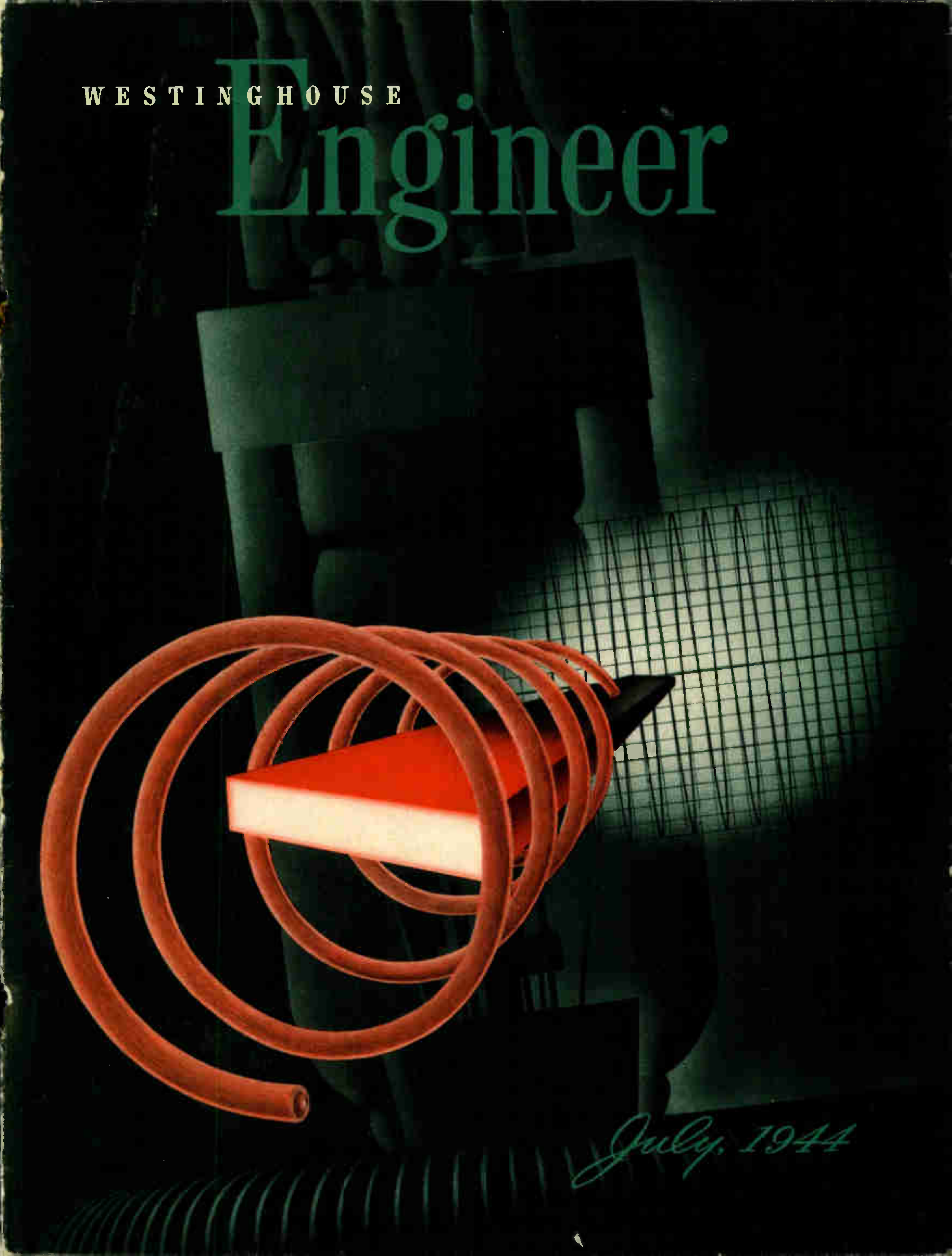
WESTINGHOUSE

Engineer



July, 1944

Network Calculator

• • • MATHEMATICIAN PAR EXCELLENCE

Engineers have a penchant for mathematics—so it is commonly believed. Yet the calculating board, often called the network calculator, was the result of a desire to solve problems with the least mathematics. When the plans for the electrification of the Virginian Railroad were being drawn, in the middle '20s, two crews of three men each worked several months with a battery of adding machines making the necessary calculations of short-circuit currents, voltage regulation, and telephone interference for the almost endless combinations of circuits and loads. Each team would work furiously for a couple of weeks, and then spend the next week or so checking the results of the other team. With other railroad electrifications in the offing, with power systems growing so large and so complex in their interconnection, the solution of power-system problems by mathematics was becoming a monumental task and in many cases utterly hopeless. Electrical systems threatened to become a Frankenstein out of control unless some simpler means of solving their involved problems was concocted. This led to the a-c calculator, first completed in 1929.

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The calculating board is based on a simple principle: that any electrical device—be it generator, transformer, motor, or transmission line—can be represented by a simple circuit consisting of an inductance or capacitance and a resistance, and a power source. These equivalent circuits and power sources in miniature behave electrically just as their physical counterparts.

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System problems involving two power sources are not too difficult to calculate. Problems entailing four power sources represent the maximum of complexity that can be solved mathematically—and here the work is protracted and tedious. The calculating board, however, can take on systems having eighteen power sources almost as easily as two or four. Because, in large systems, generators pretty much act in groups instead of individually, no system is too large for the calculating board to handle.

The calculator has played many roles, including that of judge. On at least one occasion, the operating and engineering departments of power companies have disagreed, with some heat, over a system matter. An analysis by the calculator provided an irrefutable answer. The calculator is free from the human characteristics of opinion and unintentional wishful thinking.

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"Screwball ideas" of system operation have their chance to be "heard" with the a-c calculator. Connections, modes of operation that engineers are unwilling to risk on the actual system can be tried safely on the calculator. One engineer wished to know if a certain emergency procedure following a possible but extremely unlikely transformer failure would be safe. The board showed it would, with consequent saving of many dollars for a special protective system.

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The d-c calculating board, which uses direct-current power through the equivalent networks, is as useful today as 25 years ago. It is adequate for problems of a-c equipment that do not involve phase angle, such as those of circuit breakers and fuses.

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Because of their bulk and cost, a-c calculating boards probably never can become common. Since 1929, thirteen have been built in the United States. Of the nine of these built by Westinghouse, one is for its own use, two are used by engineering schools, one by an electrified railroad, and the remaining five are used by power companies.

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VOLUME FOUR JULY, 1944 NUMBER FOUR

On the Side

The Cover: Symbols of the fast-growing use of heating with alternating currents are the copper coil and glowing bar. The surface of the bar is heated to cherry redness almost instantly by the surrounding inductor coil through which flow currents of several hundred thousand cycles per second.

Another powerful wind tunnel has been added to the growing number being used to further man's skill in the air. It is installed at the birthplace of the Flying Fortress, Boeing Aircraft Company's Edmund T. Allen Memorial Aeronautical Laboratories. An 18 000-hp induction motor will provide winds of speeds up to 700 mph. A magnetic coupling permits operation at reduced speeds.

The several hundred men who recently attended the ninth annual Machine-Tool Forum in Pittsburgh sponsored by Westinghouse heard, among many things, about: a new motor-control scheme by which the load on a cutting tool can be maintained nearly constant by automatically adjusting the feed speed to compensate for the varying depth of cut or hardness of the material; of a scheme for obtaining speed ranges of 1500 to 1 by use of servo-mechanisms; of a tracer mechanism by which the cutting tool of a machine can be made to follow precisely the contours of a model of some complex shape as a ship propeller blade, airplane propellers and hubs, fins on cylinder heads, etc.

Among the shadows that foretell coming events is the granting of television licenses to three Westinghouse Radio stations, KYW in Philadelphia, KDKA in Pittsburgh, and WBZ in Boston.

In This Issue

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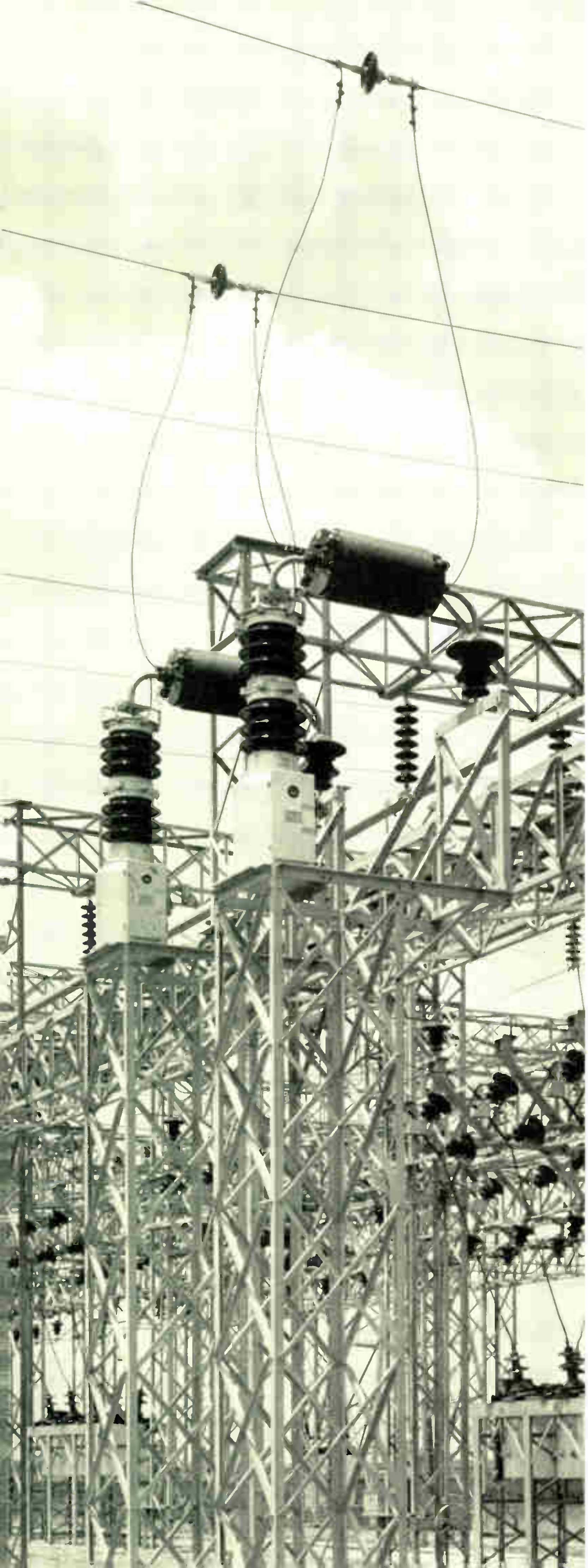


Modern Power-Line

Recognition that high-frequency signals could be transmitted over power-line conductors to convey intelligence was much like discovering that telephone wires had been strung parallel to transmission lines and turned over to power companies for their exclusive use. Nearly all services provided by telephone lines, such as voice communication, telegraph, telemetering, and remote control can also be operated by carrier current over the conductors that carry power.

POWER-LINE carrier is an outgrowth of developments made during the first world war. It was in France in 1918 that General Squiers of the U. S. Signal Corps made experiments with carrier currents. Later, in 1920 or 1921 he used carrier currents successfully on power-transmission lines.

A carrier current is a high-frequency current that is modulated at lower frequencies corresponding to the intelligence to be transmitted over a communicating channel. For example, it can be modulated at voice frequencies if it is desired to transmit speech. Or it can be keyed on and off in a straight telegraphic manner to provide a code signal that can be used for several purposes.

The term power-line carrier implies carrier current as applied to power systems. Carrier frequencies normally used lie in the range from 50 to 150 kilocycles. Lower frequencies, in the audio range, are also used over wire channels for a variety of control and telemetering functions and will not be discussed here.

The frequency range was chosen for best transmission characteristics over the channel involved. Thus, for example, a 1000-cycle tone can be sent by modulating a 100-kilocycle carrier wave and thus sent over a channel that passes 100 kilocycles readily but virtually blocks 1000 cycles. A 100-kilocycle signal would encounter very little noise interference, whereas at 1000 cycles the signal power would have to be comparatively large to be above line noise.

Small Signal Energy Exceeds Line Noise and Travels Long Distances

Two fundamental facts help in the appreciation of the significance of carrier transmission over power lines. First, a carrier signal above the usual level of stray or noise-producing voltages can be introduced on a transmission line with small amounts of power. The surge impedance of an average line is about 500 ohms. Thus, 50 volts at carrier frequency results in 0.1 ampere, or 5 watts. A 50-volt signal can therefore be placed on a line with a small oscillator of only 5 watts power. The 50-volt signal is some 500 times greater than noise voltage, which, though widely variable, is of the order of 0.1 volt under usual conditions. Noise in the carrier-frequency region is attributable to overstressing of insulation, spitting over of insulators, corona, arcing at poor connections and the like. Larger noise voltages are obtained under abnormal conditions such as drawing out a low-current arc by an air-break switch.

A second major point is that a carrier wave travels a long distance without suffering any serious decrease in strength (attenuation). For example, the 50-volt carrier signal men-

Carrier Equipment

—*What It Is and What It Does*

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

tioned previously will travel about 200 miles along a straightaway transmission line before being attenuated to 5 volts, which is still 50 times the average noise figure of 0.1 volt. Taps and spur lines subdivide and reduce the signal energy and greatly increase the attenuation over that found in a straightaway transmission line.

How Carrier Developed

After the last war many of the power systems of the country that had previously consisted of a great many small, isolated properties were interconnected for improved economy and reliability. Carrier communication offers economical and reliable communication service for dispatching power on these rapidly growing interconnected systems. It experienced a period of rapid progress. Its reliability was amply demonstrated, during the Mississippi River flood of 1927, when the excellent performance of the power-line carrier equipment was in marked contrast to all other communication facilities in that flooded region.

In the early period of rapid development prior to 1928, carrier was employed almost exclusively for communication although there was at least one installation for remote control of circuit breakers.

Carrier was next used for protective relaying, a very simple unmodulated carrier set being used for this purpose. By 1933 carrier was established in this field and provided much faster fault clearance on high-voltage lines, and permitted important interconnections designed for simultaneous clearing from both ends. This increased the stable power limit of parallel lines by limiting the time required to clear one of the lines in event of a fault. It also made possible fast reclosing of single tie lines, since sequential tripping of circuit breakers was no longer necessary. However, numerous improvements in the relaying schemes and simplification of the carrier equipment were required to produce the reliable high-speed carrier relaying of today, which is generally recognized as the best all-around protection for transmission lines.

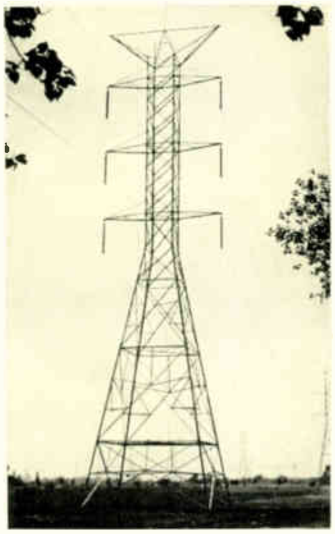
Circuit breakers had been remote controlled before 1928. Supervisory control over wires was already highly developed. The adaptation of the existing schemes to operate over a carrier channel was comparatively simple. However, the Boulder Dam to Los Angeles transmission lines were the first to use extensive supervisory control over a carrier channel.[1] To increase the speed and reliability of control operations a new supervisory control system was developed, which depended on code rather than answer-back for reliability.

Telemetering and load control followed soon after carrier relaying and today represent important uses of carrier. Particularly during the present war, with its attendant restrictions in the use of critical materials, telemetering and load control have been invaluable. They have increased the safe loading on tie lines by providing accurate and prompt information regarding load conditions and a means for manual or automatic remote control of tie-line loads. This use of power-line carrier is rapidly expanding.

Carrier Communication

Carrier-communication equipment is used both for dispatching services and for conducting the normal and emergency operations of a power system economically over long distances. The continuously available channel provides a ready means of transmitting intelligence to vital points, thereby permitting closer scheduling of power flow and prompt action in case of emergency.

The basic elements of a carrier-communication system are shown in Fig. 1, which illustrates the more elaborate equipment. The familiar handsets connect to the carrier set, which contains the transmitter having an output of 20 watts, modulated by voice frequencies. This power can be stepped up to 150 watts by the power-amplifier unit if such increased power is required. The modulated carrier is fed into the transmission line through a coupling capacitor, which is nothing more than a series capacitor between the carrier set and the line. Its lower end is grounded for 60 cycles through a drain coil, but this has no effect at the carrier frequencies. The line-tuning unit is an inductive reactance for neutralizing the capacitive reactance of the coupling capacitor. Thus the carrier set in effect feeds directly into the surge impedance of the line, which is usually of the order of 500 ohms.



Line-to-line coupling is illustrated in Fig. 1, the carrier signal being impressed between two of the phase wires of the line. This is distinguished from line-to-ground coupling, illustrated later. Figure 1 also shows the apparatus required by the carrier system.

The carrier set contains also the telephone unit, which is an automatic telephone exchange. The equipment shown has selective dial ringing. There may be several sets on a carrier channel, the two shown being representative. Further sets can be added as required to communicate with those already installed on the same frequency. Any one of the line extensions can be connected into a PBX board as shown on the right and there multiplied to any number of extensions. The line extensions at any one point supplied from a given set can be arranged for intercommunication if desired, or this feature can be blocked out to avoid tying up the carrier phones by local calls when they should be available for incoming calls over the carrier channel.

The carrier-set receiver demodulates the carrier signal from remote points, while the control unit provides the automatic

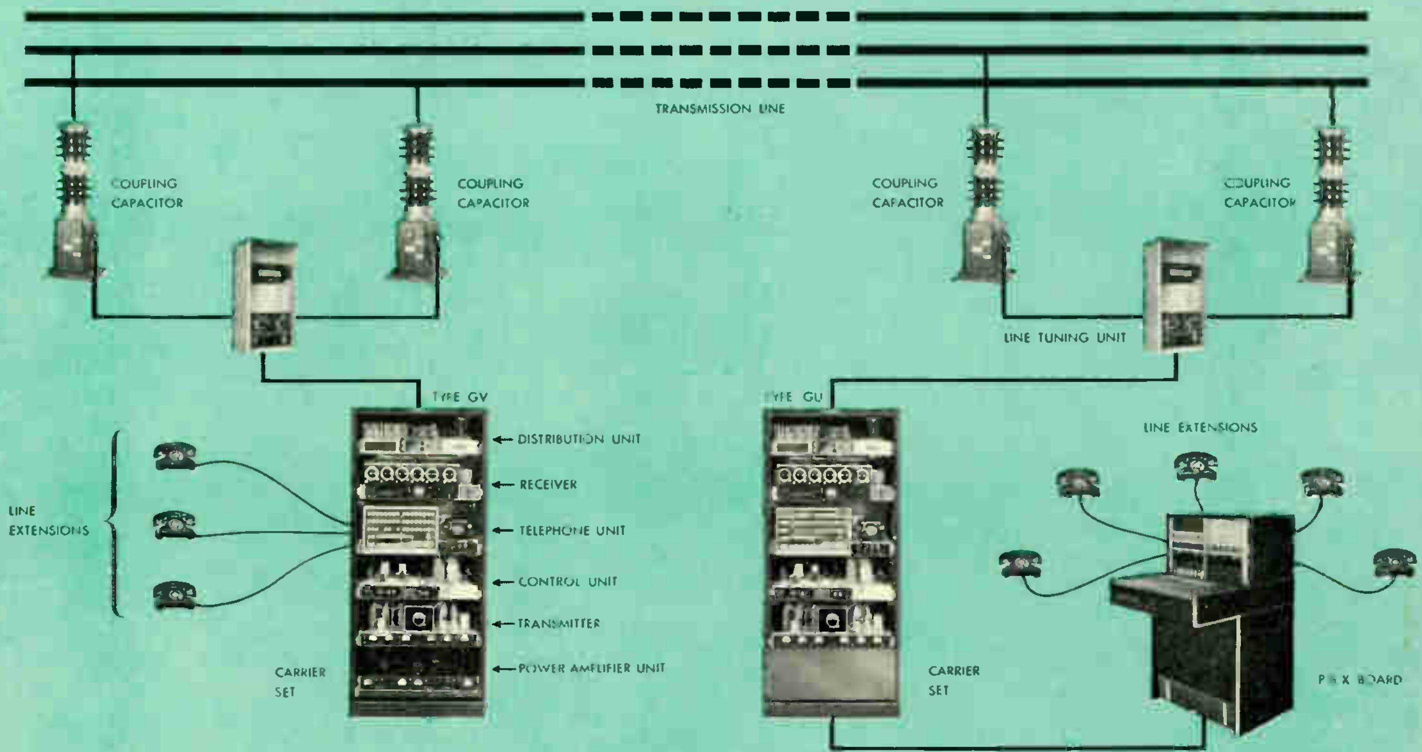


Fig. 1—*Modern carrier equipment provides automatic telephone facilities over power-transmission conductors.*

switching from "transmit" to "receive" as the conversation progresses. A distribution unit at the top distributes power to the other units. Line traps, not shown, may also be required to prevent dissipation of the carrier signal over undesired lines.

Such complete equipments are in use on several of the large power systems of the country and represent the finest in carrier communication equipment. Simplified equipments, costing less, are also available. For example, code bell calling can be substituted for the selective dial ringing.

However, chief among these simplified arrangements is the two-frequency duplex equipment for point-to-point communication between two stations. While two carrier frequencies are required, with the consequent necessity of double-frequency tuning of line traps and line-tuning units, this equipment eliminates most of the automatic telephone equipment and also the control unit required in the more elaborate single-frequency equipment.

With the two-frequency equipment, voice channels are active in both directions continuously so that the speakers can cut in at any point in a sentence or word as in normal conversation, instead of having to wait for the end of a sentence.

The two-frequency equipment is generally used simply between two stations. However, voice signals can be carried into a PBX board at either end to serve as a link in a more extensive communication system.

Simplex push-to-talk equipment again uses only a single frequency and requires less equipment. Quite adequate for dispatching service, it does not lend itself to carrying through a PBX board to serve as a link in a more extensive telephone system as do the equipments heretofore described; however, no voice quality is sacrificed. It has the advantage characteristic of single-frequency systems that three or more stations can be operated on a single carrier channel and intercommunicate with each other. The use of a single frequency is an obvious advantage when the frequency spectrum is crowded. It also results in further savings in the use of single-frequency tuning of line traps and line-tuning units.

Point-to-point communication is also possible as an adjunct function with the carrier sets used for intermittent functions such as relaying and supervisory control. In fact, combining several functions over a single carrier channel is one of the interesting and important possibilities described in more detail later. Usually some compromise in performance is necessary, however, which should be recognized in making joint-use applications.

Carrier Relaying

Carrier relaying has usually been employed for one of the following reasons:

- To improve stability
- To prevent relay operation during out of synchronism
- To permit quick reclosing
- To increase system design flexibility
- To reduce shock to the system
- To prevent line-to-ground faults from becoming three-phase faults
- To improve ground relaying
- To provide a combination of services

However, today, carrier relaying is simply the logical choice for a network of high-voltage transmission lines, and many systems are changing whole groups of lines over to it. Carrier is the only form of pilot protection economical for lines longer than a few miles. Pilot protection is becoming more and more desirable because the first line of defense is practically independent of other lines; correct instantaneous relay operation does not hinge on adherence to a fixed system set-up. Operating conditions resulting from maintenance of lines do not interfere with correct relaying and additions, and new interconnections do not necessitate an immediate restudy of the whole relaying system. A fault on any line is cleared instantly at both ends without requiring time coordination.

