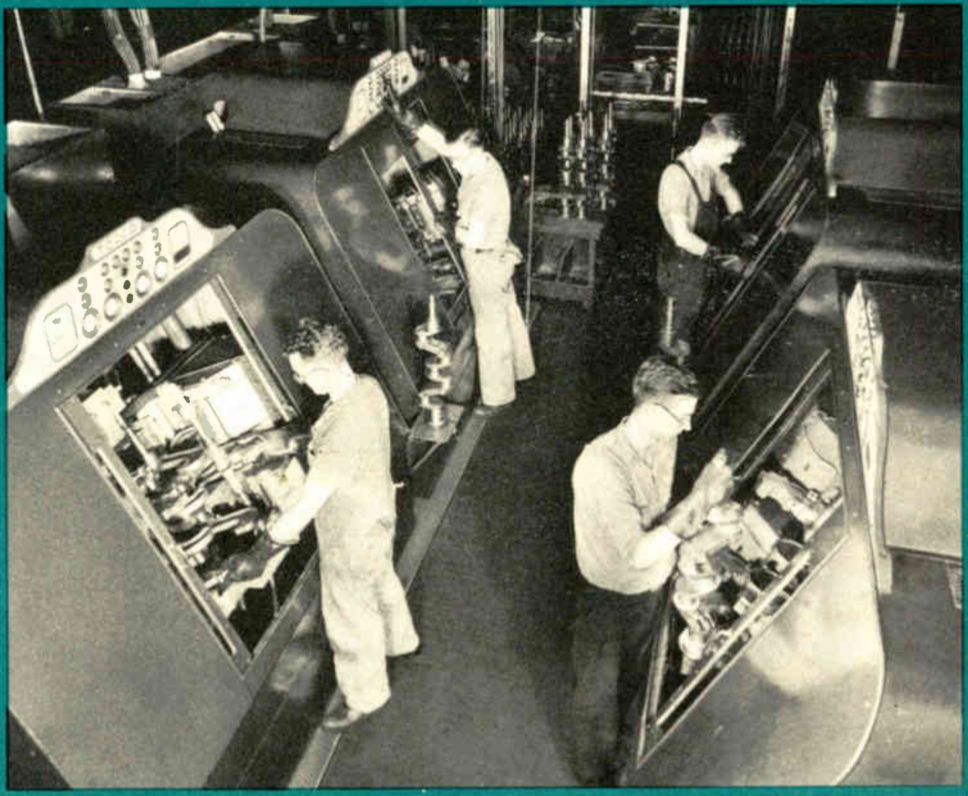
WESTINGHOUSE Engineer

August, 1941

Induction Heating Joins the Production Line – – –



Use of frequencies of several thousand cycles for surface hardening is fast growing. The process is being used for hardening crankshafts, cams, track rollers and link pins of tractors, and other steel and alloy parts where extremely hard wearing surfaces are demanded. Many of these play a major part in the defense program. The possibilities of induction heating will be discussed in the November issue.

VOLUME 1 • AUGUST, 1941 • NUMBER TWO

WESTINGHOUSE Engineer

In This Issue

COVER: *The artist presents an advance conception of the Grand Coulee powerhouse. Actual views are shown on page 47.*

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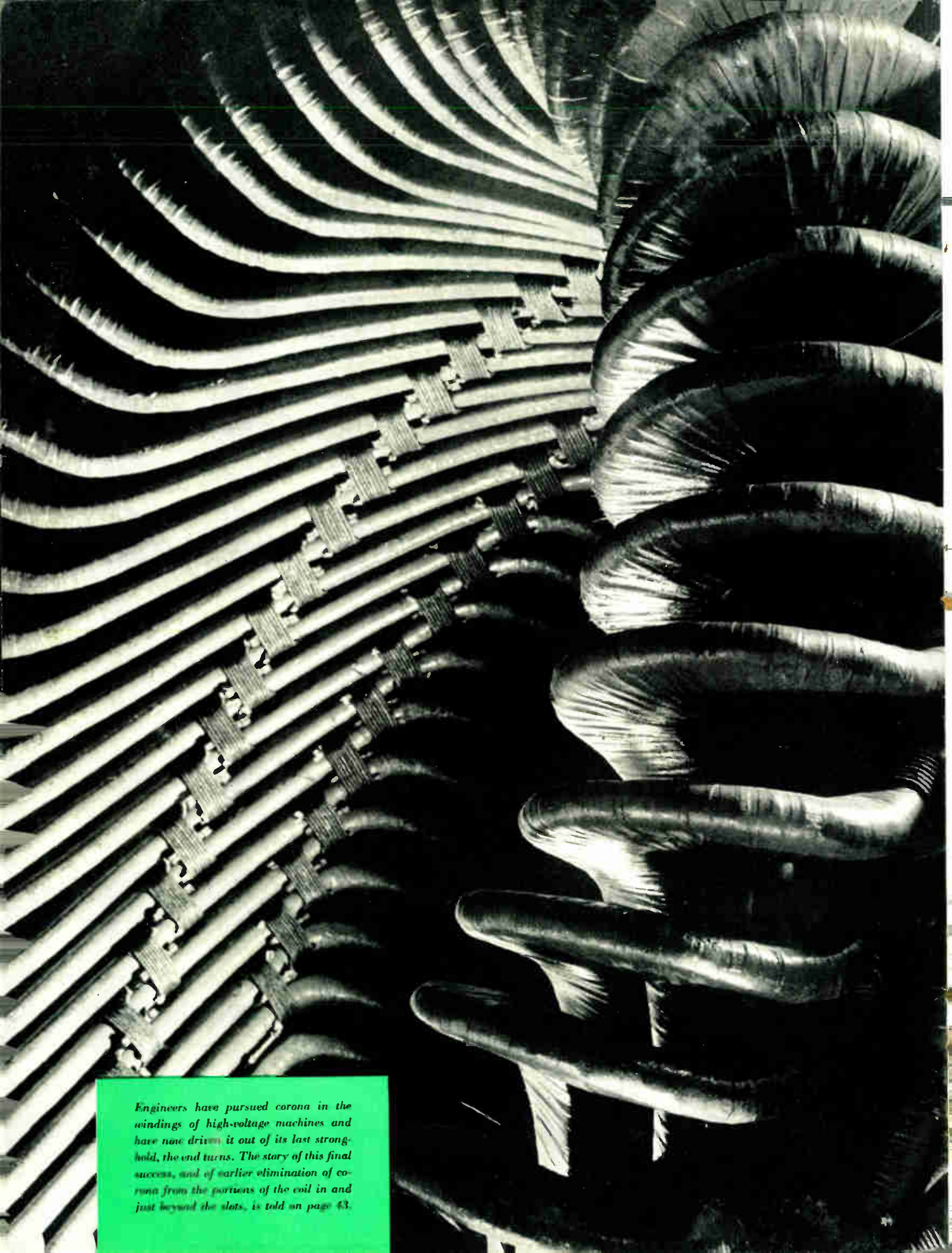


