systems operate by comparing the direction [illegible]r flow at the line terminals. Protective schemes, whic[illegible]oy only directional comparison to locate the fault, a[illegible] to applications where power is fed *in* through all term[illegible] of the circuit to the fault. This ideal condition is not o[illegible]ed in all circuits, however. Frequently, there may be a parallel tie, as indicated in Fig. 3. A fault near one of the line terminals may cause power flow *out* at another line terminal. As a result, simple directional comparison relays cannot be used to locate the trouble because the open contacts of one relay block operation of all relays. To obtain satisfactory operation, the directional elements of these d-c pilot-wire relays must be biased so as to hold their contacts in the tripping direction against the maximum counter torque developed during faults on the protected section. The relays must also have sufficient torque to block operation when minimum external faults are encountered. The resulting compromise decreases the protection.

Distance-measuring carrier-current and pilot-wire protective circuits can similarly be blocked by current flowing out of one terminal of a faulted line. However, in this case instantaneous sequential tripping is obtained because the relay nearest the fault trips, independent of the carrier or pilot-wire circuits, through its first-impedance or instantaneous ground element. Hence, carrier-current and pilot-wire circuits that use instantaneous and ground relays operate to trip sequentially, with the last breaker opening in about eight cycles after the first is tripped.

Relays that employ a combination of voltage and current to locate faults on three-terminal lines are subject to certain operating limitations. Directional comparison relays may not operate, or may require special settings to allow operation, when power flows out of one terminal of a faulted three-terminal line. Similarly, distance-type relays may be difficult to set so as to obtain high-speed operation over a large portion of the line because the apparent circuit impedance, measured by the relays, differs from the actual impedance of the line. The HZ distance-measuring relay, used with a carrier-current circuit, enjoys a distinct advantage in this respect, however, because the instantaneous first-zone element nearest the fault always operates to give instantaneous tripping, leaving the remaining terminals to operate as on a conventional two-terminal line.

HCB Pilot-Wire Relays

The HCB pilot-wire relay is particularly well suited t[illegible] application on three-terminal lines, within its range of [illegible] tion. The HCB relay is a single-element, high-speed devic[illegible] that operates by comparing the magnitude and phase position of currents in each of the line terminals.[1, 2] To do this, it employs a combined positive- and zero-phase-sequence filter, and a single polarized relay element at each end of the line, connected together through two pilot wires. The current filter adds phase and ground currents, with variable multiplying factors, to obtain a single alternating-current output that is connected to the pilot-wire circuit. The relay elements operate to compare the current output from their local filters with that transmitted over the pilot wires. Normally, current is circulated over the pilot wires through restraining coils, so as to hold the relay contacts open with a torque that increases with the magnitude of the load or fault current transmitted through the line. Faults that occur on the protected circuit cause a reversal of current in one line terminal. This effectively blocks the flow of pilot-wire current, raises the voltage across the pilot wires and relay operating coils, and causes instantaneous tripping. The circuit is basically simple, and inherently selective in operation.

When the relays are applied to protect a three-terminal circuit, one is required at each line terminal. It is operated, as on two-terminal lines, by comparing the magnitude and phase position of the current at the line terminals. As long as the total current that flows in the line equals that which flows out, a similar amount of pilot-wire current is circulated through the relay restraining coils to prevent its operation. On the other hand, current that is fed through only one line terminal to an internal fault can trip relays at each of the other line terminals.

By comparing the magnitude and direction of current flow in the various terminals of the circuits, as is done in a type HCB pilot-wire relay, many of the operating limitations are eliminated. The pilot-wire circuits from the three terminals are usually paralleled, with all branches of the circuit made up with equal impedance. This balance is obtained with adjustable resistors, connected on the relay side of the insulating transformers as shown in Fig. 4.

The operating characteristics of a standard HCB relay, with 200-ohm, parallel-connected pilot wires, are illustrated in Figs. 5, 6, and 7. The curves shown in Fig. 5 illustrate the minimum trip conditions, assuming that current is fed in all terminals to an internal fault. Curves of Figs. 6 and 7 are to be used when current is fed through the line to an external fault, or when an internal fault is encountered near one line terminal. A portion of the fault current (in this case) is assumed to flow *out* of one line terminal.

As the curves show, considerable current can be fed out of one line terminal when the circuit is faulted without affecting the relay operation. All relays can be tripped by power fed in only one line terminal. In this case, the minimum trip current somewhat exceeds the sum of the relay trip settings (three times the setting of each relay), the exact value being determined by the pilot-wire characteristics. To illustrate the use of these curves, first assume that a circuit, similar to that shown in Fig. 3, is faulted near the tap. A minimum of 0.5-ampere ground current fed in through each relay causes tripping, as shown by Fig. 5. This assumes that all current transformers are of the same ratio, and that the relays are set for most sensitive operation. If current is fed into only one line terminal, approximately four times the trip setting of each individual relay ($4 \times 0.5 = 2.0$) is required to trip all relays. This arises from the fact that all operating-coil current transmitted over the pilot wires to trip the remote relays flows through the restraining coil of the energized relays. In other words, the restraint current is greater under this condition. Consequently, a larger trip current is required.

If the circuit shown in Fig. 3 is faulted near one line terminal, and the effective generation connected at that point is small, a portion of the fault current may flow out of one line terminal through a parallel circuit to the fault. This will tend to reduce relay operating-coil energy because the current distribution approaches a through-fault condition. The relay-tripping characteristic for this condition is illustrated in Figs. 6 and 7.

The operating characteristic that is obtained when fault currents of equal magnitude are fed in terminals p and n, is illustrated in Fig. 6. The entire fault current would be fed out terminal m, if that branch of the circuit were faulted externally. The plotted fault current would then fall directly on the dash line, which is in the middle of the no-trip area. Faults at X (see Figs. 3 and 4) would result in some current flowing out terminal m and back in n. The curve in Fig. 6 shows that more than five amperes (relay current) must flow out of terminal m to block relay operation when the fault

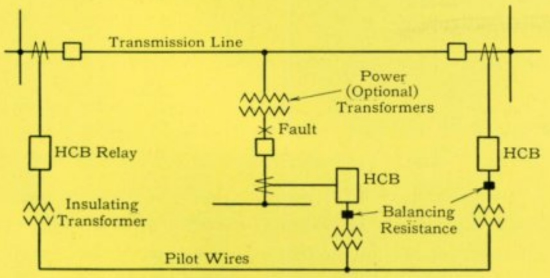


Fig. 4—*A representative three-terminal circuit protected by pilot-wire relays of the HCB type.*

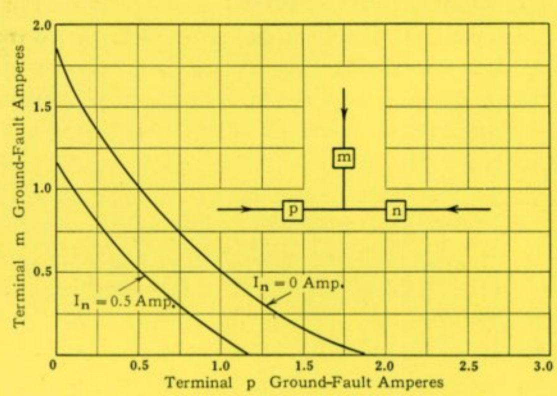
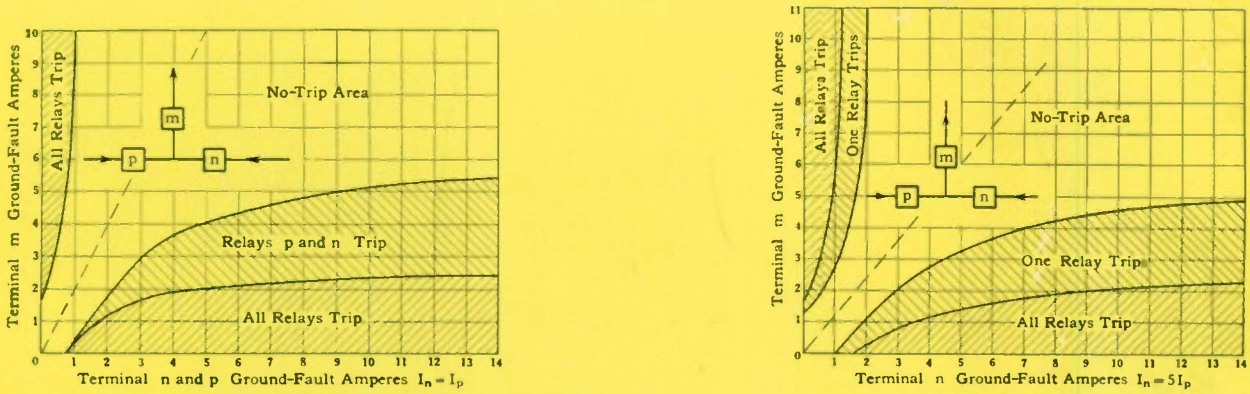


Fig. 5—*Tripping characteristics of pilot-wire relays on a three-terminal line for internal ground faults. (Relays set for maximum sensitivity. Pilot-wire resistance (each branch) 200 ohms; capacity negligible.)*



Figs. 6 and 7—*Typical operating characteristics of HCB pilot-wire relays on a three-terminal transmission line for two conditions of fault-current magnitude. Instantaneous direction of ground fault currents is shown by arrows. All currents are in phase. Relays are set for maximum sensitivity. Pilot-wire resistance in each branch is 200 ohms. The capacity between the wires is considered negligible.*

current that is fed in terminals *n* and *p* exceeds ten amperes. With ten amperes fed into the *n* and *p* terminals and two amperes out of *m*, all relays will trip instantaneously, while three amperes flowing out of terminal *m* will result in sequential operation. In this case, breakers *n* and *p* will trip instantaneously, while *m* will trip immediately afterwards. The curve in Fig. 7 illustrates the operating characteristic when the current in terminal *n* is five times the current in terminal *p*.

The foregoing discussion has assumed that the power circuit requires relays at all terminals. However, circuits similar to Fig. 4, which use relatively small delta-connected power transformers, can be protected as a two-terminal line. This can be done if the maximum fault that can occur on the tap is below the phase relay setting. This applies to all types of relay protection. Differential relays connected around the power transformer, in such an application, can detect relatively small faults and initiate a remote trip signal that will, in turn, open breakers at the remote terminal, if required.

The pilot wires should preferably be enclosed with cable sheaths, protected from lightning, induction, and differences in station ground potentials so as to maintain a continuous circuit at all times.[3] The shunt capacity between pilot wires should not exceed 0.5 mfd per terminal for 500-ohm circuits. As indicated in Fig. 8, continuous d-c supervision can be supplied with the relay to ring an alarm whenever any branch of the circuit is opened or faulted.

A number of HCB relay installations have proved this to be a reliable means of obtaining high-speed (one cycle) relay protection on three-terminal lines. Standard equipment is used, so that in many cases existing circuits can be expanded simply by adding a third relay. It is anticipated that use of the three-terminal pilot-wire circuit, with HCB relays, will make practical the savings that are inherent in construction of many three-terminal power circuits. The arrangement is particularly well adapted to application in congested areas where power circuits are short and heavily loaded. Longer circuits can be provided with high-speed relay protection by use of carrier-current relays. Circuits of lesser importance can be protected with impedance, or induction-type overcurrent relays with some sacrifice in speed or selectivity.

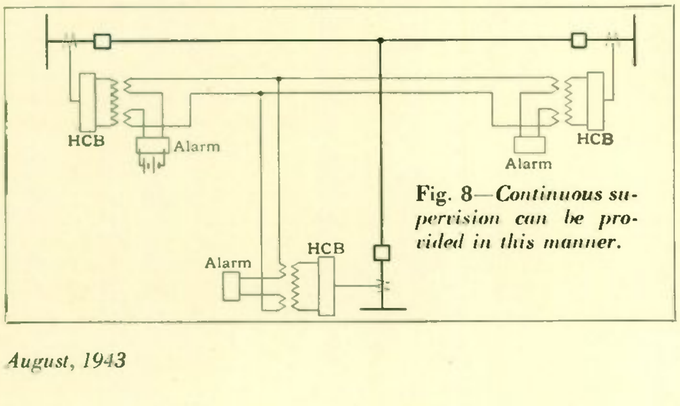


Fig. 8—*Continuous supervision can be provided in this manner.*

REFERENCES

1—"A Single Element Pilot-Wire Relay," by E. L. Harder and M. A. Bostwick, *Electric Journal*, November, 1938.
2—"Ratio Differential Protection of Transmission Lines," by R. M. Smith and M. A. Bostwick, *A. I. E. E.*, August, 1939.
3—"Protection of Pilot-Wire Circuits," by E. L. Harder and M. A. Bostwick, *Electrical Engineering*, September, 1942.

On Standardization*

There appears to be developing on the part of plant designers a definite trend toward the adoption of not over two or three combinations of turbine steam pressures and temperatures based on overall plant costs.

The overall effect on cost per net kilowatt-hour of rather broad departures from mathematical optimum thermal cycle, based on fuel costs and load factor, is comparatively small.

Standardization should cover not only the steam conditions and kilowatt ratings but also should include voltage, power factor, and short-circuit ratio of the generator, if possible.

Today over a hundred different turbines are available between 500- and 7500-kw capacity. By joint effort of purchasers and manufacturers this unnecessarily large number of available sizes can be reduced to a small fraction of the present total.

Where large numbers of one size can be sold, the cost of the standardized apparatus becomes so attractive as to make it difficult to justify the cost of special apparatus. Better operating results are obtained as continuous duplication of equipment eliminates design errors, and cumulative design margins are largely eliminated.

**Extracts from a paper presented by C. A. Powel, Manager of Headquarters Engineering Department, Westinghouse Electric & Mfg. Co., before the Edison Electric Institute, New York, June 3, 1943.*

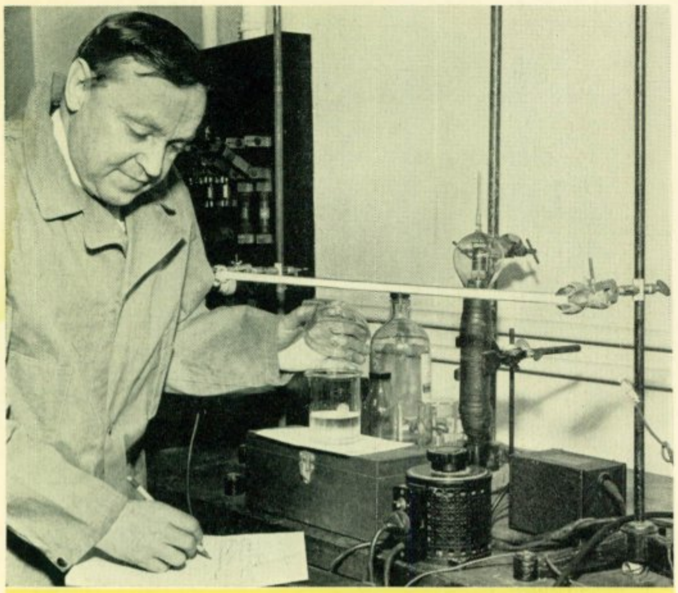
Stories of Research

Sterilamp Photons Destroy Virus

DISEASES, only a few centuries ago, raged across whole continents, virtually unchecked. Medical discoveries, isolating the bacteria responsible, have minimized the effects of many of these scourges. However some of the most serious and widespread diseases do not arise from bacterial causes, and comparatively little has been accomplished to curtail their ravages. Such diseases—among them the common cold, scarlet fever, and poliomyelitis—are believed to be caused by virus. Because a virus is so small, only recently has one been seen, and then only in outline under an electron microscope. Now, research has developed a method whereby as high as 99.9 per cent of the virus particles can be inactivated—by bombardment with photons from an ultraviolet-producing lamp, such as the Sterilamp.

Bacteria are killed by ultraviolet of the proper wave length. Several years' successful operation of the Sterilamp has definitely proved this. But to what extent and by what mechanism viruses are susceptible to ultraviolet radiation has not been fully known. To this end Dr. Rentschler has been conducting tests for two years, and has uncovered many interesting facts that are important to human health. He finds, for example, that bacteria and viruses are not put out of commission by radiation in the same way. Bacteria of the air-borne variety can be completely destroyed by subjection to enough ultraviolet radiation of the proper wave length. Experiments with bacteriophage, a type of virus, proved that the problem of its destruction was not so simple. It appears that bacteria, when struck at any point by ultraviolet rays, receive an injury often immediately fatal. Also, the accumulated energy of different photons striking bacteria is lethal. Virus, on the other hand has an Achilles' heel. Apparently it must be struck by the ultraviolet photon at a vulnerable point or it is unaffected.

So little is known of the nature of bacteriophage that it is still a moot question as to whether it is a living organism or merely an inanimate chemical compound. It is known that mysterious filter-passing matter "feeds on" or destroys bacteria. In fact, "feeding" bacteria to a culture of bacteriophage is one of the methods of proving the existence of active specimens. Six arbitrary units of ultraviolet radiation were found to inactivate 50 per cent of the bacteriophage specimens, but it took twice that amount, 12 units, to inactivate an additional 25 per cent in another experiment. When 400 units were applied, better than 99.9 per cent were destroyed, but still a small percentage managed to avoid being struck in the vulnerable band of the molecule.



Dr. Rentschler, in bombarding bacteriophage with ultraviolet photons from the Sterilamp, shows that these viruses are vulnerable.

Prepare the Surface and See All

ANCIENT Greek building-construction contracts contained a *sine cere* (without wax) clause to prevent wax being used to hide flaws in marble work. Today wax is used not only to help detect flaws, but also to disclose essential metallurgical characteristics, shown in metals through metallography. By putting an exceptionally high polish on a sample of metal and examining it through a microscope, its past, present, and probable future can be read. The rub comes in putting the polish on the surface of the metal specimen.

Miss Ferguson examines the polished surface of a sample by means of a microscope. The insert is a photomicrograph of an unusual flaw. Here is detailed a fractured inclusion in a fracture.

For several years a particularly satisfactory procedure applicable to a wide variety of materials has been used by Miss Mildred Ferguson, of the Westinghouse Research Laboratories. Her technique involves the use of rotating horizontal wax discs.

The micro-sample of metal is first rough ground to a plane surface on a carborundum disc. It then goes through three, sometimes four, finish polishing steps. An aluminum disc is filled with melted paraffin, the surface of which is scraped smooth and flat. This serves as the base or support for the abrasives used in the finish polishing. The abrasive powders or dusts are suspended in a good grade of green soap solution and are applied to the rotating paraffin disc as needed. Any tendency for the wax to deposit as a film on the specimen is overcome by using sufficient soap solution.

The three or four steps of the finish polishing operation use successively smaller abrasive dusts. The fourth step is taken only where high resolution of structure is necessary.