The five basic elements of a carrier relay system are shown in Fig. 2. The relays at each end of the line are set to trip quickly for faults over the entire protected line, but are restrained from tripping for faults beyond the remote end by a carrier signal sent back from the remote end indicating that the fault is beyond that point. It is worthy of note that de-

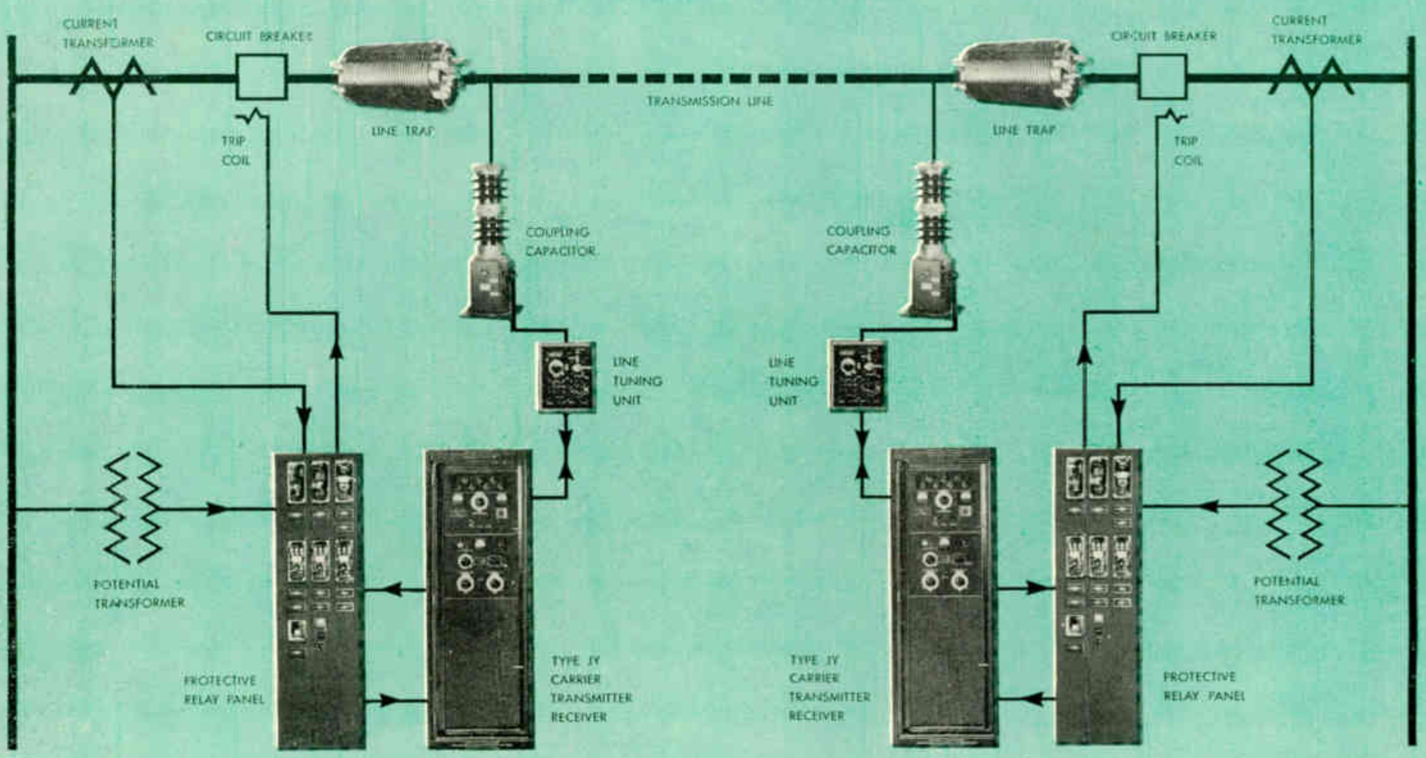


Fig. 2—*Carrier relaying requires five basic elements at each terminal.*

pendence is placed on carrier transmission over the line only when the fault is "external" and the line itself is not faulted. Line traps are required to prevent the transmitted carrier signal from being short circuited by a nearby fault outside of the protected line.

If the carrier sets are outdoors, the line-tuning unit is included in the set and only four physical components are involved. In fact, even with the carrier set indoors, if the distance to the coupling capacitor is not over a few hundred feet, the tuning unit can often be included in the set. A matching transformer is then required, mounted as a part of the coupling capacitor.

The relay equipment shown is the high-speed distance-type carrier scheme.[2] If the carrier is cut out of service, the relays still provide the best type of non-carrier protection. Complete step-distance characteristic back-up protection is provided at all times by this equipment.

A simplified carrier relay scheme[3] (HKB) is also available, not incorporating back-up protection but requiring only a single operating element for complete phase and ground carrier relay protection. Currents at the two ends of the line are compared for fault discrimination and hence potential transformers are not required. This scheme is ideal where existing relays are adequate for the back-up function.

The carrier set shown is representative of a new rack-and-panel type of equipment,[4] which provides flexibility for the addition of other carrier functions, as well as ease of inspection and maintenance. It is operated directly from a 125- or 250-volt station battery providing adequate carrier energy for relaying applications at these plate voltages. This improvement was made possible with the advent of the beam power tubes such as the 6L6 and the 25L6. Previously, dynamotors, a transfer panel, and a power pack were necessary in order to obtain the required high-voltage direct current from the station battery—a requisite for reliability of protective relaying.

Telemetering

The war has brought about increased use of carrier telemetering, which is essentially the remote indication and metering of real and reactive power and other electrical and position quantities. The effective operation of a system hinges on the operator knowing the power flow at the vital points of the system. Usually interconnecting lines are of prime importance since stability, heating and contractual limits must not be exceeded. Unusual shifts of power have been required in order to meet war-time load demands with the most economical use of water power and steam-generating facilities, and minimum use of oil power generation. The effective and safe use of existing transmission systems has been greatly increased by carrier telemetering, which provides an accurate and prompt indication of power-flow conditions at all times.

The basic elements of a carrier-telemetering system are shown in Fig. 3. It is assumed that the power supplied from a generator into the system at one point is to be indicated at a remote power-dispatcher's office. The impulse-transmitting meter is similar to a conventional watthour meter except that its contact-making device operates at a rate proportional to the speed of rotation of the disc. This contact arrangement keys the carrier transmitter at a corresponding rate sending pulses of carrier current over the transmission line to the receiver at the load-dispatcher's office. In the receiver the carrier pulses are amplified and rectified, the resulting d-c pulses entering the impulse receiver. This latter instrument converts the rate of incoming d-c pulses into a proportional value of smooth direct current which actuates the indicating or recording instrument calibrated directly in terms of the power quantity being measured.

Kilowatts, reactive power, or kva can be transmitted in this way as well as other quantities if it is desired.

Carrier Load Control

Telemetering is frequently used in conjunction with load-control equipment. Carrier load control is essentially the process of remote controlling the load over a tie line or the power output of a generator by means of signals sent over a power-line carrier channel. These signals can be initiated manually by the power dispatcher or automatically by load controllers located in his office.

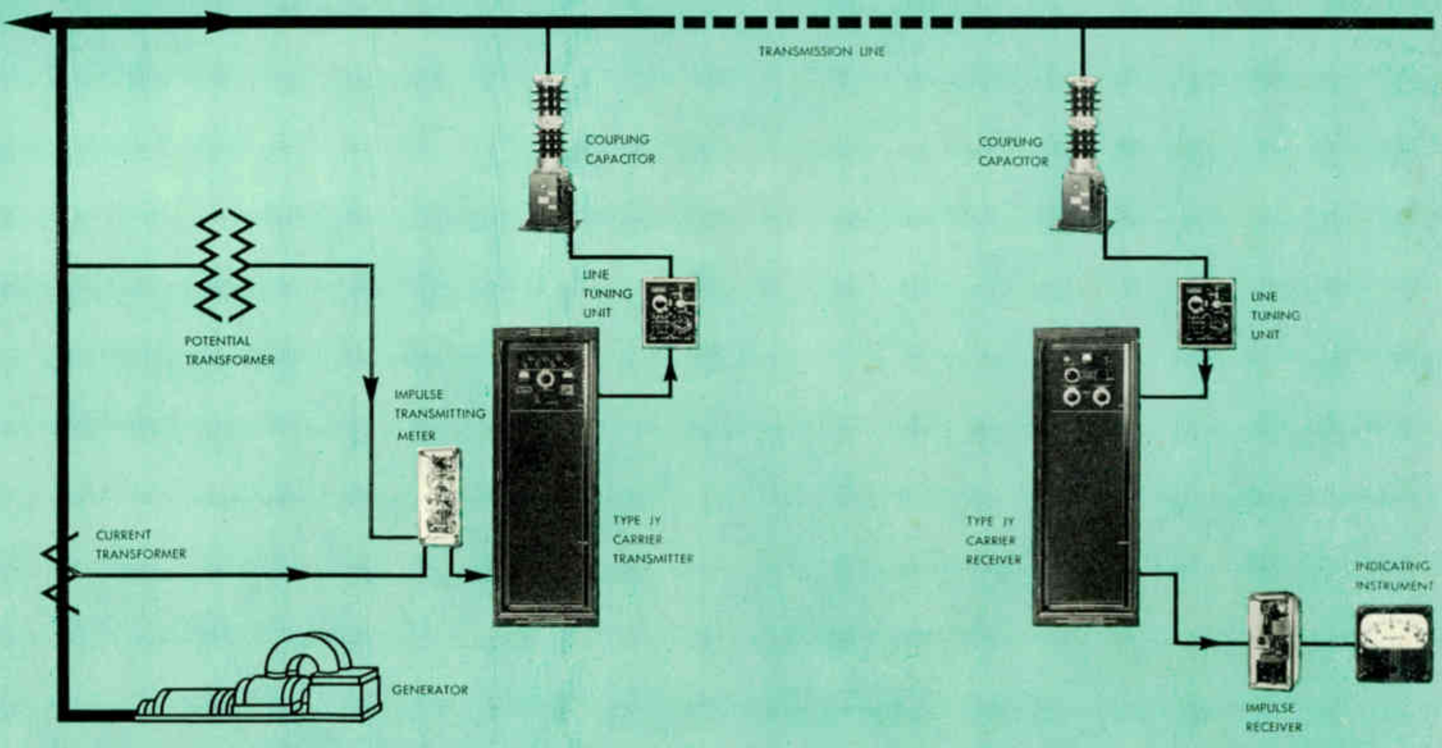


Fig. 3—*Metering signals can be transmitted over a power line to a remote point by carrier using these equipments.*

The description of a typical combined telemetering and load-control system will serve to illustrate how the combined functions operate. Two power systems *A* and *B* are indicated in Fig. 4 and are assumed to be connected by two tie lines for which the billing points are at *M* and *N*. The dispatcher's office for system *B* is located at point *O*. System *B* is extensive, having steam and water-power generation, but the steam generation is normally operated on a block-load basis and any required load swings are handled on the hydroelectric station, which does not have enough water flow for continuous delivery of power.

The requisites for controlling the total load interchange between the two companies over the tie lines are, first, an indication at point *O* of the interchange power, and, second, a means of controlling the hydroelectric plant as required to maintain the desired tie-line loads. Power indications from *M* and *N* are brought to *O* by means of telemetering equipment similar to that previously described. At point *O* these quantities are totalized and go into a single load controller. The load controller is essentially a load-recording instrument except that it has "raise" and "lower" contacts that are operated if the total tie-line load is above or below the desired value. A load-control carrier channel is set up between *O* and the hydroelectric plant *H* over one of the power lines connecting between these two points. When the load controller at *O* indicates that more power should be generated by system *B* in order to increase the power flow toward system *A*, a raise indication is sent over the carrier channel. For simplicity, assume that two carrier frequencies are used between *O* and *H* for performing the load-control function although, as will be pointed out later, this would probably be accomplished by two audio tones over a single carrier channel. One frequency would be used for increasing power and the other for decreasing power and will be hereafter designated as the raise and lower frequencies, respectively.

The load controller at *O* initiates the carrier set which sends out the raise frequency and transmits a signal whose duration is proportional to the deviation of interchange power from that required. This signal is received at *H* and actuates the speed-changing motor on the governor of the waterwheel generator. There is a waiting period to give the telemetering equipment an opportunity to respond to this change and then if further correction is required another raise impulse is sent out, but if the load is nearer to the desired value the duration of the subsequent impulses becomes smaller until the system finally stabilizes with the desired load over the tie lines. For a lowering operation the reverse takes place.

If several remote hydroelectric stations are used to control the load, the tie-line load controller is arranged to control one of the stations as indicated above and the control of the remaining stations is by proportional-load controllers. The desired proportion of load to be carried by each of the water-power stations is set up on the proportional-load controllers in the dispatcher's office. Telemetering channels from the several hydraulic stations to the dispatcher's office provide an indication in each of the proportional-load controllers of

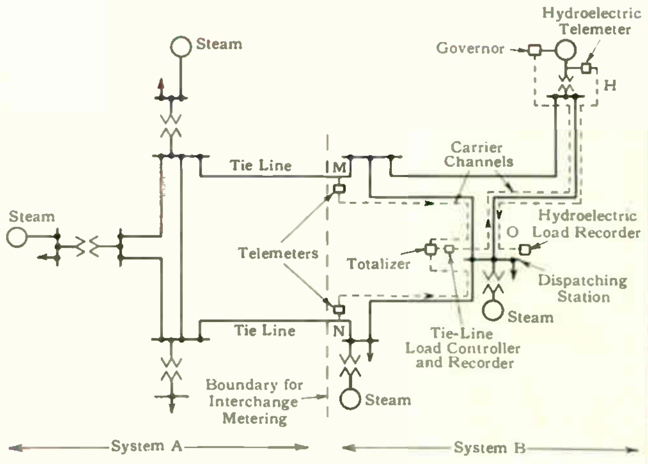


Fig. 4—*Power-line carrier telemetering and load control.*

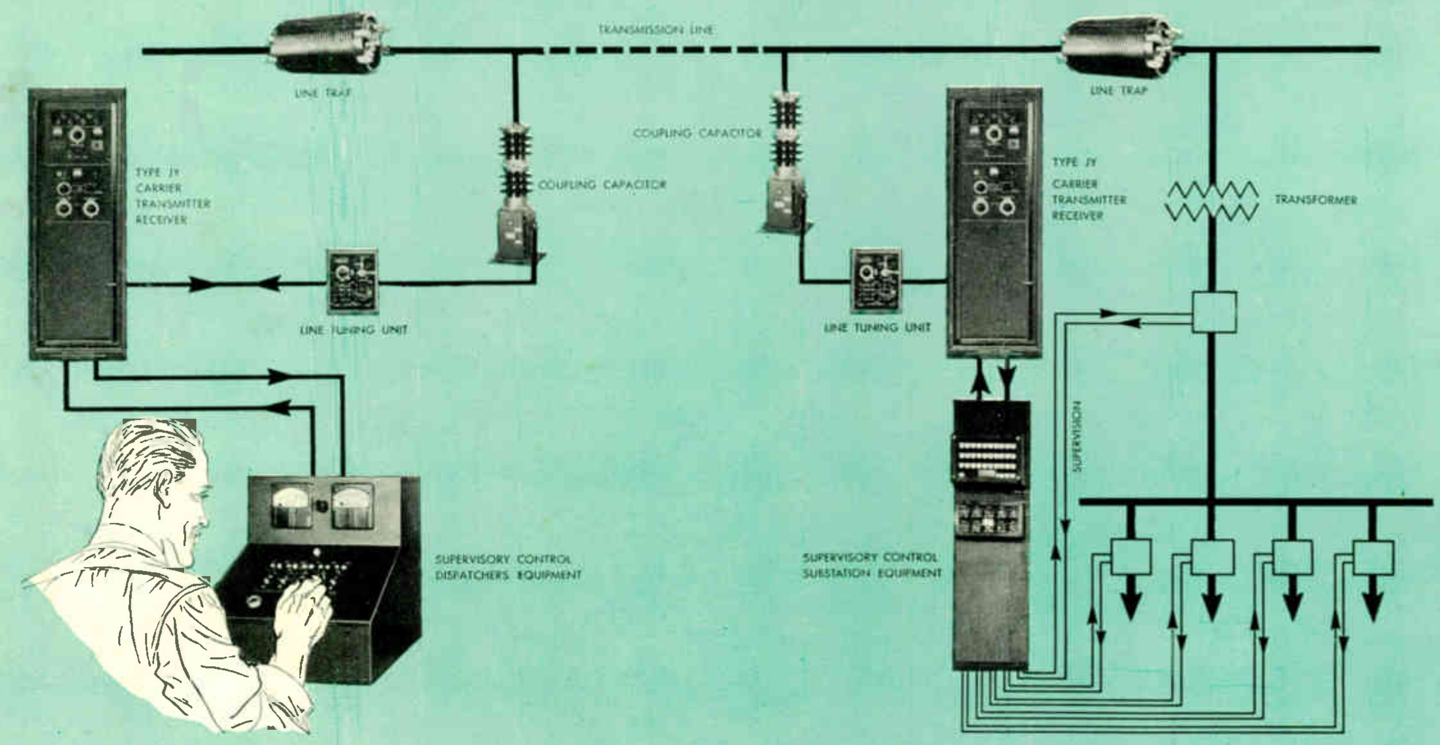


Fig. 5—*Supervisory control of distant equipment can be accomplished over a power-line carrier channel.*

the load on that particular station. In case the load carried by a particular station differs from the proper proportion with respect to the master station, the proportional-load controller sends out raise or lower impulses to increase or decrease the load of its particular station until the proper proportional load is obtained among all the stations involved.

If one of the hydroelectric plants contains several machines, all of which are to be actuated in response to the load-control signals, the usual procedure would be to put the primary control on one unit and install proportional-load controllers that would subsequently redivide the load among other units.

Carrier Supervisory Control

Supervisory control, as the name implies, is both control and supervision. It differs from ordinary remote control in that many devices or "points" are controlled and supervised by means of a single wire or carrier current. Carrier supervisory control differs but little from similar equipment operated over wires. The only difference is in the particular manner of sending certain quantities.

Supervisory control is advantageous in making it unnecessary to staff isolated stations and in placing the control of widely separated circuit breakers at the finger tips of one centrally located operator. It would be impracticable to provide wire channels to control many tie switches and stations located at isolated points along transmission lines. Carrier supervisory control is an ideal solution. Control of the Victorville and Silver Lake substations out in the desert along the Boulder to Los Angeles lines was a notable example of the application of carrier supervisory control.

The basic elements in a simple supervisory-control system are indicated in Fig. 5. In addition to the supervisory-control equipment at the dispatcher's office and at the substation end, a complete two-way carrier channel is required. This includes the transmitter and receiver at each end, the line-tuning units, coupling capacitors, and any line traps.

The control and supervision of five circuit breakers from a remote point are shown in Fig. 5. Corresponding to each breaker controlled there is an escutcheon plate on the supervisor's equipment that includes indicating lights showing the position of the breaker and a control switch for its operation.

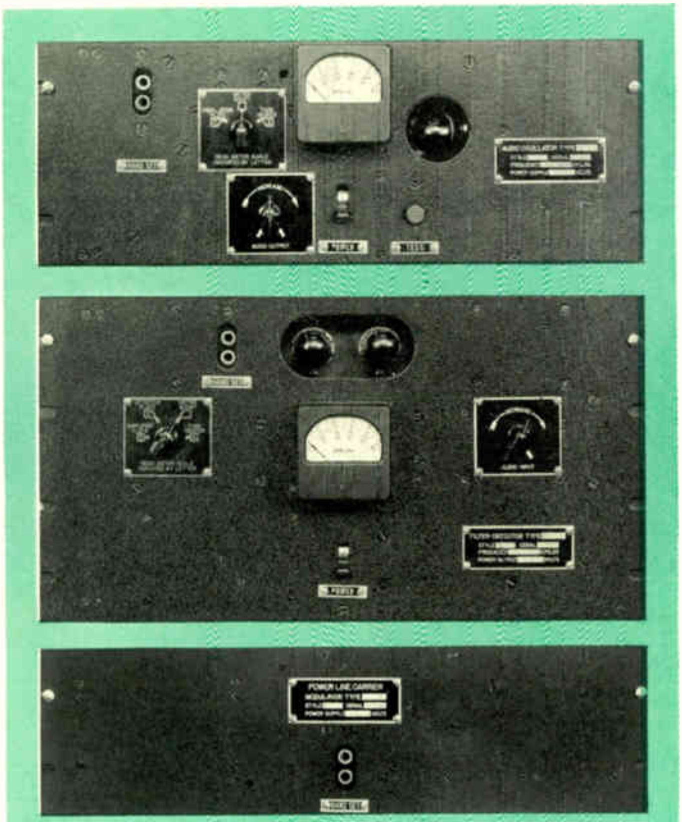
Any automatic or locally performed operations of the circuit breakers are also reported over the carrier channel so that the operator has a continuously correct lamp indication of every device controlled.

The coded signals are sent over the line by straight telegraphic keying of the carrier channel, a contact in the dispatcher's equipment keying the transmitter to send out a preselected series of carrier pulses corresponding to the particular code used. The equipment is similar to the automatic telephone equipment of dial telephones except that it is unnecessary for the operator to remember the number; he simply presses a button and the equipment in effect dials the number.

In addition to controlling circuit breakers, several metering or position indications can be carried over a supervisory control channel, and the quantities measured can be controlled simultaneously. For example, indication and control of amperes, volts, watts, power factor, reactive volt amperes, or position of a device can be performed over the carrier channel utilizing one supervisory point per quantity.

After the operator has a sufficient indication of a particular quantity he can disconnect from that point by the master reset key. Or, if there is no objection to continuous carrier on the circuit, any one quantity can be left indicating continuously. Frequently this is most convenient for the operator as he can select some particular quantity that affords the chief basis for operation. He can at any time change positions to check other quantities returning to the most important quantity for continuous indication.

Demand and integrating metering can also be carried over the carrier-supervisory control channel. During the demand interval the meter at the sending end stores up impulses proportional to the integrated kilowatthours. At the end of the demand interval the metering takes over the carrier channel for a short time and sends through a number of pulses in rapid succession corresponding to the accumulated kilowatthours during the demand interval, such as 15 minutes. The receiving meter responds to this total number of impulses in each par-



Panels for tone carrier equipment. The top panel is a tone transmitter; center, a receiver; and bottom, a modulator.

A high-power, single-frequency automatic simplex communication carrier set, which includes dial-telephone features. As many as ten line extensions can be selectively called. Automatic compensation holds the voice levels constant at all points.

ticular group. This is a demand indication. It also runs the integrating meter ahead by an amount corresponding to the number of impulses in that group and thus corrects the integrating meter each 15 minutes to the correct value. In so doing, it utilizes the carrier channel only a very brief part of the total time so that it is available the remainder of the time for supervisory control functions.

If voice communication is to be operated over the same carrier channel as is used for supervisory control it is desirable to use one supervisory control point for ringing and to lock out the supervisory control equipment while the telephone conversation is taking place. This prevents any misoperation due to a possible chance coincidence of a series of voice impulses with the code used for supervisory.

Tone Modulation

To economize on the carrier-frequency spectrum and to increase the selectivity from noise interference, a carrier channel can be modulated by a number of audio tones. As many as ten separate audio tone channels can be operated over a single carrier channel. The new carrier-current equipment lends itself especially well to the addition of tone transmitters and receivers because of the flexible rack and panel construction. The components of the tone equipment illustrated are the modulator panel and the tone transmitter and receiver. The tone transmitter operates into the carrier transmitter through the modulator.

If two tones are to be transmitted each way and if it might be necessary to send signals both ways simultaneously, then the carriers for the two directions must be set on different frequencies. The equipment at each end would then be identical in appearance and would consist of the carrier transmitter and receiver, the modulator, two tone transmitters, two tone receivers, and coupling equipment. It would usually be sufficient to tune the line-tuning unit intermediate between the two carrier frequencies used.

A carrier channel may be used for the transmission of relaying signals, without interfering with the use of the audio tones as described. In this case, the line traps should be tuned for the frequency of the carrier transmitter at that particular end of the line because the main function of the line trap in relaying is to prevent short circuiting of the transmitted signal by a nearby fault outside of the protected line.

The tone equipment lends itself quite admirably to telemetering functions both because of the ability to transmit several telemetered quantities over a single carrier channel and because of the added freedom from noise obtained by the combined selectivity of carrier and tone selective circuits. It also works in well for load control, using one tone for raise and one for lower. Also in relaying applications it is frequently desirable to transmit a remote trip indication to the remote end of a line to open the breaker at that end in event of operation of the sensitive transformer differential protection at the near end. Two tones are usually used for this purpose for security.