Engineers have pursued corona in the windings of high-voltage machines and have now driven it out of its last stronghold, the end turns. The story of this final success, and of earlier elimination of corona from the portions of the coil in and just beyond the slots, is told on page 43.

New Facts About Impulse Blades

Steam-turbine impulse blades have stood in the revealing light of research for a year and a half. Engineers have actually watched the movements of many individual blades subjected to wide variations of steam, load, and speed. Some 70 000 pictures have been taken of blade motion. The program of study, while not finished, has been extremely fruitful of information that is already being put to practical use in turbines. The essence of the new, unreported knowledge is given here; the background of the research program and the first lesson learned—the unavoidability of blade resonance, previously described[1] *—are reviewed on page 36.*

Prepared from facts supplied by
R. P. KROON
Manager, Development Engineering, Steam Division, Westinghouse Electric & Mfg. Co.

EVERY winter before youngsters are allowed to skate on the local ice pond, the ice is carefully examined and all air holes and weak spots are roped off or marked. This is much like the impulse-blade situation. The field of turbine impulse blades has been subjected to intensive exploration and charting so that perilous designs can be confidently avoided. Not only have questionable constructions been tagged, but methods of analysis have been brewed from the great mass of experimental data by which weaknesses of impulse blade forms can be predicted and thereby avoided.

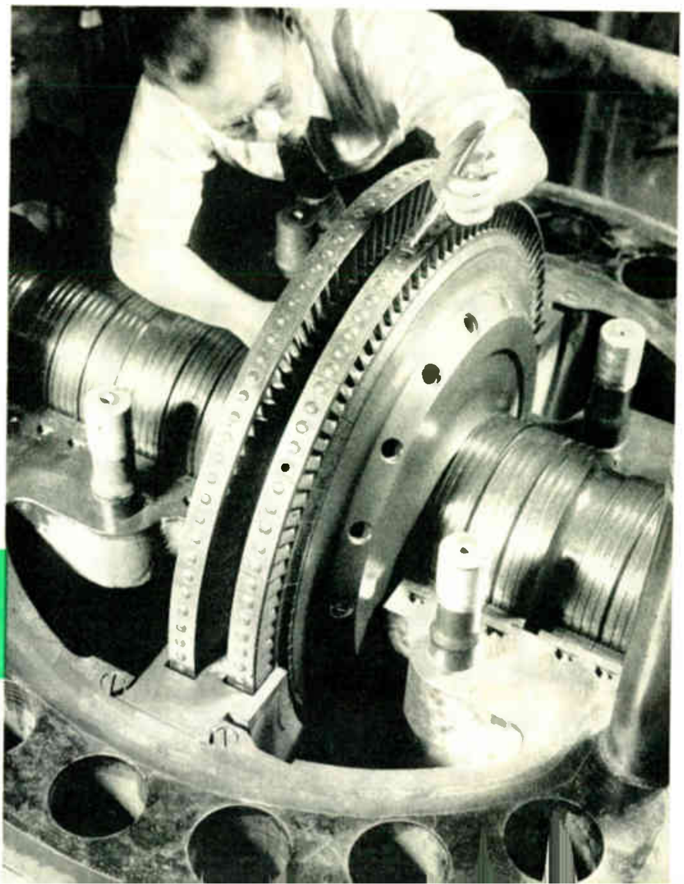
Although the experimental work is not finished, it has reached a stage where important conclusions and basic principles can be discussed. The principal work remaining consists of final checks by life tests and the trial of promising ideas.

The ability of an impulse blade to "take it" is measured by three factors: its strength, its damping, and its natural frequency. These blade attributes are, to a large extent, independent of each other. The first of these three—whether or not a blade is strong enough to do the work required of it—depends on two things, inherent blade strength and the forces imposed on the blade by the load. Inherent strength, which is measured by fatigue tests, has been a subject of extensive investigation for several years in the Westinghouse Research Laboratories. Data on load forces, the second phase of blade strength, has been obtained by the optical tests now being conducted on the two experimental machines. Each of these two sets of tests, the fatigue tests and the optical tests, provides basic information bearing on impulse-stage construction. The correlation of the data from these two sources and the acid test of correctness of resulting conclusions will come with the life tests on the three rotors at Schuylkill Station, Philadelphia Electric Co.