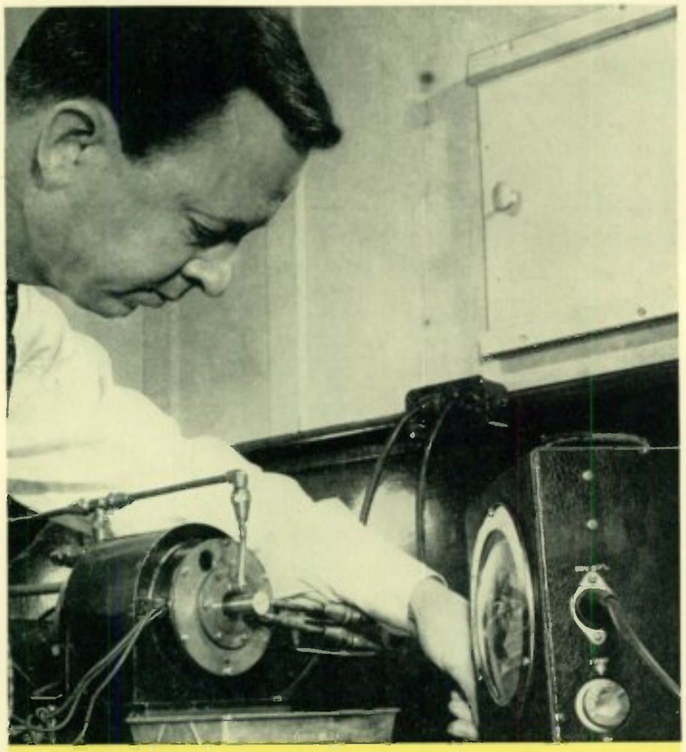
The results obtained by this process are outstanding. An experienced operator can polish an ordinary steel specimen in ten to fifteen minutes through the first three steps and, if the fourth is desired, complete all four in from 20 to 25 minutes. Notwithstanding this speed, sharp and irregular edges—such as fractures—need not be beveled for fear of catching on the base. Edges do not become rounded. Inclusions remain intact without adjacent pitting. In one case this held true even with a fractured inclusion in a fracture as shown in the illustration. While relief polishes are not easily obtained on a wax base, this is a desirable feature if high-power micrographs are required for constituents of varying hardness observed in one field. Pits and "comets" are seldom encountered in this process. The polish obtained through use of all four steps is not known to lack any requirements for the degree of resolution demanded in an industrial-research laboratory.

60 000 RPM

Rapid turnover is one sign of good business, and in the high-speed grinding business a turnover that produces a peripheral velocity of about 5000 feet per minute has been found to be best. This has not involved any major prime-mover problems with larger grinding wheels, but with the very small wheels used in internal grinders the speed of available motors was stepped up by a system of belts. Slippage and rapid wear of the belts have made such schemes unsatisfactory. A new motor has been developed by Mr. R. M. Baker, of the Westinghouse Research Laboratories, that delivers five horsepower at 60 000 rpm.

Ordinarily a five-hp, two-pole motor is a fairly large and heavy affair, about 11 inches high and 17 inches long overall, and weighs 120 pounds. In this case, however, it is comparatively small, about 4½ inches in diameter by 6 inches long, and weighs but 12 pounds. The speed of this two-pole motor depends on the frequency of the current used. At 500 cycles per second it develops about two and one-half hp at 30 000 rpm; at 1000 cycles per second, five hp at 60 000 rpm.

The terrific rotational energy developed at 60 000 rpm precluded the use of any but the strongest materials in the motor. Instead of using ordinary highly permeable soft iron for the laminations of the rotor, a special air-hardened chrome iron was used. This is less permeable, requiring provisions in the design to overcome the increased losses, but it had the strength necessary to resist the centrifugal force developed at



Mr. Baker checks the high-speed motor with a stroboscope.

speeds of 60 000 rpm and more. At these speeds any slight maldistribution of weight would be fatal so the armature is carefully balanced on the dynamic balancing machine.

At elevated speeds, bearings become a problem. Also positive means for dissipation of heat engendered by electrical losses is necessary at these speeds. In this motor, the bearings are the forced-oil feed type and the motor is water cooled.

High-Altitude Brushes

Horticulturists spend years and much money developing grains and other plants that can withstand the rigors of northern winters and yet produce in sizeable quantity. Research engineers have been faced with a kindred problem in connection with brushes for the d-c generators of high-altitude planes. Generator brushes perform excellently at sea level and even on planes that fly at altitudes of several thousand feet. But planes that fly the regions of the substratosphere have presented a set of stringent conditions too severe for the ordinary strains of brushes. Brushes that would last indefinitely at normal altitudes, were ground to powder in two hours of flying above 30 000 feet.

This apparatus enables Dr. Elsey to simulate the atmospheric conditions of pressure and humidity that prevail at altitudes upwards of 30 000 feet where brush wear in fighter planes has been excessive. The new type brushes are 50 times better than the old.

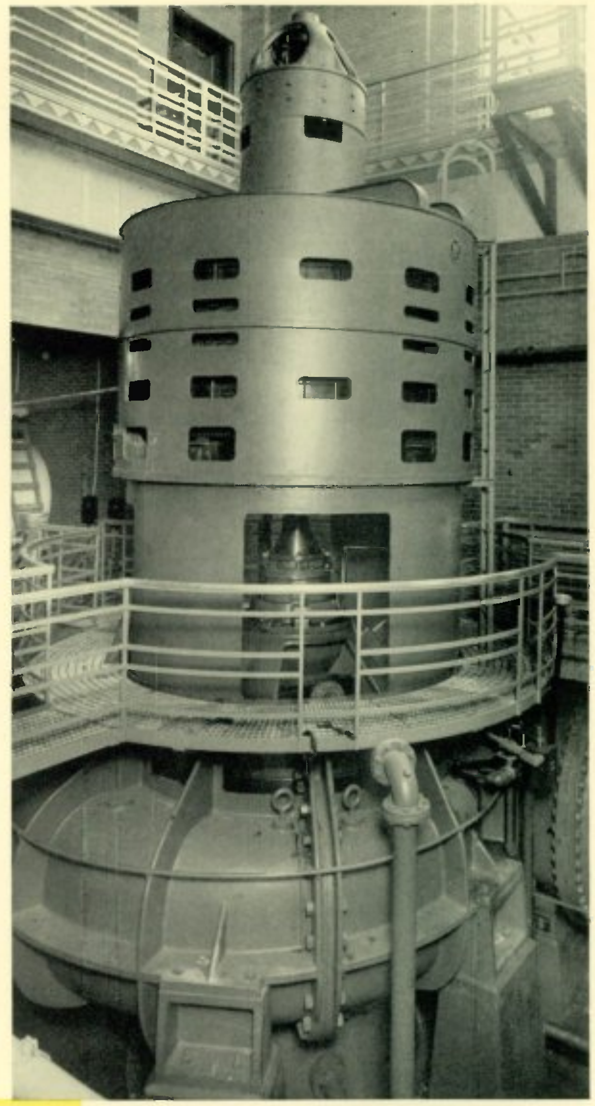
Clearly, with so many of this war's battles being fought in these upper regions, new brushes capable of meeting the different conditions of the substratosphere had to be developed—and quickly.

Research has again come through, by supplying a special treatment for otherwise standard brushes, by which the brush life above 30 000 feet is increased by about 50 times, to 100 hours.

When Dr. Howard Elsey, of Westinghouse Research Laboratories, and brush engineers undertook to remove this vulnerable point from high-altitude combat planes, they were posed with the problem of reproducing atmospheric conditions such as those encountered at extreme altitudes. Obviously, tests at 30 000 to 40 000 feet cannot be made at will. Dr. Elsey succeeded in developing a slip-ring brush-wear testing device that operates under a glass bell. In this bell the conditions of very low pressure and low relative humidity that give rise to excessive brush wear are duplicated. From this research work evolved a treated carbon brush, impregnated with an anti-dusting compound that establishes and maintains the required oxide film on the commutator surface, preventing the brush from being ground away. These brushes, operating under normal load and proper conditions of ventilation, etc., have a rate of wear of about one mil per hour. Thus, the immediate problem of keeping planes in battle condition for a longer time is licked. Further work is being done to improve upon that which has been accomplished. This work is so fundamental that here again a war-inspired effort will be of lasting value.

Large Multispeed A-C Motors

Mechanical clutches, electrical couplings, Kraemer drives, and many other schemes for obtaining multiple speeds from alternating-current motors have met with different and fluctuating degrees of popularity. Meanwhile, multispeed motors have long continued to enjoy a quite stable position of usefulness, but little affected by the rise of other methods of obtaining multiple speeds. Their field of application, while limited, is important, and within it there are several types and combinations of large, multispeed motors. The relationships, advantages, and limitations of each can be understood without taking a graduate course in motor design.



Multispeed a-c motors are used for driving pumps and fans. In this municipal sewage plant application, two-speed vertical synchronous motors drive large centrifugal pumps.

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Westinghouse Electric and Mfg. Company

All but a comparatively small percentage of large alternating-current motors are single speed, but for certain applications it is necessary or desirable that the motor have more than one operating speed. Multispeed alternating-current motors have long been extremely satisfactory for many drives where a single, constant speed is a disadvantage. It is common engineering practice to design and build both induction and synchronous motors that provide two, three, or four different speeds by a fairly simple switching arrangement. These multispeed motors are used in a wide range of sizes, from a few horsepower to several hundred horsepower.

Multispeed alternating-current motors are classified as variable torque, constant torque, or constant horsepower depending upon the requirement of the load. The variable-torque multispeed a-c motor is used for those applications in which the torque of the driven load varies as some function of the speed, usually as the square. Centrifugal pumps, fans, and blowers are good examples of variable torque drives. In these typical applications, the torque varies nearly as the square of the speed.

Induced- and forced-draft fans in power plants must frequently be operated at more than one speed so that the combustion rate in the boiler can be adjusted to meet the steam requirements of the station load. The output of pumps must sometimes be adjusted to meet similar requirements. Adjustment of pump or blower output by the use of a multispeed motor is always preferable to adjustment of a blower damper or pump valve because of the higher efficiency at the reduced output.

Constant-torque multispeed motors are applied to pulverizers, ball mills, rod mills, rubber mills, and kindred machines. The nature of these applications is such that the torque requirement is constant at all operating speeds. The horsepower rating of the motor varies directly as the speed at which it operates.

Constant-horsepower (i.e., the product of torque and speed is constant) multispeed motors are used, for example, to drive hoists, rolling mills, and slab millers. When a hoist is raising a light load, it can safely operate at a higher speed than when raising a heavy load. Inasmuch as the torque requirements are lower with the light load operating at higher speed, a constant-horsepower motor is desirable.

The fundamental speed of a synchronous or induction motor is a function of the applied frequency and the number of stator poles, the speed of the induction motor being somewhat less than a synchronous motor due to slip. The speed of 60-cycle synchronous and induction motors of different numbers of poles is tabulated in table I.

Methods of Obtaining More Than One Speed

The speed of a wound-rotor induction motor is adjusted by means of resistance in the secondary or rotor circuit. Using this method, the speed can be adjusted downward to approximately 30 per cent of rated speed. However, speed regulation is poor with a resistance in the secondary circuit, especially at the lower speeds. This causes a change in speed with any change in the torque of the driven machine, which may be undesirable.

Because the ventilation is less at low speeds, the torque output of a standard motor must be reduced as the speed de-

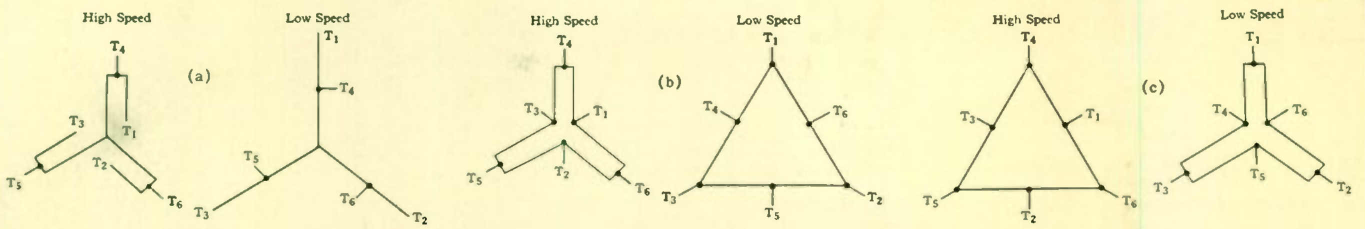


Fig. 1—The three wiring schemes for single-winding, two-speed squirrel-cage motors having a two-to-one pole combination. In each of the three schemes, terminals T_4, T_5, and T_6 are connected to the line for high speed, and terminals T_1, T_2, and T_3 are connected to the line for low speed. The two-parallel-star (T_1, T_2, T_3 connected together) and series-star (T_4, T_5, T_6 open) arrangements in (a) provide variable torque. In (b), the two-parallel-star (T_1, T_2, T_3 connected together) and the series-delta (T_4, T_5, T_6 open) arrangements provide constant torque. The series-delta (T_1, T_2, T_3 open) and two-parallel-star (T_4, T_5, T_6 connected together) arrangements in (c) provide constant horsepower.

creases. Thus a wound-rotor induction motor, used for speed control, can be applied only to a variable-torque load such as a blower or pump, unless especially designed for other types of load. The disadvantage of speed control by secondary resistance is partially offset by the fact that any number of operating points can be obtained, depending only upon the number of steps in the secondary resistance.

Two-speed operation of a squirrel-cage induction motor is obtained either by means of two windings, each connected for a different speed, or by means of a single winding that can be connected in two ways for two speeds.

When the speed ratio is two to one, two-speed operation is usually obtained by a single winding that can be externally connected for the desired speed. The normal three-phase, single-speed motor is essentially a six-phase machine as far as its operation is concerned because it has six 60-degree phase-belt groups per pair of poles. At the higher speeds, a two-speed, single-winding motor operates with the six normal 60-degree phase-belts per pair of poles. For operation at the lower speeds, the winding is reconnected so that three-phase groups instead of six-phase groups constitute a pair of poles. Each phase group then spans 120 electrical degrees at the low-speed connection, whereas at the high-speed connection it spans 60 electrical degrees. Thus, when the winding is connected for 120-degree phase belt, the motor operates at half of the maximum speed.

The number of poles in the secondary winding must always be the same as that of the primary winding. No reconnection is necessary in the secondary of the squirrel-cage induction motor because the poles are induced by the primary winding and will always have the correct number.

From the fact that the entire winding is used at each speed, it may appear that a single-winding, two-speed motor would be no larger than a single-speed motor. However, every two-speed motor is a compromise in design. The coil pitch or throw that is best for one speed may be entirely unsuitable for the other speed. If a single-speed motor has twelve slots per pole, it is desirable that the primary coils span ten slots or the coil pitch is $10/12 \times 100 = 83.3$ per cent.

Assume that an 8/16-pole motor has 96 slots so that the eight-pole winding has 12 slots per pole, and the 12-pole winding has six slots per pole. Thus, a coil pitch of 10 slots on the high-speed winding gives a coil pitch of $10/6 = 167$ per cent on the low-speed winding. Obviously this produces an uneconomical low-speed winding. A compromise coil pitch must therefore be used, and a throw of eight slots is the probable choice, giving a coil span (or per cent pitch) of 67 per cent on the eight-pole winding and 133 per cent on the 16-pole winding. Typical connections for single-winding multispeed motors are shown in Fig. 1 (a, b, and c).

It is a fundamental rule of design that for the same outside diameter of the stator punchings, a low-speed motor will have a larger rotor diameter than a high-speed motor. Again, in a two-speed motor, a rotor diameter must be chosen that is smaller than desirable for the low-speed and larger than desirable for the high-speed connection.

If the speed range is not two to one, two separate windings are used as shown in Fig. 2 (a). These windings are usually interlaced, i.e., coils A, A, A, etc., are connected to form one winding, and coils B, B, B, etc., are connected as the second winding. Connections for the two windings are made on opposite ends of the motor. Only half of the coils are used at one time. The two windings are independent except for the fact that all coils must have the same span and depth.

It would be possible to use a four-layer winding, as shown in Fig. 2 (b). In this case the two windings can be entirely independent, and the coil pitch of each winding can be chosen to give the best design. However, this type of winding is seldom if ever used because of the extra insulation space required by the four coil sides in each slot.

Each set of coils of the two interlaced windings obviously must have the same throw or pitch, that is, they must span the same number of slots. As in the single-winding motor, the coil throw or pitch is a compromise. Usually it is chosen so that it lies midway between the desirable pitch for the high-speed and low-speed windings.

TABLE I—SPEEDS OF 60-CYCLE SYNCHRONOUS AND INDUCTION MOTORS

Poles	Synchronous Motor Speed*	Squirrel-Cage Induction Motor Approximate Speed Full Load
2	3600	3564
4	1800	1780
6	1200	1185
8	900	888
10	720	710
12	600	590
14	514	505
16	450	440
18	400	390
20	360	351
22	327	319
24	300	292

*Rpm = 120f/P, where f = frequency, and P = number of poles.

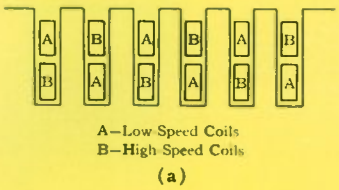
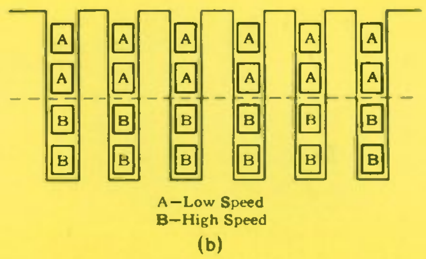


Fig. 2—The stators of squirrel-cage induction motors can be provided with two separate windings. These separate windings can be arranged in two layers, as in (a), or in four layers as in (b). In the two-layer arrangement, the coils are interlaced to reduce the number of coils by half. However, in certain ratios of pole combinations, this is not feasible. Where the pitch requirements of the two speeds cannot be compromised, two separate windings in four layers, not interlaced, are used. In this four-layer arrangement, (b), the two windings are at all times electrically independent.



The two-winding, two-speed motor is subject to most of the limitations of the single-winding motor, plus the fact that only half of the winding is used at one time. Obviously this results in a motor having higher losses and also larger in physical size than a single-speed motor. The two-winding motor has one advantage over the single-winding motor. The turns in the coils of one winding can be changed without affecting the other winding. Thus, it is usually possible to design a two-winding motor so that it has a higher power factor than the single-winding motor although the efficiency is usually less.

Three-speed operation is obtained by means of two interlaced windings, one of which is reconnected as described in an earlier paragraph. The most common numbers of poles are 4–6–8, 6–8–12, 8–12–16, or 12–16–24. One winding is reconnected for the highest and lowest speed. The second winding is used for the intermediate speed.

A four-speed motor is similar to a three-speed motor, except that both windings are reconnected for different speeds. A typical pole combination is 6–8–12–16 poles. One winding is connected for six and 12 poles, while the other is connected for eight and 16 poles. A four-speed motor uses the four-layer winding, illustrated in Fig. 2 (b).

Wound-rotor induction motors are sometimes designed as multispeed machines. This type of motor has two operating speeds at which maximum efficiency is obtained. Operation at other speeds is obtained by means of secondary resistance. The efficiency in this operating range is low as in the single-speed, wound-rotor motor.