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High-Frequency Heating in Industry

Those rascals—eddy currents, skin effect, and dielectric loss—now have important jobs in the field of induction and dielectric heating. Their characteristics harnessed, they are proving to be marvelous workmen, doing many things in the field of metal melting, brazing, soldering, hardening, and curing. Such operations are being done better or faster, and, in fact, many cannot be done by any other method.

INDUCTION and dielectric heating are already in the industrial big time. The capacity of apparatus installed in the United States and Canada exceeds 300 000 kw. This includes equipment for hardening, brazing, forging, and melting. At present about one half of the installations are for melting, one fifth for surface hardening, and the remainder for other heating work. In the last year and a half 9300 kw of induction-heating equipment has been installed for the flowing or finishing of electrically deposited tin. This tin-flow apparatus, which looks for all the world like broadcast transmitters, is more than two and one half times the total power of all the radio broadcast stations of the United States. Tin flowing is, to be sure, a spectacular example of induction heating, but it represents only one of scores of uses now being used commercially in a big way.

Probably the first use of high-frequency heating was not by industry but by the medical profession. The suggestion that high-frequency currents might purposefully be used for heating came from d'Arsonval, famous French physicist after whom is named a basic electric-instrument principle. In 1890, while experimenting with high frequencies obtained with a Hertz wireless set, d'Arsonval found he was able to pass two or three amperes of current through the human body without producing any muscular contraction or sensation other than that of heat. He thus obtained the clinical high-frequency currents. Most hospitals and many doctors' offices have one or more of these fever-inducing machines.

The Miracle of Heating without Heat

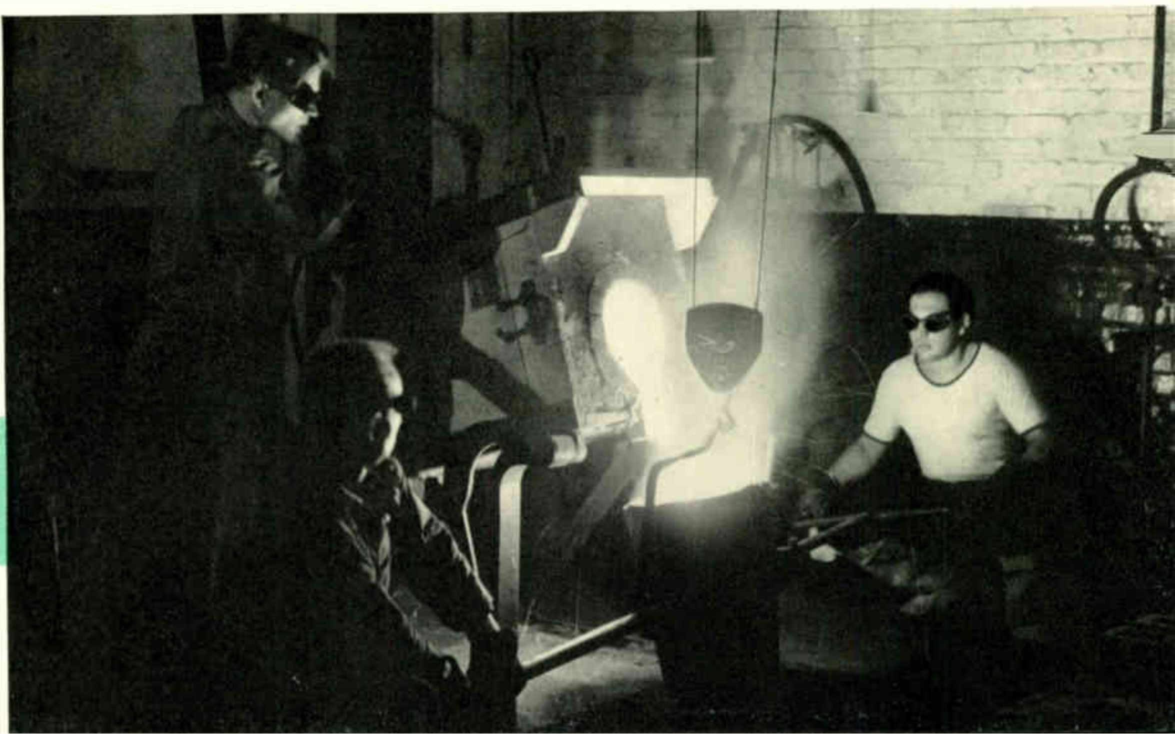
The industrial magic of a-c heating—either induction or dielectric—is miraculous on several counts. One, and most important of all, by this means, heat can be established *inside* a material. Second, with metals, heat can be concentrated on or within some specially selected or localized portion and applied so quickly the remainder of the metal stays cool. The interior of non-metals is heated as rapidly as the outer surface. In the third place, the phenomenon of internal heating occurs without any mechanical contact with the material. And fourth, the electric apparatus that is the cause of this heating may not even get warm.

This so-called magic of heating with alternating currents rests on two well-known and fairly simple electrical principles—that is, they are simple as long as the explanations are confined to effects and not to what happens within the molecular structure.

The first is the principle of induced currents. That is, when any electrical conductor, magnetic or non-magnetic—in short, any metal—is surrounded by a coil carrying an alternating current, corresponding electric currents flow in the conducting metal itself. These currents, flowing against the electrical resistance of the conducting material, cause an energy dissipation within the material, according to Ohm's law, (I^2R). This energy dissipation appears as heat in the same way that a lamp filament becomes white hot by the flow of current through it. This is the principle underlying a-c induction heating.

Induction works fine for the heating of materials that conduct electricity, but it won't do for poor conductors of electricity, such as plastic, plywood, glue, paper, and arthritic joints. These materials are also heated by alternating currents (of higher frequency), but in a different way. We simply make an electrical condenser, which consists of a sandwich in which two metal plates or electrodes connected to the a-c circuit are the slices of bread and the substance to be heated is the filling. Because this middle stuff to be heated is a poor electrical conductor—generally very poor—it is termed a dielectric, which gives to this second major division of a-c heating its name, dielectric heating.

With the sandwich we have made a condenser, which electrically is just like capacitors used on power systems to



Possibly the oldest industrial use of induction heating has been for melting small batches of metal. (Photo courtesy Ajax Electrothermic Co.)

Oscillators are no longer tailor made. This standard 20-kw unit is built for frequencies of 450 kc, and 2 and 10 mc.

improve power factor or reduce light flicker. They work just the same way. When the applied alternating current charges the two electrodes alternately positive and negative, an electric field is set up through the dielectric, which is the insulation stuff to be heated.

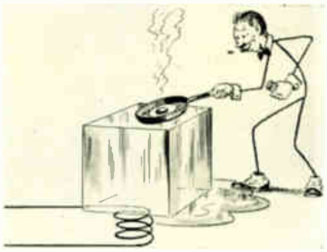
The theory of what happens within the structure of the dielectric is complex and not too well defined. An understanding of the exact mechanism is fortunately unnecessary. It will suffice to consider that the applied alternating electrical stress causes a molecular agitation, and the resulting friction—as friction always does—causes heat. Most important, the rapidly changing electric field develops heat all through the material, while the plates themselves remain cool except for what heat they absorb from the dielectric.

This heat in power-factor correction capacitors is undesirable. Designers of these capacitors struggle to cut down this dielectric heat loss. But, one man's meat is another's poison. Dielectric-heating engineers base their whole show on this loss in non-conducting materials. They simply take advantage of the fact that there is no perfect electrical insulator.

A noteworthy fact, however, is that the faster the current alternates, i.e., the higher the frequency, the greater the agitation of the molecules, and the more rapidly internal heat is developed. For this reason dielectric heating is done at really high frequencies—generally in the megacycle or millions of cycles per second class.

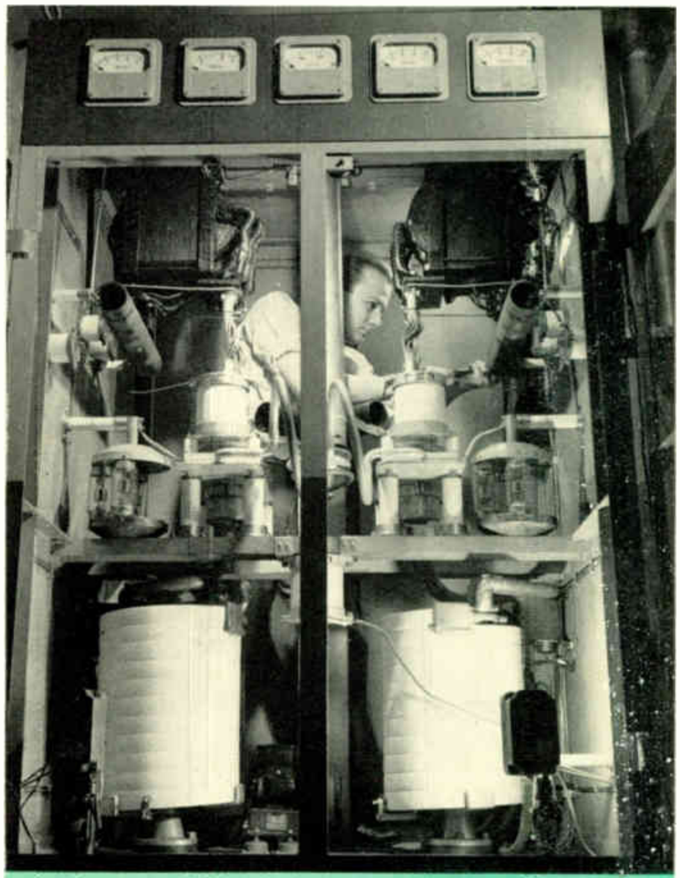
Induction or Dielectric Heating Simply Gets the Heat Where It Is Needed

One thing must be kept clearly in view. Use of alternating currents for either induction or dielectric heating is simply a means of getting heat into a substance. There is no mystical benefit from the electric current. The heat, once it is established inside the material, is the same old finger-burning heat familiarly obtained with a gas flame or torch.



Induction heating, once a stunt, is now industrially important.

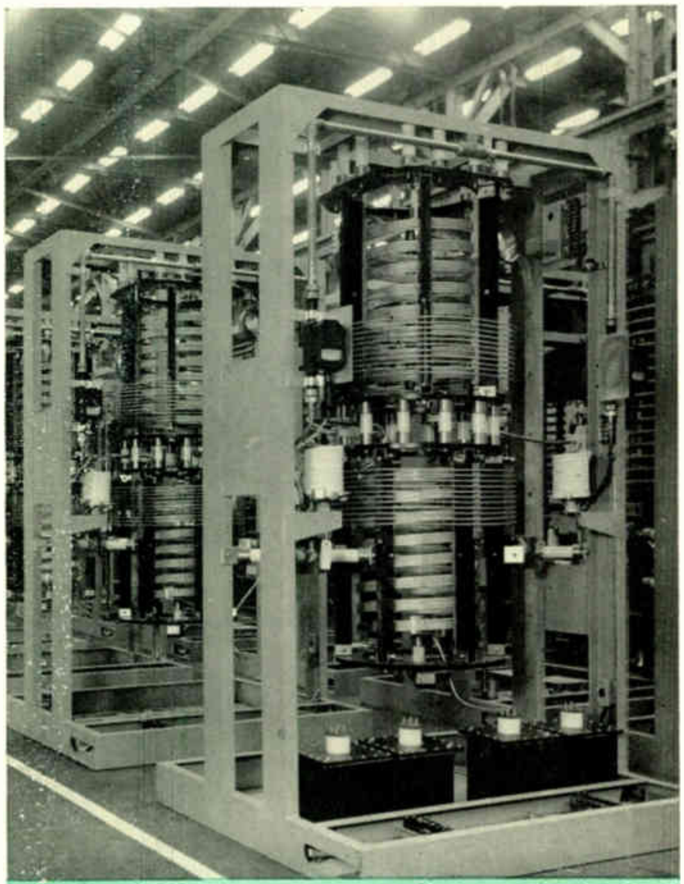
The salient feature of induction or dielectric heating is that it is the first time in history that we have a means of generating heat *inside* a substance (except by electric conduction and the limited and impractical method of heating obtainable by flexing or working the object). By all other methods—flame, hot liquid or gases, etc.—the heat must flow in from the outer surface. The maximum rate of energy transfer from the walls of a furnace maintained at 2000 degrees F to a body at room temperature is only about 3 Btu per minute per square inch. By induction heating, energy can be transferred to a piece of steel from 30 to 90 times faster with no difficulty, or at the high rate of 100 to 250 Btu per minute per square inch.



This laboratory oscillator has been used to supply power for a variety of induction- and dielectric-heating experiments.

From this ability of alternating current to develop heat within material stems many advantages of this form of heating. This is why so much is being heard about dielectric heating in connection with plywood and plastics. The marvelous new plywoods are made possible by superb synthetic glues. However, these synthetic binders are thermosetting; they set permanently when heated for a short time to not more than 350 degrees F. The thickest plywood that can be made using these superior binders and using the old methods of heat curing with steam platens is about an inch, because the heat must flow in from the outside. The outer layers reach the curing temperature long before the deep, inner layers get more than warm. The result is overcuring of the synthetic binder or scorching of the outer layers of wood. If the heating is done more slowly, the time becomes uneconomically long, running into days or weeks; if it is hurried to save time the product is ruined. The same general principle holds for curing large blocks of plastic. Both plywood and plastics are poor conductors of heat, so that thickness becomes an absolute obstacle if the heating must be done from the outside.

Heating with high frequency is a much different story. When plywood or plastic is made to act as the dielectric of a condenser, i.e., dielectric heating—the innermost layers or portion get hot as quickly as the outer parts. Except for mechanical limits, thickness doesn't matter. Plywoods made up of as many as 148 layers of birch veneer and measuring over a foot thick have been made using phenolic-resin adhesive and cured dielectrically in a few minutes. Many-layer plywoods made in this manner have tested tensile strengths of 45 000 pounds per square inch, but weigh only half that of aluminum.



All the 200 000-cycle power for induction flowing of tin on tin plate is being supplied by electronic oscillators of this type.

In evaluating induction and dielectric heating another advantage should be included, the ease of control, not remotely approached by any other heating method. The heating can be started or stopped instantly or made to vary according to any prescribed pattern. No preheating of a furnace is necessary; no excess heat is stored in any chamber or heating medium.

Uses of the Alternating-Current Heating Spectrum

In examining the frequency spectrum to see what bands are used for what, it is convenient to begin on familiar ground—with ordinary power frequencies of 50 or 60 cycles. Although a-c heating is frequently thought of as being done at "high frequency," this is not always so. Power-system frequencies are used for induction heating of localized areas of metals for forging and upsetting. Where the metal is a good conductor and is quite thick, and it is to be heated throughout, nothing is gained by going beyond power frequency, which is obviously the more economical power supply. Low-frequency induction heating may also prove useful for certain heat treating.

Because heating is relatively fast only a light, soft scale is formed. The virtual absence of scale, which is a hard abrasive, greatly extends the life of the forming punches and dies. Working conditions near induction heaters are better than around gas- or oil-fired furnaces as almost all the heat involved is generated directly in the charge piece. The only heat to which an operator is exposed is the heat radiated from the charge as it is removed for forging.

These low frequencies are also used to heat autoclaves and large chemical vats, the process being particularly useful where the absence of flame and fumes is an advantage. Work in the laboratory indicates that power frequencies can be used for drying various substances, such as large sections of formed heat insulation which is molded very wet, although in general drying dielectrically is not economical.

The 2-kw models of the high-frequency oscillator (5, 15, and 30 mc) are as compact and simple as a radio set.

Putting Skin Effect to Work

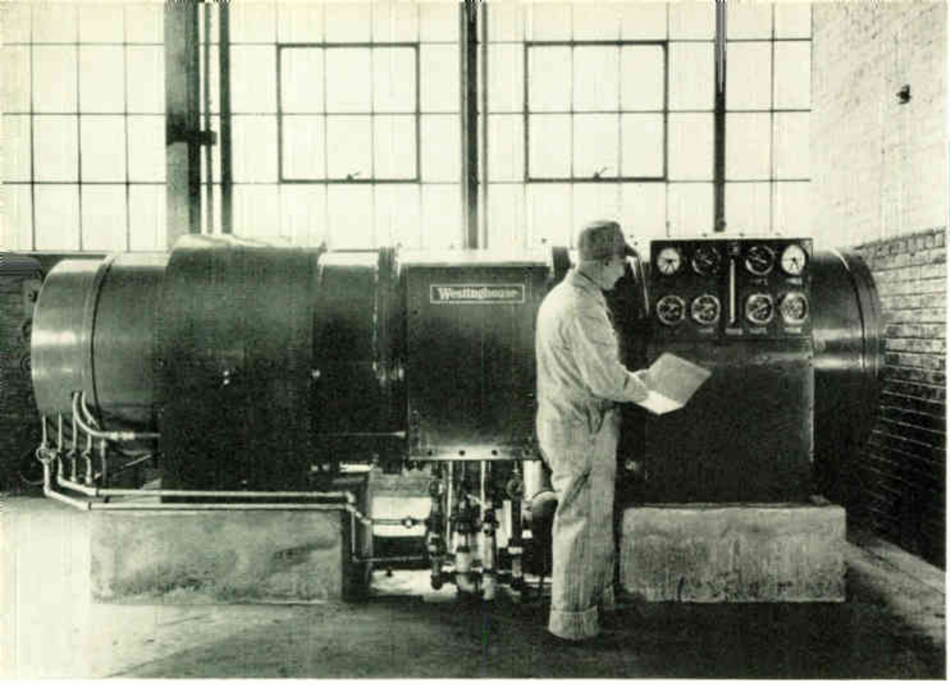
Most induction- and all dielectric-heating work, however, is being done at higher than commercial power frequencies. Leaving power-system frequencies and moving on up the spectrum, the engineer begins to make use of an important characteristic of alternating currents—skin effect. At the low frequency of 60 cycles the crowding of current to the surface of a conductor is relatively slight, but as the frequency increases skin effect becomes more and more marked. At a few thousand cycles virtually all of the current flows in but a small fraction of the depth of a conductor. At ultra-high or radar frequencies, all current flows on the surface; the inside of a conductor could be removed, leaving but a thin shell, without affecting the current flow.

Surface Hardening—Skin effect, a headache to power engineers, is put to good use by the induction-heating experts. Extensive use is made of 3000 and 9600 cycles for surface hardening of metals and promising experimental work is being done at much higher frequencies. Consider a crankshaft with its many bearing surfaces. These surfaces should be just as hard as possible for minimum wear. But only these bearing areas should be hardened. The steel underneath and elsewhere throughout the crank must have maximum toughness. Needed then is a means of differential heat treating—a means of heat treatment for exact and limited portions of the shaft without affecting the interior of the metal or the other parts of the crankshaft.

For the induction engineer this differential heating is simple. A coil or collar, called an inductor, is placed around the bearing surface to be hardened, and current at several thousand cycles is passed through it. This induces high-frequency eddy currents in the crankshaft metal, but because of skin effect they crowd into the surface of the metal—just where the heating is wanted. The surface metal gets red hot quickly in a matter of perhaps two to ten seconds before the heat has time to wander off where it isn't wanted. When the correct hardening temperature is reached, the current is shut off, the hot surface is quenched in water or oil, providing a hardened crankshaft bearing surface. The job takes but a few seconds.

Dielectric cooking, theoretically possible, is still experimental.

The Ohio Crankshaft Company, for example, has turned out hundreds of thousands of inductively hardened crankshafts for aircraft, tank, Diesel, and other engines. On a production-line basis, a workman simply slips a crankshaft into

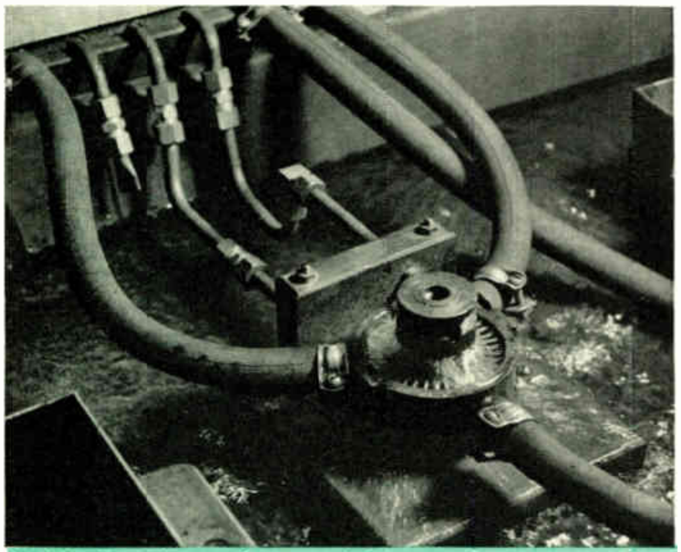


When a centralized source of 9600-cycle power is required for hardening, large m-g sets such as this are employed.

position in a heating unit in which the inductors are properly located for the several bearing areas of that type of shaft. He pushes a button and walks over to tend the next unit. Meanwhile, the high-frequency currents of the correct magnitude flow in each inductor, are automatically shut off at the correct instant a few seconds later, after which the jets of quench fluid automatically squirt from the inductor onto the treated areas. The machine then shuts down and waits for the operator to return, the four to twenty bearing surfaces having been properly hardened. One man can tend four typical units, turning out one 13-bearing crankshaft every two minutes.

Induction heating is useful for differential hardening of internal surfaces as well as for exteriors. The Budd Induction Heating Company specializes in hardening internal surfaces, such as the walls of cylinders for internal-combustion engines, the interior of automobile hubs, and oil-well pipes. For this work the inductor coil of the right size and shape is placed within the object whose inner walls are to be hardened. Again using the principle of skin effect, currents are made to flow in the surfaces nearest the coil.

Induction hardening offers many production advantages—in fact, it is best adapted to high-production processes. Rocker-arm shafts for airplane engines are surface hardened in the areas on which the rocker arms operate. One thousand shafts per hour are treated on one unit. The shafts move automatically one at a time through an inductor, are stopped by an indexing mechanism for just the right length of time, and then move automatically into the quench zone, and finally out of the machine.



For this hardening operation the inductor is a single-turn collar that also carries the quench fluid. (Ohio Crankshaft Co.)

Rings, liners, and casings can be heated for installation or removal by induction heating. This trick is being used to place tires over railroad-car wheels and for the insertion of gun liners. Shell casings are made of deep-drawn steel, in which the section to be drawn is inductively heated.

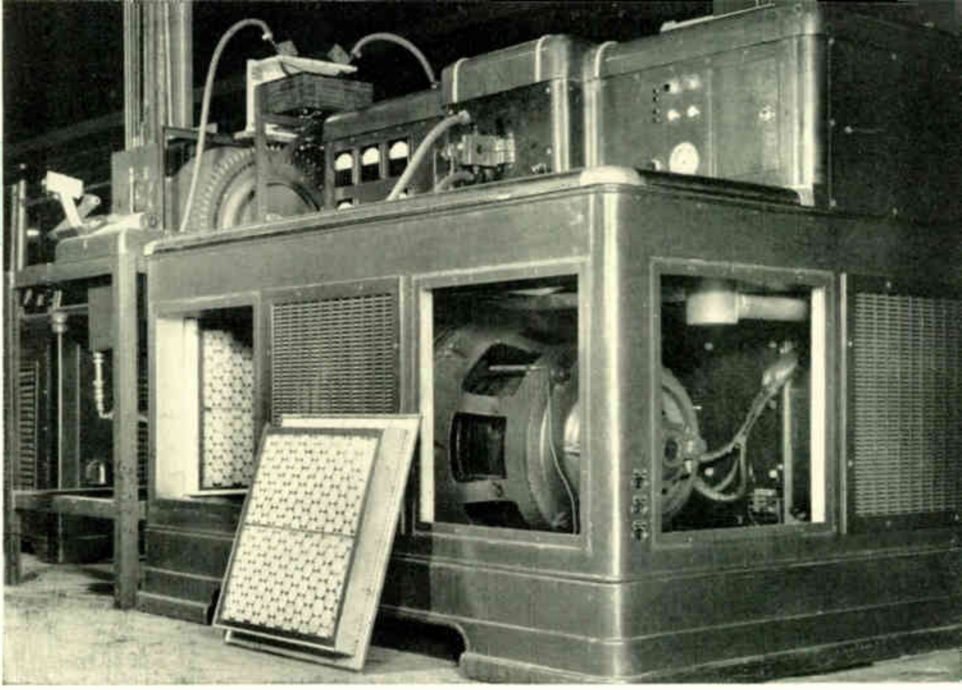
The frequency band between commercial frequencies and 15 000 cycles also includes induction melting, in which field the Ajax Electrothermic Corp. is active. Most induction furnaces have been used for melting of small batches of steel, of not more than 5000 pounds per melt. Induction melting is used where an accurate composition of the finished product is needed, such as nickel-chrome alloys, certain tool steels, permanent-magnet alloys, etc. A few installations have been made of induction melting in a vacuum or in a controlled atmosphere. Most melting is done at 1000 cycles, although some is done on a small scale at 3000 cycles, and a few laboratory furnaces use 12 000 cycles.