The optical studies were intended to supply new information on three important aspects of the problem: the forces on blades, blade damping, and blade natural frequency. The results can be separately considered.

Blade Forces

An entirely new concept of the forces on an impulse blade as it moves into and out of a steam jet was presented by the first optical records. The force diagram is not a flat-top curve with gradually rising front and a smoothly diminishing tail, as might be expected. The manner of build-up of blade forces can be traced in Figs. 3 and 4. A blade at position 1 is idle. As it sweeps into the steam zone, position 2, it is struck first on the back as steam fills the space between it and the blade ahead. Thus it experiences a negative force, in other words, one counter to the direction of rotation. This is shown by the negative dip in the force curve. This force is of rather low magnitude. It is what happens at the exit that demands attention. As a blade is just about to swing out of the jet, position 4, it is suddenly relieved of negative pressure as the space between it and the blade ahead suddenly empties of steam. The result is a sharp shock that may be much greater than the force in the center of the steam zone, position 3.



To provide full-scale test conditions the Philadelphia Electric Company extended the facilities of their Schuylkill Station. A mirror is here being fitted into an impulse blade in the Schuylkill experimental unit.

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[1] In an article "Superposed-Turbine Blade Research" by F. T. Hague, in *Mechanical Engineering*, April, 1940, p. 275.

There would be no peak exit shock if there were no exits, i.e., if steam were admitted completely around the cylinder (known as full admission) at all loads. It is preferable at partial loads, however, to close some steam nozzles entirely, leaving the others fully open, instead of throttling some or all of them. This is because throttling steam means a loss of efficiency. Knowledge of the exit shock points clearly to the desirability of as few exits per revolution as possible. Thus, at partial loads, instead of having several admission zones, steam enters through a single arc about the cylinder. As loads change the length of this arc of admission is changed.

The magnitude of the sharp-peaked shock force depends on the pressure drop across a blade row. In other words, in superposed turbines this shock is greater at light load than at full load because the back pressure on the impulse stages is less, that is, the pressure drop is greater. Oddly enough, therefore, the load on the blades is more severe with small steam flows through the turbine than with large ones.

Optical studies, in addition to indicating the presence of the exit shock and what effects it, also show how it can be reduced. By throttling the steam passing near the exit end of the steam zone, position 4 of Fig. 3, the peak is

THE EARLY STAGES OF IMPULSE-BLADE STUDY—IN REVIEW

When large superposed turbines were introduced five years ago engineers suddenly found themselves beset by unanticipated obstacles—as sometimes happens when familiar boundaries are exceeded. Impulse blades in two large turbines broke at their roots a few hours after beginning operation. Stronger, heavier blades were tried, but they, too, failed with disquieting promptness. To push ahead by brute strength alone seemed unwise; it was imperative to find out exactly what was happening in these new turbines. The research on impulse blades that had been going on for years had to be greatly extended.

First, some new tool had to be devised for the exploration. Nothing less than facts from blades operating under actual, full-scale steam conditions would do. But they were not easy to obtain. Blades are inside a thick steel casing and are revolving 60 times per second, driven by steam of pressure more than a half ton per square inch, and hot enough to make steel visible in the dark. However, a highly successful scheme was developed. This was an arrangement of light beams, lenses, and mirrors by which blades themselves write their own record on film as steam pressure or temperature, load, or speed are changed. The essentials of the scheme are shown in Fig. 1 and a representative record is given in Fig. 2.

Two such exploration tools were made. One is a small turbine used in the laboratory where steam pressures and temperatures are limited to 400 pounds and 600°F. Based on experience with this small machine the program of studies was formulated for a larger unit in the Schuylkill station of the Philadelphia Electric Company, where steam of 1250 pounds and 900°F is available. This turbine has two rows of impulse blades identical to the first two of a 50 000-kw superposed turbine. Each experimental turbine is arranged so that film records can be made of blade movement while one variable—speed, load, pressure, or temperature—is changed. Altogether, 70 000 records have been made—equivalent to over two miles of film.

The work at Schuylkill comprises a study of three separate rotors. With each, records of blade movement are made under controlled conditions. This is followed by a life test of that rotor. The first rotor has heavy-duty single blades (blades that stand alone, each with its own root), dual blades (two blades on a single root), and blade segments (a group of two or more blades with individual roots and connected together across their top by a shroud), and with several methods of connecting the shrouds of adjacent blades. This rotor includes blades identical to those that have failed. Except for life tests, experiments with this rotor have been completed.

The second rotor has lighter blades, as shown in Fig. 5, of a type frequently used in smaller machines. Work on this rotor, too, has been finished except for life tests. A view of this rotor is shown in the lower half of its casing on the preceding page.

The third rotor, not yet built, is expected to provide facts on blades designed to embody the improvements suggested by results with the first two rotors.

All the optical studies of impulse-blade performance have been on variations in construction and not to compare different materials. All experimental blades have been of 12 per cent chrome steel, which has the best damping of any known material suitable for present-day turbines.

Before the first optical records were available, suspicion was directed as a result of mathematical study to resonant vibration as causing the trouble. This had seemed implausible because it meant that blades were vibrating at an extremely high harmonic of the fundamental impulses. Ordinarily a high harmonic in engineering structures can be ignored. Theoretical considerations indicated that such resonance could well be causing blade-root failure because it would raise the blade stress to several times the non-resonant stress.

The first pictures prove unmistakably this notion of resonant vibration. Each blade is struck a sharp blow every time it enters the steam jet, which, in a 3600-rpm turbine with a single steam zone, is 60 times per second. The pictures show that some blades vibrate at about the fortieth harmonic of this impulse frequency. As a result the root stresses increase four-fold.