In a multispeed, wound-rotor induction motor, the secondary or rotor winding must be reconnected for the same number of poles as the primary. If the speed ratio is two to one, only one winding is used for the primary and only one for the secondary. If the speed ratio is not two to one, two separate windings must be used in both the primary and secondary. Six collector rings are required if a single-winding secondary is used. If two secondary windings are used, five collector rings are sufficient because one ring can be common to both of the windings.

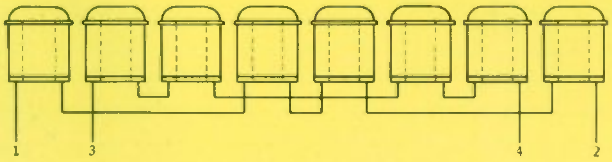


Fig. 3—Schematic diagram of the field connections for a two-to-one speed-ratio synchronous motor. For high-speed operation, terminals 1 and 4 are connected to the exciter and 2 and 3 are connected together. Low speed is obtained by connecting terminals 1 and 3 to the exciter and terminals 2 and 4 are short-circuited.

Synchronous motors are also built as multispeed machines. When the speed ratio is two to one, the armature or stator winding is reconnected in exactly the same manner as the primary winding of an induction motor. The rotor, or field winding, is connected in two circuits as shown in Fig. 3. Four collector rings are required. For low-speed operation, the polarity of the poles is alternately north and south (N S N S N S N S). For the high-speed operation, one circuit is reversed with respect to the other. Two adjacent poles have the same polarity (N N S S N N S S), giving the effect of half the number of poles in the low-speed connection.

When the speed ratio is not two to one, it is necessary that two different stators and rotors be used. In effect, this consists of two separate motors mounted in a common set of mechanical parts.

Multispeed operation of either a synchronous or induction motor is obtained at a slight reduction in efficiency, when compared with a single-speed motor. A comparison of the performance of a two-speed squirrel-cage motor, a wound-rotor motor, and a two-motor drive is given in table II. The application here considered is that of a fan or blower drive in which the torque effort varies approximately as the square of the speed.

Although the multispeed motor has certain disadvantages, as described above, it also has advantages that account for the widespread use of the multispeed squirrel-cage induction motor. The price of a multispeed motor is less than the equivalent number of single-speed motors. Less floor space is occupied and installation is easier because of the fact that only one foundation is required. The largest use of multispeed motors is in powerhouses where these motors drive fans or blowers and pumps. The large number of installations made over many years is proof of the reliability and good performance of the multispeed motor.

TABLE II—TYPICAL PERFORMANCE OF TWO TWO-SPEED COMBINATIONS OF INDUCTION MOTORS

	700/350 HP 1192/893 RPM 6 and 8 poles			1350/700 HP 887/709 RPM 8 and 10 poles		
Type of Motor	HP	RPM	Eff. (%)	HP	RPM	Eff. (%)
Two Single-Speed Squirrel-Cage Motors	700 350	1192 893	92.6 92.0	1350 700	887 709	93.4 92.9
Single-Speed Wound-Rotor Motor	700 350	1192 893	93.1 69.5	1350 700	887 709	93.7 74.8
Two-Speed Squirrel-Cage Motor	700 350	1192 893	91.6 90.1	1350 700	887 709	92.2 90.9

Characteristics of Copper-Oxide Rectifiers

The copper-oxide rectifier is deceptive. How it works can be stated in a single sentence, but the exact mechanism of its rectifying ability continues to defy analysis. Being but a disc or plate of copper oxidized on one or both sides, it is simple in physical construction. Yet, bringing it to its present state of perfection presented inordinate difficulties in manufacturing techniques and took years to accomplish. Easy and almost foolproof to use, the copper-oxide rectifier has many complex and interrelated characteristics often overlooked and which merit review.

I. R. SMITH
Rectifier Engineer
Westinghouse Electric & Mfg. Co.

Mr. Smith with a plate-type rectifier.

ROUGHLY twenty years have passed since the discovery by Dr. L. O. Grondahl that large areas of copper coated with cuprous oxide could be made to rectify. The development of a rectifier with large contact area came at an opportune moment, resulting in an immediate large business from the need existing for such rectifiers as trickle chargers for the d-c radios of the early twenties. Today the production of copper-oxide rectifiers has reached its highest point, though limited entirely to war needs. In fact, the copper-oxide rectifier has made a definite contribution to the war effort, filling many unique requirements that might otherwise have been very difficult to satisfy with any of the other types of rectifiers.

As a gauge of the importance of the rectifier, a rough estimate shows that more than 150 millions of the various sizes of rectifier discs have been placed in service on this continent alone.

The copper-oxide rectifying element is an integral combination of copper and cuprous oxide. Neither copper nor cuprous oxide has asymmetric resistance, but the combination of the two materials when properly joined together is asymmetric to a surprising degree. Current will pass through the element readily in the direction oxide to copper, but with great difficulty in the direction copper to oxide.

Manufacture commences with the selection of the copper, which must be of the highest purity. The ensuing steps are: preparation for oxidation, oxidation in controlled atmosphere at a temperature not much below the melting point of the copper, annealing at an intermediate temperature, and finally quenching in cold water. Temperature, time, and method must all be closely controlled for satisfactory results.

At this point, the rectifying element has its final characteristics, but further work is needed to remove the coating of cupric oxide unavoidably acquired in the process and which is so high in resistance as to be detrimental.

Small-capacity elements, which are made as discs in diameters ranging from 0.09 inch to 1.5 inches, are usually oxidized on only one side. Large-capacity elements are made as plates with areas ranging from about 10 to 50 square inches per side.

Numerous modifications of the process are used, their purpose being to obtain elements of different resistance characteristics, suitable for special applications.

No theory has yet been found for the mechanism of rectification by copper oxide that explains all the known effects. The rectifier is generally considered to consist of three elements: a good conductor (copper); a poor conductor, or semi-conductor, (cuprous oxide); and an insulating layer, known as the barrier layer, located between the two conductors. The barrier layer has never been actually located or identified, but its existence and dimensions (10^{-4} cm or less) have been determined by measurements of electrostatic capacity and other careful experimental work.

Characteristics

The most illuminating information about a rectifier is obtained from its volt-ampere characteristics, such as shown in Fig. 1. This curve represents the static characteristic of the rectifier; that is, values are obtained by impressing a d-c voltage across the rectifying element and reading the corresponding current without delay. Such a condition actually exists in service only in the case of an intermittent load of short duration, such as the closing of an oil circuit breaker.

The dynamic characteristic of the rectifier is that which the rectifier has in normal continuous operation. It differs from the static only in the back direction; that is, when a voltage is impressed across an element in the back (high-resistance) direction, the current does not remain at its initial value but increases somewhat, reaching stability in a few hours.

The forward volt-ampere characteristic, when expressed in terms of unit area, applies to all sizes of discs or plates, apparently without limit. The back volt-ampere characteristic is modified somewhat by the fact that part of the conduction is over the edges, so that a relatively higher back current is expected for small discs, where the ratio of edge to area is greater. With proper care the edge effect can be greatly reduced, so that for all practical purposes the back

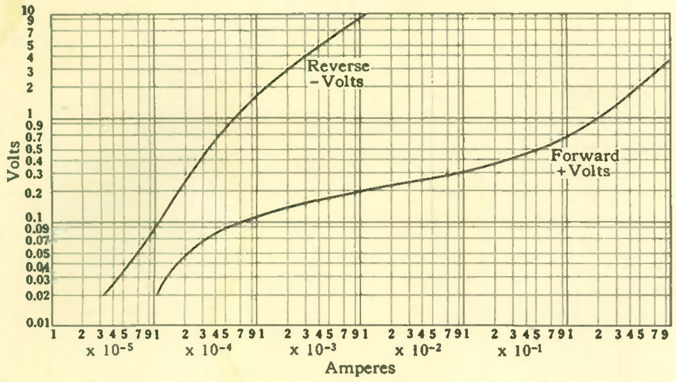


Fig. 1—*Volt-ampere characteristic of a new $1\frac{1}{2}$ inch copper-oxide disc.*

volt-ampere characteristic can also be expressed in terms of the unit area.

In neither direction does the rectifier have a constant resistance. In the forward direction, the resistance is quite high in the region of zero voltage, but drops rapidly as the applied voltage is increased. In the back direction, resistance reaches a maximum at about one volt, falling off slowly for higher voltages.

Although copper itself has a pronounced positive temperature coefficient of resistance, the copper-oxide combination turns out to be just the opposite, having a pronounced negative characteristic, as Fig. 2 shows. This works out usually to be an advantage for the forward characteristic, inasmuch as increasing temperature means less resistance and less loss. In the back direction, however, the reduction in resistance at higher temperature causes increasing back current with more loss. The effect of temperature then must obviously be taken into account in determining the safe operating rating for the rectifier, which in fact is a characteristic that is true of most types of electrical equipment.

A valuable characteristic of the copper-oxide rectifier, which is not found in all types of rectifiers, is the absence of any delay or time lag in operation. This results from the fact that the operation of the rectifier is truly electronic, and there is no electrical forming period required to establish a rectifying layer, nor is there any voltage breakdown necessary before current can flow. Regardless of the value of the applied voltage or at what part of the wave it commences, current instantly flows and at the rate to be expected. Furthermore, this instantaneous response is obtained regardless of the previous history of the rectifier; that is, it makes no difference whether the unit has just been operating previously or whether it has lain on the shelf for years without any operation at all.

The fact that the copper-oxide rectifying element has a measurable electrostatic capacity has already been mentioned. The dielectric is considered to be the insulating barrier layer. As might be expected, the capacity varies directly with the area of the rectifying surface. It also varies somewhat with the voltage applied and with the frequency.

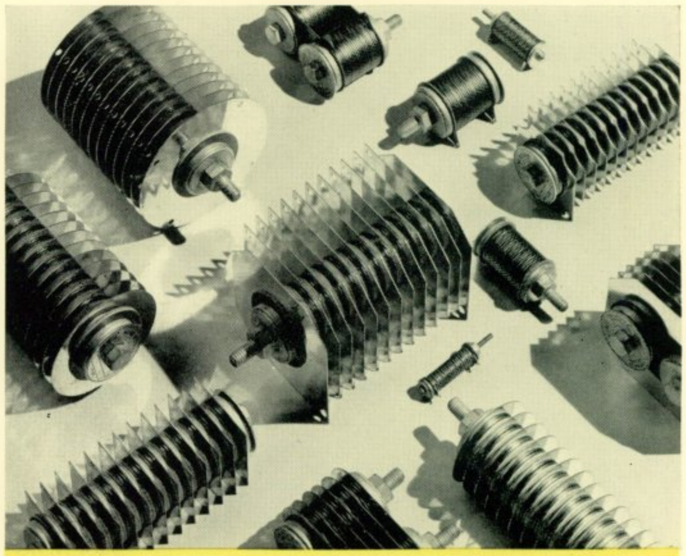
At ordinary commercial frequencies, the capacity effect is of no importance and need not be considered. At higher frequencies, above 1000 cycles, the capacity effect must not be overlooked. Most high-frequency work is in the instrument field where the capacity effect is reduced by reducing the size of the rectifying element.

Ratings

Losses in any rectifier are of two kinds. There is a loss caused by flow of forward or load current through the low-resistance direction of the unit, which decreases with increasing temperature. There is a second loss resulting from the passage of leakage or back current, which increases with increasing temperature. The total loss is the sum of the two, and may increase or decrease with increasing temperature, depending on which loss predominates.

The problem of rating is twofold. First, it is necessary to determine what the actual losses are for various operating temperatures at the proposed loading, and then to determine whether the rectifier is capable of dissipating those losses without excessive temperature rise.

Having determined the loss curves and the temperature-rise curve of the unit in question, it is necessary only to combine these two to find whether the rating chosen is satisfactory. How this works is shown in Fig. 4. Three different



The disc-type copper-oxide rectifier is made in a multiplicity of forms and sizes for many uses. Individual stacks vary in output capacity when self-ventilated from a maximum of about 30 watts down to about 0.001 watt, a range of 30 000 to 1. The 30-watt unit weighs $6\frac{3}{4}$ pounds, giving an ouput of 4.45 watts per pound.

total-loss curves are shown for a bridge-type rectifier to illustrate the method. All are for the same output. The losses in curve *A*, however, are for the case where the output is obtained at a high voltage and low current; in curve *B* the output is at a low voltage and high current, while in curve *C* both voltage and current are median values corresponding to actual ratings used in practice. The temperatures used for the ordinate scale are the actual operating temperatures of the unit.

Curve *D* is the temperature-rise curve of the unit, showing the temperature that results from the dissipation of any amount of watts within the unit. By starting this curve at 35 degrees C, which is the ambient on which the rating is to be based, this curve shows the total temperature of the unit at that ambient.

Curve *D* is now compared to each of the other curves. Curve *A* shows an unsafe condition, because it does not in-

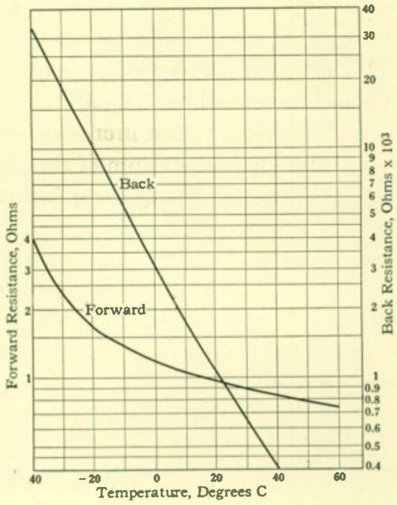


Fig. 2—*The effects of temperature on the forward and backward resistance of a rectifier.*

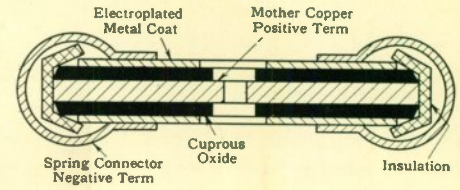


Fig. 3—*For large rectifying elements a plate construction is used instead of the disk- or washer-type stacks on a bolt under pressure. The outer surface of the oxide is covered with an electroplated coating of nickel, which then is used for current collection. The current is collected from the nickel coating as the negative terminal in any convenient manner.*

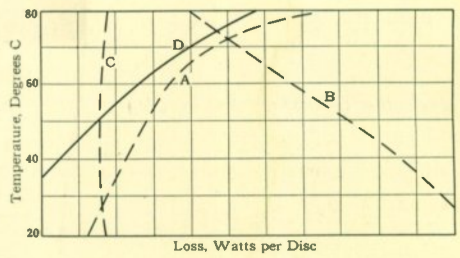


Fig. 4—*Selection of rectifier rating involves a comparison of the loss curves* (A, B, *or* C) *with the temperature-rise curve* (D).

tersect curve *D*, so there is no point at which the unit will operate stably.

Curve *B* is just the opposite from curve *A*. It can be said to be too safe. The unit temperature rises until the point of intersection of *B* and *D* is reached, where the rise will stop, because at this temperature the unit dissipates all the losses generated. At any increase in temperature, such as might be caused by increase in ambient, the watts generated actually decrease. Stability, it will be seen, is measured roughly by the size of the angle intersected between the two curves.

Curve *C*, as might be expected, gives results midway between the other two. The angle of intersection is less than for curve *B*, but is still large enough to give a good factor of safety. Stable operation results even if the ambient increases five or ten degrees.

All curves are based on the same output, hence their relative positions give the relative efficiencies. It is evident that the ultra-safe operation of curve *B* is obtained at the expense of efficiency, while curve *C* gives the best efficiency combined with adequate safety to the rectifier.

This analysis should make it clear that the safe operating temperature of a copper-oxide rectifier is not a definitely fixed figure, such as 75°C, but is a function of the rating of the rectifier. A given rectifier could operate quite safely in 50°C ambient at one rating, and yet be unsafe in 30°C ambient at another rating.

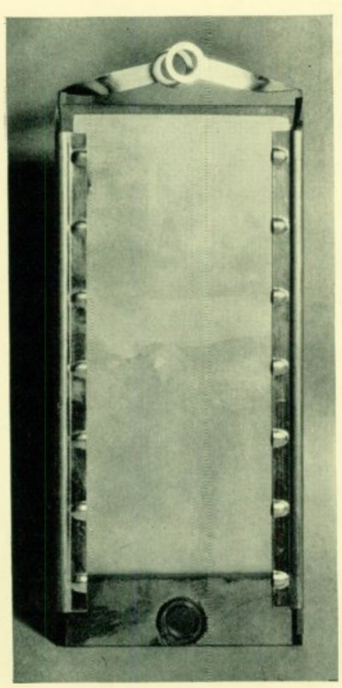


Plate copper-oxide rectifiers are made in several sizes, the smallest being 4⅜ inches square, the largest 4⅜ by 12 inches. The largest plate has an active area of 87 square inches, equivalent to 70 of the 1½-inch diameter discs. Plates are assembled in rows on insulated studs with space between for ventilation. By proper arrangement of the separating spacers, which can be insulating or conducting, plates can be connected in parallel, series, or series-parallel as desired.

All ratings, of course, must be determined from aged characteristics to be sure that the rectifier can deliver its full rated output after it has fully aged.

Efficiency

Rectifier efficiency is defined to be the ratio of d-c volt-amperes output, as measured with D'Arsonval type instruments, to the rms a-c watts input. On this basis, a single-phase rectifier can have a maximum efficiency on resistance load of 81 per cent, because the form factor of the output voltage and current at best will be 1.1. In a three-phase, full-wave connection, where the form factor of the output is nearly unity, the maximum theoretical efficiency is 96 per cent. In practice, of course, the unavoidable internal losses in the rectifier prevent attainment of the efficiency theoretically possible.

Because a rectifier acts like a series resistance, the forward losses are substantially constant for a given load current, regardless of the load voltage. Hence, as the output voltage is increased, efficiency increases, up to the point where increased back losses become large enough to offset the increase in output. This is shown in Fig. 5.

When, on the other hand, load voltage remains fixed and current is varied, the back losses are substantially constant and the efficiency is determined by the forward loss. These losses vary with the square of the current, except for the reduction in resistance which also takes place with increasing current. Eventually a maximum point is reached, beyond which the increase in forward loss is greater than the increase in output, so that efficiency begins to drop off.

Rectifier units alone range in efficiency from 65 per cent single phase to 85 per cent three phase at their best point.

Efficiency discussions are often misleading. Every rectifier has its most efficient operating point, which should be at its full-rated voltage. Consequently, at any lower voltage a lower efficiency is obtained. As voltage is increased above the rating of a single element, a second element must be added. The maximum efficiency of the two elements in series then is reached at double the voltage rating of a single element, and so on. Obviously, each time an element is added in series efficiency drops until the output voltage is increased to the new maximum-voltage rating.

Different types of rectifiers then, that may have maximum points of efficiency occurring at different voltages per element, cannot be compared except under carefully specified conditions, because for some other set of conditions their relations may be considerably altered. So, it is not enough to say that the efficiency of rectifier A is 60 per cent, rectifier B is 65 per cent, as these values may not be based on the same conditions. Instead we must find out what the relative efficiencies are for the voltage, current, and type of load under consideration, at the ambient temperature involved, for the type of circuit used, and not only for new, but also for aged conditions. One must also remember that rectifiers quite frequently do not operate at their most efficient point for various reasons so that general statements as to rectifier efficiencies, which are usually based on most favorable conditions of operation, do not necessarily apply.