15 000 to 100 000 Cycles a No Man's Land

So much for the frequencies up to about 15 000 cycles. From this point on, up to about 100 000 or a little more, is a virtual no man's land as far as induction heating is concerned. This is not because these frequencies are not equally useful but because of a practical limitation; namely, the lack of suitable generators of sufficient capacity and at reasonable cost for these frequencies. The most practical and economical generator of frequencies in the 15 000- to 100 000-cycle band is the spark-gap oscillator. To be sure, many spark-gap oscillators are in successful service, supplying power in this frequency band for induction heating, mostly for experimental or laboratory use because they are limited in output to a few kilowatts. The largest size has an output of about 16 kw. Furthermore they require considerable attention. Spark-gap oscillators can be and are used for frequencies above 100 000 but their efficiency falls off as frequency increases.

The absence of a practical generator of large power output, at reasonable cost, in the 15 000- to 100 000-cycle band has not proved serious. There is, of course, one theoretically best minimum frequency for heating every substance, whether conductor or non-conductor. Within the last couple of years, the choice of proper frequency has been reduced to the use of curves and formulas and the end result to be obtained, whereas previously it had been mostly a matter of experience and cut and try.

Fortunately, however, the ideal frequency is not critical. Unlike the sharp-peaked tuning curves long associated with "radio" applications, the efficiency vs. frequency curves for a-c heating for almost all materials are broad and fairly flat over a wide range of frequencies. If the ideal frequency for heating a certain material is 75 000 cycles, there will be a negligibly small sacrifice in efficiency if a frequency of 450 000 cycles is used at which the cost of the power supply is less.



Induction-hardening sets, such as this of the Ohio Crankshaft Co., contain the m-g power-supply unit in the base.

100 000 to 450 000 Cycles, the Upper Induction Band

Electric power in the range between 100 000 and 450 000 cycles, which is just below broadcasting band, is supplied by electronic generators. These are being applied to a wide variety of induction-heating tasks. In this region skin effect in conducting substances becomes a prominent factor. The penetration is extremely shallow and the heating rapid. Thus, this frequency band is used where the heating must be done quickly in concentrated areas to avoid heat conduction to other parts, or where extremely shallow heating is needed. Also these frequencies are used where the parts are small—chisels or wrist pins, for example—where the surface heating must be done quickly.

Outstanding example of this class of heating is that of flowing tin on electrolytically formed tin plate. Electrically deposited tin, although it saves from half to two thirds of the tin, leaves the tin surface dull and porous. However, if the tin is heated just to the flow point, it refreezes with the desired hard, uniform, bright surface. This is accomplished by induction. The tinned steel strip is unwound at speeds up to 1000 feet per minute and passed through an inductor coil supplied with power at about 200 000 cycles. The tin reaches the flow point in a small fraction of a second and with almost equal speed refreezes as it is quenched.

Many other uses for the 100 000- to 450 000-cycle band are being found. An interesting and illustrative one is the hardening of rock bits used in the drilling of oil wells. Several of these bits on the end of a tool are lowered into the hole and rotated to bite their way through the rock to the oil-bearing sands. The harder the teeth the longer these bits stay sharp, i.e., the longer they can stay down on the job—which means less lost time in removing the string of rods from the hole. Heretofore, each tooth surface has been carbided by heating it individually to redness with a torch and sprinkling over it a layer of tungsten-carbide particles. To heat and harden the 20 teeth in this manner consumes the better part of an hour and requires a skilled torch operator.

In an induction-heating coil the job is done in a couple of minutes. The tungsten-carbide particles are held on the teeth by an adhesive, while the whole bit is brought to white heat by a 200 000-cycle field. All 20 teeth are carbided simultaneously and uniformly. Furthermore, this can readily be done in a protective atmosphere.

Soldering offers a big field for induction heating. A terminal block for airplane control wires has 30 connections to be soldered. Girls had been soldering these leads individually by hand, the job requiring about 15 minutes. A simple setup in the laboratory showed that all 30 joints could be soldered simultaneously by induction in about 15 seconds.

Spouts on metal cans such as contain lighter fluid, household lubricating oil, etc., are soldered inductively in about two seconds using a 300-kc oscillator. Such repetitive induction soldering lends itself to high-speed, automatic, moving-belt methods.

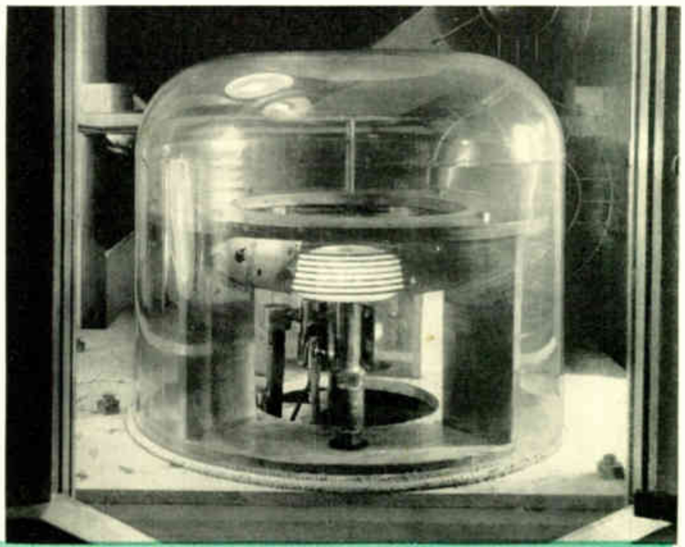
Induction brazing is another comer. Most of this work is done near the upper end of the induction-heating spectrum, i.e., about 450 000 cycles. An expensive mold, for example, can be made by brazing in the induction furnace several simple parts instead of making the mold out of solid stock requiring expensive and difficult machinery. Super-hard cutting alloys can be tipped onto the supporting stock, by the induction process, in oxygen-free atmospheres.

Frequencies still higher than about 450 000 cycles and below 1500 kilocycles cannot be used for induction heating because of interference with broadcast frequencies. Perhaps they will be used in the bands above the broadcast frequencies, but thus far not much practical use has yet developed for induction heating at these super-frequencies. Induction heating is yet young; the war has interfered with experimental work, and even the most obvious uses of it have not yet been thoroughly explored and digested.

Dielectric Begins About Where Induction Leaves Off

The field of dielectric heating is in the ultra-high frequencies—say from 2 000 000 cycles to upper limits yet unexplored. It is in the band from say 2 to 100 megacycles that so much ground work in dielectric heating is being done. It is at these frequencies, for example, that the plywood and plastic curing methods mentioned earlier are being performed.

Theoretically, any insulating material, i.e., *any* dielectric,

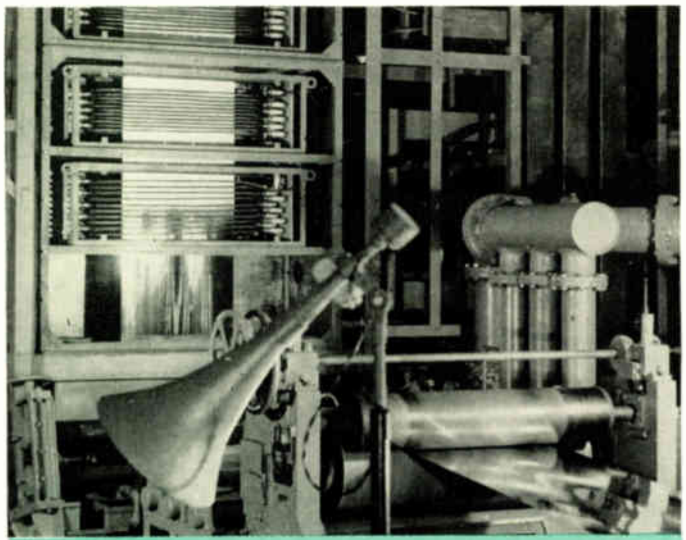


In the protective atmosphere of this bell jar, a rock bit is being inductively heated for hardening in only a few seconds.

will absorb energy when placed in a high-frequency field. How readily a material absorbs energy from the electric field is determined by its loss factor. This loss factor is made up of two things—the power factor of the material and the specific inductive capacity—both of which are relatively fixed characteristics of a given material. Each substance has its own loss factor. For glass it is 0.02; for woods, 0.06 to 0.32; fiber, 0.25; and so on. The lower the loss factor the less heat that can be generated in that substance by a given frequency and voltage. The only alternative is to raise the voltage or increase the frequency. Although the heat produced within a given dielectric varies as the square of the voltage, a practical limit is often reached, because the voltage-stress limits of most dielectrics is fairly definite. For materials of exceedingly low loss factor appreciable heating can be obtained only by the use of ultra-high frequencies such as several hundred million cycles. Even so, a few materials such as polystyrene have such a low loss factor that they are outside the scope of present high-frequency generators. It may be that out of radar work will come generators of sufficiently high frequency and low cost to bring such materials within the range of practical dielectric heating. But that is for the future, not today. The answer to the often-raised question: Can such and such material be heated dielectrically? is, with rare exceptions, not that it can't be done, but whether it is practical from the standpoint of economy.

Dielectric heating is being used by the plastics industry not only for curing of plastics but also for preheating the plastic material before it is placed in the molds. Plastic preforms can be brought up to just below the curing temperature much more quickly—and what is important—much more uniformly by dielectric equipment. The gains have been significant. Mold wear is reduced, and the molding pressures—which strongly weigh on press cost—can be lowered by 25 to 40 percent.

Lumber can be cured dielectrically, although this will not likely prove the most economical method of doing it in general. In the case of the more expensive woods, as for furniture or pianos, the storage and other facilities required for the two or three years needed for air drying can be reduced. Likewise, the waste factor and inventory charges are decreased. Drying of lumber in a few hours by electronic means is possible. It is simply a matter of economics.



As tin plate speeds downward between the induction coils, the tin is brought to the flow point in a fraction of a second.

Dielectric heating is a great boon to cabinet makers. Furniture can be put together with the new synthetic resins, dried almost instantly by dielectric-heating guns. The cabinet makers can thus avoid the use of nails, screws, and other metal fastenings that require concealment.

Fabrics of synthetic plastic or synthetic rubber can be stitched without thread by passing the seam through an electronic "sewing machine" that brings each tiny spot successively to the thermosetting temperature instantly, thereby joining the layers permanently.

Several years ago shoe manufacturers began using dielectric heat provided by electronic equipment to dry the glue holding the soles onto the uppers of ladies' shoes. The established method had been to use steam-heated platens, but because the heat had to work through the leather to the glue this had a tendency to overheat the leather and overcure the outer portions of the glue before the innermost part reached the correct temperature. By using dielectric heating and a glue with a high dielectric loss factor only the glue gets hot, and it does so uniformly.

Coils and condensers are star players in the a-c heating show.

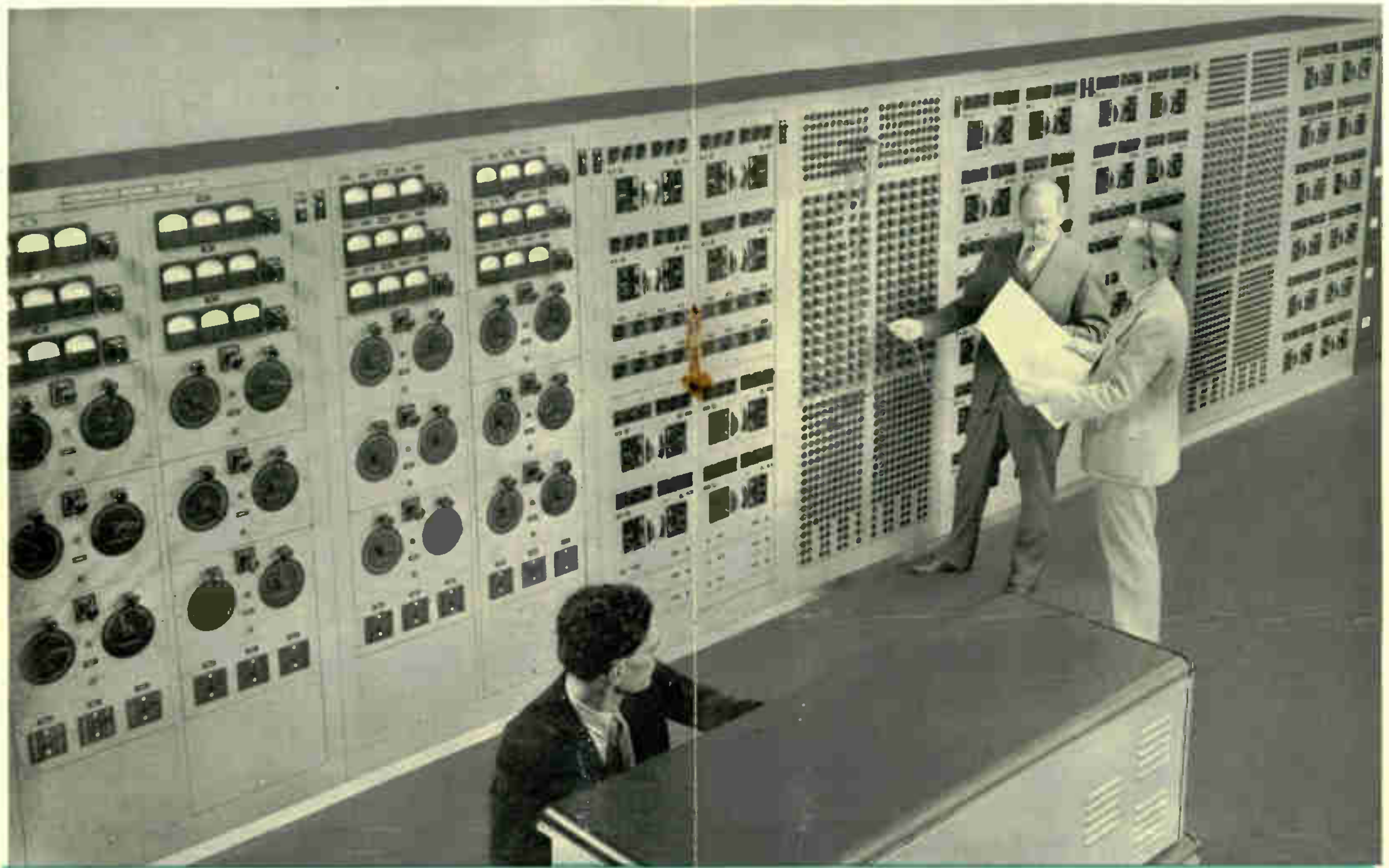
Sometimes the variation in loss factor by the different constituents of a substance can be utilized to good advantage to provide a differential dielectric heating. It is possible to kill weevils or other organisms in grain, food products, etc., even when packaged. The organisms have a higher loss factor than the product, so they reach a killing temperature before the product is injured. Again the limitations of the process are not technical ones but those of economics which have not yet been fully proved.

Dielectric heating has been tried for some jobs and, for one reason or another, found wanting. Glamour or the spectacular—except in the field of showdom—has little economic value and seldom transcends cost in importance. The possibility of cooking dielectrically has been much discussed, perhaps leaving the impression that dielectric cookers will become common household devices after the war. Certainly not soon after the war. Also the ability of dielectric cooking to compete with present methods is doubtful. Engineers are unwilling to say because there is yet so much to be done before the matter can be settled—and war production in the electronic field does not leave much time to look into such matters as choice of frequencies, techniques of heating non-homogeneous foods like meats with their bone, fat, and fibre, the matter of effect on vitamin content, etc. Certain it is that foods can be cooked dielectrically. Corn has been popped, hot dogs cooked, hams baked, frozen foods thawed, others cooked in their containers—but only the sketchiest of answers have been obtained. Dielectric cooking remains one of the great unexplored fields.

So, we see our old friends, the inductor coil and the condenser in new roles. Both have had bad habits that have often annoyed us. Inductors have often played annoying pranks by giving rise to troublesome heating in unsuspected places. The heat loss within capacitors has been a nuisance. Now these very traits are enabling the inductor and the condenser to play stellar parts in our new show, which is to be an industrial headliner—Induction and Dielectric Heating.

Charles A. Scarlott

Bus voltage, current distribution, associated power factor and watt or var distribution are read on the master instruments.



After the problem has been outlined and a line drawing made, such as held by the author, the actual system impedance data is converted to percent or per unit on a common kva base. The calculator is then "loaded" by adjusting the value of load impedances and generator outputs as set forth in the problem.

Each component of a power system has its electrical counterpart on the calculating board, such as this resistor-reactor unit.

actual system must be simple and so arranged as to reduce the time of "loading the system" to a minimum.

In the design and arrangement of the new Westinghouse a-c calculator, these requirements were given fullest consideration. The physical arrangement of the new calculator, and the mechanical and electrical details, are designed to provide maximum production as measured in terms of calculator data per hour. Individual circuits are so arranged that the units requiring adjustment during the course of a study are located close to the operator at the instrument desk.

The calculator has been arranged with two master instrument desks, which permit working two problems simultaneously where the total number of elements for problems does not exceed the available number of units. Because the two master-instrument desks must logically be separated to prevent interference between the operating personnel of the two problems, remote electrical control of several generator units is provided on the second instrument desk, together with duplicate metering instruments of these units.

Number of Circuits

The number and types of circuits provided in the calculator are listed in table I. Generator circuits have been increased by one half and the total number of circuits by a sixth. In addition to this quantitative increase, greater effectiveness has been achieved by extending the range of impedances, particularly for load circuits.

The calculator provides improved mechanical and electrical features that result in increased speed of operation, higher accuracy, and greater convenience to the user. The most outstanding improvements are listed below.

1—Increased number and range of circuits that represent the corresponding parts of an actual system.

2—Two instrument desks permitting simultaneous study of two parts of same system or for two independent studies.

3—Improved metering facilities including:

a—Instruments with adjustable scale markings such that actual system power quantities are read directly without use of multipliers.

b—Instantaneous electrical selection of any circuit for metering purposes.

4—More compact arrangement with all frequently adjusted devices within easy reach of the operator.

5—Generator units with independent control of voltage and phase angle. This simplifies the adjustments corresponding to a station operator's control of excitation and prime-mover governor setting.

TABLE I—NUMBER AND TYPES OF CIRCUITS PROVIDED AND THEIR PURPOSES

No. of Circuits	Type	Purpose
18	Generator units with voltmeter, ammeter and wattmeter	To represent generators, phase-shifting transformers, etc.
18	Low-loss reactors	To represent internal impedance of generators
152	Resistor-reactor units (Series connection)	To represent lines, reactors, transformers, etc.
48	Resistor-reactor units with "load adjusters" (Series or parallel connection)	To represent shunt loads
48	Condenser units	To simulate line-charging capacity, synchronous or static condensers, etc.
36	Autotransformer units	To represent transformer taps
36	1 to 1 ratio transformers	To represent mutual induction
48	Metering jumper circuits	For bus connections
6	2 to 1 ratio transformers	For extended range problems

Information Obtainable from the Network Calculator

The problems for which a-c calculators have been used generally fall into four classes, those involving load-division, short circuits, miscellaneous application and circuit studies, and transient stability.

The most common ones of each class are as follows:

Load-Division Problems

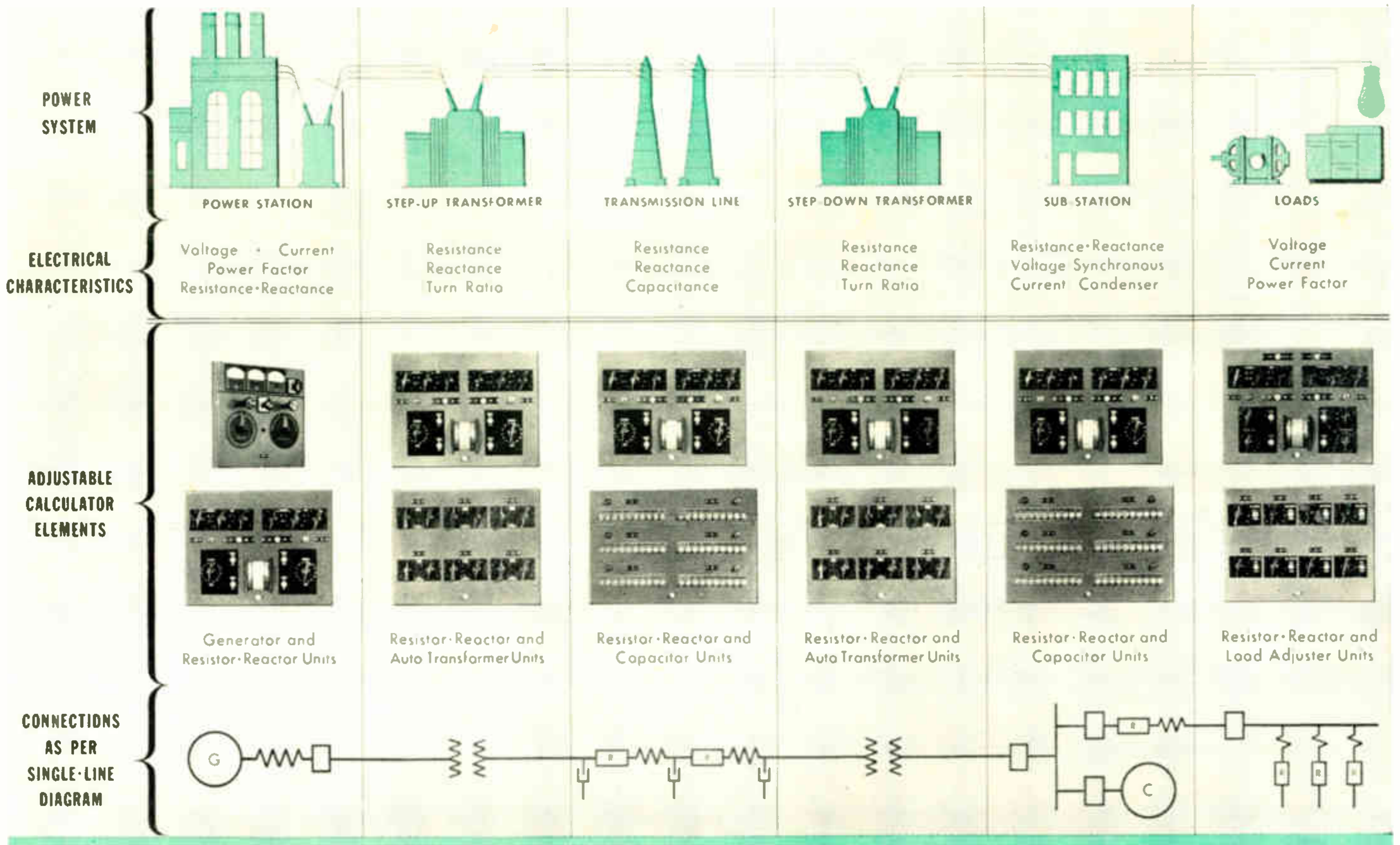
a—Circuit loading—both kw and kvars (wattless current flow).
b—Bus voltages.
c—Corrective condenser capacity as needed to improve power-factor or voltage conditions.
d—Optimum ratings of transformers.
e—Tap range of transformers.
f—Improvements derived from load-ratio control equipments.
g—Improvements derived from out-of-phase (quadrature) control.
h—Location of new generation facilities to give best overall results.
i—Effect of new transmission circuits.
j—Effect of rearranging existing circuits.
k—Best location for new substations.
l—Best location for bus or feeder reactors.
m—Effect of changed system loading.
n—Effect of changed transformer reactance.
o—Effect of temporary loss of transmission circuits.
p—Effect of temporary loss of generation.
q—Improvements from increased system voltages.
r—Improvements from changing conductor sizes.