The solution to most problems of resonant vibration is either to change the frequency of impulses or the natural frequency of the vibrating object. Neither can be done here. The rate of impulse is fixed by turbine speed and number of steam zones. The natural frequency of practical blade structures is so high that, even though manufacturing tolerances are small, some blades will unavoidably be in resonance at every speed. Changes in speed as small as two per cent cause changes in blade-root stress of 400 per cent. The unavoidability of resonant operation of some impulse blades was one of the first lessons of the optical studies and has been previously reported in some detail.[1] Turbine engineers are faced with the stiff requirement that each blade with a steam area of only three square inches must be strong enough to deliver, while vibrating at its natural frequency, more power than an average automobile engine.

Fig. 1—*Blade movement is recorded on film by an arrangement of mirrors and light beams.*

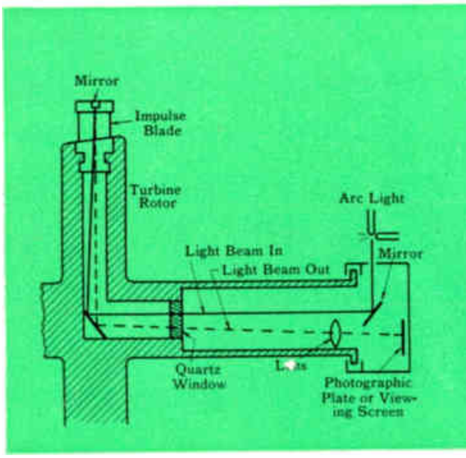
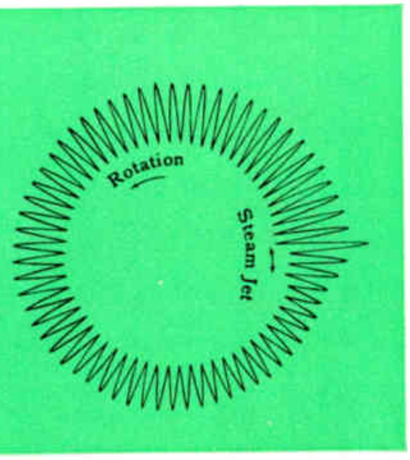
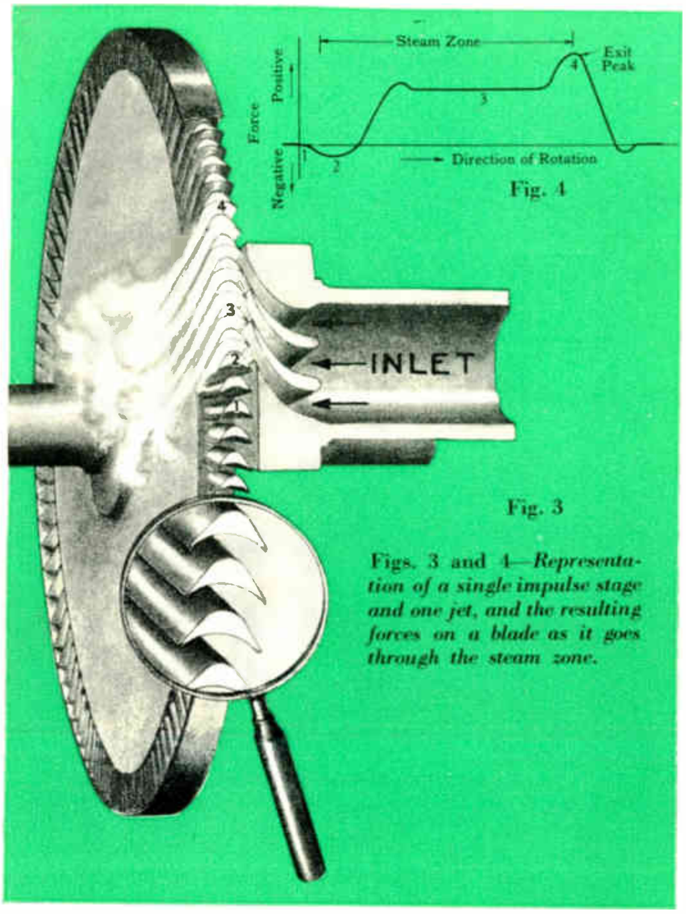


Fig. 2—*Representative record shows resonant vibration of impulse blade.*



[1] Described in reference on preceding page.



Figs. 3 and 4—*Representation of a single impulse stage and one jet, and the resulting forces on a blade as it goes through the steam zone.*

materially lowered. This can be accomplished by a simple change in nozzle construction at a sacrifice at light loads of less than one per cent in overall efficiency in the average superposed turbine. At full admission, which is to say full load, the modification entails no loss in efficiency.

In addition to unavoidable resonant vibration induced by partial admission[2], the experimental turbines have provided proof of another vibrating influence, which does impulse blading no good. Each steam nozzle or vane causes a wake in the steam flow. It had been suspected that blades as they passed through the nozzle jet would react to flow irregularities and, if blades vibrated in step with these disturbances, serious resonant vibration might result. These suspicions have been confirmed and the degree of disturbance for different conditions and constructions has been established. When pressure drops are less than certain amounts the influence of the wakes behind the nozzle vanes is not important. With larger pressure ratios the irregularities in the steam force acting on the blades increase rapidly.

The phenomenon of wake vibration is now known and contributing factors have been tabulated. It can be avoided in any machine by properly choosing the nozzle pitch.