Regulation

Voltage regulation of rectifiers, because of their internal resistance, is relatively large. Again, because the resistance drop for a given load is fixed, the regulation improves as the output voltage increases. Where a flatter voltage-regulation curve is needed, compensating means must be employed. A saturable reactor, for example, can be arranged to increase the applied voltage as the load increases, thus maintaining the voltage output of the rectifier unit constant.

Power Factor

A copper-oxide rectifier acts like a series resistance, and has little effect on power factor. Substantially power factor is determined by the type of load and by the rectifier transformer and other accessories. However, there is a slight deviation from unity power factor in the rectifier itself, resulting not from any displacement in phase between the voltage applied and the current flowing, but only because of the varying resistance characteristic of the rectifier in the region approaching zero voltage.

Form Factor

Form factor, the ratio of rms to average values of output, is likewise affected by the resistance-voltage characteristic. Thus, the form factor is lowest at loads of maximum resistance and increases as load resistance is decreased.

Series and Parallel Operation

With copper-oxide rectifiers there is no limit to operation in series or parallel or both. Units operating in parallel divide current inversely as their forward resistance so that any number can be so operated provided there is reasonable agreement in their forward resistances. Likewise, elements in series divide voltage in proportion to their back resistance, and again there is no limit to the number that can be placed in series. Thus, copper-oxide rectifiers have been built for voltages as high as 100 kv, requiring thousands of discs in series, and for currents as high as 5000 amperes continuously from a single rectifier, requiring nearly 200 plates in parallel. Banks as large as 60 000 amperes have been made.

Copper-oxide rectifiers have taken over the job of starting airplane engi

Atmosphere

Rectifier design must take account also of the environment in which the rectifier may be placed. Another factor, in addition to temperature which has already been discussed, is the nature of the atmosphere. Corrosive vapors, combined as they usually are with moisture, may destroy the rectifier completely.

Humidity affects the disc type of rectifier, if unprotected, by acting on the aquadag coating and increasing the forward resistance of the rectifier.

These effects can be guarded against by the use of suitable high-grade insulating varnish coatings. Complete protection against humidity effects can be obtained in this way for any type of copper-oxide rectifier, permitting the rectifier to be used safely in locations of extreme humidity such as along the seaboard or on board ship.

Varnish coatings also protect against mildly corrosive conditions. Where severely corrosive conditions exist, no varnish protection can be expected to give more than temporary immunity; either the rectifier must be removed from the immediate location, or it must be totally enclosed with considerable reduction in rating. Or, in the case of forced-draft types, good ventilating air can be brought in through ducts or the heat developed can be taken out by way of a heat exchanger. Plate-type rectifiers again can be immersed in oil, while disc-type units can be built in a special construction which allows them to dissipate their heat, but which prevents the discs being reached by the atmosphere.

. *Thus power is used from the airport system instead of from batteries.*

Immersion in Oil or Inerteen

While disc-type units have been operated successfully under oil, in general the idea is not recommended because of the possibility of oil getting into the aquadag coating with a resultant increase in resistance. This can, of course, be effectively reduced by proper varnish coatings.

The plate-type rectifier, with its electroplated coating, is free from such effects and can be operated under oil or Inerteen quite satisfactorily.

Heat can be dissipated either by natural circulation of oil and loss of heat to the tank walls, which can be fan-cooled, or by forced circulation of oil through a heat exchanger, which transfers the heat to air or water.

Intermittent Duty

One of the advantages of the copper-oxide rectifier is its ability to withstand high overloads for short periods of time, because of its high thermal capacity, particularly in the disc type. The extent of overload permissible is a function of the duration of the load and of the time off between loads. This has enabled the rectifier to be applied economically to many forms of intermittent loads. The number and variety of intermittent load cycles, however, make it difficult to lay down general ratings to cover all possibilities. It is better to work out rectifier designs for specific applications, in which the duty cycles are definitely known, than to try to establish general rules of rating to cover all conditions.

Overload

The effect of overload on a continuously rated unit depends on whether it is a current or voltage overload and on the temperature reached by the unit. Naturally, current overload is less dangerous, the temperature increases but the applied voltage actually decreases. Such overloads can be handled for long periods of time without appreciable damage. Voltage overloads are another matter, particularly because they are usually accompanied by corresponding current overloads. The effect of any overload depends upon its duration and extent, but because it is more likely to cause failure of the rectifier, overload in voltage is never permitted.

General statements on permissible overloads are not made because of the many variables involved. In specific instances, there are exceptions. For example, electroplating rectifiers are all guaranteed to stand 25 per cent overload in current for two hours.

Life and Aging

The copper-oxide rectifier is outstanding among rectifiers of all types in the matter of long life. Where life of other types of rectifiers is measured in terms of thousands of hours the life of the copper-oxide rectifier is measured in years. It affords life in a rectifier of the same order as that obtained from other types of industrial equipment.

This is not intended to mean that rectifier characteristics remain fixed during all this time at their original values. Changes do occur, generally referred to as aging. Both directions of rectification are affected. Such changes are found in all types of metal rectifiers.

In the back direction, no change in resistance occurs unless the rectifier is loaded. During periods of no operation, the back resistance remains fixed or may even increase slightly. During operation, however, the back resistance decreases somewhat from the value originally measured. The greatest part of this change takes place during the first 24 hours of operation. Beyond that time, the rate of change is very small. After several years of operation, the direction of change reverses and the back resistance begins again to increase. The extent of the change in back resistance depends upon applied voltage and operating temperature.

In the forward direction, the resistance changes are a function only of temperature without regard to operation. At temperatures just above five degrees C, no change whatever occurs. As temperatures increase above that point, forward resistance begins to increase with time.

For any ordinary application, the aging of a copper-oxide rectifier is of little concern to the user. Units are always rated according to their aged characteristics so that they are always able to deliver full output. Voltage adjustment is provided when needed so that output can be held up to full rating at all times.

In some applications, particularly where used as valves, it is necessary that resistance values be accurately known. Here again, as long as aged characteristics are used, no trouble need result.

Frequently, the effect of other parts of the circuit on output is forgotten when discussing the effects of rectifier aging. Two cases will illustrate the great importance of this factor.

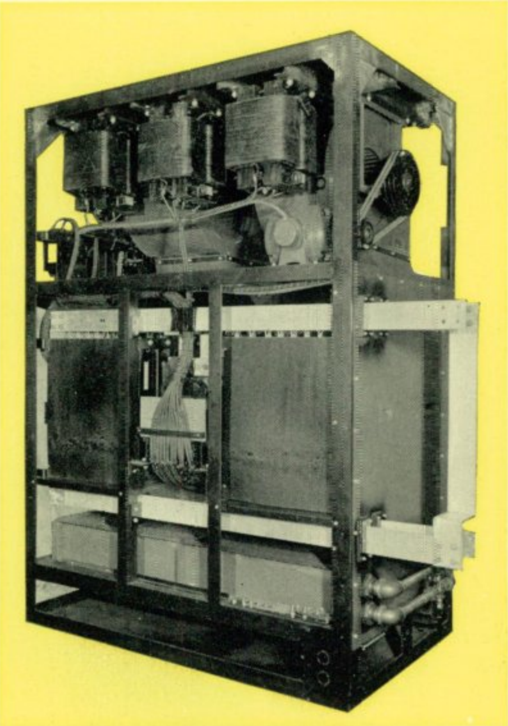
In the first place, let us say that the rectifier resistance when new is half the total circuit resistance, including the load. Assume then that as the rectifier ages its resistance doubles. Because the remainder of the circuit is unchanged, the applied voltage must evidently be raised 50 per cent to maintain the same current. If a fixed voltage is applied, the current flow will reduce to two thirds its former value.

In the second case, the rectifier resistance when new is one tenth of the total circuit resistance including the load. Now, if the rectifier resistance doubles, the a-c voltage need only be raised 10 per cent to maintain the same current, or for the same applied voltage, the current will reduce only nine per cent. In other words, a given percentage of change in rectifier resistance has had about five times as much effect in one case as in the other. By proper proportioning of circuit constants the effect of aging can be nearly eliminated.

The aging results obtained in the field on elevator-type rectox units are illustrated in Fig. 6. The curve shows the change in output voltage averaged over a large number of units, which operated as shown for seven years up to the point where readings were no longer taken. These same rectifiers have by now added four or five more years to their life, with no indications that they will ever stop. In this application, rectifiers are operated directly from the a-c line, and there is no means of raising the voltage. The amount of aging has been so small, however, that there is still ample output to operate the load satisfactorily.

A general discussion of the rectox rectifier must cover many angles and so cannot go very far into any one. The intent has been, however, to give a rough picture of the present status of this device, including its characteristics and performance.

In 20 years, the rectifier has come a long way. Those more closely connected with it feel that it has by no means reached its limits, but that future developments will broaden its field far beyond what can be seen now. Even if no further gain be made, however, the copper-oxide rectifier still remains an exceedingly useful tool in many varied forms and one that matches in interesting features any other electrical device that has been made. Certainly there is yet no evidence of any tapering off in the rate of new applications for the copper-oxide rectifier.



This is one of 24 plate-type rectifier units to supply low-voltage current for an electrolytic tinning line. Each unit delivers 2500 amperes at 12 volts. From a water-cooled heat exchanger seen in the base, cooling air is circulated inside the housing (covers not shown). The output can be varied over a ten-to-one range by means of saturable reactors.

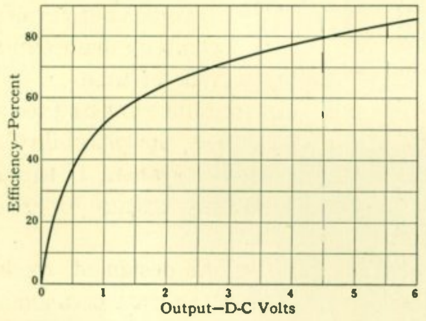


Fig. 5—*As this curve of a typical three-phase, fan-cooled rectifier shows, efficiency increases with the applied voltage.*

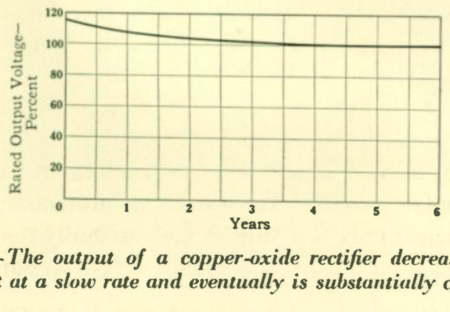
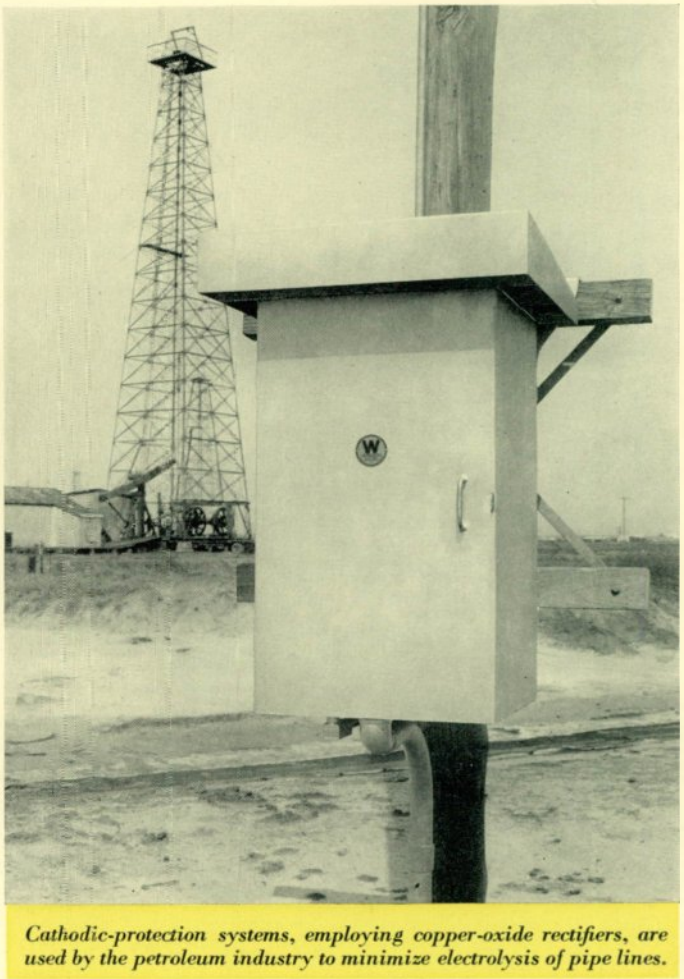


Fig. 6—*The output of a copper-oxide rectifier decreases with age—but at a slow rate and eventually is substantially constant.*



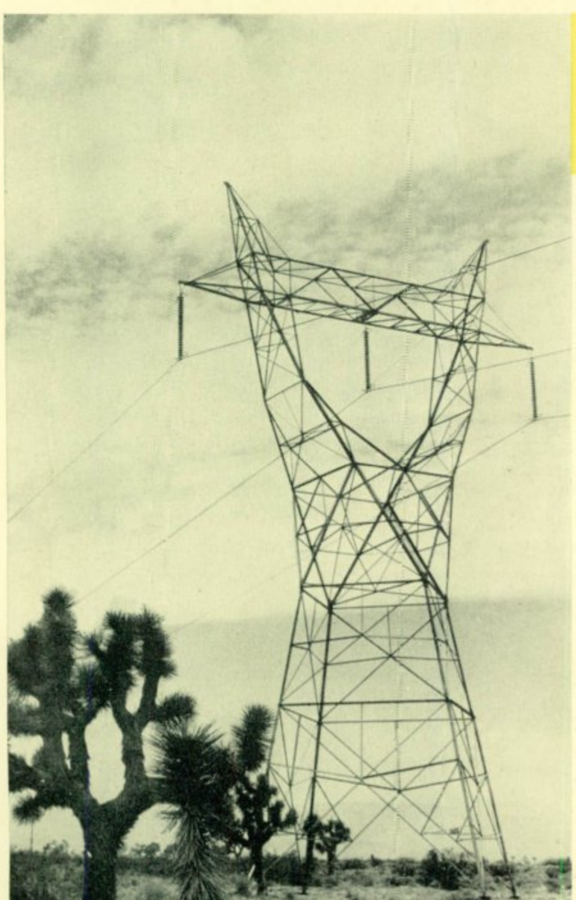
Cathodic-protection systems, employing copper-oxide rectifiers, are used by the petroleum industry to minimize electrolysis of pipe lines.

The Principles of High-Speed Relaying*

Most electrical apparatus sooner or later reaches a state of "package" development that a portion, frequently a large portion, of the applications can be made without special engineering. Such is true of lamps, motors, instruments, switches, and even generators. Not so with transmission relays. Each protective-relay application must be custom engineered, leaving with many the impression that relaying requires special knowledge and training. That relaying—even high-speed relaying—can be reduced to simple, easily grasped principles is demonstrated here.

W. A. LEWIS
Director, Dept. of Electrical Engineering, Cornell University

THE transmission engineer is faced with two alternatives. He can attempt to prevent electrical faults on his system altogether or he can isolate failures that do occur so effectively and so quickly as to prevent appreciable disturbance to service. The first alternative appears impractical. The solid insulating materials most widely used in electrical apparatus are organic and are subject to gradual deterioration with time, as a function of temperature and electrical stress. To design apparatus so that the possibility of failure is nil after many years of service involves a prohibitive initial cost. The deterioration of insulation beyond a safe operating point is often detected by periodic tests. However, testing equipment and procedure are not yet developed to such an extent that all impending failures can be anticipated and apparatus replaced before a failure occurs. Hence, failure-proof transmission line apparatus does not appear feasible at present.



Economics Determine the Amount of Protection

On overhead lines the problem is somewhat simplified by the fact that air and inorganic porcelain or glass are the principal insulating materials, and gradual deterioration is a factor of much less importance. However, lightning, the principal cause of an electrical failure on overhead lines, is a factor extremely variable in its severity. The cost of building a line that will not flash over for any severity of lightning stroke is, again, prohibitive. Even if such a lightning-proof line were achieved, occasional failures would occur from mechanical causes. There is always the possibility of objects striking the line, floods washing out towers, or other mishaps of infrequent occurrence. The cost of guarding against all such hazards is too great; a system without any electrical failures is at present beyond practical possibility.

Hence, the second part of the problem of maintaining continuity—the effective and prompt isolation of those faults that do occur—still remains. As faults become fewer, the difficulties of maintaining a relaying system for their isolation become greater. Devices that function infrequently are difficult to maintain in assured perfect operating condition over long periods of time.

It becomes a difficult problem to determine what balance should be maintained between expenditures to reduce the possibility of outage and expenditures to improve the protective system. If the protective system is fully effective, only a moderate expenditure for reducing the number of faults is justified.

This principle is particularly valid in the design of overhead lines where most faults are flashovers that result in little permanent damage and following which the line can be immediately restored to service. Where two parallel circuits are used, operation with one circuit removed can almost always be tolerated, at least for short periods. In such cases it is therefore essential only to design the system so that the possibility of a second failure on the remaining line, before the first can be restored to service, is negligibly small. This means, of course, that the line must be designed to minimize permanent damage that prevents immediate restoration to service. Precautions must be taken against breakage of insulators, burned conductors, destruction of towers by wind or ice, and similar hazards. However, the protection against lightning must be sufficient only to minimize the possibility that a flashover occurs on both circuits simultaneously. From a purely eco-

*This discussion is based on a paper originally presented before the Midwest Power Conference, Chicago, April 9, 1942.

nomic standpoint the cost of a further reduction of lightning outages must be balanced against the greater maintenance expense resulting from more frequent operation of circuit breakers on the system.

High-Speed Fault Clearing Is Important

Rapid isolation of the fault is one of the best ways to guard against burning down conductors and breakage of insulators from the heat of the arc. For this reason alone, rapid fault isolation is highly desirable. In addition, the disturbance to the remainder of the system is greatly reduced. Higher loads can be carried with the same margin of stability, and the annoying effects of voltage dips on lights and in shutting down motor loads because of low voltage are minimized. For all these reasons high-speed fault isolation is important and desirable.

New standard power circuit breakers open their circuits in eight cycles or less on a 60-cycle basis. More rapid circuit breakers are available when needed. However, the most rapid circuit breakers obtainable cannot achieve rapid fault isolation if not provided with a high-speed relay system to initiate breaker operation. In protecting against line faults, the time in which the fault can be finally cleared is limited as much by the characteristics of the system and the action of circuit breakers as by the design of the relays alone. The reason for this should be fully understood.

The Basic Relaying Problem in Line Protection

The problem is illustrated by a double-circuit sectionalized line, as shown in Fig. 1. A single circuit can be then treated as a special case, by opening one of the lines. The lines shown are assumed to connect two parts of a large system, each part of which may contain both loads and generation, so that the lines can act either as one-way transmission lines or as tie lines transmitting power in either direction.

For proper operation of the relay system, when a fault occurs at any point between buses *G* and *H* on the lower line, as at *F*, circuit breakers *a* and *b* only should open. Hence, not only must the proper relays operate, but all other relays must be prevented from operating.