Short-Circuit Problems—Balanced and Unbalanced Faults

a—Determination of maximum short-circuit values for circuit-breaker interruption duty.
b—Bus voltages during short circuit at point remote from fault location to give a measure of system performance under fault conditions, such as dropping of important motor load, etc.
c—Maximum and minimum fault currents and voltages for relay settings to give best selective action.
d—Determination of optimum values for neutral-grounding devices.
e—Maximum and minimum fault currents for proper application of transmission-line expulsion protector tubes.
f—Effect of mutual coupling between parallel circuits, on short-circuit current and voltage values.
g—Effect of zero-sequence voltages and currents on ground relays and inductive coordination problems.

Miscellaneous Apparatus and Circuit Problems

a—Optimum design characteristics for large synchronous motors at some distances from source of generation.
b—Best starting methods for large motors—effect on system voltages and pull-out of loaded running motors.



All rotating and static elements of a power system can be represented by the proper combination of calculating-board units.

c—Solution of large, or special low-voltage, or primary networks.
d—Unbalanced current and voltages on three-phase system resulting from unsymmetrical loading.
e—Effects of large welding equipments or electric furnaces on system voltages and normal loading.

Stability Problems

a—Steady-state limits.
b—Transient limits for various types of faults.
c—Optimum switching time, for various types of faults.
d—Improvements resulting from high-speed reclosing.
e—Effects of changing inertia (WR^2) of rotating apparatus and influence on stability limits.
f—Determination of increased system stability and load transfer over important tie lines caused by speed, three-pole or single-pole tripping and reclosing.

Procedure in Making Studies

Regardless of the type of problems, the various steps in the work on the a-c network calculator follow a general pattern. First, the nature of the several problems to be investigated should be outlined in logical steps to minimize set-up time on the calculator because of changed line constants, loading, and generation. The next step is to prepare a single-line diagram of the system showing all essential circuits that have a bearing on the proposed studies. On this diagram should be indicated the impedance data for all line sections, ratings of transformers, regulators, reactors, capacitors, etc., including their respective impedance data. Similarly, full rating and impedance data for the several generators on the system should also be indicated on the diagram.

For load or regulation studies, reasonably accurate kva loadings and associated power factor at the several substations and main stations are required. Likewise, the expected or desired generation assigned to the several power-supply stations needs to be known. For transient-stability studies, the inertia constants (W^2R) and speed of all important synchronous machines are required, including the W^2R of the associated prime mover.

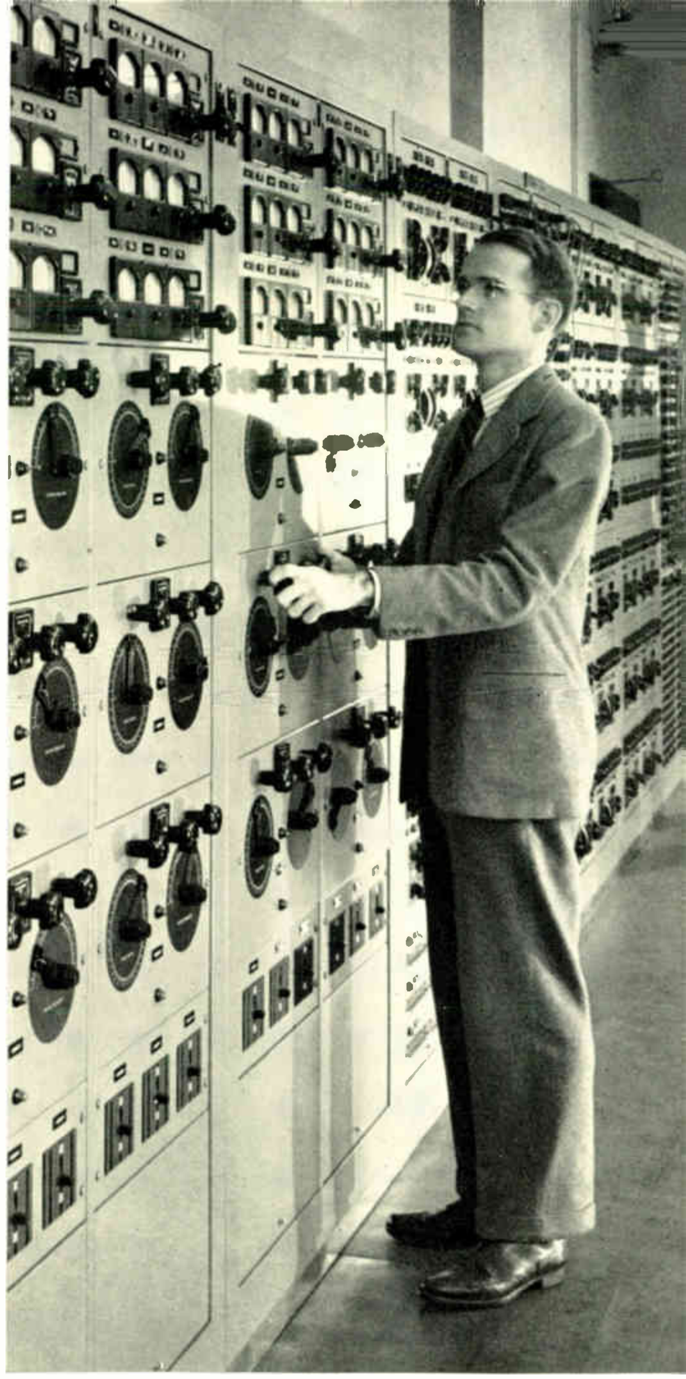
The next step is to convert the actual system impedance data to percent or per unit on a common kva base such as 100 000 kva or even decimal or multiples thereof. These values are then used in setting up the system and the calculator in accordance with the single-line diagram. The calculator is then "loaded" by adjusting the values of load impedances and generator outputs as set forth in the outline of problems to be investigated. By means of the master instruments, readings of bus voltage and current distribution over various lines, associated power factor, or watt and var distribution are recorded. These results are then converted to actual system values and analyzed to determine what system changes are required to improve operating results, such as low bus voltage or excessive line drop, undesired current distribution through the network, and the like.

With improved technique in calculator operation and with the increased facilities for rapidly obtaining calculator readings, the time required for the solution has been materially reduced. This permits the power-company engineer to analyze the results during the progress of the study so that the board has an active part in system planning instead of simply being a check upon completed plans.

◆ *Calculating boards are applicable to circuit problems from the simplest to the largest—from two $r + jx$ circuits in parallel to interconnected systems that cover several states.* ◆

The Network Calculator Brought Up to Date

Every branch of science and engineering has its "guinea pig." For airplanes, it is wind tunnels; for ships, it is model basins; for medicine, it's rats. For checking the complex electric power systems in line with present-day needs, engineers employ the a-c calculating board. Fortunately, the exactness of the laws of electricity permits precise determination of circuit behavior when using relatively minute proportional system factors. A new a-c calculator incorporates features that facilitate the solution of power-system problems involving load division, apparatus, short circuits and stability.



The adjusted generator output is read directly in power-system units.

SINCE 1929, when a-c calculators were first made available, engineers have taken advantage of this ingenious engineering tool to solve many electrical problems associated with the design and operation of electrical power systems. These solutions have resulted in economies that follow from maximum utilization of existing equipment, better service continuity and assurance that capital expenditures, when necessary, will adequately fulfill system requirements.

The wide diversity of these problems pointed to the need of many improvements in calculator design and operating technique. These facilities have been incorporated in a new a-c calculating board which is so designed that modern power-system and allied problems are solved quickly.

How the Calculator Represents Actual System Conditions

The a-c network calculator is a practical, adjustable, miniature power system whereby an actual or contemplated electrical network can be established on a small scale to permit the study and analysis of operating or design problems. To accomplish this, the various branches of the electrical network are represented by a suitable number of variable resistors, reactors, and capacitors adjusted to proportional values. Shunt loads are represented by similar resistors and reactors or capacitors with interposing transformers. Synchronous apparatus involving phase and magnitude of generated or bus voltage and power output are represented by static, adjustable, artificial generators. Each of the several calculator elements terminate in flexible connectors that can be plugged to a series of bus receptacles to reproduce the desired system connections. Suitable measuring instruments are provided to permit reading voltage, current, power, and phase-angle quantities for the many elements of the calculator. Each artificial generator circuit has its own complement of instruments consisting of a voltmeter, ammeter, and wattmeter, while a master set of similar instruments supplemented by devices to read vars, phase angle, and vector components can be quickly transferred to any element of the calculator. The various elements are generally connected to represent one phase, line to neutral, of a balanced three-phase system. Where unbalanced system conditions are to be investigated, one or more single-phase networks representing the positive-, negative-, and zero-sequence components of symmetrical coordinates are almost always employed.

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Consulting Switchgear Engineer
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Voltages, currents, power, etc., that would exist in the actual system are determined by measuring like quantities in the calculator circuits and applying suitable multiplying factors fixed by the scale to which the network has been set up. The electrical conditions in an existing or proposed system can thus be quickly, easily, and accurately observed.

The design of a large calculator, particularly one used successively by different power companies, which requires close scheduling, should be such that the various elements can be easily and quickly adjusted. The physical arrangement must be orderly so that the necessary temporary connections between the elements representing the system under study can be readily made and checked. The instrument equipment must be adequate, rugged, and quickly transferable from one circuit to another. Further, the energy taken from the calculator network by such instruments must not affect the readings within the rational accuracy limits of the problem. Suitable means for adjusting load division between the parts of the miniature system to reproduce similar situations on an

Computing Transformer Coils Graphically

The electrical engineer often has need for transformers of various capacities and voltages which may or may not conform to manufacturing standards. In any event, many prefer to design their special-purpose transformer. This article shows how.

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When confronted with the necessity of building a special transformer, reactor or coil, the engineer can usually find the data for the design of the magnetic characteristics in a handbook, text book or even from a prepared chart. However, there are few reference works giving practical design details useful where the coils are to be hand wound and the tools available are limited to those usually found in a small shop or laboratory. Knowing the power available and the needed output of the transformer, the problem is greatly simplified by the use of the following chart, sketches, and attendant formulas.

The first consideration is to establish the number of turns needed on the primary and secondary and also to determine the area of the core cross section. A fundamental formula for transformer design is:

$$E=4.44\,BANF\times10^{-8}\ \ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

where B = Flux density in lines per square inch
A = Gross core area in square inches
N = Number of turns of winding
F = Frequency in cycles per second

The home designer probably will use a commercial silicon sheet for the core. For this material, 65 000 lines per square inch is a conservative value for B. Substituting for B in eq (1):

$$E=2.89\,ANF\times10^{-3}\ \ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

At this point the engineer must determine the balance between A and N, i.e., a small core area and many turns or a larger core area and fewer turns. An empirical formula that results in a transformer having good voltage regulation with relatively few turns (an important consideration in hand-wound coils) is as follows:

$$n=\frac{34}{\sqrt{\text{Watts output}}}\ \ldots\ldots\ldots\ldots\ldots\ldots\ (3)$$

where n = Turns per volt

The primary and secondary voltages are known, as are the watts output and frequency of the current. The number of turns of the primary and secondary coils are found by simple substitutions. Approximately five percent should be added to the number of secondary turns to allow for the voltage drop at full load.

All factors in eq (1) now have an established value except A. By substitution, the value for A is readily determined and the nearest size standard punching used. A square core-area cross section is used as this design gives best performance.

It is now necessary to choose the wire size for the primary and secondary coils and compute the size of the resulting coils which are paper insulated between layers and paper insulated between core and coils. Inspection of the chart in Fig. 1 shows three graphs for determining wire size. From the capacity in watts of the transformer and the voltage of the primary and secondary, the respective primary and secondary current in amperes is determined. As the coils under consideration are hand wound, the line on the chart giving 1000 cir mils per ampere is used. The computed current of the coil is read on the ordinate and the intersect of that value with the curve is read on the abscissa as the wire size to choose. If this value falls between B & S gauge wire sizes, choose the next larger size rather than the smaller.

From the chart, the turns per linear inch of winding are found by reading the intersect of the wire size and the "turns per linear inch" graph on the outside row of ordinate values. A factor of 95 percent is about right to compensate for the difference between machine-wound and hand-wound coils.

A typical core is shown in perspective in Fig. 2. The coil is wound on the middle leg of the core and fills the two windows. The factors to be considered in the winding of each layer are shown in Fig. 3. The factors to be considered in computing the space occupied by the prerequisite number of layers are shown in Fig. 4. It is evident that for each succeeding layer, there must be an allowance, not only for the intervening layer of insulation, but also the factor for the radial space occupied for a given wire size.

In computing the d-c resistance of the two coils, it is necessary to know the length of wire in each coil in addition to the wire sizes used. On the chart in Fig. 1, read up from the wire size to the intersect with the linear graph labeled "Ohms per 1000 feet at 25 degrees C." Then read over in the outside row of ordinate values for the ohmic value per 1000 feet. Determining the length of a wire comprising a coil is largely empirical due to the number of factors affecting the length of the mean turn. Obviously, the length of the outside turn is greater than those nearer the core. This is further complicated by the fact that the radial depths along the sides outside the windows are greater than those that lie within the core windows. This is because the insulation between layers and about the core is lapped on the sides outside the windows. Here also the leads are brought out. The radial depths of the sides outside the windows are relatively unimportant; only those within the window are limited. The methods of computing the primary and secondary mean-turn length, as shown in Figs. 5 and 6, are purely empirical. Experience covering a great many coils, whose resistance was computed by this formula and subsequently measured, shows that the error inherent in the method is well under ten percent. The calculations usually yield a higher resistance than actual.

Typical Example Showing This Method

Assume that a 100-volt-ampere transformer with a 110-volt primary and 350-volt secondary is to be hand wound. The available power is 60-cycle current. By substitution in eq (3), the number of turns per volt is found to be 3.4 ($n=34/\sqrt{100}$). With a primary voltage of 110 volts, the total number of primary turns is 374. Similarly, with a secondary voltage of 350 volts, the secondary turns number 1190. However, five percent is added to this number of turns to allow for drop at full load

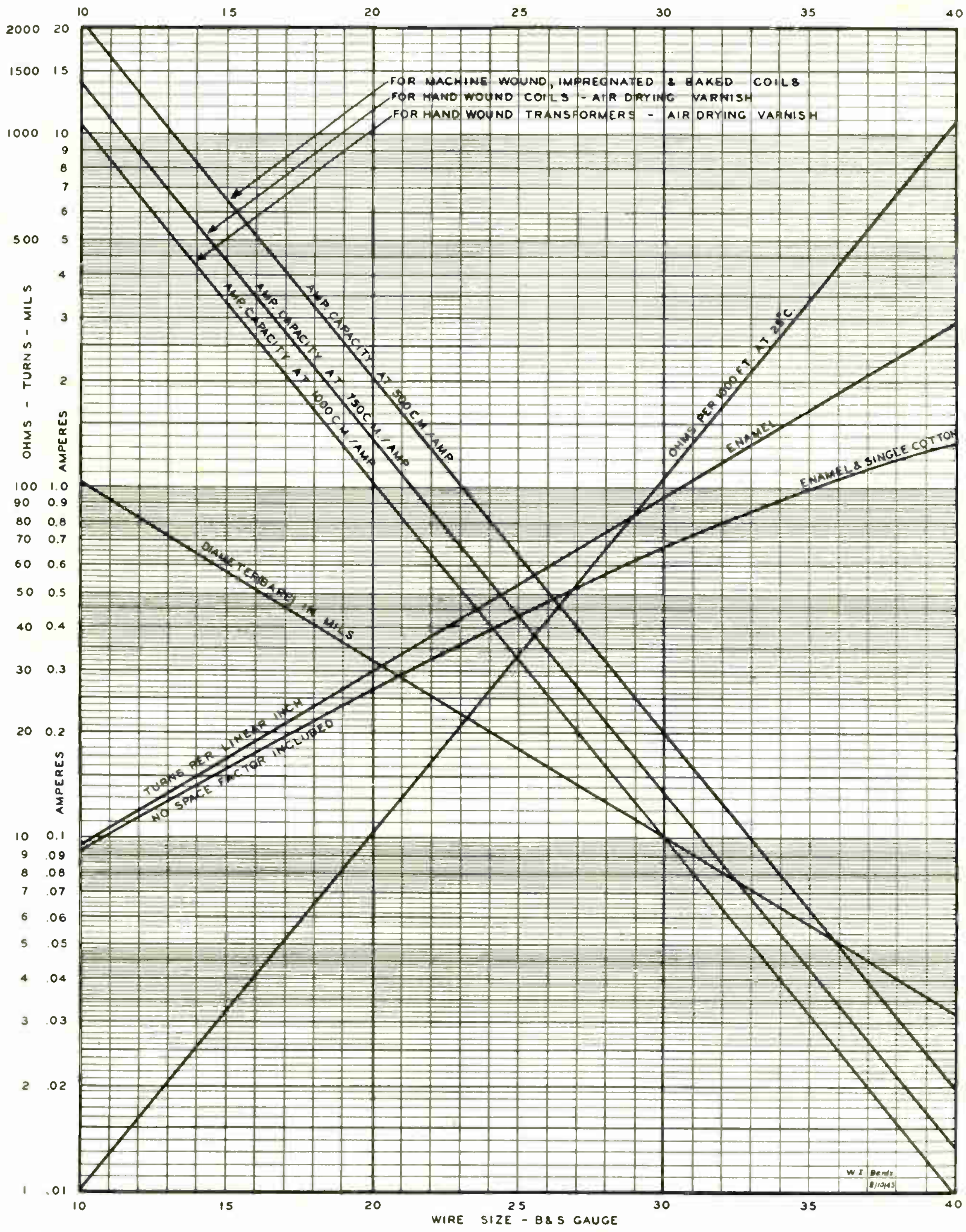


Fig. 1—*Wire size, resistance, diameter and other factors needed in computing transformer coil size are found on this chart.*

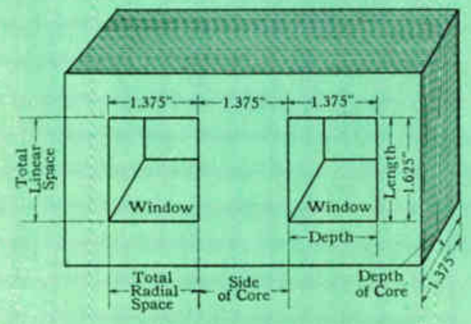


Fig. 2—*The dimensions important in designing a transformer coil are shown in this typical transformer core. Specific dimensions are developed in the problem at the end of the article.*

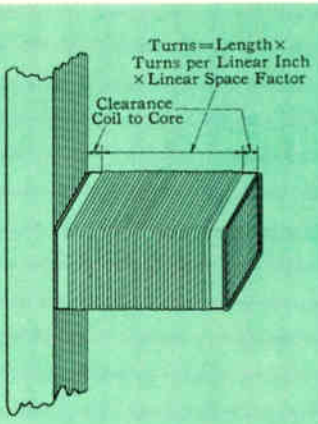


Fig. 3—*The linear space occupied by the coil is equal to the sum of the length of the layer plus the clearances between the ends of the coil and core.*

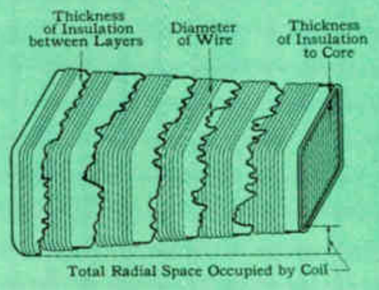


Fig. 4—*The total radial space occupied by the coil is equal to the sum of (a) the number of layers × the turns per linear inch × the radial space factor and (b) the number of layers less one × the thickness of the insulation between the layers of copper wire.*

and the actual number of secondary turns becomes 1240. By rearrangement of eq (2):

$$A=\frac{110\times10^{-3}}{2.89\,NF}\text{ or }A=\frac{346}{nF}=1.69\text{ sq in}\ldots\ldots\ldots(4)$$

A factor of 90 percent is used to derive the net core area which equals 1.86 sq in. The nearest standard size punching has a gross core width of 1.375 inches. A square core cross section is desired; therefore, a core measuring 1.375 inches by 1.375 inches is chosen, resulting in a gross area of 1.89 square inches. This approximates eq (4).

Using this size punching, the window area is 1.625 inches long by 1.375 inches deep. The coils are to be layer wound and each layer insulated with paper 0.007 inch thick.

The principal problem is to determine if the window space is adequate. To do this, the coil size must be computed starting with the size wire needed for the coils.

Since the coils are to be layer wound, enamel wire is the logical choice for both primary and secondary coils. The full-load secondary current is 100/350=0.286 ampere. Assuming an approximate efficiency of 92 percent, the full-load primary current will be 100/115×1/0.92=0.95 ampere.

Referring to the chart in Fig. 1, it will be seen that the wire size should be chosen on the basis of 1000 cir mils per ampere. The primary should be wound with No. 20 enamel, which, as shown on the chart, can be wound 30 turns per linear inch. Similarly, the secondary should be wound with No. 25 enamel at 53 turns per linear inch. A linear space factor of 95 percent is about right for hand-wound transformer coils using either of these two wire sizes.

Allowing 0.25 inch at each end of the coil leaves a net winding space of 1.125 inches for each layer, Fig. 3. The primary will be wound next to the core and ⅛ inch thick insulation used between the core and first layer of the primary, Fig. 4.

Primary Coil

The primary-coil radial space is computed as follows:

Turns per layer = 1.125×30×0.95 = 32 turns
Number layers required = 374/32 = 11.7 = 12 layers

Allow a 90-percent radial space factor for the primary coil.

Space for insulation next to core	=0.125 inch
12 layers of copper = 12/30×1/0.90	=0.445 inch
11 layers of paper at 0.007 inch	=0.077 inch
Total for primary	0.647 inch

Secondary Coil

The radial space required for the secondary coil is computed as follows:

Turns per layer = 1.125×53×0.90 = 54 turns
Number layers required = 1240/54 = 23 layers

Allow a 95-percent radial space factor for the secondary coil.

Space for insulation next to primary	=0.063 inch
23 layers of copper 23/53×1/0.95	=0.450 inch
21 layers of paper at 0.007 inch	=0.147 inch
Total for secondary	0.660 inch

The total radial space required for both coils is 0.647+0.660=1.307 inches, which is less than the window opening of 1.375 inches in the core selected.

To determine the resistance of the primary coil it is developed from the chart in Fig. 1 that No. 20 wire has a resistance of 10.3 ohms per 1000 feet at 25 degrees C.

From Fig. 5, the primary mean length of turn=

$$4\left(1.375+\frac{0.647}{2}\right)+4\pi\left(\frac{0.647}{8}\right)=7.82\text{ inches}$$

$$\text{Length of primary coil}=374\times\frac{7.82}{12}=244\text{ feet}$$

Resistance = 10.3×244/1000 = 2.52 ohms at 25 degrees C

To determine the resistance of the secondary coil it is developed from the chart that No. 25 wire has a resistance of 33.5 ohms per 1000 ft at 25 degrees C.

From Fig. 6 the secondary mean length of turn=

$$\left(1.375+0.647\right)+4\times\frac{2\pi}{4}\left(\frac{0.660}{2}+\frac{0.647}{2}\right)=12.2\text{ in.}$$

Length of secondary coil = 1240×12.2/12 = 1260 ft
Resistance = 33.5×1260/1000 = 42.2 ohms at 25 degrees C.