Impulse blades can vibrate in two directions, crosswise or axial, as well as rotationwise. Both have been studied. On single blades crosswise stresses are usually much less than those in the plane of rotation, but are more complex, less easily correlated, and less susceptible to prediction by formula. They do not lend themselves as well to simple generalizations in a discussion of this sort.

A group of blades has two modes of crosswise vibration, which to a large degree is responsible for its complexity. The group may tend to rotate about the middle blade as a center; also the group may move back and forth axially as a unit. The stress induced by crosswise vibration differs widely for various blade constructions. With the data collected as to the factors influencing crosswise vibration and the relative merits of different constructions, trouble from this quarter can be avoided.

Damping

It is remarkable that such large differences in blade damping exist between various constructions. Usually no correlation exists between blade strength and its ability to damp out vibration; the strongest blade does not necessarily have highest damping.

Optical studies have shown there can be a wide discrepancy between the inherent damping ability of the material of which blades are made and that of an actual blade fastened to a turbine spindle. The damping of blades with multiple-fit roots in the Schuylkill unit was found to be far greater than for the material alone. When these blades are tied by shrouds into groups, the average damping is about double that of a single blade. Dual blades have shown large variations in damping, ranging from about that of the material alone to damping higher than for single blades.

The optical studies give assurance that by proper construction blades will have sufficient damping to meet all present demands. Blades without the complexity of artificial

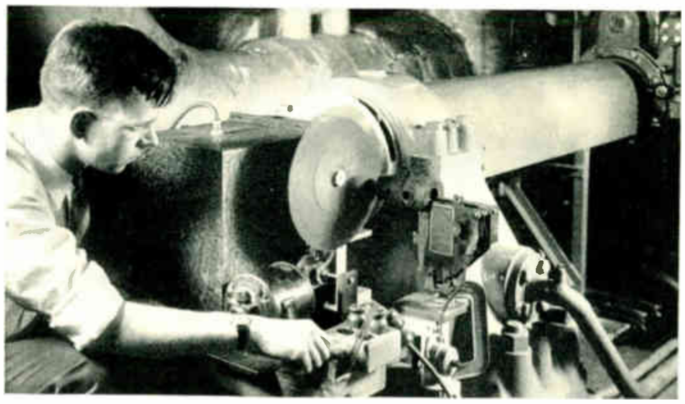


Fig. 5—*Arc-light and recording mechanism of optical system.*

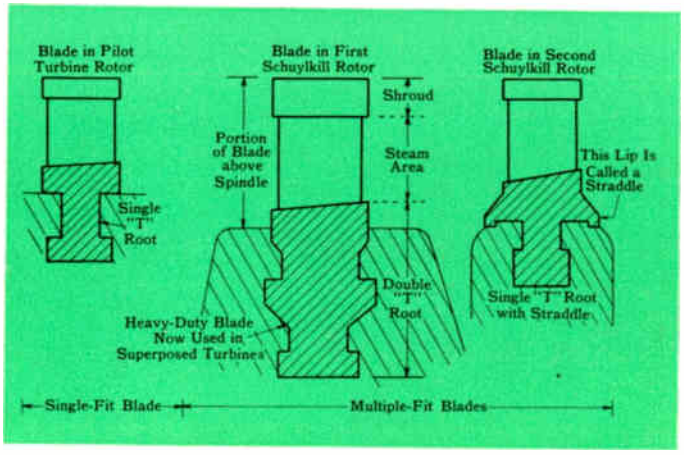


Fig. 6—*Types of impulse blades on which optical tests have been made.*

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[2] Described in reference 1, page 35.

dampers are obviously preferable. But, with a look to the future when load conditions may be even greater than at present, the possibility of artificial dampers has been thoroughly examined.

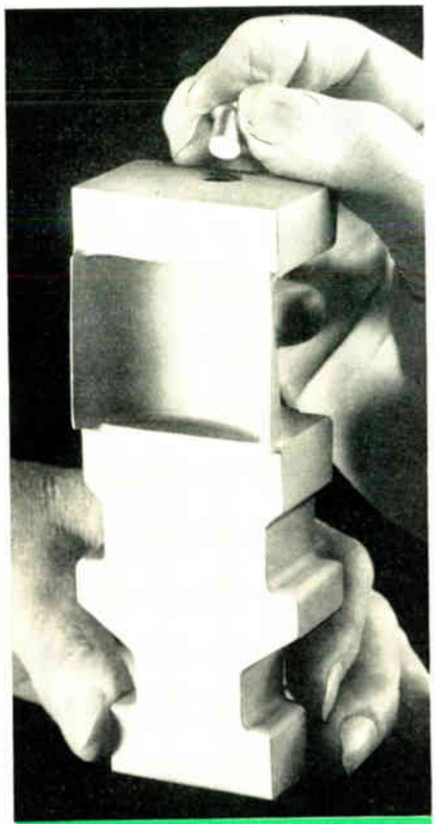

Fig. 7—*Heavy-duty impulse blade with double-***T** *root. A mirror is being inserted in the top of blade shroud.*

Of the different kinds of artificial dampers tried at least two could be successfully used when needed. The most likely one consists of a small capsule sealed into the outer end of the blade. Inside the capsule is a cylindrical metal roller and a fluid of high viscosity. As the blade tends to vibrate the cylinder rolls from side to side forcing a change in level of the liquid on each side of it. By proper selection of the capsule and cylinder diameters the combination can be tuned to give extremely high damping factor.