The action of all relays must be determined by the electrical quantities available to them. Whether a relay is operated or not by a particular fault must be based entirely upon the magnitudes and phase relations of the electrical quantities supplied to it.

At point *a*, for example, on a three-phase system, the electrical quantities available for relay operation consist of three voltages and three currents, that is, the line-to-neutral voltage of each of the three phases, and the line current in each line. Any other voltages or currents must be formed by combinations of these six quantities. The magnitudes and phase relations of these quantities depend on the type and location of the fault; amount, type, and location of connected machinery; and the impedance characteristics of the system and of the fault. If a particular fault is moved a short distance along a circuit, the values of all six quantities at every relay location not immediately adjacent to the fault are changed only slightly.

With this consideration in mind, suppose that fault *F*, originally located just to the left of circuit breaker *b*, is moved a few feet to the right, past the circuit breaker, to a location on the bus, such as at *Y*. The impedance per phase of the circuit breaker and the short length of circuit between *F* and *Y* is usually so small that current and voltage magnitudes in the fault itself and in all parts of the system except between *F* and *Y* will not be changed perceptibly. Hence, all six electrical quantities available to the relays at *a*, regardless of the type of relays used, are not measurably different for faults at *F* or at *Y*. The same condition holds if the fault were moved further to the right just past circuit breaker *e*, to location *Z*, or to other nearby points.

However, to meet the requirements of proper relay operation, circuit breakers *a* and *b* (and no others) should be tripped for a fault at *F*; circuit breakers *b*, *d*, *e*, and *g* (and no others) for the fault at *Y*; and circuit breakers *e* and *f* (and no others) if the fault is at *Z*. In other words, circuit breaker *a* should be tripped if the fault is at *F*, but not if it is at *Y* or *Z*, although the electrical quantities available to the relays at *a* are essentially the same. At *a* there is no distinction between a fault just within and just beyond the remote end of the section, and therefore no basis for proper relay operation. As a result no high-speed relay system at *a* can operate correctly unless some further basis for discrimination between faults just within and just outside the far end of the section can be found. This fact is generally true, and is independent of the type of relay protection.

Discrimination by Time Delay

To achieve proper discrimination, either of two additional principles is used to supplement the basic electrical response of the relays. These are (1) time delay, or (2) transmission of further information from a remote point. Time-delay discrimination is based on the expectation that changes in the

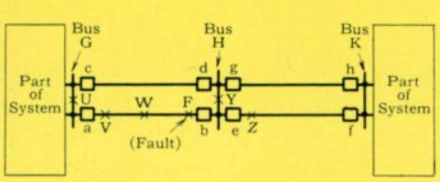


Fig. 1—*Single-line diagram of a two-circuit sectionalized transmission line connecting two parts of a power system.*

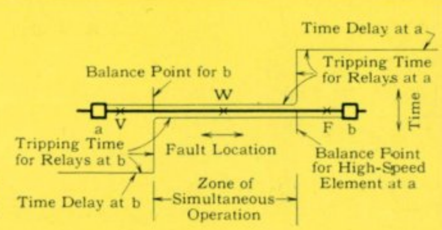


Fig. 2 — *Relay tripping-time diagram for a section* a-b *between* G *and* H, *Fig. 1.*

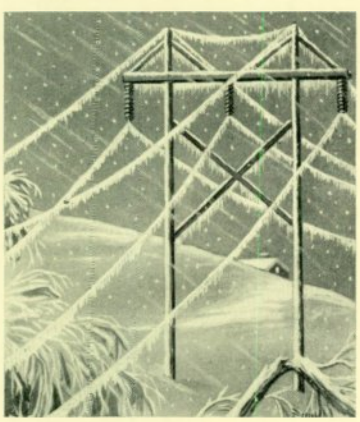
voltages and currents will occur within a short time because of the action of other circuit breakers and relays nearer the fault, which will permit the relays in question to determine whether the fault is within or beyond the section protected by the relays. Unless such changes occur, the use of time delay provides no basis for satisfactory operation.

Discrimination by Transmission of Further Information

The transmission of this further information may take the form of pilot-wire protection, using an auxiliary or pilot circuit for the purpose. Alternatively, the transmission can be by carrier current in which the power circuit itself is the communication channel. The carrier current uses a frequency far removed from that of the power so that the power and communication channels can be separated at the ends of the transmission circuit.

With the time-delay principle, the delay necessary for the correct operation of the relays at *a*, for example, depends upon the speed of operation of the relays and circuit breakers at *b*, which produce the necessary circuit changes. Hence, the overall speed of operation, for faults near the end of a line section, is essentially dependent upon other factors besides the relays.

When pilot-wire or carrier-current methods are used, the delay must be sufficient merely to insure that the signal is properly received. With modern systems the additional time required for this purpose is very short, often one cycle or less on a 60-cycle system. Thus pilot-wire or carrier-current methods practically obviate the need for appreciable time delay. However, cost and operating problems incident to the signaling circuit usually restrict these forms of protection to the more important circuits.



These statements can be clarified by referring again to Fig. 1. With the fault at *F*, large fault currents flow through circuit breaker *b* to the fault, and the voltage of the faulted phase or phases is much less than normal. If the fault is at *Y* or *Z*, the voltages applied to the relays at *b* do not change appreciably. However, the direction of fault current through the circuit breaker *b* is reversed. This provides a definite basis for determining, for the relays at *b*, whether the fault is to the left or the right of *b*. Hence, there is no difficulty in designing a relay scheme that trips circuit breaker *b* when the fault is to the left, as at *F*, and does not trip that breaker when the fault is to the right, as at *Y* or *Z*.

Circuit breaker *b* is also expected to trip when the fault is at *Y*, but the relays that produce tripping for the fault *Y* are the bus relays protecting bus *H*. They are entirely separate from the line relays under consideration at present. So far as the line relays at *b* are concerned, a fault at *Y* or at *Z* is outside of the line section being protected. Hence, in this particular case the line relays at point *b* should not operate.

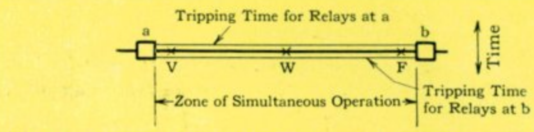


Fig. 3—*Tripping-time for pilot-wire or carrier-current protection.*

As soon as circuit breaker *b* opens, the voltages and currents at *a* change. For a fault at *Y* or *Z*, the path from bus *G* through circuit breaker *a* to the fault is opened, and fault current through *a* ceases. Hence, the tendency for the relays at *a* to trip is removed, and if the time delay provided at *a* is sufficient, breaker *a* does not trip. If, however, the fault is at *F*, fault current continues to flow through *a*, and the change when *b* opens is relatively slight. Hence, the relays at *a* continue to function, and after the expiration of the time delay, tripping at *a* follows. Thus, proper discrimination at *a* results only because of the action at *b*. If some form of pilot or signaling channel between *a* and *b* is available, the action at *b* can be anticipated, and the delay need be sufficient only to allow the transmission of the signal as to whether *b* is to open or not. Hence, in a fundamental sense, the successful operation of pilot-wire or carrier-current relays relies on the same time-delay principle—that proper functioning of the relays for a fault near the remote end of the line section is dependent upon the action of other relays at the remote end. The essential difference is the amount of time delay needed.

If the fault is near the left-hand end of the section, as at *U* or *V*, the problem is reversed. There is then no difficulty in obtaining proper operation of the relays at *a*. Relays at *b*, however, have no basis for discrimination, except as some change is provided by the relays at *a*, either by pilot signal, or by the opening of circuit breaker *a*.

When the fault is near the center of the line, as at *W*, the voltages and currents at the relays are such that the relays at both *a* and *b* can be made to trip without any risk that they will trip incorrectly for a fault external to the line. Hence, for a region near the center of the line section, no time delay is needed, and high-speed relay operation at both ends of the line can be provided.

Comparison of Relay Systems

Unless pilot-wire or carrier-current relaying is utilized, an appreciable time delay in final clearing is necessary only for faults near the ends of the line section, but for these faults the delay is inherent. The many kinds of line relaying available differ, however, in the method by which the time delay is secured, in the amount of time delay necessary, in the fraction of the line section at the center for which simultaneous high-speed tripping can be secured, and in the conditions for which the relaying will not operate as desired. To facilitate comparison of the different forms of relaying, a tripping time vs. fault location diagram is often used, as shown in Fig. 2. The abscissa represents a possible fault location, and the corresponding ordinates the tripping time for the relays when the fault is at that location. The trace above the axis represents the time for the relays at *a*, and that below the axis for the relays at *b*.

When faults occur in the central portion of the line sec-

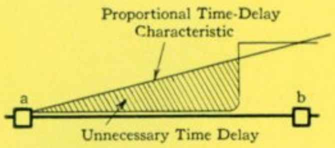


Fig. 4—*Proportional tripping-time diagram for relays at a.*

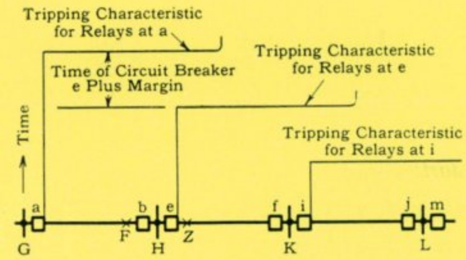


Fig. 5—*Tripping characteristics for definite-time-delay relays.*

tion, as shown, the relays at both ends operate safely at high speeds and rapid fault isolation results. Obviously it is advantageous to have the zone of simultaneous operation as wide as possible without introducing the possibility of incorrect tripping for faults outside the line section. The width of this zone depends upon the accuracy with which the relays can determine the fault location, and it is in this respect that the various relay systems differ widely. The more complex and expensive relay schemes have the wider zones of simultaneous operation, finally reaching pilot-wire or carrier-current protection in which this zone covers the entire section, as shown in Fig. 3. The tripping time may be slightly increased by the delay necessary to insure the transmission of the signal from one end to the other, but with modern schemes this time need be only slightly greater than the time of the high-speed relays themselves.

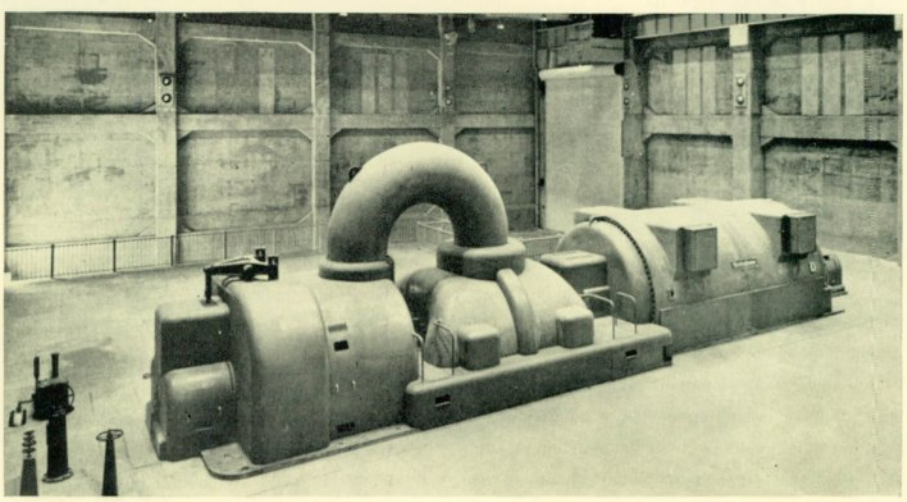
When pilot wire or carrier current is not used, two different modes of operation are necessary at every relay location, that is (1) high-speed operation for faults in the near portion of the section, and (2) delayed operation for faults in the far portion of the section. These two modes of operation can be obtained by incorporating two separate elements in each relay, or by utilizing a more complex mechanism that combines the two functions in a single operating element, either directly or with the aid of auxiliary devices. Actually, the two essential requirements are: rapid operation should occur for a fault immediately adjacent to the relay location, and action for faults at the opposite end of the section should be sufficiently delayed. In some cases these requirements can be met in another way by using a relay that has a time-delay characteristic proportional to the distance from the relay to the fault, as shown in Fig. 4. However, this form of characteristic results in unnecessary delay for faults in the greater part of the line, shown by the shaded area in Fig. 4.

Other shapes of characteristics are possible, but all satisfactory characteristics must meet the two requirements that fast operation occur for nearby faults and delayed operation for faults near the far end of the section. If this delay is not provided, erroneous tripping results when the fault is just beyond the end of the section. If high-speed tripping is not provided, the time delay must become cumulative when several sections occur in series, as shown in Fig. 5. For the relays at *a* to trip for a fault at *F*, they must also be able to trip for a fault at *Z*, because no difference between the two faults can be detected at *a* until either circuit breaker *b* or *e* has opened. But when the fault is at *Z*, circuit breaker *a* should not open, and the relay time delay at *a* must therefore exceed the relay time at *e* plus the circuit breaker time at *e* by a small but adequate margin. In the same way, the relay time at *e* must exceed the relay time at *i* plus the time of circuit breaker *i*, and so on. Only the farthest section can have truly high-speed relay operation. For the relays at *b*, *f*, *j*, etc., the time delay must be cumulative in the opposite direction, if each has a single definite-time characteristic.

As has been indicated, the relaying requirements just described apply to any type of relaying, and differences in results among overcurrent, balanced current, or distance types of relaying can be considered by comparing the characteristic curves and noting how the actual curves differ from the best possible curves, either in the extent of the high-speed zone, or in the added time delay necessary in the delayed zone. Another factor of great importance in comparing the merits of relaying systems is the variation in the characteristic curve with changes in system conditions, as one relaying system may be able to approach the ideal shape closely under favorable conditions, but departs greatly from it otherwise.

(*To be continued*)

An additional 65 000-kw power-generating unit has just been installed by the Los Angeles Bureau of Power and Light to supplement the energy normally derived from Boulder Dam. This reserve capacity is provided by a 3600-rpm tandem-compound turbine with twin condensers, driving a three-phase, 60-cycle, hydrogen-cooled generator. To insure continuity of power to this 450-square-mile war-important area, this installation generates substitute energy in the event of a secondary energy shortage at Boulder Dam and at other times operates as a spinning reserve to the Boulder transmission lines. The latter duty established the need for almost instantaneous pickup of load. This turbine generator is designed to increase power development from 5000 to 65 000 kw almost instantly. The rate of steam flow is increased from 60 000 to 500 000 pounds per hour in less than half a minute.



Motor-Starting Power Factor and Voltage Dip

Starting current has long been considered the principal line-disturbance factor and is accepted as the criterion by which single-phase, repulsion-start induction motors are rated with respect to voltage dip. However, the increasing use of capacitor-start induction motors with their high starting currents, but lessened light-flicker effect, shows that not only the starting current but also the power factor must be considered in judging single-phase induction motors.

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Industrial Motor Engineer
Westinghouse Electric & Mfg. Company

A CAPACITOR motor draws a larger current at starting than the comparable repulsion motor, yet the voltage dip it causes may be considerably less. The reason lies in the much better starting power factor of the capacitor motor.

This situation makes it clear that single-phase motors can no longer be compared on the basis of starting-current magnitude alone, as has been done for years. Single-phase motors have always been viewed critically with respect to the voltage dip caused at the instant of starting because this voltage dip in the power circuit may cause annoying light flicker. As long as single-phase motors had approximately the same starting power factor, the magnitude of the starting current gave a simple and adequate means of evaluating the effect a motor will have on the system at instant of starting. But the rise in importance of the capacitor motor, with its relatively high power factor, makes starting-current magnitudes inadequate as a measure of the effect of the single-phase motor on light fluctuation.


The author with repulsion-start, single-phase motor.

For comparable torques, although the starting current of a capacitor motor is higher than a repulsion-start motor, the disturbance on the line is about the same because of the higher power factor of the capacitor motor. This is well illustrated by a comparison of the locked-rotor or starting characteristics for a 1½-hp, four-pole, single-phase motor of both the capacitor-start and the repulsion-start induction-running types. These characteristics are shown in table I.

Any line-voltage drop caused by motor starting can be considered as made up of two principal components. These are the resistance and reactance drops, which are not in phase. The resultant of these two drops, vectorially, is substantially the amount of drop in the line voltage. This voltage drop does not subtract directly from the line voltage. The power factor determines the angle at which it subtracts.

If a line or circuit feeding the motors, for example, has a resistance of 0.3 ohm and a reactance of 0.5 ohm, the resultant starting voltage at the motors can be determined from the circuit constants and the locked characteristics of the motors, and the drop can be calculated. Where 230 equals the normal line voltage, where the value 0.01 is a scale factor used in diagram, and where 100 divisions equals unit or 100 per cent voltage the resistance drop of the repulsion motor,

$$R_R = \frac{36 \times 0.3}{0.01 \times 230} = 4.7;$$

the reactance drop of the repulsion motor,

$$X_R = \frac{36 \times 0.5}{0.01 \times 230} = 7.8;$$

the resistance drop of the capacitor motor,

$$R_C = \frac{44 \times 0.3}{0.01 \times 230} = 5.8;$$

the reactance drop of the capacitor motor,

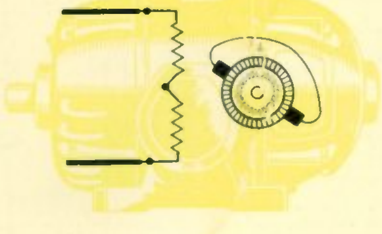
$$X_C = \frac{44 \times 0.5}{0.01 \times 230} = 9.5.$$

An arc of a circle with a radius of 100 divisions or squares is drawn with center at O (Fig. 1). This represents unity, or 100 per cent line voltage. A line from O to E_1 is at an angle θ_C, whose cosine equals the capacitor motor, locked-rotor power factor. In this case the cosine will be 0.87; the angle is 29½ degrees. Another line from O to E_2 is at an angle θ_R whose cosine equals the repulsion motor, locked-rotor power factor. In this case the cosine will be 0.50; the angle is 60 degrees.

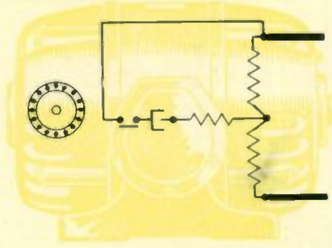
The resistance of the capacitor motor, R_C, (which equals 5.8 divisions) is plotted in a vertical line from point E_1. The reactance of the capacitor motor, X_C, (which equals 9.5) is drawn horizontally from the end of R_C. The line E_C from O to end of X_C represents the voltage at the capacitor motor. Voltage at the repulsion motor, E_R, is similarly determined.

TABLE I—STARTING CHARACTERISTICS OF 1.5-HP, 4-POLE, CAPACITOR-START AND REPULSION-START INDUCTION-RUNNING MOTORS

	Capacitor	Repulsion
Locked-Rotor Current, amperes	44	36
Locked-Rotor Power Factor, per cent	87	50
Terminal Voltage	230	230



Arcs scribed through E_C and E_R will give percentages of line voltage for each motor. In this case the arcs coincide and $E_C = E_R = 91$ per cent of original voltage of 230. This illustrates that on this particular circuit the voltage drop is no higher for the capacitor-start motor than the repulsion-start motor, although the starting current of the capacitor motor is 22 per cent higher than that of the repulsion motor.