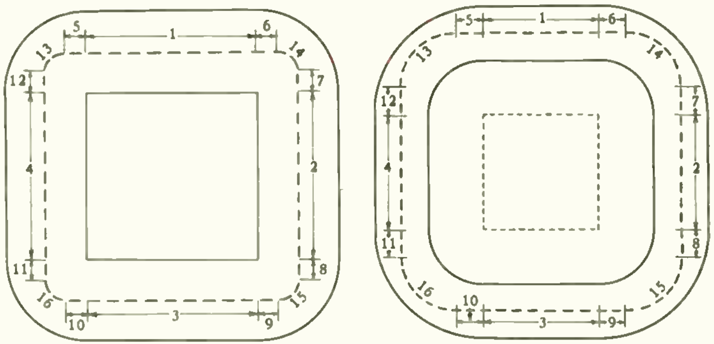


Fig. 5

Fig. 6

Figs. 5 and 6—*The mean length of a primary-coil turn and secondary-coil turn respectively are computed as follows.*

The sum of (a) 1, 2, 3, 4 which equal the four sides of the core, (b) 5 through 12 which equal 8×Radial Depth /4, and (c) 13 through 16 which equal 4π×Radial Depth /8: the sum of (a) 1, 2, 3, 4 which equal the four sides of the core, 5 through 12 which equal 8×Radial Depth of Primary/2, and (c) 13 through 16 which equal

$$4\times\frac{2\pi}{4}\left(\frac{\text{Radial Depth of Primary}}{2}+\frac{\text{Radial Depth of Secondary}}{2}\right)$$

A New Flow Gauge

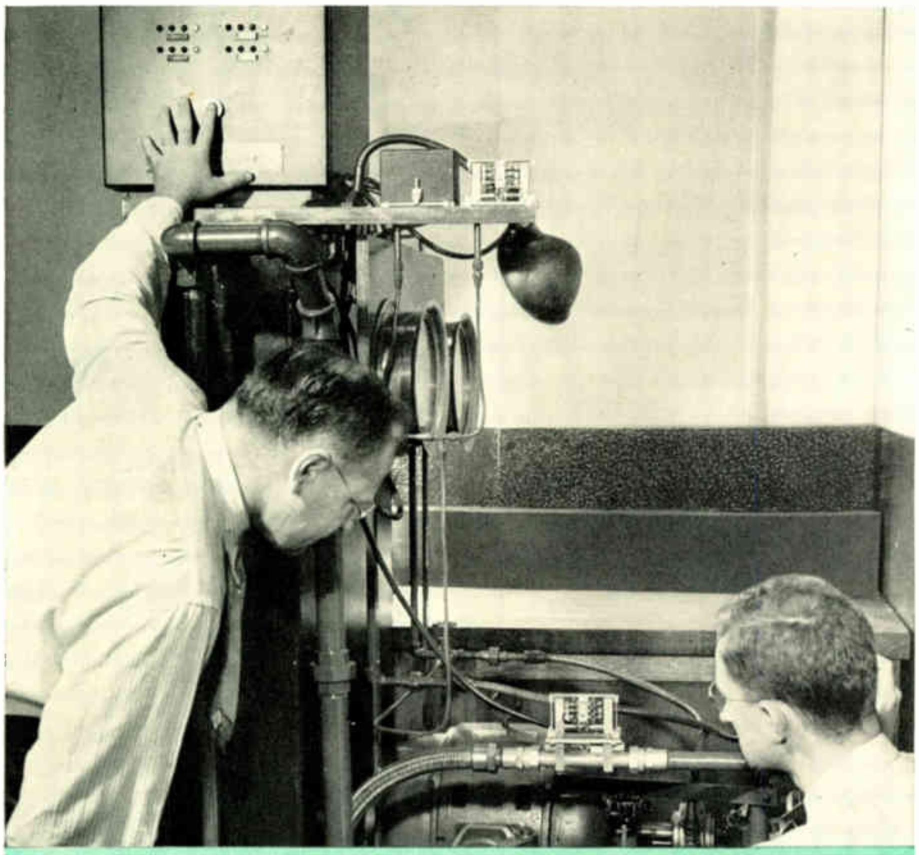
Electricity can't be seen, has no sensible weight, is definitely an intangible. Yet it can be measured accurately and with ease. Water, gasoline, molasses—any liquid—can be seen, have plenty of weight, and usually lots of force. But the flow of liquids has always been troublesome to measure.

Because some war materials manufactured today are as dangerous to make as they are in use, life itself depends upon an accurate knowledge of the flow rate of liquids, be they war materials or necessary coolants. A new flow gauge recently developed by Dr. S. J. Mikina, of the Westinghouse Research Laboratories, indicates rate of flow of liquids electrically—positively and immediately.

This flow switch has an orifice-type element within a stainless steel tube that is connected directly into the liquid-flow line. The pressure drop across the flow-measuring orifice is transmitted by two venturi tubes to a pair of metallic bellows that operate a system of electrical contacts. The metallic bellows expands and contracts within a sleeve, which enables it to withstand the bursting forces.

The flow meter can be calibrated for any desired set of conditions of flow. For example, in one case six sets of contacts, through a system of colored lights in various combinations, give indications of excessive rate of flow, normal flow, subnormal rate of flow, and dangerously low rate of flow or stoppage. The indicators operate automatically, and when proper rate of flow is restored indicators show the return to normal but certain lights remain on to show which flow gauges indicated trouble. The flow gauge is accurate within two and one half percent. It is easily installed and is surprisingly small—about the size of a two-deck box of playing cards.

The type of flow gauge described here withstands maximum pressure of 800 pounds per square inch, and is designed to operate at half that pressure. However, a similar gauge can be designed to operate at any pressure and any rate of flow such as for measuring the flow of feed water to a high-pressure (1200 pounds per square inch) boiler.



Dr. S. J. Mikina (left), aided by I. M. Holliday, tests the new flow gauge on laboratory apparatus which develops pressures as high as 800 lb per sq in. on the piping system.

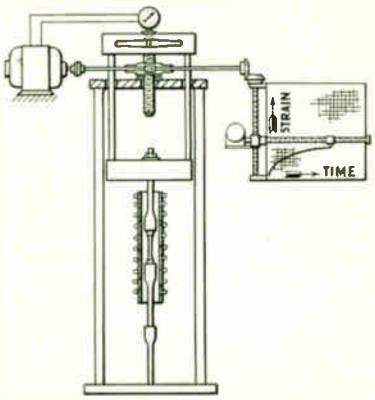
Mr. Manjoine checks the graph automatically scribed by the creep-to-rupture test machine.

Creep-to-Rupture Tests—Fast

Time and tide wait for no man. Research development, however, must perforce wait upon tests that take time, especially creep tests. Anything that can facilitate test procedures is of vital import to our time-conscious war work. Creep tests on high-temperature alloys for turbines and other uses were conducted by exerting a constant load which sometimes required 1000 hours (six weeks) to carry the test to rupture of the specimen. A creep-to-rupture test machine developed by Mr. M. J. Manjoine, research engineer, performs the complete test in from five to 100 hours.

The ordinary creep-to-rupture procedure poses a number of difficulties. Because the test piece is kept at an elevated temperature, the measurement of elongation must be made inside a furnace by an extensometer. Also, this elongation measurement at high temperatures required various parts of the extensometer and allied equipment to protrude from the furnace. The necessity of including in the furnace proper the clamps, etc., of the elongation-measuring equipment made it difficult to set up the tests and make sure of the accuracy of the readings. In addition to eliminating these undesirable features, Mr. Manjoine's machine provides a continuous record of creep with time without the necessity of manipulating a weight in loading the specimen. It scribes its own creep-to-rupture chart, measuring precisely the elongation at rupture, and automatically shuts off the machine at the point of rupture.

The salient feature of this apparatus is



A diagrammatic view of the machine.

The motor-driven screw-jack exerts a force on the bottom of the force-measuring bar. When sufficient force is exerted, contacts on an extensometer, which is mounted on the bar, open and the motor stops. The test piece, shown in the electric furnace, elongates under the stress at elevated temperature and the compressed force-measuring bar tends to spring back into shape. However, this closes the contacts in the extensometer so that the motor operates long enough to bring the pressure exerted to the required amount, thereby exerting a constant pressure on the specimen. The turning of the motor shaft drives a train of gears which give an amplified vertical motion to a scribing pen. A clockwork mechanism supplies the horizontal motion so that a creep vs. time graph is drawn.

the automatic constant loading of the specimen. Heretofore this was accomplished by the manipulation of weights and levers, as on a weighing scale, to maintain a constant force on the test piece. This is now accomplished by a motor-driven screw jack exerting force upon a force-measuring bar or stiff loading spring in series with the test piece. The motor drive is controlled by a system of electrical contacts. When the test piece elongates with the consequent slackening of load, contacts close and the motor operates to raise the screw jack and thus restore the preset loading. When the original loading is regained, the contacts open and the motor stops. The operation is continuous and the loading of the specimen is constant.

The amount of rise of the jack obviously is the plastic-flow elongation of the test piece and the extension pieces of the system. The elongation of the extension pieces and that portion of the test piece outside the gauge length is compensated by a factor and an effective gauge length determined. This factor is a function of the shape of the test piece and is substantially the same for the various types of alloys.

The minute relative movement of the upper head of the machine and the frame is amplified mechanically and drives a recorder pen vertically; a clockwork drive moves the pen horizontally. The resultant graph is a complete creep-to-rupture record of elongation versus time.

The procedure previously followed in creep testing was to determine the percent elongation at rupture by fitting the two pieces together, measuring the combined length, and comparing with the original length. This method is not precise as it is impossible to mate exactly the jagged ends of the test piece. However, the distance traveled by the screw jack can be conveniently and accurately measured because a precise elongation graph is drawn. The scribing mechanism is electrically operated, the test piece itself being part of the circuit. Obviously, when the specimen breaks, its rupture breaks the circuit and the point of rupture is precisely determined.

In addition to these obvious advantages, this machine occupies a floor space of but 15 inches by 15 inches. These dimensions are for a machine capable of exerting a force of 10 tons.

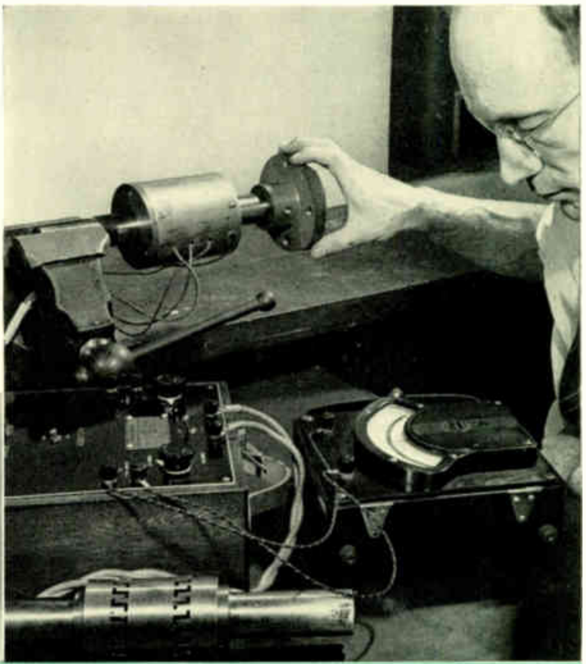
A Torque Meter with a New Twist

IMAGINE a power-plant operator trying to run his machines efficiently without any means of knowing the power output of his engines. Ridiculous on the face of it! Nevertheless, that is what the aircraft pilot is asked to do. There he sits in his cabin with one, two, or four powerful engines inaccessible to him; he is surrounded by, to the layman, a mystifying maze of instruments that surely tell the pilot everything he conceivably could want to know about any part of his ship. Yet there has been no accurate practical means of informing him on one vital point, how much power (torque) each engine is delivering to each propeller. That is the information necessary to guide him in control of the several variables affecting engine efficiency, such as engine speed, carburetor adjustment, and propeller pitch. And a few percent more efficiency may mean many more all-important miles of flight from the available gasoline.

A modification of the old and versatile magnetic strain gauge looks like it is the answer to this problem. This torque meter, mounted on the shaft between engine and propeller, measures the almost imperceptible twist in the shaft and turns out its findings as a small electric current that registers on an instrument on the panel in front of the pilot. And it does so with an accuracy of better than two percent. Yet the torque meter is insensitive to extremes of temperatures.

Fixed to the shaft are three magnetic-material rings. Between each outer ring and the center ring are a series of interlocking teeth closely spaced. Any twist in the shaft causes a slight shift in the relative positions of these teeth. As these teeth form a portion of the magnetic path of two encircling magnetic coils, any changes of distance between the teeth changes the reluctance of the magnetic circuit. The coils, being in a bridge circuit, reflect this change of reluctance in a proportionate current that is read on a convenient meter.

In the same manner that the torque meter is applied to the propeller drive shaft in the gear housing, it can be applied to the shaft of motors on test whose power output is used to drive airplane-plant generators. Thus, the torque is measured accurately without interfering with the power generation. This scheme also lends itself readily to tying in with a recording-type instrument for a continuous record of engine output on test.



The magnetic torque meter is rugged and shock resistant, yet a finger-tip twist of a steel bar is readily measured. At the left, the assembly in front is affixed to the shaft and revolves inside the coil housing in the rear. There is no connection between the two, other than a magnetic field, hence the maintenance-free operation so desired.

Electrical Steel for Transformers

—Thinner and Better

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Research Engineer, Transformer Div.
Westinghouse Electric and Mfg. Co.

Electrical steel application to high-frequency transformers in the past has been a compromise. This service demands thinner-gauge core laminations to reduce eddy-current losses. But permeability decreases and hysteresis loss increases with reduction in gauge. No longer is it necessary to compromise on the least of the three evils. Hipersil, in paper-thin ribbons for radio transformers, has low hysteresis losses, high permeability, and low eddy-current losses.

The demands of the armed services during the past two years for new and better equipment have greatly accelerated the development of improved and smaller transformers. Because improvement of transformers depends largely upon the quality of the electrical sheet steel used in the core, much emphasis has been placed on the production of better core materials. These developments have been made primarily for communication equipment, but they will have an important bearing on the postwar design and application of transformers.

For many years the transformer designer has been limited by the available grades and quality of the electrical steel. While it is true that there have been several grades of transformer iron from which to choose in designing a piece of apparatus, the limited selection imposed relatively severe restrictions in design. These core materials can be grouped roughly into the high-silicon steels, the medium-silicon steels, and the alloy steels, mostly in gauges of 14 mils or thicker, with some 7- or 5-mil steel for the higher frequency applications. Magnetic quality has been fairly well fixed over the past dozen years.

With the rapid advances in electronics, it became apparent that new transformers, especially for communications equipment, would require better materials than had been available. Also, for certain applications, transformers were desirable but could not be used because available core materials were inadequate for the desired performance. This was not because of any single characteristic but a need of improvement of all transformer-steel characteristics. A thin-gauge steel with high d-c permeability and low coercive force particularly was needed. With this definite need, the old idea of designing transformers or other components to suit the available material would not work, and a new thought had to be injected, that of designing the material for the application.

The design of core material to suit the application was actually started thirteen years ago when the specification for Hipersil electrical steel was written. The desirable properties for power-transformer applications were stated in this specification, which served as a goal to which the development of Hipersil[1] was directed during the entire period of eight years before it became a standard item of production. It was necessary to increase the permeability of the electrical steel and lower the hysteresis loss in order to achieve a balanced economical design of power transformer. The permeability was increased at operating inductions by raising the "knee" of the saturation curve with preferred grain orientation of the silicon steel used in the core.

The permeability of silicon steel can be improved and the hysteresis loss lowered by arranging the crystals in one predominate direction instead of allowing them to lie at random. The cube edge of a single crystal of silicon-iron alloy is the most easily magnetizable direction and by having a preponderance of cube edges in one direction, permeability is greatly increased and coercive force lowered. By this means, the "knee" of the saturation curve is raised considerably. This follows from the fact that the portion of the magnetization curve from the origin up to the "knee" is the easily magnetizable portion. The magnetizing force necessary to take the steel through this portion of the curve is such that its component in the most easily magnetizable direction of each individual crystal is sufficient to magnetize the crystal in that direction, as shown in Fig. 1. If these directions are already lined up in the path of the applied field, it follows that permeability will be higher and coercive force lower.

All continuously rolled silicon steel exhibits some degree of orientation as the result of rolling, showing properties somewhat better in the rolling direction than in any other direction. By straining the material in a particular way during cold rolling and following with a closely controlled cycle of heat treatment, the crystals may be oriented still further. This manner is such that the individual crystals in the crystal lattice line up with their cube edges essentially parallel to each other and parallel to the direction of rolling.

To use this oriented steel and obtain the desired properties in the transformer core, a new core construction was developed so that the flux is parallel to the grain or rolling direction at all times. This was accomplished by use of the wound construction shown in Fig. 2. The increase in permeability obtained with Hipersil over that of cores made from ordinary high-silicon steel is shown i Fig. 3.

The best thickness of the core laminations for use in a transformer depends on the transformer application. Permeability decreases with reduction in gauge whereas hysteresis loss increases. However, eddy-current losses decrease with reduction in gauge. Plotting these characteristics as functions of the desired transformer, a point can be selected where the gauge thickness will be the best possible compromise, giving

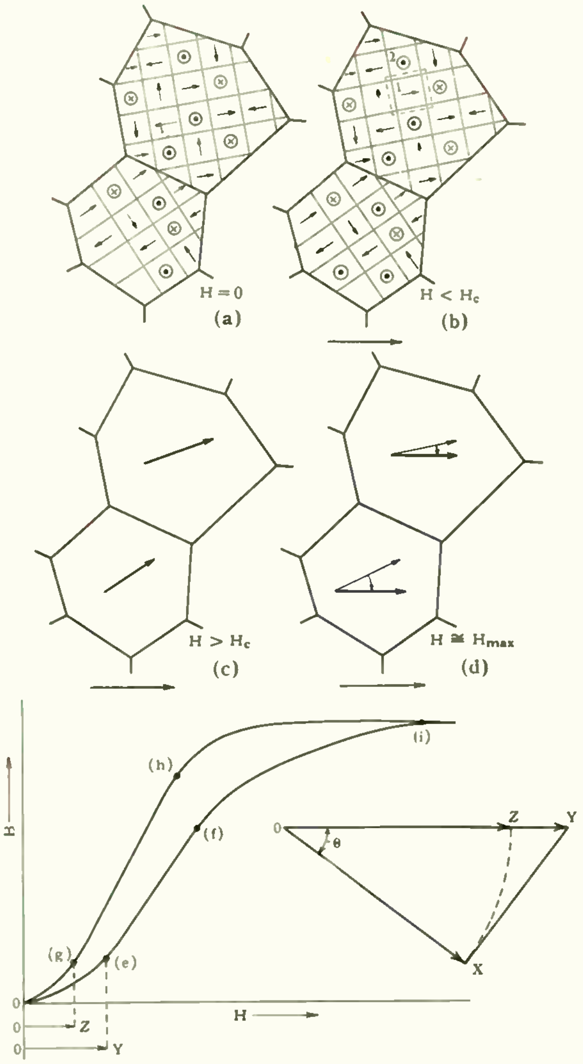

Fig. 1—*Effect of positive field on two grains of electrical steel.*

In (*a*) the grains are divided into idealized magnetic domains whose magnetism is in the direction indicated by the arrow. In (*b*) a small positive field is applied which causes a slight boundary displacement. Domains favorably oriented are enlarged as 1 in (*b*) and those unfavorably disposed are reduced, as 2. When the applied field is increased beyond a certain strength, the domain boundaries shift suddenly (Barkhousen effect) so that in effect the grain or crystal becomes one domain with magnetic saturation along the cubic axis making the smallest angle with the applied field, as in (*c*). Practically all the change in induction from (*e*) to (*f*) on the magnetization curve occurs during this domain-boundary shift process. The vectorial representation of the coercive force involved is shown below the magnetization curve. The force required to saturate the crystal along its cube edge is indicated in the vector diagram as the vector OX.

When the cube edge of the crystal (most easily magnetizable direction) deviates from the direction of the applied field by the angle as shown in the diagram, the actual coercive force is vector OY. Obviously, from the magnetization curve and the vector diagram, if the cube edges of the crystal are aligned with the approximate direction of the applied field, then the component lies along the line of the applied field and becomes vector OZ.

Thus the observed coercive force is smaller for highly oriented materials in which the applied field is nearly in the direction of a cube edge. In addition, the change in induction which occurs at the coercive force is greater in oriented steels, as is evident from the vectors in diagram (*c*). The value of raising the "knee" of the magnetization curve in transformer-core steels is indicated by the increase of the portion (*g-h*) over (*e-f*). The flattening of the curve between (*f*) and (*i*) shows the complete saturation of the crystal in the field direction, indicated in (*d*).

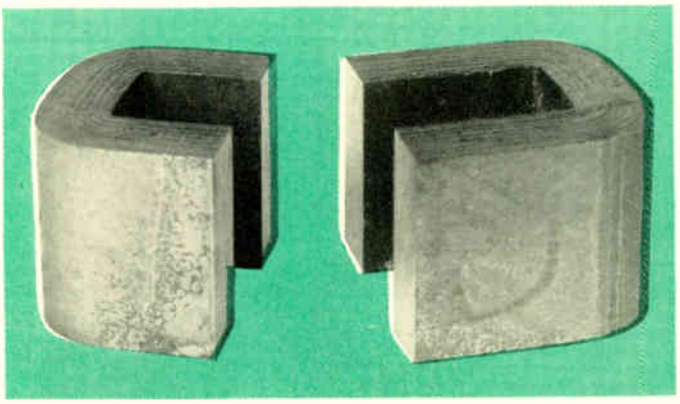

Fig. 2—*The core is made by wrapping the continuous strip around a mandrel. After impregnation and annealing it is cut in two as shown.*

the greatest degree of permeability with lowest hysteresis and eddy-current losses.

Along with the war and new aircraft developments came the need for 400- and 800-cycle transformers. Studies made of the properties of various gauges of Hipersil showed that a seven-mil oriented steel would be best suited economically for these applications.

Curves of loss versus gauge flattened out at about seven-mil thickness, and at this value a good balance between hysteresis and eddy-current losses is obtained.

This oriented core steel was first used in a 400-cycle, three-phase transformer developed for an aircraft electric power system. It was necessary to obtain minimum weight and, therefore, to operate the transformer core at high induction. With the low loss and high permeability of the Hipersil core, low total losses were obtained with a better balance of copper and iron losses, greater short-time overload capacity, lower

Fig. 3—*These curves show the relative permeabilities of silicon steel and Hipersil cores.*

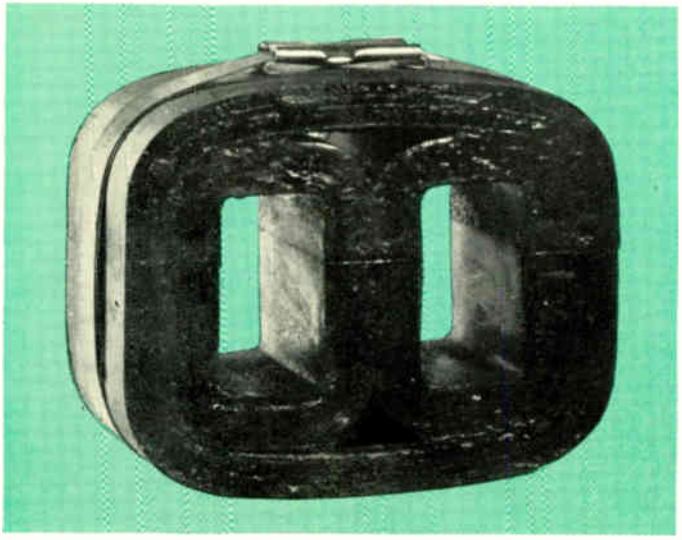

Fig. 4—*By using this 30-pound Hipersil core in a 400-cycle, 33.7-kva transformer, a 50-percent overall saving in weight was achieved.*

impedance and better voltage regulation than possible with standard core material. This transformer is rated at 33.7 kva at 400 cycles, has an efficiency of 95 percent at full load and weighs only 30 pounds. This represents a saving in weight of 50 percent over similarly rated transformers of standard materials and design. The core used in this transformer, Fig. 4, is of the wound, butt-joint construction that allows the flux to travel with the grain as much as possible. A comparison of core loss versus frequency for this new seven-mil oriented material is shown in Fig. 5.

An outstanding example of rapid development of an electrical steel to meet a specific need is Hipersil for transformers for square voltage waves. These waves are used in television and allied techniques to produce sharp definition of images or signals and have a very rapid rate of voltage rise. Square waves differ from sine waves in that the front and back sides of the waves are steep and the top flat. A square wave can be thought of as made up of an infinite number of frequencies starting with, say, audio frequencies (1000 cycles) and extending into the medium radio-frequency range of 300 to 3000 kilocycles. The limits to these frequencies determine the fidelity with which the square wave is reproduced by the transformer. Core material in square-wave transformers must have high permeability and low losses over a wide frequency range to effect good fidelity. In particular, the high-frequency performance must be better than that of materials previously available.