Natural Vibration Frequency

Blades should be so proportioned that they have high natural frequencies of vibration for two reasons. First, the larger the number of vibration cycles per second the more opportunity for blade vibration to die out between successive steam shocks and the lower is the resultant vibratory stress in the blade. Second, the higher the frequency (within the practical range) the less serious is the effect of peaks in the force diagram on the vibration of the blades.

The studies of blade vibration frequency have a two-fold purpose: to show which constructions have the highest frequencies and to show how to predict the frequencies with a reasonable degree of accuracy.

The highest frequency at which any particular blade can vibrate would be obtained if the blade could be solidly gripped at the top of the root where it enters the spindle. This is never achieved in practice. All actual constructions fall below this figure, by amounts that differ widely.

It is interesting to observe that impulse blades operate at frequencies equivalent to high-pitched sounds. The small blade with single-**T** root vibrates at 2030 cycles per second, or one-eighth less than the calculated maximum frequency. This is roughly twice the frequency of the musical note, high C. The individual blade with double-**T** root had a frequency of 1420, slightly more than half the frequency calculated, assuming upper shoulder to be clamped solidly. Dual blades have shown even larger differences between the actual and the calculated maximum frequencies of vibration.

These are average figures. There can be a wide variation in the frequency of different groups of the same type, and even of the same group at different speeds. The widest variation was found in crosswise direction, where a variation range of 34 per cent was measured for the same segment.

It appears that whenever the blade root has several areas of contact with the spindle, different specimens of the same type of blade group manifest large variations in frequency. When there are several pairs of shoulders and perhaps straddles, how much load is carried by one shoulder and how much by another? The degree of fixity at the root is uncertain, and in applying multiple fit designs, one must allow for wide variations in frequency.

The Future

The joint impulse-stage research program by the Westinghouse Company and the Philadelphia Electric Company is of great significance. In general it connotes a new manufacturer-utility cooperative approach to the fundamental major problems of the power industry. Specifically the premises for an ideal steam-turbine impulse-blade design are gradually being revealed from this research. These ideal constructions will be put to the acid test of actual operation in a third rotor for this Schuylkill turbine.

THE GIST OF IMPULSE-BLADE FINDINGS

Remembering that all the returns are not yet in, the highlights of sixteen months of looking into the two experimental turbines can be set forth as follows:

1—The optical tests provide factual evidence of the undesirability of single blades, standing alone.

2—At reduced loads it is desirable to have one steam jet per revolution instead of several spaced jets. Blade shock is thereby limited to once each revolution.

3—Blades receive a sharp, extra wallop as they leave the steam jet. This additional peak of force is serious at large pressure drops. This peak can be reduced with negligible sacrifice in efficiency by throttling the steam near the end of the zone.

4—Resonant vibration of impulse blades cannot be avoided in partial-admission operation. Some of the blades are in continuous resonance with the once-per-revolution impulse by the steam jet.

5—Wakes in steam-flow beyond the blades react on the blades to cause vibration. Resonance of blades with these impulses can be avoided by proper arrangement of blades.

6—Both crosswise and rotationwise vibrations are present. Crosswise vibrations are sometimes smaller and less important but are more complex and difficult to predict. Although crosswise stresses are not yet fully explored, the variations between different constructions and their order of magnitude are known.

7—For each set of steam and load conditions there is a preferred number of blades in a group. This can now be predicted mathematically for a given condition.

8—Damping varies widely with different root shapes. Multiple-fit types of blades show most damping.

9—Sufficient damping can be obtained without artificial dampers for all present turbine requirements but successful dampers are available and can be applied when and if required.

10—High natural frequencies of blades are desirable. All blades when fixed to the spindle have an actual natural frequency somewhat less than the calculable frequency. The reductions differ widely for various root forms.

Bargains in Heat—Buy One Btu, Get Two Free

By reversed-cycle refrigeration a room or building is either heated or cooled by a single machine. This somewhat mysterious procedure is an accomplished fact for both office buildings and homes. With the recent introduction of a window-type air conditioner a room can be heated or cooled by turning a single control. When heating, it delivers 7700 Btu, although only 2800 are purchased from the electric company. This smacks of buried treasure, of something for nothing, but as shown here the law of conservation of energy has not been repealed.

REGIS D. HEITCHUE
Air Conditioning Engineer,
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& Mfg. Co.

You need look no farther than your own kitchen to see the workings of reversed-cycle refrigeration. The electric refrigerator has all the elements of this fascinating heating scheme. Suppose the ice trays are filled with "cold" tap water. Soon this water becomes ice. In the process the kitchen is heated by an amount equal to the electric energy used by the motor plus the amount of heat taken from the tap water in the trays.

Every refrigerator, air conditioner, or reversed-cycle heating system works exactly this same way; in fact the name "reversed-cycle" refrigeration is a misnomer. As shown in Fig. 2 heat is extracted from air or water, is combined with the heat developed by the motor and compressor and added to some other air or water. If the cooled air or water is sent to the living or working areas, it is the conventional air-conditioning system. If, instead, the heated water or air is circulated, it is a "reversed-cycle refrigeration" plant. This heat comes from two sources, the electric energy converted to heat by the motor and compressor, paid for as kilowatt hours, and that of the substance cooled. It is because this second quantity of heat can be taken from the free air or from low-cost water that the system has the appearance of giving more than is paid for. We are simply extracting heat from an additional source, which, although of lower temperature than the room being heated, still contains a large quantity of heat that can be made available.