With this method of plotting, the values of the reactive components, X, are always plotted in a straight line parallel to the base, and resistance component R, plotted in a straight line parallel to the vertical axis. Therefore, if the line OE_1 or OE_2 is established for a given motor, the effects on different lines or circuits can be easily determined. Or the limits of the R and X components of a line can be established for a maximum line drop.

The capacitor motor in question had a lagging power factor. If it had a leading power factor, its X_C would be plotted to the right of the end rather than to the left of the end of R_R. Therefore, the voltage would be higher than E_C. If the X_C component were for a leading power factor, there should be no voltage drop at starting; and if larger than 8.5 units, there would be a voltage rise at starting.

For a strictly accurate figure for the line-voltage drop, the R and X components of the entire circuit, including the transformer, should be included in the computation. Also, it would be necessary to assume E_C and E_R, then ratio the motor locked-current in proportion to assumed E_C and E_R over 230. If, in computing the voltage drops with these currents, the resultant E_C and E_R do not equal the assumed values, other assumptions for E_C and E_R must be made.

The procedure shown, however, is entirely adequate for purposes of comparison to show that the high-starting current of the capacitor motor should be no deterrent to its use. It can cause no more power-line disturbances or voltage drop than a motor that has a low-starting power factor.

The increased post-war need for motors for appliances warrants every consideration of the relationship between the high power factor of the capacitor motor and voltage dip.

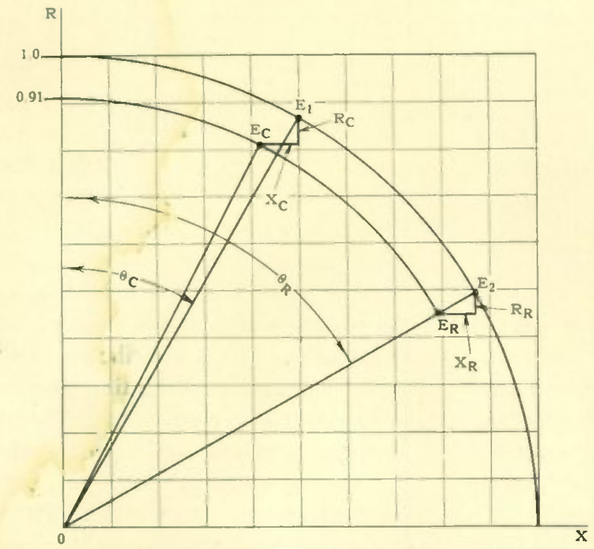


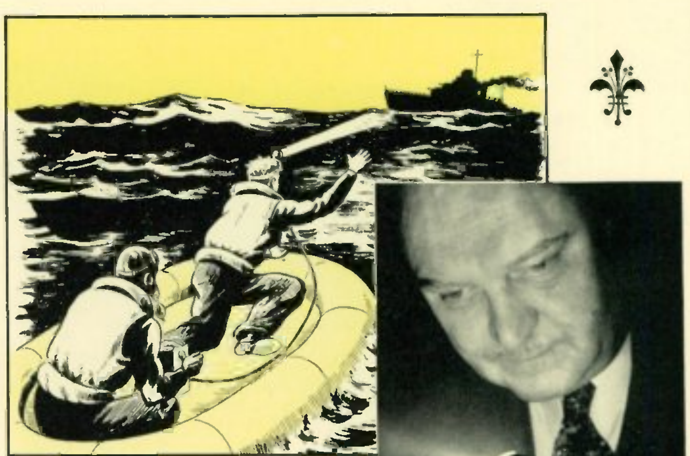
Fig. 1—*This vector analysis of the principal components of the cause of voltage drop (out of phase resistance and reactance drops) gives a clearer understanding of the importance of motor power factor in motor-starting line disturbance. Despite the fact that the capacitor-motor starting current is 22 per cent greater than that of the repulsion motor, the voltage drop of the line is the same for each because of the difference in phase-angle relationship (θ_C and θ_R).*

Life-Raft Beacons

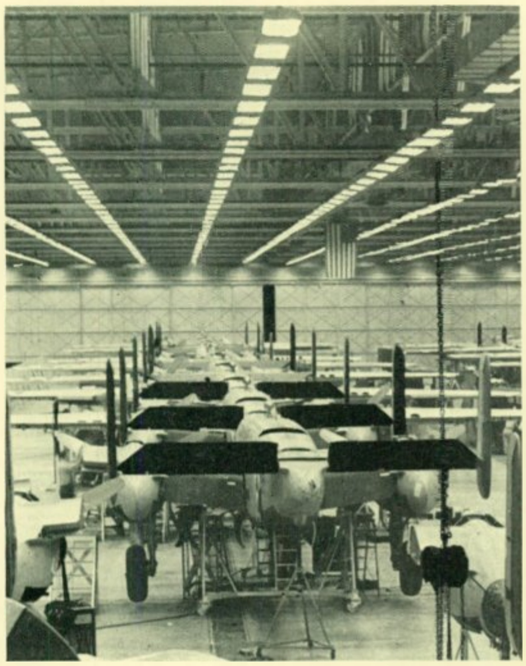
A HIGH order of navigation is required to find even the larger islands represented on world maps as mere pinpricks. Finding the survivors of a plane crash on the high seas has been considered practically hopeless, and in most cases heretofore has proved so. Every attempt has been made to take care of any flying contingency. To the self-inflating life raft, carried by ocean-flying military planes, has been added a short-wave transmitter with a range of 400 miles to act as a beacon to guide rescuers to the scene. Now a new type of lamp has been developed by Westinghouse so that rescuers can be accurately guided over the last dozen or so critical miles, which are the hardest when operating with the radio locator apparatus alone.

Navy specifications called for a lamp producing a light beam visible for 12 miles. This round bulb with integral silvered reflection requires no lens or external reflectors. Although smaller than a golf ball it projects a 1500-candlepower beam with a theoretical range of 60 nautical miles. This is reduced somewhat in actual practice by the presence of water vapor in the atmosphere.

This six-watt, walnut-sized searchlight is mounted in a waterproof housing and is worn on a head band, leaving both hands free. It is wired to the small hand-cranked generator that powers the radio-transmitter. By means of a make-and-break switch this lamp can be keyed for visual signaling. The life of this sea-rescue lamp is 100 hours and is far superior to ordinary signal flares. Used intermittently in conjunction with the radio transmitter, the lamp has a life of many days. Even if used continuously for 10 hours a night, it will last 10 nights.



Only six watts and the size of a walnut, this new lamp throws a 1500-candlepower beam nearly 60 miles.



Engineering for Seeing With Fluorescent Lighting

Outstanding novelty of the world's fairs of New York and San Francisco—only four years ago—was fluorescent lighting. Already it has reached full stature as a method of lighting. Tens of thousands of buildings use it; thousands of war factories depend on it. Out of this brief but intensive experience with it, certain principles regarding its use have become well defined; its advantages and disadvantages are clear cut—providing stable guidance for its future use.

WILLIAM H. KAHLER
Lighting Engineer,
Westinghouse Electric & Mfg. Co.

THE extensive use of fluorescent lighting in the war plants of the nation is a measure of the acceptance of this lighting by industry. This is particularly exemplified by the use of fluorescent lighting in the majority of the nation's aircraft assembly plants, large engine factories, gun plants, and thousands of smaller plants engaged in precision war production. The acceptance of fluorescent lighting by industry for actual operations is attributed to five definite characteristics of this new light source. These factors contributing to its success are high efficiency, low brightness, extended shape, color, and coolness.

Applications to Industry

The lighting engineer has several different light sources and many types of luminaires at his disposal. It is his responsibility to select the most suitable lighting system for the particular type of manufacturing involved.

For rough, non-precision work such as steel mills, forge shops, foundries, shipyards, mines, and the like, it has been found that mercury or filament lamps are more suitable. Fluorescent lighting is most useful where precision workmanship is encountered. Critical prolonged seeing tasks demand the quality of illumination that is economically supplied by engineered fluorescent lighting. In aircraft plants, textile mills, drafting rooms, machine shops, intricate assembly and inspection work, this type of lighting is particularly effective because in these applications the inherent qualities of fluorescent lighting are utilized to best advantage.

High Efficiency—Increased Illumination

Lighting research, in recent years, shows that higher illumination levels are essential for maximum industrial efficiency in many operations. In a precision machine shop or tool room, for example, at least 50 footcandles of general lighting are recommended. With filament lamps in industrial diffusers, approximately seven watts per square foot would be required and this is a very high load density for lighting. Continuous-strip fluorescent lighting, because of its higher efficiency, can provide 50 footcandles with but three watts per square foot, which is a practical load density. This great reduction of load means a considerable saving of copper in the lighting distribution system and, in addition, the lighting operating cost is reduced. The copper saving is enhanced when the lighting-load power is distributed at the higher voltages permissible in fluorescent lighting systems.

Many modern industrial plants, particularly in the South, are air conditioned. With intensities of 35–50 footcandles, the heat from the lighting system is an appreciable portion of the total air-conditioning load, but the lower load density of fluorescent lighting reduces this heat to a reasonable value.

The vast aircraft program has demanded buildings of sizes

The author measuring light intensity at a work position.

Fourteen miles of fluorescent tubes light the prefabrication and manufacturing areas in the Kansas City plant of North American Aviation Inc. Here well-diffused light eliminates the need for supplementary lighting for most of the underneath work on the Mitchell bombers. Adequate intensities are provided for highly precise machining operations and small-tool production without specular glare and minimized direct glare.

that were not even dreamed of ten years ago. These buildings have truss heights of 40 to 50 feet, and are 200 to 600 feet in width. Heretofore it was believed that only concentrating-type high-bay reflectors were suitable for these high mounting heights. It was soon learned, however, that widespread fluorescent equipment could be used in these large areas at 40 to 50 feet mounting height, with light utilization equal to that of concentrating equipment. The reason for this high utilization is that illumination depends upon the ratio of building width to mounting height rather than mounting height only.

In a high, narrow building, having but a few rows of luminaires, much of the light from widespread reflectors would be cast on the walls and windows, and thus lost. Concentrating reflectors are used in these circumstances to utilize more of the available light. In a building where the width is several times the height, most of the direct light from the luminaires reaches the working area without striking the walls, and consequently, widespread fluorescent equipment can be used in these large factories.

The quality of light and quantity of light are of equal importance to good seeing conditions. Included in the factors of quality lighting are absence of direct or reflected glare, elimination of harsh shadows, good vertical illumination, even distribution of light and suitable color.

Glare, which is the worst offender to seeing, is minimized by reducing the source brightness and increasing the brightness of the surroundings that serve as a background for the source. The fluorescent lamp, because it is a low-brightness source, minimizes direct glare. This characteristic is especially useful in aircraft plants where workers are frequently looking upward and their eyes are unshielded from the light sources suspended above.

Where specular metals are handled, processed, or inspected, reflected glare may be annoying if high-brightness light sources are used. Here again a low-brightness light source solves the problem. In the textile mill specular reflections from the warp on the loom are eliminated and seeing tasks become markedly easier with fluorescent lighting.

To prevent sharp shadows lighting must be well diffused, that is, it must literally come from all directions. Fluorescent equipment serves this purpose for several reasons. First, the luminaires direct light in all directions because they have a wide distribution of light. Second, the lamp is a light source of extended shape. Third, many luminaires are used at relatively close spacing. These three factors combine to produce a lighting system that approaches one large area of light in its effect.

In factories where there are large overhanging assemblies such as the wings of planes, well-diffused light eliminates the necessity of supplementary lighting for most of the underneath work. Properly engineered fluorescent lighting provides adequate intensity on the underneath surfaces of wings in large plane factories as well as on the top surfaces.

In textile mills the shadows of the drop wires and harness on the looms are a source of eye strain. The shifting shadows are completely eliminated by fluorescent lighting.

Diffusion also furnishes high vertical illumination, which is necessary when the visual task is located in a vertical plane, such as the side of a car, tank, or plane.

High illumination levels are required in a machine shop, because the seeing tasks involve the discrimination of fine detail on flat or curved surfaces. High intensity is not the complete answer, however, for adequate seeing conditions in the application. The markings on steel scales and micrometers can be easily seen and accurately discriminated only when illuminated by a large area, or extended source of low brightness. Continuous-strip fluorescent lighting, because it is an extended low-brightness source, provides the high visibility necessary for these precision tasks.

Visual requirements in drafting are severe and prolonged. Optimum lighting calls for elimination of shadows and no annoying direct or reflected glare from paper, tracing cloth, and instruments. Semi-indirect fluorescent lighting meets these requirements because the light is especially well diffused, and source brightness is low.

Many Colors Obtainable

For the first time in the history of illumination, many colors of light are obtainable without the use of color filters. The color of light emitted by fluorescent lamps depends upon the chemical composition of the phosphor coating on the tube wall. Exceptionally high efficiencies are produced by green, gold, blue, and pink lamps. The red is least efficient, but produces many more lumens per watt than a filament lamp with a glass filter. The two standard colors for general illumination are daylight and 3500-degree white.

The 3500-degree white lamps (3500-degree Kelvin color temperature) are by far the most popular and best suited industrial lamps for general lighting because they are 13 to 17 per cent more efficient than the daylight lamp. Also the color of light is more pleasant, and is psychologically more acceptable to plant personnel.

Color Matching

The daylight fluorescent lamp is the nearest practical approach to natural light thus far attained. Many industrial color problems, such as occur in printing plants or paint factories, find their solution in the use of fluorescent daylight lamps, to furnish general illumination perfectly acceptable for the desired color discrimination. One manufacturer of lacquers and enamels constructed a special color-matching booth using these lamps to match sample color panels. Intensities of 175 to 500 footcandles can be obtained in this booth, the intensity depending upon the reflectivity of the colors being matched.

One limitation of the fluorescent lamp as a color-discrimination light source is that it is somewhat deficient in red as compared to natural light. Therefore, a red- or brown-colored material will not appear to be exactly the same color under fluorescent as under natural light. Also, there will be color differences between filament lighting and natural light, because the filament lamp emits more red than the natural source. Therefore, before the application of any light source to a color problem it should be tried on the actual materials and colors involved.

Coolness

The fluorescent lamp has been referred to as cold light. This is not exactly true, because, like other electrical apparatus, it does emit heat in proportion to its total wattage. However, the heat per footcandle on a work surface is only a fraction of that of filament lamps for two reasons. First, the high efficiency of fluorescent lamps means fewer total watts for a given lighting task. Second, the fluorescent lamp actually directs less radiant heat toward the worker than a filament lamp of equal wattage.

Therefore, it is now possible by means of fluorescent lighting to concentrate several hundred footcandles on a work center where particularly critical seeing tasks are required without subjecting the operator to annoying heat.

Luminaires Tailored for Seeing and Economy

The two types of fluorescent lamps that are used for industrial lighting are the 40- and 100-watt sizes. These are the largest lamps in the fluorescent group. The lighting industry has standardized on reflectors for either two or three 40-watt lamps or for two 100-watt lamps. Forty-watt lamps are slightly more efficient and have a lower brightness than the 100-watt lamps. The 40-watt equipment is therefore particularly suitable for supplementary lighting where the workers are subjected to direct lamp brightness. Using the 100-watt size fewer lamps are required for an installation because this lamp has twice the lumen output of the 40-watt lamp. Also, the 100-watt lamp is more rugged and has a longer life, so that maintenance is minimized. The 100-watt lamp, because of these characteristics, should be installed in most industrial areas where it can be applied to a practical layout.

The standard fluorescent luminaire consists of a reflector and a wiring channel. All lamp holders and lamp operating auxiliaries are included with the channel. To facilitate maintenance, luminaires are constructed so that the reflector is easily removed for cleaning. Starters are located so they can be replaced without removing the lamps.

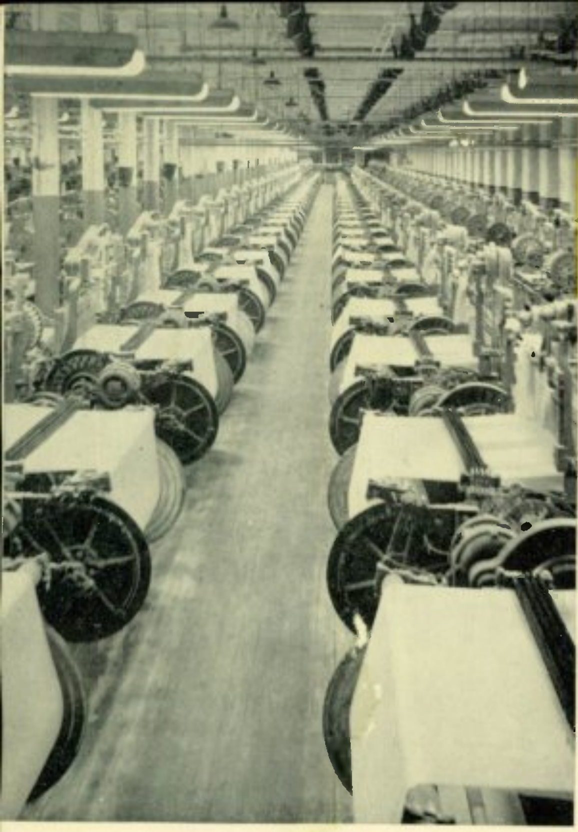
These units can be installed and wired as individual units on symmetrical spacings, or can be run in continuous strips. The first method is generally used to provide intensities up to 30 or 35 footcandles. When higher levels are desired, the reflectors are mounted end to end on wire channels to form continuous lines of light. This type of mounting allows a greater concentration of luminaires for a given area, and hence a higher level of illumination. The wire channel eliminates conduit and thereby reduces installation cost. A much neater appearance results with strips, because a forest of scattered reflectors is eliminated.

Specialized Fluorescent Equipment

To meet the requirements of various conditions of operation in industrial processes, special lighting apparatus is necessary. The dust present in the air in certain parts of grain mills and powder plants is explosive, and fluorescent units must be dust-tight and approved by the Underwriters' Laboratories for application in these hazardous locations.

If corrosive, non-explosive vapors are present around the luminaires, the equipment must be totally enclosed and made vapor-tight. However, should the vapors be explosive,

Properly engineered high-bay-mounted fluorescent lights provide evenly distributed, high-intensity lighting applicable to such critical seeing tasks as machine-shop and assembly work. Note the absence of shadows in the plant.



The diffused light from the fluorescent lamps eliminates the shadows from the drop-wires and harness of the looms in textile mills that have previously been a source of eye strain.

the equipment must be explosion-proof and listed by Underwriters as acceptable for this type of hazardous location. Fluorescent equipment is now available for the above applications also.

In many industrial processes light intensities of the order of 100 footcandles are required for quick, accurate, and comfortable visual discrimination in critical seeing tasks of fine detail. It is usually not practical to provide these illumination levels with general lighting, so luminaires close to the work are used to supplement the general system. Fluorescent lighting is especially suitable for these supplementary applications as a result of its inherent characteristics of low brightness and minimum heat effect.