A preliminary study of the problems involved determined the properties required in the electrical steel, such as thinness of gauge, high d-c permeability, and low coercive force, while a further study of the economies of rolling and processing showed ultimate properties that could be attained in production quantities. Because of the great need for this type of transformer, the development had to be accomplished by definite stages, the first stage being to develop a three-mil silicon unoriented core. The next step was to reduce the gauge of the steel to two mils, which has been used to some extent, showing about a 20 percent improvement in effective permeability and reduction of iron losses under operating conditions over the three-mil steel. With existing facilities, successful samples have been made of two-mil, highly oriented steel which show properties two to three times better than the unoriented steel.

As a first large-production step in this development, new equipment is being obtained to make the material considered ideal at this time, which will be one and one half mils

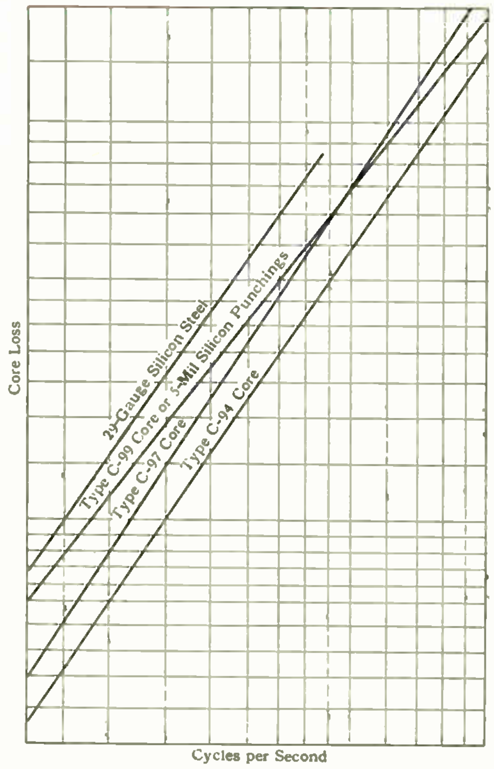

Fig. 5—*Core losses of seven-mil silicon steel (C-94), fourteen-mil Hipersil (C-97), and unoriented five-mil Hipersil (C-99).*

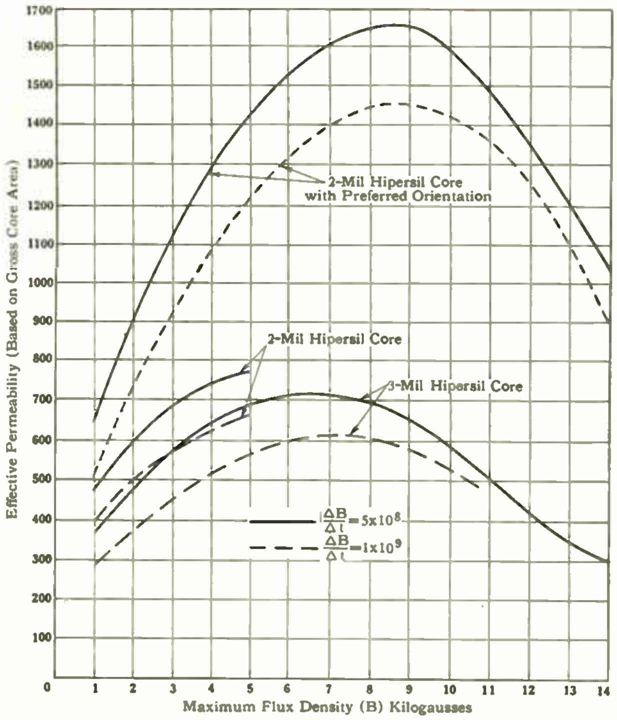

Fig. 6—*A comparison of the effective permeability of cores at different rates of change of flux with respect to time.*

thick and highly oriented silicon steel. Material of this gauge is considered ideal from the present standpoint of performance characteristics consonant with production problems and production costs. However, gauges as low as three-quarter mil have been made and used experimentally to determine characteristics of core steel of that degree of thinness.

The development of these thin-gauge Hipersils is an outstanding example of the value of engineering a magnetic material to fit the application because the transformers are performing jobs today thought impossible two years ago. The figure of merit for a transformer core material of this type is the effective permeability under high rates of change of flux with respect to time. The curves of Figs. 6 and 7 illustrate the improvement obtained under various conditions for the three stages in the development. The two-mil oriented Hipersil core is now ready for production use and will greatly aid our military communications problem.

The discussion so far has been largely confined to the magnetic material itself, but along with the development of these new materials has necessarily come the development of new techniques for using these materials to obtain additional advantages. An outstanding example is the use of wound-type cores in which the material (about one half as thick as the paper used in this magazine and as flexible as the aluminum foil formerly used in wrapping candy bars) is slit into narrow ribbons, wound on a mandrel of required window dimensions, annealed as a unit and impregnated solidly with a plastic to bind the laminations together. The core is cut to allow insertion of machine-wound coils, making use of low-reluctance butt-joint design.

This type of construction has several advantages. It is the most economical way to handle these thin-gauge materials. The space factors of the cores are very high, being about 95 percent for 14-mil, 93 percent for 7-mil, and 90 percent for 3-mil Hipersil. These space factors represent a 10- to 15-percent improvement over stacked cores, depending on the gauge. (Space factor is the ratio of the volume of core iron to the volume of coil space and is a factor in design calculations of transformer induction.) A further advantage is that the core is used in the transformer in exactly the final annealed form, which is most important in handling good magnetic materials. The less disturbance of the material after annealing the better the quality in the finished transformer. An additional advantage for the butt-joint core is that the gap can be easily varied for use in reactors or special applications where the voltage is unidirectional. Finally, it saves many important manhours in assembly time. The core construction lends itself to very easy framing and mounting, and some typical examples are shown in Fig. 8.

The rapid development of these new types of magnetic materials and of core constructions has given the high-frequency transformer designer a great deal of freedom. These same thoughts may be well applied in postwar development to standard apparatus whereby, with designing materials to suit the application, we should be able to make more and more improvements and designs of greater economy for standard apparatus.

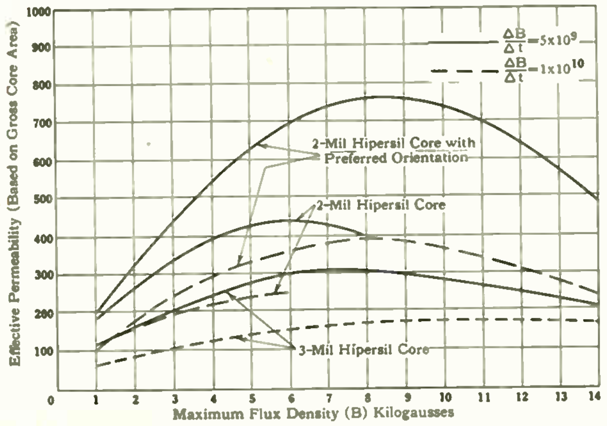

Fig. 7—*Additional curves to show the development of two-mil Hipersil with oriented grains at high rates of change of flux.*

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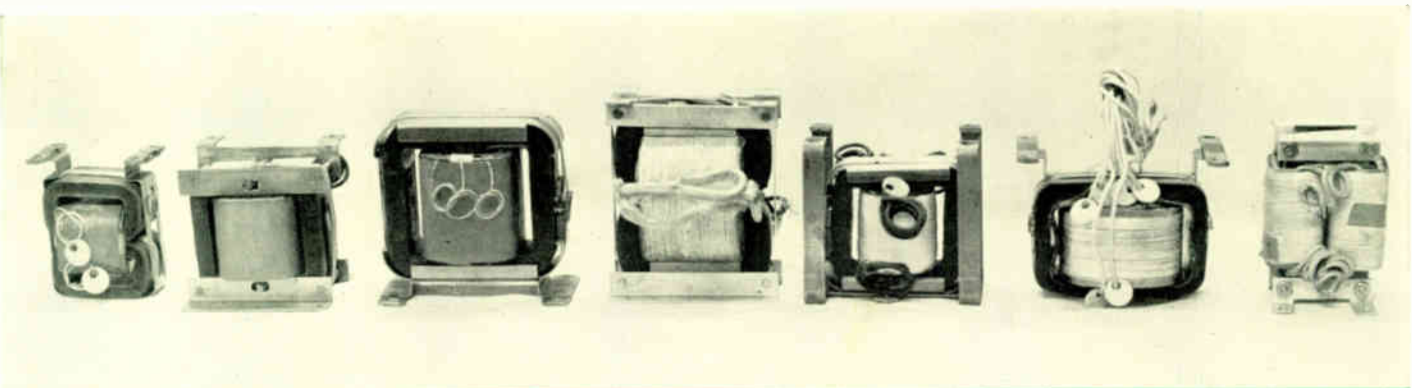
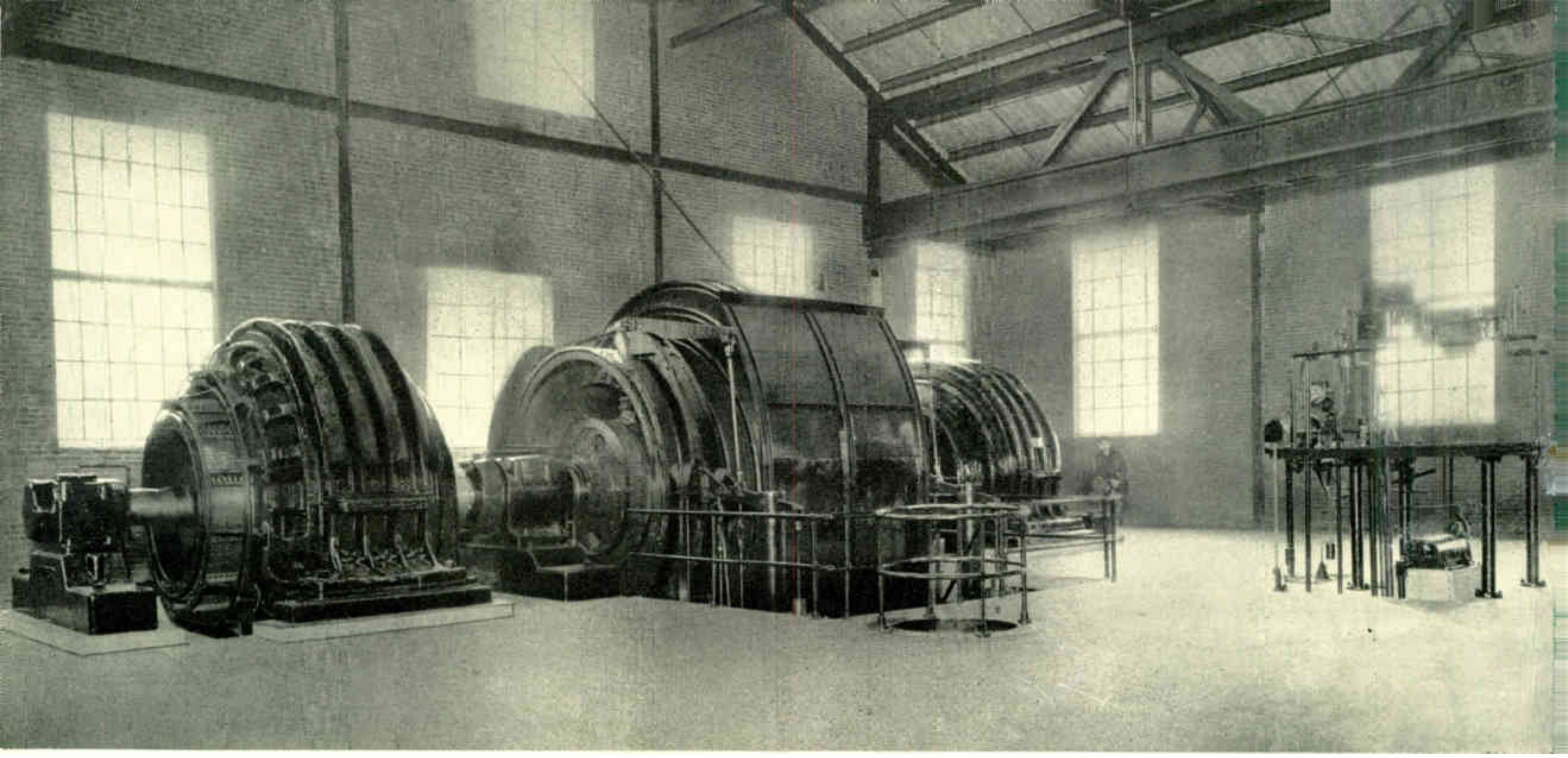


Fig. 8—*These core constructions show the adaptation of Hipersil-wound cores to various types of transformers and the mounting method.*



Rototrol Control of Mine-Hoist Drives

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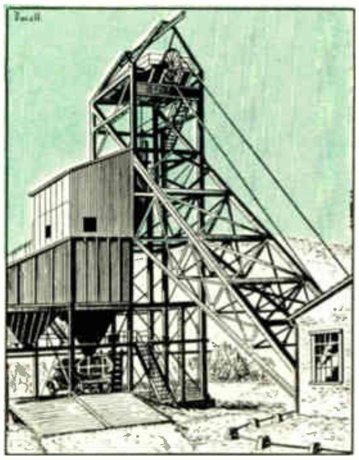
Good fielding is important in control engineering as in baseball. Two small generators called Rototrols, each equipped with several special and interrelated field windings, provide a quality of regulation for both speed and current, such as for a hoist drive, that is unequaled by the conventional battery of switches, relays, and resistors—and the overall cost is no greater.

The speed of a mine-hoist drive should correspond solely to the position of the master-switch lever and should be independent of the load on the hoist. When the hoisting speed is purely a function of master-switch position, and independent of the load, the operator does not have to "jiggle" the master switch to compensate for changes in hoist loading. This requirement is particularly important in bringing a mine cage to a landing or pulling a loaded skip into the dumping position.

The mechanical parts of the hoist have definite limits of strength, and the electrical equipment has a definite amount of commutating ability. Hence the hoist drive should limit the torque to the maximum value for which the machine was designed in addition to providing strict control of the speed. Of course, this torque limit must be sufficiently high to enable the hoist to operate under maximum load conditions.



Automatic limitation of torque reduces maintenance and shutdown charges by lengthening the life of hoist ropes, by preventing undue wear on other mechanical parts, and by reducing commutator maintenance. Torque limitation prevents the inexperienced operator from abusing the equipment and relieves the good operator from the necessity of constantly watching indicators to avoid overstressing any of the equipment.

The Rototrol and attendant equipment comprise a hoist control that provides both good speed regulation and torque limitation proper for the application.

The Rototrol, an Accurate Amplifier

The Rototrol is a small direct-current generator, similar in design and appearance to conventional exciters, but has more field windings. It can amplify small amounts of energy supplied to its fields, thereby providing ample energy for the control of even the largest electrical machine. It is a sensitive amplifier, capable of working on small inputs to its fields to produce a large output in its armature circuit. This sensitivity is obtained by providing the Rototrol, in addition to one or more separately excited fields, with a self-energizing field connected so that it feeds a small portion of the output power back into the field circuit as additional excitation to produce still more output. For each application, the design of the self-energizing field and the external resistor is such that it is impossible for the output of the machine to build up by itself, which would result in instability. The output is always under the control of the small separately excited fields. These fields are energized by small currents proportional to motor torque, motor speed, or any other control functions desired.

Automatic speed regulation and automatic torque or current limitation of a hoist motor are achieved with the Rototrol by connecting the control fields to measure the speed and torque of the hoist motor and by comparing these with a standard that is determined solely by the position of the master-switch lever. By governing the motor speed and torque in accordance with this standard, automatic speed regulation and automatic torque or current limitation are secured for all positions of the master switch.

Control of Speed

A conventional adjustable-voltage drive, which is used for many purposes other than for mine-hoist drives, is shown schematically in Fig. 1. The speed and direction of rotation of the motor is a function of the generator voltage because the motor field current is constant. The voltage of the generator is controlled by its field excitation. The direction and strength of the generator field current are governed by magnetic contactors working in conjunction with a resistor. Omitted from Fig. 1 for purposes of clarity is a system of vibrating relays to improve regulation of low speeds and another such system to limit the motor current during acceleration and, consequently, limit the torque the motor can produce. Despite the complexity of these systems of relays, the low-speed regulation and current-limiting characteristics of the relatively simple Rototrol are superior.

Only the basic units of the conventional system are shown in Fig. 1. The manner of adding a Rototrol to regulate the motor speed is shown in Fig. 2. The self-energizing field and armature of the Rototrol are connected in series. The generator-field excitation is now supplied by the Rototrol. The number of turns on the self-energizing field, and the resistance of the external circuit are such that the excitation from this field is just sufficient to sustain, but not to build up, voltage generated in the armature. This is accomplished by matching the winding of the field with the external circuit so that, by means of an adjustment on an external resistance, it operates on the linear portions of the saturation curve (known as the air-gap line). Once this resistor setting has been made—it is not a difficult operation—subsequent operation is automatic. The adjustment of the external resistances is made by permanent taps that are not subject to change and the control stays in adjustment without further attention.

The motor speed is determined in accordance with a fundamental equation, which is sufficiently accurate for large, compensated machines such as those used for hoists:

$$\text{Speed}=\text{Constant}\times(\text{Armature Voltage}-\text{Armature } IR \text{ Drop}).$$

The motor-armature voltage is measured by the voltage field (Fig. 2). The IR-drop field, which is shunted across the generator interpole winding, measures the interpole IR drop. This drop is proportional to the motor-armature IR drop because the interpole and armature are in series and carry the same current. The relative polarities of the voltage field and IR-drop field are such that their ampere turns oppose each other, i.e., are subtractive, thus satisfying the above equation. These speed-measuring ampere turns, as a whole, are so balanced against the pattern field that, considering the pattern field as a reference, the voltage field is subtractive and the IR-drop field is additive.

By balance is meant that, for a given stable condition, the

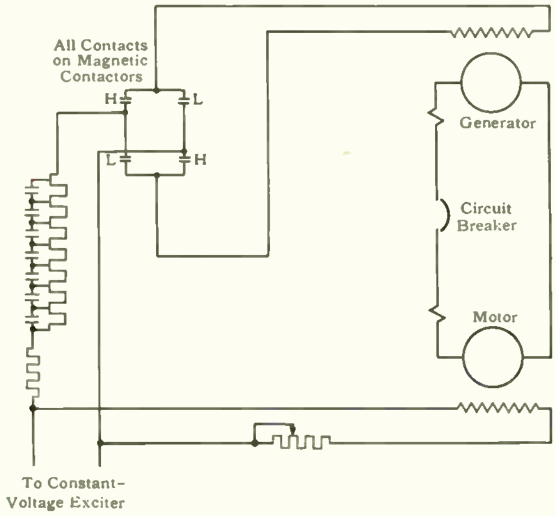


Fig. 1—*A schematic diagram of the usual variable-voltage drive. For reasons of clarity, the numerous regulating relays and the detailed wiring are not shown.*

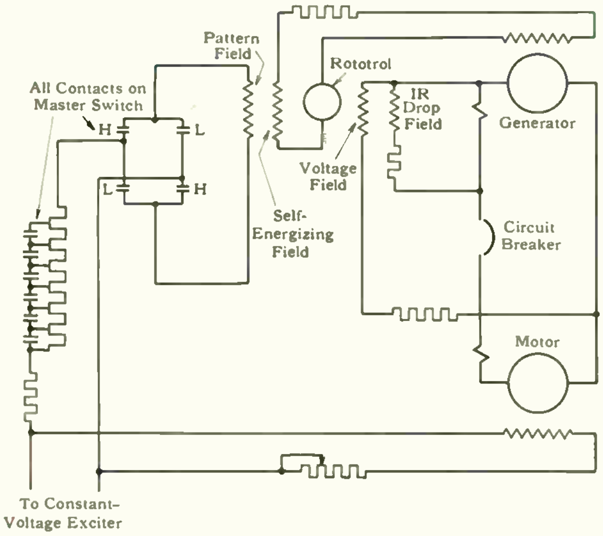


Fig. 2—*The conventional variable-voltage drive scheme shown in Fig. 1 with the Rototrol added to regulate speed.*

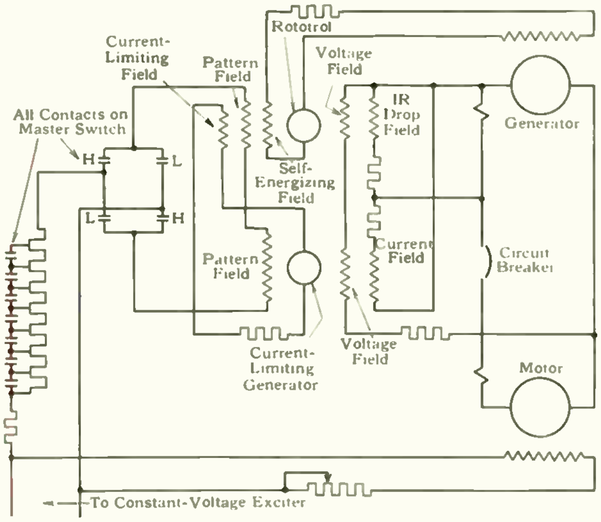


Fig. 3—*The conventional variable-voltage drive scheme with a Rototrol for speed regulation and a Rototrol which operates as a current-limiting generator for current regulation.*

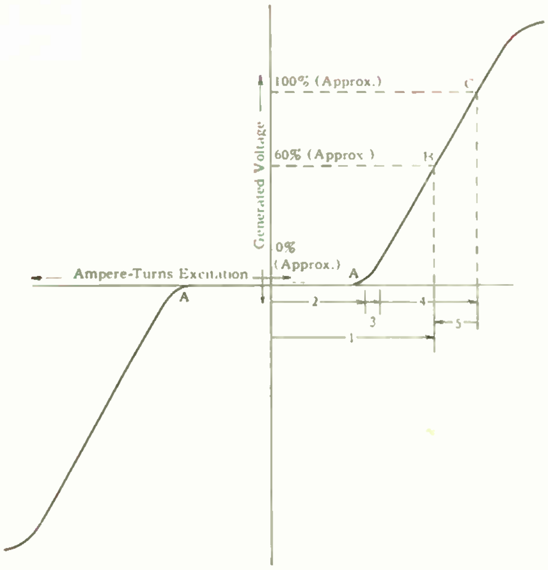


Fig. 4—*The generated voltage is the armature voltage necessary to energize the current-limiting field. The arrows show the direction of the force from the fields as follows: 1—Net ampere turns needed to generate required voltage; 2—Portion of ampere turns from current field used to saturate shunt; 3—Portion of ampere turns from current field used in cancelling excitation Rototrol receives from IR-drop field; 4—Ampere turns from pattern field; 5—Ampere turns provided by the voltage field.*

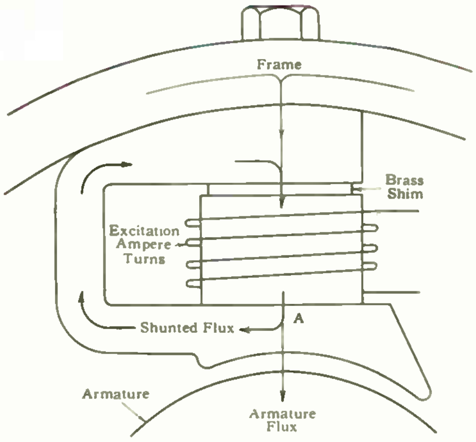
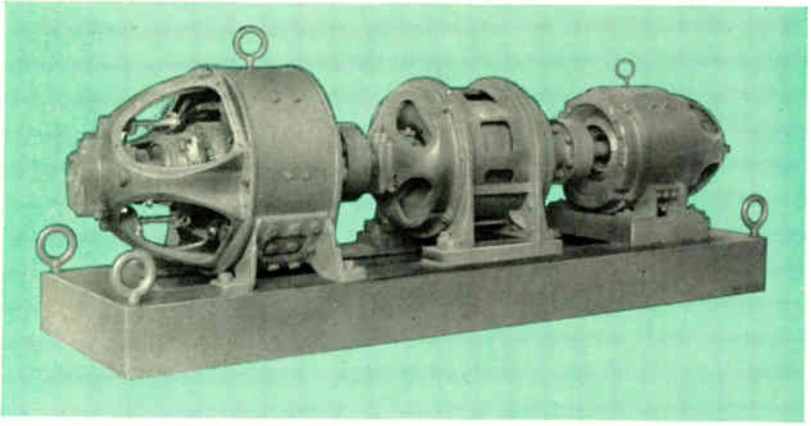


Fig. 5—*Because the shunt has no air gap and an air gap is in the path of the flux that enters the armature, substantially all flux flows through the shunt because of its low reluctance. Little flux crosses the gap into the armature to generate voltage. The air gap (brass shim) at the top of the pole carries both the armature and shunt flux, and hence does not influence the division of flux. It determines the spacing of points A-A, in Fig. 4, and the slope of the characteristic beyond point A.*

ampere turns of the pattern field are exactly opposed by the two fields that together measure the motor speed. The pattern field is solely under the control of the master switch. In other words, the amount and direction of the current through the pattern field indicates the position of the master switch and corresponds to the speed at which the operator wishes the hoist motor to run, whereas the other two fields indicate the actual speed at which the hoist motor is running.