Successful Heating by Refrigeration

In Large Buildings—An outstanding example of the use of refrigerating machinery for winter heating is the air-conditioning plant in the new Administration Building of the United Illuminating Company, New Haven, Conn. This building is situated over a large underground body of water, the temperature of which is practically constant at 55°F throughout the year. This water is pumped through water coolers that reduce its temperature to about 45°F. The heat removed from the water in the evaporators is given up at the condensers to a closed hot-water heating system. The overall coefficient of performance of this plant is approximately four, meaning that for each unit of heat supplied by the electrical system a total of four heat units is made available to the building. A portion of the water-chilling and condensing equipment of this heating and cooling plant is seen in Fig. 1.

When cooling is desired, the warm water from the condensers is discharged to the sewer and the cool water from the evaporators is circulated through air-conditioning units throughout the building in the usual way.

Somewhat smaller is the air-conditioning installation at the Westinghouse building in Emeryville, California. Here, the apparatus automatically either heats or cools, depending upon the outdoor temperature. The equipment consists of two 7½-ton compressors, standard evaporators, and air-cooled condensers. Outdoor air supplies the heat. Of particular interest is the ingenious method of handling the air in this installation, shown in Fig. 3. By this system a heat gain of five is obtained with outdoor air at 35°F and with heating air at 95°F.

In the Home—The application of reversed-cycle refrigeration in the home presents a different picture. Although we are willing to spend whatever is required to heat the entire living quarters in the winter, we generally are content with cooling one room, such as the living room or bedroom, in the summer. Consequently, the entire cost of the reversed-refrigeration heating plant would be charged against winter operation. This would probably make the cost of operation higher than with any present heating methods.

There are, however, many days in the spring and fall and in some locations even in the summer, when a little heat is

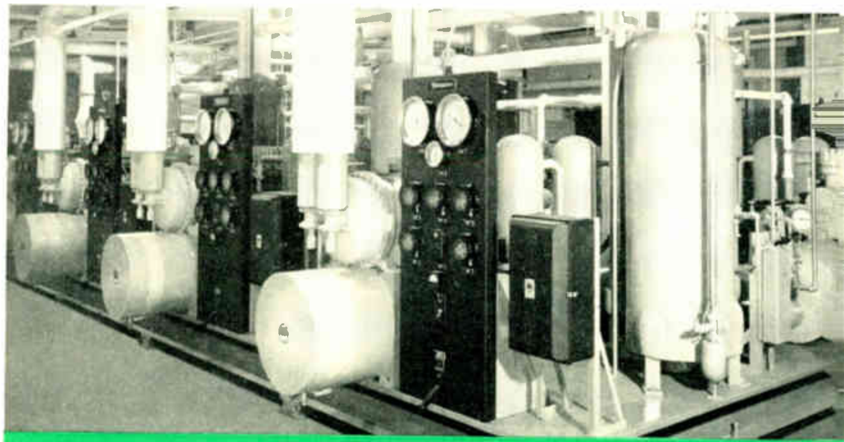


Fig. 1—These eight 40-ton water-chilling units and a bank of eight 40-ton condensing units constitute the heating plant for the offices of the United Illuminating Co., New Haven, Conn. In the summer these machines keep the office cool. The "heat" source in winter is water of 55° F from wells.

welcome. The short time this heat is needed does not justify starting the furnace, especially if we are satisfied to remove the chill from only, say, the living room. This is particularly true in apartments and hotels where once the large heating plant is shut down in the spring it is not started again until the fall, and vice versa in late summer months.

> *"A substance may be heated above the atmospheric temperature by means of a properly contrived machine; the corresponding machine, or the same machine worked backwards, may be employed to produce cooling effects."*
>
> These prophetic words were written by Lord Kelvin in 1852. They appeared in his article "The Economy of the Heating or Cooling of Buildings by Means of Currents of Air" printed in the *Proceedings of the Philosophical Society of Glasgow*, v.3, p.269.

A small self-contained heating and cooling unit, sufficient to heat and cool a single room, has been made available. It can be installed in any standard window, requires no water or drain connection, and plugs into an appliance outlet. Heating or cooling is selected simply by operating a special four-way valve.

This new type of room air conditioner is mounted in the window, as shown in Fig. 4, so that the condenser coil (air-cooled) is outdoors and the evaporator coil is indoors. Instead of using an expansion valve, the pressure differential between the condenser and the evaporator is obtained by a capillary tube. It is nothing more than a long metal tube with a tiny hole for the liquid to pass through, furnishing the same effect as an expansion valve. The capillary tube is, to a large extent, responsible for the success of the unit, because it works equally well with refrigerant flowing in either direction. When the valve is turned to the cooling position, the hot discharge gas flows into the condenser, liquefies, and passes through the capillary tube to the evaporator, where it cools the room air. With the valve turned to the heating position, the hot gas from the compressor goes to the coil inside the room and heats it. The liquid flows in the reverse direction through the capillary tube to the outdoor coil, which now acts as the evaporator. The refrigerant, being cooler, absorbs heat from the outdoor air circulated over it. The flow diagram of the refrigerating circuit is shown in Fig. 5.

The heating capacity of this unit is 7700 Btu/hr if the temperature is 60°F outdoors and 75°F indoors. Under these conditions the compressor motor draws 820 watts and the coefficient of performance or heat gain is 2.75. When used to cool it can remove 6000 Btu/hr with outdoor temperature of 95°F and indoor temperature of 80°F and 50 per cent relative indoor humidity.