Both the small and large fluorescent lamps will be used in thousands of supplementary applications in the future, because of the superior lighting quality and high efficiency that is obtained. Cash registers, weighing scales, home ranges, machine tools, instrument dials, and show cases are just a few of the specialized applications for fluorescent lighting.

Electrical Distribution System

Standard voltages for most filament lamps range from 110–125 volts. The reason for selecting this voltage range rather than higher voltages is that filament lamps are more efficient and rugged at this voltage.

Here again fluorescent lamps differ from filament lamps in that the ballast can be designed for almost any primary line voltage and the secondary or lamp voltage is always the same for any one lamp size. Standard fluorescent ballasts are available for 110–125, 199–216, or 220–250 volts. A new fluorescent ballast is now available with a 265-volt primary for operation from 265–460-volt, three-phase distribution systems. It operates four 100-watt lamps and considerably less material per lamp is required than for two-lamp ballasts.

With the present shortage of electrical materials, it is essential that we stretch our stock piles of copper and iron as far as sound engineering will permit. Therefore, a detailed analysis of a typical lighting system was made to determine which standard distribution voltage would require the least amount of copper in the system. The results of the study are summarized in table I.

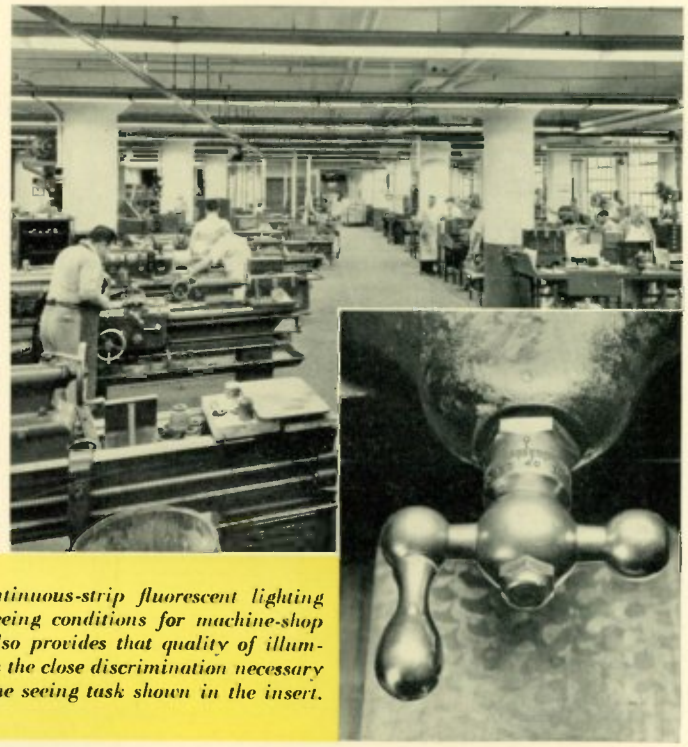
The typical plant covered 700 000 square feet and was designed for 50 footcandles using continuous fluorescent strips with two 100-watt lamps per reflector. Only the three-phase distribution system is considered because it requires approximately 20 per cent less copper than single-phase, three-wire systems.

This analysis brings out two definite points of interest from an engineering standpoint.

1—As the distribution voltage is increased, the copper is reduced because smaller conductors can be used.

2—Fluorescent lighting can be installed with a less total consumption of copper than a filament lamp installation, if the higher voltage distribution is used.

It is evident, therefore, that the design of a fluorescent lighting system must be based on all of the characteristics peculiar to this type of equipment in order to utilize to the fullest extent all of the advantages that contribute to a well engineered industrial lighting system.



Not only does continuous-strip fluorescent lighting provide excellent seeing conditions for machine-shop operations but it also provides that quality of illumination that permits the close discrimination necessary as exemplified in the seeing task shown in the insert.

Effect of Line Frequency

Standard fluorescent equipment is available for operation with both 50- and 60-cycle circuits, but the 50- and 60-cycle ballasts are not interchangeable. A 60-cycle ballast should not be used on 50 cycles because of the higher lamp current, thus reducing lamp life and overheating the ballast. A 50-cycle ballast should not be used on 60 cycles as the lamp current is reduced, reducing light output and possibly lamp life.

Operation at frequencies less than 50 cycles presents a serious problem in the elimination of cyclic flicker. Fortunately, there are few locations in this country with such low frequencies. In Canada, where 25-cycle distribution is com-

TABLE I—POSSIBLE COPPER SAVINGS IN TYPICAL FLUORESCENT LIGHTING SYSTEM

Power Supply at Lighting Panelboard	FLUORESCENT LAMP SYSTEMS			FILAMENT LAMP SYSTEM
	120/208 Volts 4-Wire 3-Phase	208 Volts 3-Wire 3-Phase	265/460 Volts 4-Wire 3-Phase	120/208 Volts 4-Wire 3-Phase
Luminaire Voltage	118	208	265	120
Lamps per Ballast	2	2	4	—
Total Distribution Copper—pounds	1831	1561	705	3184
Total Luminaire Copper—pounds	1740	1740	1270	89
Total Copper in Lighting System—pounds	3571	3301	1975	3273
Relative Weights of Total Copper Required	100%	93%	55%	92%

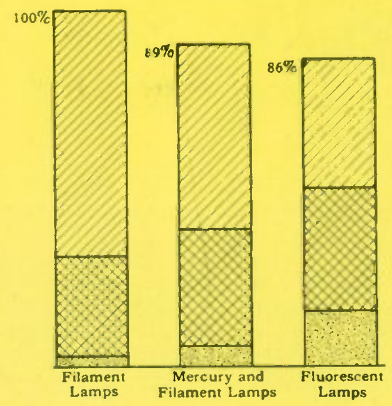


Fig. 1

This chart shows graphically the relative annual costs of the several types of lighting. The somewhat higher non-operating cost of the fluorescent lighting is more than offset by the much lower cost of the power.

mon, three lamps are operated in a fixture from a three-phase circuit, thus minimizing annoying cyclic flicker.

D-C Operation

The fluorescent lamp is essentially an alternating-current device and all published ratings are based on a-c operation. However, these lamps can be operated on d-c circuits with special starting auxiliaries and resistance ballasts, but the efficiency is reduced because the losses inherent in the auxiliaries are approximately equal to the lamp wattage.

With the 30- and 40-watt lamps, one end of the tube generally becomes dim after operating for some time on direct current. This condition can be rectified by reversing the direction of current in the lamp once a day by installing a polarity-reversing switch.

Several outstanding fluorescent installations have been made where only d-c power supply was available and these applications have been successful where the lamp manufacturers' recommendations have been followed. Because of the low efficiency, d-c operation is not recommended for general illumination, but is often very desirable for supplementary lighting even at the sacrifice of efficiency.

The Economy of Fluorescent Lighting

After studying the many advantages of the quality fluorescent lighting the plant owner always wants to know, "How much does it cost?" This question must be answered in two parts, initial cost and annual operating cost. The latter, however, is the only true picture of lighting expense for initial cost includes only the total first cost of installing the system and does not include any allowance for operation.

Annual operating cost of any lighting system includes: (1) non-operating overhead, which includes depreciation and interest, taxes, and insurance on initial investment; and (2) operating expense including cost of lamp replacements, maintenance, and power cost.

When comparing the cost of fluorescent lighting with that of other systems, all of these operating and non-operating items must be included. If only initial cost is considered, the comparison is misleading because fluorescent costs considerably more initially than other types of equipment. When the cost analysis is all inclusive, it is usually found that fluorescent lighting is more economical than a comparable filament-lamp installation, as illustrated in Fig. 1. The main saving in fluorescent lighting is in reduced power required, because of higher lamp efficiency. It is impossible to make an arbitrary statement as to which is cheapest in all cases, however, until an actual cost study is made because the rate of depreciation, operating hours, power rate, and other factors have a controlling effect on the final result, and these vary widely with different cases.

Cost does not solely determine the best lighting method. Lighting quality and quantity are both fundamental factors of good visibility, and any sacrifice of either one for the sake of a small cost differential is short-sighted economy. Economic lighting quality and quantity are achieved only by sound illuminating engineering, utilizing the lighting tools best suited to the needs of a specific problem.

The illumination needs of a power-house turbine room are served by this unique custom-built lighting installation. In these two lines of light, 40-watt fluorescent lamps are used in conjunction with 500-watt filament lamps to provide light of a pleasing color. Despite the high mounting height of 60 feet, the average illumination is 22 footcandles

What's New!

A 100-to-1 Speed Range, from A-C Lines

The search for a satisfactory motor with a wide adjustable-speed range for alternating-current operation has been continuous since the commercial acceptance of alternating current. Many moderately successful schemes, some mechanical and some electrical, have been developed to attain this end. Each of these developments has some undesirable feature (limited speed range, poor speed-torque characteristics, high loss, high first cost, bulky or complex auxiliaries, etc.), so that frequently direct-current motors are used, although separate motor-generator sets are required. An electronic motor-speed control, known as Mot-o-trol, permits the use of alternating-current power while attaining a speed range as much as 100 to one, depending upon the base speed (full-field speed) of the motor, with fully automatic speed control and flat speed-torque characteristics below the base speed of the motor.

Essentially Mot-o-trol is a variable-voltage speed-control scheme in which the adjustable direct-current voltages for the armature and the field are supplied by electronic-tube rectifiers instead of by rotating rectifiers. The Mot-o-trol consists of a motor, a control unit, and a thyratron power-conversion unit. The motor is a conventional direct-current machine. The control comprises the resistors and switches, and its size is essentially independent of motor rating. The power unit consists of a single or polyphase grid-controlled thyratron-tube rectifier system. It rectifies the alternating current from the power line to direct current. This power is applied to the shunt motor and can be varied from zero to the rated motor voltage, or above, for direct-current armature control. Smaller thyratrons are also used in the control to provide rectified direct current for the motor field. The field voltage is held constant throughout the range of the armature voltage and is then reduced to provide the upper speed range by field weakening.

The Mot-o-trol system has a single-phase, full-wave rectifier for supplying direct current to both the field and armature of motors of one hp or smaller. For larger motors, two-phase, full-wave, or three-phase, half-wave rectifiers are used, depending on the most economical application of tubes. The salient parts of this system are a power transformer, the cabinet containing the control proper, the control station (push buttons, etc.), and a direct-current, shunt-wound motor.

Two speed-control potentiometers and reversing contactors enable the forward and reverse speeds to be placed at any desired rate within the design range. These speeds can be adjusted while the motor is running. The standard Mot-o-trol automatically regulates the motor speed to keep it constant regardless of any load within its full-load rating. Motors selected to operate with this control provide constant torque over the entire armature-control speed range and constant horsepower over the field-control range for continuous operation without exceeding safe temperature limits.

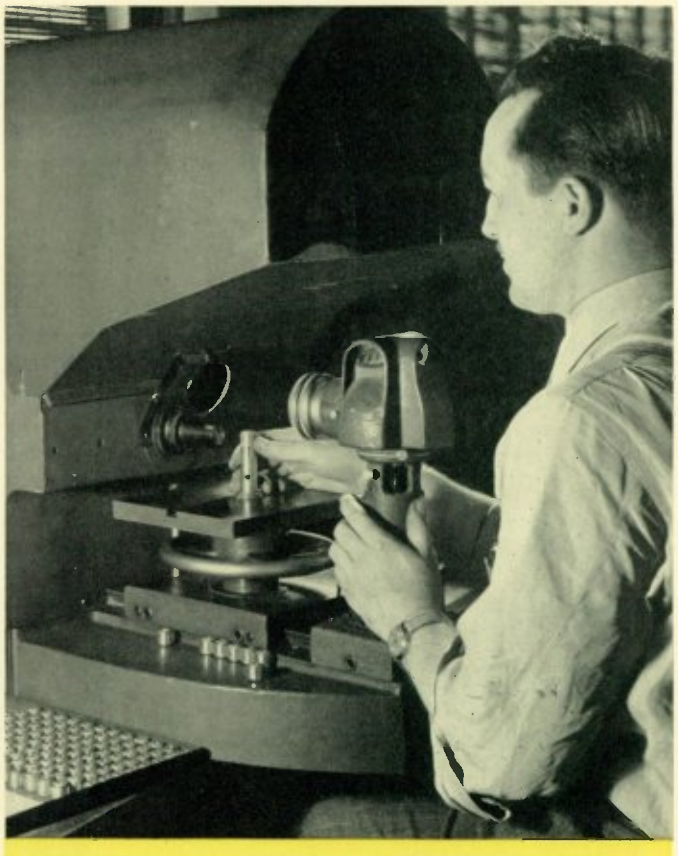
The Mot-o-trol provides that the motor is started at full field voltage regardless of the speed-potentiometer setting. Field weakening does not become effective until the motor reaches base speed. Through a current-limiting device automatic fast and smooth acceleration is provided. This current-limiting control can be set within wide limits so that accelerating characteristics can be varied to suit load conditions. The motor is quickly stopped by an adjustable dynamic-braking resistor, which is automatically connected across the armature through interlocks on the main contactors.

This d-c motor derives its power from a-c lines through the electronic device in the cabinet at the left. These electronic tubes and associated equipment give a speed range of as high as 100 to one with but two push buttons and two potentiometers as controls.

Magnifying a Hard Job Makes It Easy

The aircraft maker's constant plea to "make it do more and weigh less" has had repercussions in the production lines of suppliers. Perfect alignment of the thin strips of copper and mica that comprise the commutator of a dynamotor is necessary for satisfactory operation. Supplying current to plane radios, irregularities of segment alignment in the dynamotor commutator mean intolerable radio interference. Critical inspection of these commutators, which are about the size of an acorn, resulted in severe eye strain even though the inspectors used magnifying glasses as an inspection aid.

John R. Weeks, engineer at the Westinghouse Mansfield Plant, de-



This optical comparator increases production many times with greater accuracy and without any eye strain. The size of the commutators is evidenced by comparison with the thumb of the operator. The minuteness of the segments and separators can be imagined.

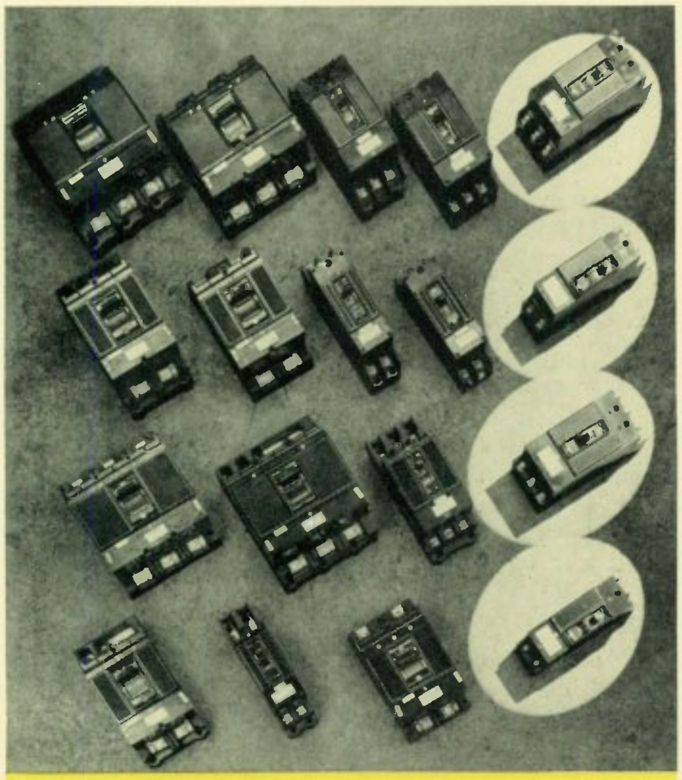
signed an optical system for inspecting these minute commutator segments, which resulted in a 20 per cent increase in production and a 10 per cent decrease in cost. With a system of mirrors, light source, and lenses applied to a projection comparator, the image of the commutator —enlarged 22 times—is thrown on a glass screen upon which are ruled, parallel vertical lines. The commutator segments can be accurately compared with these lines without eyestrain.

Four Breakers Replace Fourteen

SINCE the presentation of the first De-ion circuit breakers in 1939, the application of this breaker has fanned out into every phase of industrial and switchboard use. Many breakers were built to specific needs with a steady growth in number of types and sizes. The two prewar types—panelboard and industrial—comprised some 14 breakers in 62 styles.

Years of engineering experience in the laboratory and in service developed improvements. When the exigencies of the times demanded it, it was found possible to design and produce a compact, efficient circuit breaker with all the advantages of the old, plus savings in line with the current economy.

The 14 breakers and 62 styles have been reduced to 4 breakers and 32 styles. This represents a saving of 33 per cent in copper, and about 50 per cent in steel, and also substantial savings in tool requirements, shipping weight, and storage space. Furthermore, the redesign effected a saving of 38 per cent in the number of parts per breaker.

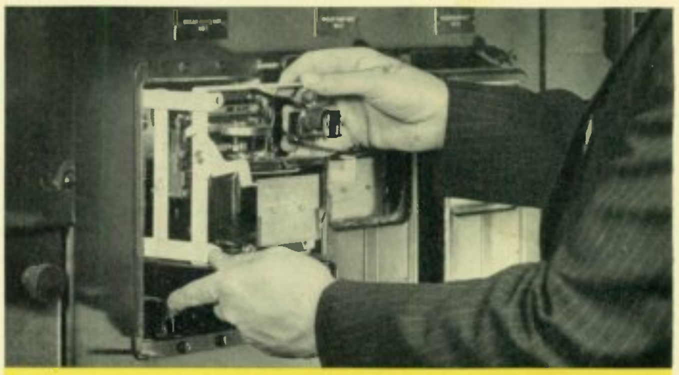


The degree of simplification of these breakers is shown by the four breakers at the right that replace the fourteen at the left.

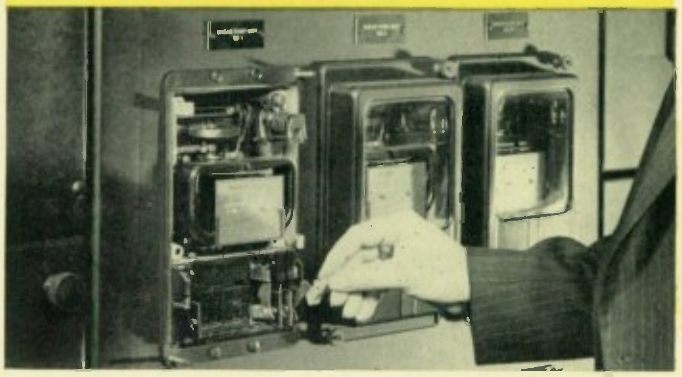
Besides conserving metals, the performance and adaptability of the breaker has been stepped up. Space restrictions introduced electrical problems that were so successfully overcome they can be applied on 600-volt, alternating-current circuits capable of producing a 10 000-ampere short circuit. The contact design has been modified so there is no lost pressure. Twice the current of the comparable old breaker is carried, and the contact pressure is increased instead of decreased with wear. A mechanical problem was deftly solved to allow full air and creepage spacings between poles and yet provide means for connecting a 100-ampere wire, a bus connection, or stud connection to the breaker terminals. The contact arm is built in two parts in order to pick up an additional three-eighths of an inch necessary to break the required test currents. A complement of this extra travel of the arm was the improved contact pressure developed through the use of an over-center, toggle-type contact arm. Also, the speed of the rupture was increased, reducing the contact burning on short circuits. Small flat brackets supporting the mechanism instead of a **U**-shaped steel frame saved material and expensive forming tools and provided greater creepage distance between live parts and the ground. Ample space was left to build barriers to isolate completely each pole from the other, thus greatly increasing electric strength between poles.