When the motor is running at the speed corresponding to a particular master-switch setting, the speed-measuring ampere turns from the voltage and *IR*-drop fields exactly cancel the ampere turns from the pattern field. All Rototrol excitation, therefore, comes from the self-energizing field. Generator excitation remains fixed. Should the motor speed vary from that desired, the balance between the pattern and speed-measuring fields is disturbed. This lack of balance results in some ampere turns from these fields acting to correct the error in motor speed.

This Rototrol unit, occupying 11 square feet, is driven by the 10-hp induction motor in the center and controls drives rated at 2000 hp.



Control of Torque

Such a system as shown in Fig. 2 provides speed regulation, the first requirement of the ideal hoist drive. The second requirement—torque or current limitation—is fulfilled by using a second Rototrol which, for purposes of clarity, is hereafter called the current-limiting generator.

As shown in Fig. 3, the first Rototrol now has five fields—current-limiting, pattern, self-energizing, voltage and *IR*-drop—and the second Rototrol or current-limiting generator has three—pattern, voltage and current.

Each control field on the Rototrol—pattern, voltage, and *IR* drop—has its counterpart on the current-limiting generator, but the current-limiting generator has no self-energizing field. The two pattern and voltage fields are connected respectively in series. The current field of the generator and IR-drop field of the Rototrol are paralleled to facilitate independent adjustment. The armature of the current-limiting generator is connected in series with the current-limiting field on the Rototrol.

The relative strengths and polarities of the pattern, voltage, and *IR*-drop fields of the Rototrol are equivalent to those of the corresponding fields in the current-limiting generator. It may be seen from Fig. 3 that the armature voltage developed in the current-limiting generator energizes the current-limiting field of the Rototrol. The proportions of the control fields on the current-limiting generator and their relative polarities are such that when necessary they can generate the proper amount of armature voltage to cancel the effect of any of the control fields on the Rototrol.

Obviously, before such a circuit can be used as a current-limiting control, some means must be employed to limit this cancelling action to those occasions where the motor-armature current would otherwise exceed the limiting value. To accomplish this, the current-limiting generator is given special characteristics. The saturation curve of the machine, shown in Fig. 4, is similar to that of conventional machines except that it is displaced to the right and left of zero by fixed amounts.

This characteristic is obtained by equipping the field poles of the current-limiting generator with a magnetic shunt. Details of the pole construction are shown in Fig. 5. For all excitations up to the point *A*, Fig. 4, the generated voltage is substantially zero. Any greater excitation results in a voltage proportional to the excitation beyond point *A*. The magnetic shunt short circuits practically all flux away from the armature for excitations below *A*.

After point *A* is reached, conditions change. The shunt is so proportioned that it saturates at an excitation corresponding to *A*, and can carry no more flux. After the shunt is saturated, flux is forced across the air gap into the armature, causing voltage to be generated. The action, after the shunt has been saturated, is similar to a conventional machine.

The current flowing in the Rototrol pattern field also flows in the pattern field on the current-limiting generator, and causes the generated voltage to be such that the current-limiting field exactly cancels the pattern field. This same action occurs for currents flowing in the voltage and *IR*-drop fields of the two machines.

By using ampere turns from the current field of the current-limiting generator to saturate the magnetic shunt, the current-limiting generator can be made responsive to the armature current (and hence torque) of the hoist motor. In other words, the cancelling action between the Rototrol control fields and the current-limiting field, energized by the current-limiting generator, is not effective until the magnetic shunt on the current-limiting generator has been saturated. This shunt is saturated only after the hoist-motor armature current has reached a certain magnitude. The pattern and voltage fields do not saturate it in performing their normal function because they are balanced against each other and their net effect is zero. The small transient departures from zero necessary to perform their regulating function are insufficient to cause appreciable saturation in the shunt.

This circuit is completely reversible, and limits motor current in both motoring and regenerative directions. Even if the operator should suddenly move the master switch to the full-speed reverse position while the hoist is running full speed forward, the predetermined limit of hoist motor current is not appreciably exceeded.

Suppose the master switch is suddenly moved to the full *On* position while the hoist is at rest. In order to keep the motor-armature current from exceeding the limiting value, the generator must be excited to produce only enough voltage to circulate this current through the motor at the speed at which it is running at that instant. Roughly speaking, this is almost zero voltage at standstill, about 40 percent voltage at 40 percent speed and about 100 percent voltage at full speed. The master switch, however, is fully advanced and the pattern field is at its maximum strength. The Rototrol is, therefore, trying to secure a balance at 100 percent speed and voltage. In order to limit current, the current-limiting field must buck the Rototrol pattern field down to the point where it can be balanced by the voltage and *IR*-drop fields at the particular speed at which the motor is running.

In order to balance, the pattern and voltage fields of the Rototrol must be equal (for explanation purposes, the *IR*-drop field—a small fraction of the total ampere turns—is disregarded). Therefore, the bucking action of current-limiting field must be almost 100 percent of pattern-field ampere turns at standstill, about 60 percent at 40 percent speed and practically zero at 100 percent speed. Figure 4 shows relative directions and magnitudes of the fields on the current-limiting generator at the instant of 40 percent speed.

Prior to this instant, when the motor was at standstill, the only voltage across its armature was its *IR* drop. The voltage field on the current-limiting generator received almost zero excitation and, therefore, the current-limiting generator operated at point *C* giving the required 100 percent bucking effect. At the instant shown, point *B* in Fig. 4, the voltage field is energized to approximately 40 percent of its full-speed strength so the current-limiting generator generates the required 60 percent bucking action. When full speed is reached, the voltage field is as strong as the pattern field (in both Rototrol and current-limiting generator) and the current-limiting generator operates at point *A*, which gives the required zero bucking action.

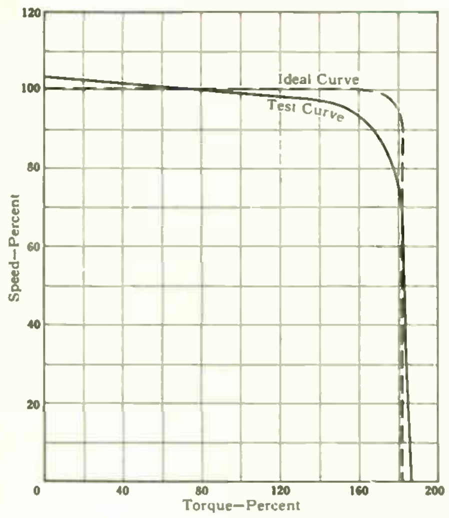
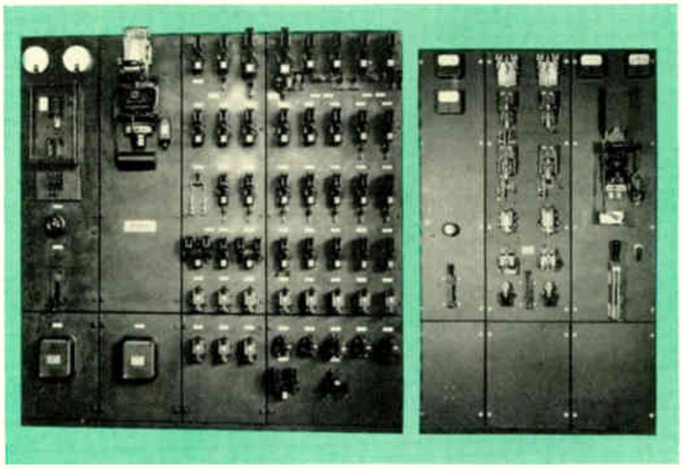


Fig. 6—*Speed-torque characteristic plotted from actual motor-test data.*

The current field performs two functions. It provides the ampere turns needed to saturate the current-limiting shunt and to cancel the excitation received by the Rototrol from the *IR*-drop field. It is called the current field instead of the *IR*-drop field because its shunt-saturating function is the greater of the two.

The speed-torque (or current) curve of a Rototrol-controlled 900-hp hoisting motor is shown in Fig. 6. A dynamic curve, taken with an oscillograph, shows that transient overshooting was limited to about 10 percent even on the severe test of suddenly swinging the master switch from full speed forward to full speed reverse.

The relative compactness of the Rototrol mine-hoist control panel (right) is compared with a conventional mine-hoist control panel (left).



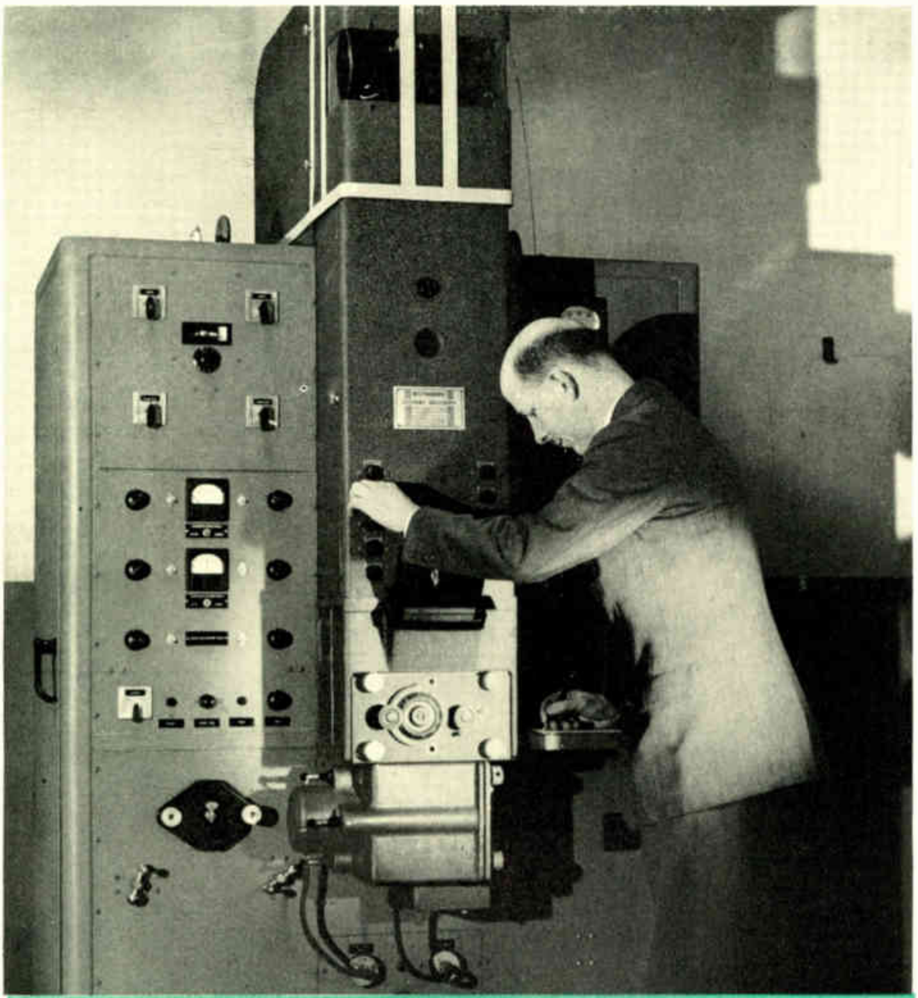
What's New!

Electronic Oscillograph—Industrial Aid

THERE are a number of devices used to show and record electrical phenomena. However, the cathode-ray oscillograph, a Westinghouse development, is the only instrument capable of making sharp, undistorted and detailed records of electrical phenomena lasting as little as a fraction of a millionth of a second. This instrument was first used in industry about fourteen years ago and has found ever-expanding use in the electrical manufacturing and power fields. Other industries, notably aircraft, also have found the cathode-ray oscillograph of inestimable value. To meet the present accelerated demands, Westinghouse has developed a new streamlined cathode-ray oscillograph.

Fundamentally, in this instrument, a concentrated beam of high-voltage cathode rays, generated in a cold-cathode tube, impinge directly upon a photographic film. The principal improvements in the new streamlined version are conservation of space, sectionalizing into functional units and a photoelectric control for exposing a film rotating on a drum. This control insures that the film always will be exposed for one revolution only although the drum speed is variable within a wide range up to 7000 rpm. This latter feature was developed to meet the requirements of aircraft-engine testing. The sharply peaked traces of engine ignition systems are difficult to read when superimposed because of long exposure.

Some of the more important studies of electrical transients that are possible through the use of the cathode-ray oscillograph are: the operation of lightning arresters and their components, the nature of steep-front impulses and their effect on insulation, circuit interruption, recovery and arc voltages and phenomena involving sparks such as airplane-engine ignition systems.



Entirely redesigned, the new streamlined electronic oscillograph is ready to meet the accelerated demand of industry for sharp undistorted records of electrical phenomena.

New Street-Lighting Globe a Smoothie

MAKERS of early street-lighting globes were not posed with many optical problems. The brightness of the light source usually was inadequate, and certainly no diffusing elements in the enclosing globe were necessary.

The incandescent lamp proved to have an objectionable brightness and methods of diffusion were sought. Coloring the globe was one answer but was quite inefficient. Configurating the glass globe proved the most efficient of the practical schemes, and this was widely used. The globes were still made of blown glass, blown into a mold that formed the diffusing configurations on the outer surface of the globes. This presented an added problem in maintenance as the irregular outer surface got dirty quicker and was more difficult to clean.

With the development of the modern Reflectolux type of luminaire and its pendant globe, which is shaped uniformly wider from bottom to top, it was recognized that these globes could be pressed in molds rather than blown. This method of manufacture produces a globe of more uniform thickness. The pressed globe is a definite improvement over the blown globe because of greater mechanical strength and more uniform light distribution. Because forming the diffusing configurations on the inside of the globe no longer is a manufacturing problem, pressed-glass Reflectolux globes with diffusion configurations are now produced with a smooth outer surface. Remaining clean longer, they present the minimum necessary maintenance time and labor.

It's News to Us

To the aviator, smoke all too often means trouble. A new device that wafts a streamer of clearly discernible smoke across a landing field often prevents trouble, as it indicates exact wind conditions where the airplane will land. . . . Automatic capacitor switching removes the limitation on industrial use of shunt capacitors imposed by overvoltage during light-load conditions. This switching is accomplished by means of relays sensitive to voltage, reactive-kva, or load-current variations. One of these relays, as the installation demands, comprises a unit that "analyzes" the conditions and promptly makes the proper corrections. . . . A pillar of light by night, created by a 16-inch searchlight, feels for the visibility ceiling to check whether airplanes can come in safely. The beam is vertical and the spot on the cloud visible. Simple triangulation determines the prevailing ceiling.

PERSONALITY PROFILES

C. C. Horstman became identified with Hipersil electrical steel at its inception and followed it from East Pittsburgh to Sharon where he sweated out its development from a metallurgist's concept to a commercial product. With the start of the war came other problems and other fields for its application to further our war-waging ability. He has followed closely the developments of Hipersil as used in radio and radar components. In 1943 he received the Silver W Award for Merit for his outstanding achievements in radio-radar development and excellent management of the Engineering Laboratory. He received his degree of B.S. in Electrical Engineering from Washington University, St. Louis, Missouri, in 1930. When press of work permits, Horstman, with his inevitable pipe, can be found engrossed in a game of bridge. He has an established rating in the national bridge association for his tournament prowess.

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The recounting of the progress of *H. A. Travers* with Westinghouse, after he received his Electrical Engineering degree at Cornell in 1906, reads like the history of the development of the Company itself. Starting the two-year apprentice course (at 16 cents per hour) in 1906, he finished in one and one half years. Entering power engineering in the Switchboard Section, he began by working up board (and we mean wooden ones) layouts and diagrams. After three months, he was made manager of the diagrams section and so remained for nearly two years. In 1911 Travers entered switchboard design work. About this time, the Switchboard Project Section, part of the General Engineering Department, merged with the Switchboard Design Section of the Power Division to become the new Switchboard Division, and Travers was identified with the New Project Section from 1912 to 1916. Since then, he has been a consulting switchgear engineer, doing special technical work and is technical advisor in switchgear matters. Until 1920, the arrangement used by the Company as a d-c calculating board was a more or less "bread-board" device. At that time, the Japanese government ordered, sight-unseen, a d-c calculating board which Travers proceeded to put together to everyone's mutual satisfaction. The need for an a-c calculating board became increasingly urgent. In 1927, building on the preliminary work of C. L. Fortescue, Travers started work on the first a-c calculating board, which was completed in 1929. Thus, Travers can be said to have sired both the commercial d-c and a-c boards. The new a-c board, latest of his efforts, is a fitting achievement to take its place alongside his work on the coordination of relay applications and other developments that led the Company to signally honor "Doc," as he is affectionately called, with the award of the Silver W and its attendant citation for meritorious achievement.

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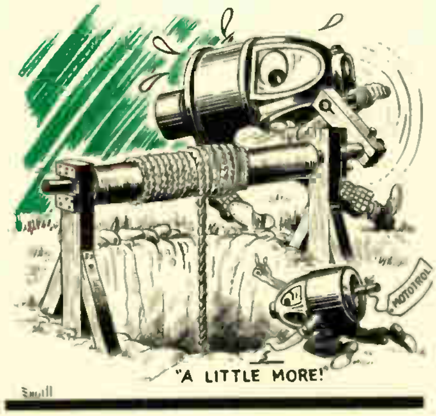

A native of the deep south, *J. G. Ivy* came to Westinghouse in 1940 after graduating from Virginia Polytechnic Institute with the degree of B. S. in Electrical Engineering. After a tour of temporary assignments during the student training course, he became an industrial engineer in the Mining Section in 1941, which position he still holds; although he expects to have a new employer soon, Uncle Sam. Coming from Memphis, Tenn., the spirit of "Ole Man River" still sings in his veins, though he must now be content to do his canoeing on the turbid Allegheny instead of the mighty Mississippi or the placid streams of Virginia.

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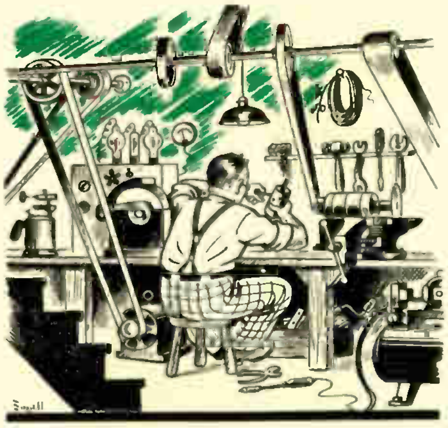
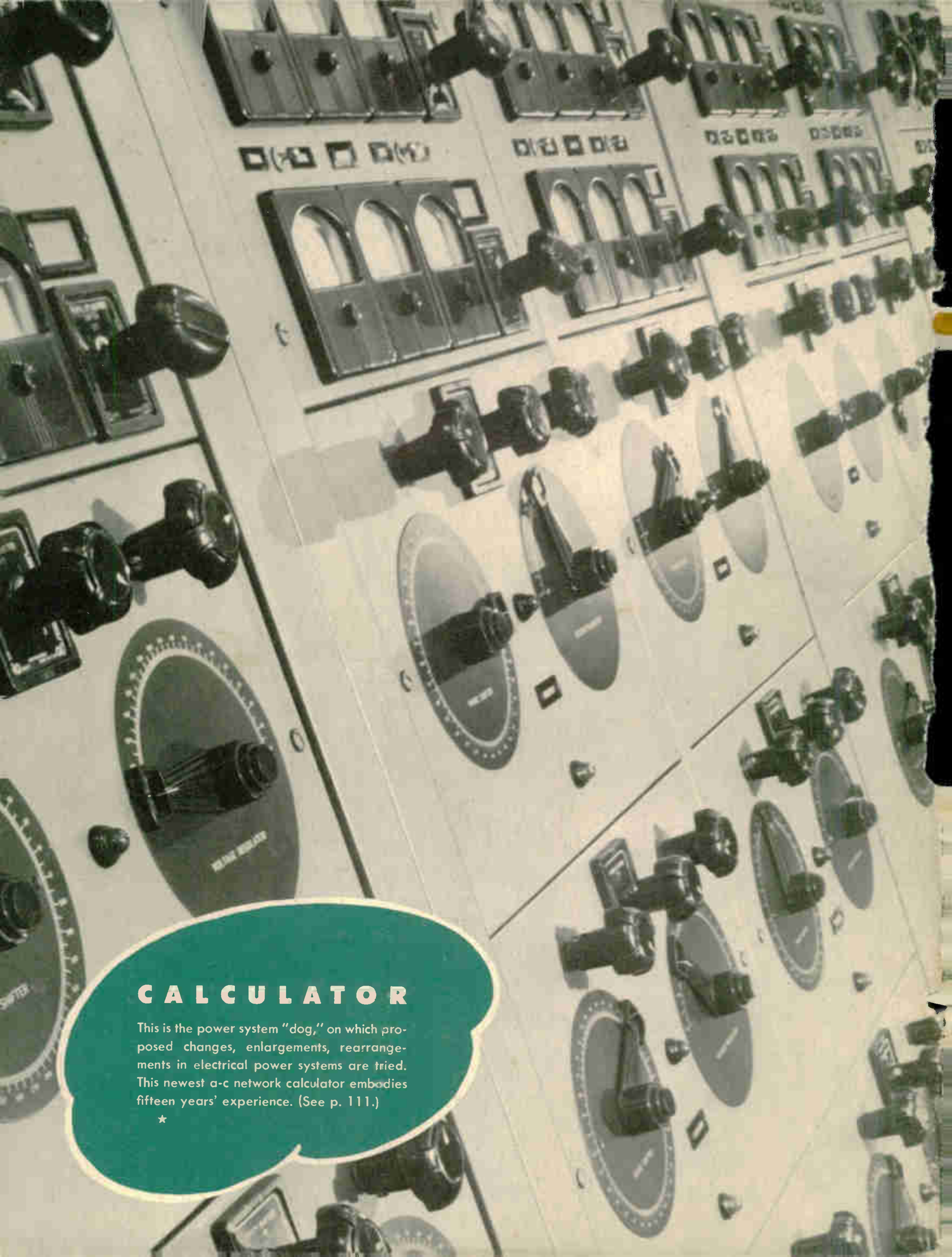
New England is dotted with textile plants, paper mills, and machine-tool factories using special control schemes, electronic circuits, and motor drives hatched in the basement of *W. I. Bendz*' home. Bendz has been in the District Engineering Department for Westinghouse in Boston since 1931. When a motor or control problem arises he is not one to fire it back to the factory for solution. He engineers it on the spot. If he is in any doubt about whether it will work, he will rig up enough stuff out of the most amazing collection of motors, switches, etc., at home to prove the principle. This practical engineering trait is doubtless a carryover from his experience as a control designer at East Pittsburgh. Bendz has been involved with the industrial uses of electronic control for 15 years, which makes him a veteran in this field. He is no stranger to high-frequency heating. In fact, while at M.I.T.(E.E. 1928) his homemade Tesla coil and associated high-voltage oscillator equipment was frequently pressed into service for quick cooking of hot dogs for himself and his classmates.





CALCULATOR

This is the power system "dog," on which proposed changes, enlargements, rearrangements in electrical power systems are tried. This newest a-c network calculator embodies fifteen years' experience. (See p. 111.)

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