Relay and Test Switch Combined in Single Case

A NEW relay case combines the protective relay and knife-blade test switch in a single convenient unit. The relay elements are mounted on a steel-frame chassis and are easily removed for maintenance and test. The elements can also be tested with the chassis in position. This new combination, known as the Flexitest, conserves panel space and simplifies the switchboard wiring.



The ease with which the relays are removed from the new Flexitest case is demonstrated in the photograph above while the manner in which the relays are tested by integral switches is shown below.



Mounted on the same case with the relay are high-capacity, self-aligning, knife-blade switches. Each circuit is identified by proper card notation on the switch handle. The relay, the case, and the switching arrangement are interlocked so that the trip-circuit switch must be open before the chassis can be withdrawn. The rugged knife-blade construction insures positive short-circuiting action. When the chassis is removed, the current-transformer secondary is automatically short circuited. Positive stops on all switch blades prevent inadvertent opening of the current-transformer secondary.

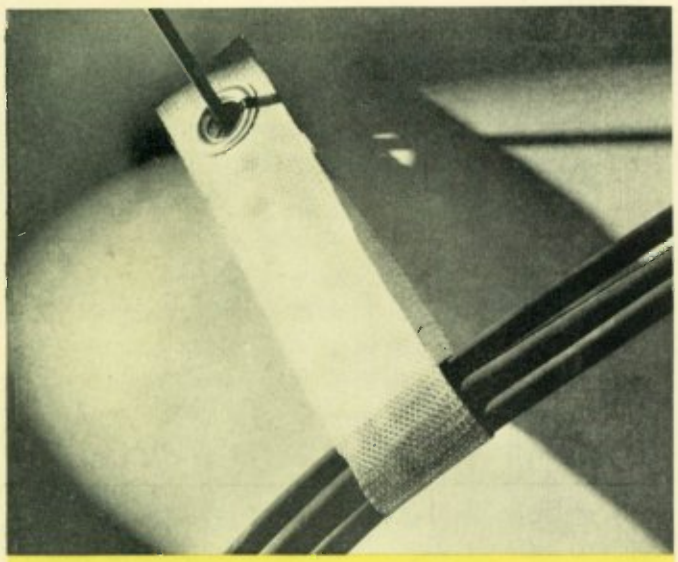
The Flexitest case is available in three sizes which accommodate standard relay elements, and is arranged either for flush or projection mounting. These elements are mounted on a removable unit chassis for ease of inspection and repair. The case has a metal cover with glass window to provide for visual inspection of relay elements and observation of relay targets.

The small- and medium-sized cases provide a maximum of ten switch positions, while a maximum of twenty positions are available in the large size. Ten circuit test plugs, ammeter test plug, and interlocking switch-handle bars are available to supplement the Flexitest case and facilitate testing. Complete testing of the relay without removal from the board is possible with this new case, yet the relay, when necessary, is simply and quickly removed from its case by means of cam-action latches.

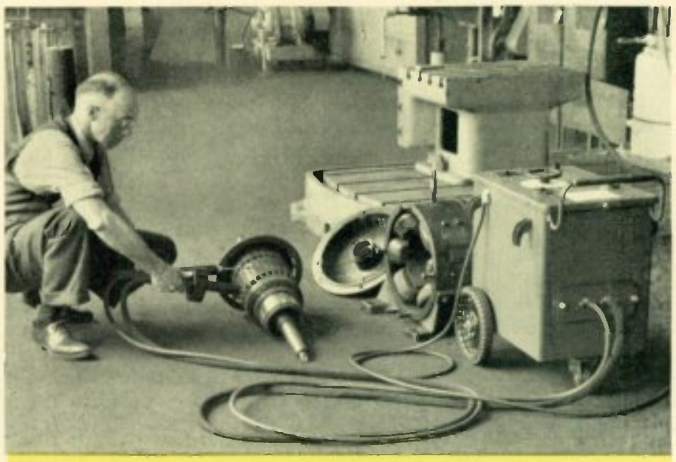
Glass Fiber Hanger Supports Cables

PRODUCTION delays are matters of national moment. Delays caused by injury to electric cables in mines, shipyards, and on construction projects can be minimized by keeping the cable up off the floor or ground where it might be damaged. Glass fibers woven into a strap by Westinghouse provide a convenient, safe, and strong support for cables.

This glass-fiber cable strap is 14 inches long by 1½ inches wide and will support 200 pounds. Each strap has a metal grommet in each end that permits nailing to wooden pillars, joists, etc. Impervious to moisture and not subject to rot, stretching, or shrinkage the glass fibers are further protected and strengthened by the application of a heat-resistance varnish that also increases their insulation strength.



A quick safe hanger for prevention of cable-insulation injury.



The new portable high-voltage insulation tester provides a convenient means of on-the-site testing that saves time and labor. It can be controlled at the set and at the end of the long leads.

Taking the Measure of Insulation Strength

THE SUCCESS of any idea is dependent on the excellence and availability of the tools for putting it into practice. High-voltage testing of insulation, long accomplished in the more important manufacturing plants and repair shops, is greatly extended in its application by a new "tea-cart" test set. A unit of two kva and a top voltage of 6000 is ample for testing low-voltage apparatus, such as in many specialty-manufacturing plants, in small repair shops, and especially for routine testing of railway-motor insulation now that it is becoming more general. This allows the unit to be lighter and more compact than previous units with their higher ratings. In addition, several important features distinguish the new test set. The voltage is continuously variable throughout the entire voltage range, and the change from one voltage to another is made without interruption, as is the case with most step-type test units. This voltage control is provided by a variable autotransformer instead of by the usual potentiometer, regulator, or tap-changing methods. To prevent the possibility of excessive surge being applied to the apparatus under test, should the switch happen to be applied at peak of the voltage wave, the test set control automatically first inserts a resistor in series with the apparatus. The test set can be controlled either from the test prods on the end of long leads or at the set itself. The tester is connected to a 120-volt, 60-cycle power outlet by a three-pole polarized plug, having one pole grounded.

An even smaller model—½ kva, 1500–3000 volts—of the high-voltage test set is also available for testing where this limited range is satisfactory. Like the larger unit it is arranged with wheels and a caster for mobility. This smaller unit can be set on a bench for stationary use simply by removing the wheels and caster.

A New Light-Duty Completely Self-Protected Power Transformer

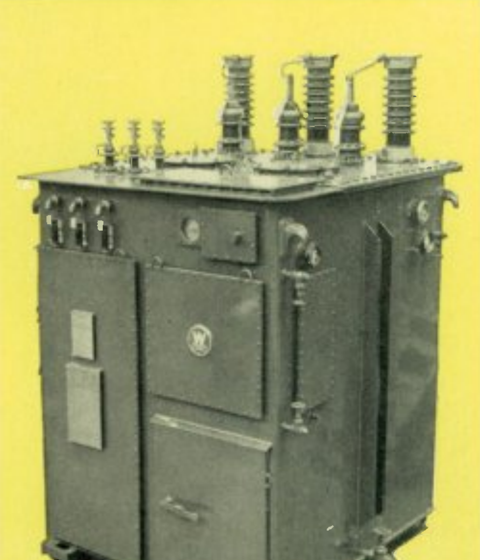
MANY good ideas start at the top and work down. An improvement for some apparatus is established, but because more expense is usually entailed, the new feature is limited to a de luxe model of the apparatus, one that can be applied where the resulting benefits warrant the additional cost. Pressure is then placed upon the designers to bring the idea within the economic scope of widespread application.

The CSP power transformer has undergone such a transition. As its initials imply it is a completely self-protected transformer unit—a complete factory-built substation unit embodied in one steel housing.

Now a junior or light-duty edition of the CSP power transformer appears that makes available to a wide variety of locations a unit that provides all the essential features of the completely self-contained substation and sacrifices only a few of the less important features. The new unit is available for 13 200 to 33 000 primary voltages in sizes from 300 to 1000 kva. It differs only from the heavy-duty CSP power transformer in that it has a somewhat smaller automatic tap changer, a lower interrupting-capacity circuit breaker, and a simplified control circuit.

The unit, however, does have lightning arresters, a circuit breaker, fusible protective links, and when required, a regulator. The transformer is automatically protected from overloads by a thermal relay (TRC type). This relay provides control of the transformer on the basis of copper temperature, which allows full but safe use of the short-time overload capacity of the transformer. This CSP transformer, operating as a power substation, replaces the more than 40 pieces of equipment usual to an outdoor open-type substation. The unit does not require overhead switching structures, and this, plus its small size, permits installation in congested urban districts.

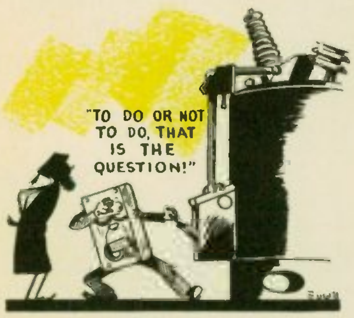
This light-duty power-transformer has three distinct advantages that have led to its use as a power unit for airfields and factories. The new version of the CSP power transformer has a low first cost per kva installed. The cost of maintenance is low. Being a completely self-contained substation, it is easily and economically installed and can be moved from place to place as the load center moves.



A self-contained, factory-built unit substation that can be moved as load needs change.

PERSONALITY PROFILES

W. A. Lewis is a living example of the merits of thoroughness. His whole career shows that whenever he applies himself to something he masters it. No matter how difficult the problem, he concentrates on it until it becomes simple for him and he can make it simple for others. In the days when but few engineers had any speaking acquaintance with symmetrical components and most engineers ranked it along with relativity, Sanskrit, and the



theory of economics, Lewis waded into it and became adept in its use as well as one of the first successful teachers of this now vital branch of calculation. He went to California Institute of Technology, and was not satisfied with simply obtaining a bachelor's degree in electrical engineering (1926), but also sought a master's degree (1927), and a Ph.D. in 1929. During his tenure at Westinghouse, 1929 to 1939, he established an industry-wide reputation as an outstanding authority on power-transmission problems and on system stability, protection, and relaying. In this period he authored many technical papers on these engineering subjects that are still considered as standard references. He has always served actively as a member or chairman of several A.I.E.E. committees. Always torn between his interest in creative engineering work and the desire to give rein to his natural aptitudes for teaching, he accepted in 1939 the post of Director, School of Engineering, Cornell University. Meanwhile he has found time to write a simple exposition on high-speed relaying, which even your editor can understand. And, brother, that is really making high-speed relaying simple!

• • •

An enormous gulf of difference seems to separate a giant motor of several thousand horsepower for a steel mill and a fist-size fractional-horsepower generator for a military airplane. But *H. E. Keneipp*, having a firm grip on motor principles, which are no respecters of size, is able to bridge the gap with ease. Until about a year ago he had spent a dozen years at Westinghouse on the design of the "big ones"—the large synchronous motors for steel-mill motor-generator sets, drives for mill stands, induction motors to run pumps for dry docks, navy yards, water plants, and the like. Now he is bending all his energies on the development of the smallest, lightest, most efficient a-c and d-c generators for airplanes. His experience has not been confined to design. For a time, early in his career with Westinghouse, he assisted in the application of electrical apparatus in steel mills. Keneipp is an Illinois man, graduating at Urbana in 1927 (B.S. in E.E.). He took advantage of the lull in business during the depression to return to his alma mater to complete work for a master's degree. He has done a deal of teaching himself. Early in the war program he assumed the fairly large assignment of teaching war-training courses three nights a week. Keneipp does not complain about the loss of tenderloin steaks, or coffee, or the wartime restriction on automobile driving, but the present shortage of Kodachrome film interferes mightily with his hobby of color photography, in which he is an acknowledged master.

• • •

W. H. Kahler couldn't wait to get out of school to enter into the electrical business. While still in high school in New England he established himself as an electrical contractor and wired nearly fifty homes. While obtaining his electrical degree from Brown University (B.S. in E.E., 1936) he continued his electrical contracting, did some consulting work, and even designed a switchboard for a neighboring college. (His new home in Cleveland, ironically, was wired by someone else.)

Although Kahler is still a very young engineer, he is an old hand at fluorescent lighting, having been associated with it at Westinghouse since it began its meteoric rise about five years ago.

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Many electrical machines, although complex in theory and in construction, have been brought to a fairly high state of perfection without inordinate difficulty. Conversely, some of the seemingly most simple devices have required years of painstaking, patient engineering to convert the idea into a highly successful mechanism. The Autovalve lightning arrester and the copper-oxide rectifier, as much as any two devices we know, are of this simple-in-idea, difficult-to-construct class—and *I. R. Smith* was in on the basement floor of the development of each. A graduate of Worcester Polytechnic Institute in 1921 (B. S. in E. E.) he did not even have opportunity to finish the usual graduate student course at Westinghouse before he was assigned to assist in piloting the Autovalve arrester through the seemingly endless obstacles that lay between concept and realization. In 1927, very soon after the copper-oxide rectifier was invented, Smith was asked to take charge of the engineering required to reduce it to practicability. To him goes much of the credit for the enormous success of this deceivingly simple rectifier. Also, he is largely responsible for the

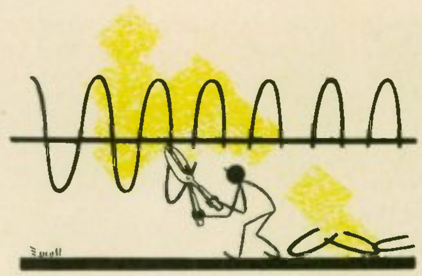

plate-type copper-oxide rectifiers and for much of the work that enables these rectifiers to be built in sizes from one-thousandth ampere to multiple units of 120 000 amperes.

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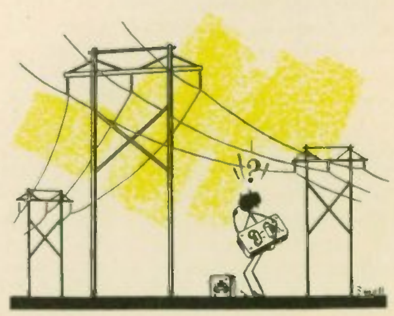
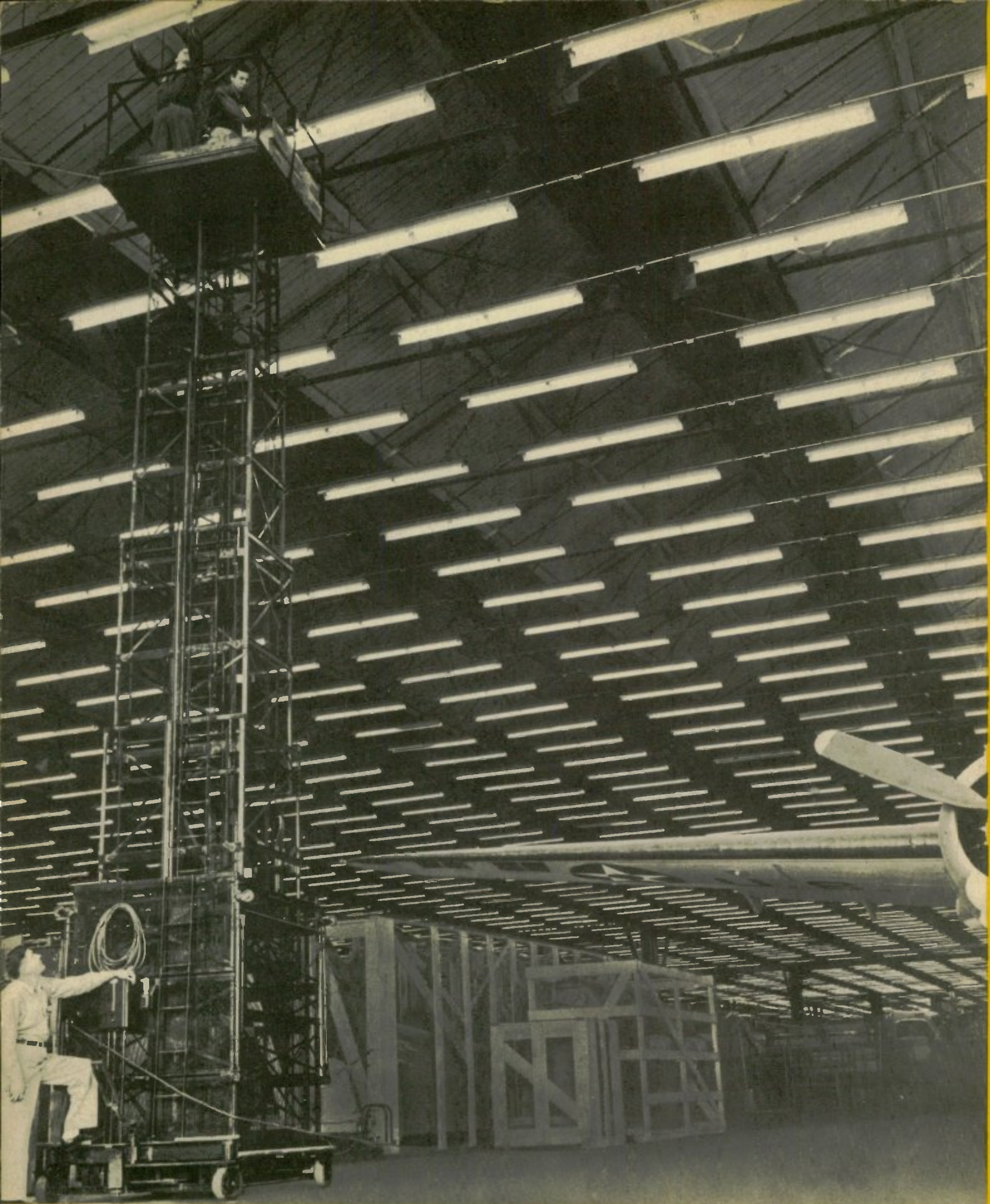
Among members of the electrical profession *M. A. Bostwick* stands as an authority on relaying, but if you were to ask him now in what he is most skilled he would probably tell you that it is how to complete a house in these days of building restrictions and material shortages. Anyway, we can vouch for his skill in relaying matters. Since coming to Westinghouse from the State College of Washington (B. S. in E. E., 1926) he has spent his full time on relay work, notably on induction relays, secondary-network relays, and pilot-wire relays. His name appears as author on some phase of relaying with increasing regularity before the A.I.E.E. and in other electrical publications. Since 1941 his time has been diverted more from relay creation to relay application.

Coauthor with Bostwick on the three-terminal line problem is *E. L. Harder*, whose name has graced these pages before (May, 1942, p. 43). Although Harder's principal duty is the solution of relay and other central-



station problems, he is an inventor as well. To him goes principal credit for the pilot-wire relay (HCB) scheme that is of special merit in connection with the problem discussed by him and Bostwick.



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