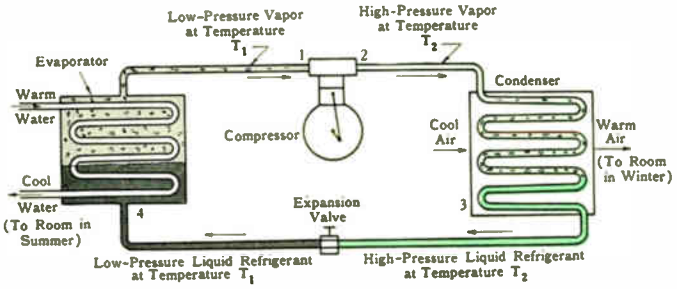


Fig. 2—*The main equipment for any refrigeration system whether it serve for heating or cooling. The refrigerant vapor rises in temperature as it is compressed (1-2), and passes to the condenser (3) where heat is taken from it until it liquefies. Passing through the expansion valve to a region of low pressure in the evaporator (4), it expands, picking up heat. The vapor now arrives at the compressor ready to start the cycle again.*

Gains of Eight to One —In Theory

Essential to the consideration of heating by reversed refrigeration cycle is the coefficient of performance, which really is an expression of the efficiency of the process. It is commonly abbreviated COP and, as in any system, is the ratio of output to input. For reversed refrigeration the output is the heat given up at the condenser, or the heat extracted from the heat source, plus the heat equivalent of the electric power used to drive the motor and compressor. Therefore,

$$COP=\frac{\textit{Heat from heat source}+\textit{heat from electricity}}{\textit{Heat from electricity}} \quad \cdots (1)$$

It is particularly helpful to express the coefficient of performance in terms of temperatures in the refrigeration cycle, because in this form it shows the practical limits of reversed-cycle refrigeration. Written in this form it is

$$COP=\frac{\textit{Compression temperature}}{\textit{Compression temperature—expansion temperature}} \quad \cdots (2)$$

With this relationship the heat gains for different conditions can be determined. Assume for a specific case that the condenser is operating at 115°F. In other words, the room-heating medium picks up heat at 115°F, which is 460°+115° or 575° absolute. Assume a heat source giving an evaporating temperature of 40°F or 500° absolute,

$$COP=\frac{575}{575-500}=\frac{575}{75}=7.66$$

This means that for each unit of heat put into the plant 7.66 units of heat would be delivered.

This coefficient of performance, however, is for an ideal machine, never attainable in practice. Actual machines, for example, have pressure losses resulting from friction of the refrigerant flowing through piping, valves, etc.; ideal machines do not. Let us then determine the coefficient of performance for an actual machine operating at the same temperatures. Suppose the machine is a standard 100-ton water-cooled condensing unit. Test data shows that 1 065 000 Btu/hr are absorbed by the refrigerant in the evaporator and that the compressor motor requires an input of 93.5 kw. The heat equivalent of the motor watts is 319 000 Btu/hr. The motor and pump losses are negligible. All of the heat absorbed in the evaporator and the heat equivalent of the motor power, if given up at the condenser, is 1 065 000+319 000=1 384 000 Btu/hr. The $COP=\frac{1\,384\,000}{319\,000}=4.34$. This system, therefore, provides 4.34 times as much heat as would be obtained if the electrical energy were converted directly to heat by resistance. Stated in another way, in a

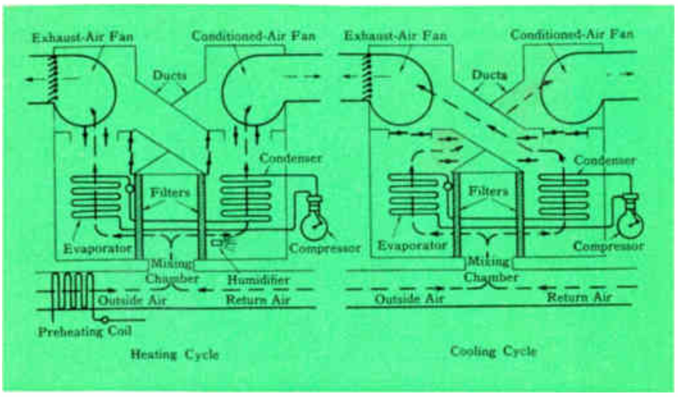


Fig. 3—*An unusual control scheme is used in the Emeryville, California, reversed-cycle heating and cooling system, to obtain a high heat gain.*

Approximately equal amounts of outdoor air and indoor air are drawn into a mixing chamber. From this chamber equal amounts of air are drawn by two sets of centrifugal fans. One stream passes over the evaporator where heat is given up from the air to the refrigerant within the evaporator; the other stream passes over the condenser where heat is given up to the air by the refrigerant within the condenser. When heating is required the air from the evaporator is discharged outdoors and the air from the condenser is circulated through the building. Conversely, when cooling is required, the cool air from the evaporator is circulated through the building and the warm condenser air is discarded. This is done automatically through a set of dampers operated by a thermostat located in the conditioned-air space. Through the use of this ingenious mixing chamber most of the heat added to the ventilation air is regained at the evaporator before it is discharged to the outdoors. The air in this chamber is at a temperature higher than the outside air temperature and lower than the temperature of the return air. There results from this a COP of 5 with outdoor air at 35°F and with heating air at 95°F. Another advantage of this mixing chamber is that the formation of frost at the evaporator is prevented. This would surely happen if 35°F air were passed over the evaporator.

resistor 3415 Btu is obtained for every kwhr of electrical energy. By supplying the same amount of electrical energy to the motor of this reversed-refrigeration heating machine there is obtained an output of 14 800 Btu/kwhr. With electrical energy costing one cent per kwhr, this is equivalent to heating with coal costing approximately $11 a ton, having a heat content of 12 000 Btu/lb, and fired with an efficiency of 70 per cent. The heat gains for other temperature conditions are shown in table I.

Reversed-Cycle Refrigeration Has Limitations

As usual the engineer finds himself faced with several economic boundaries to the application of this principle.

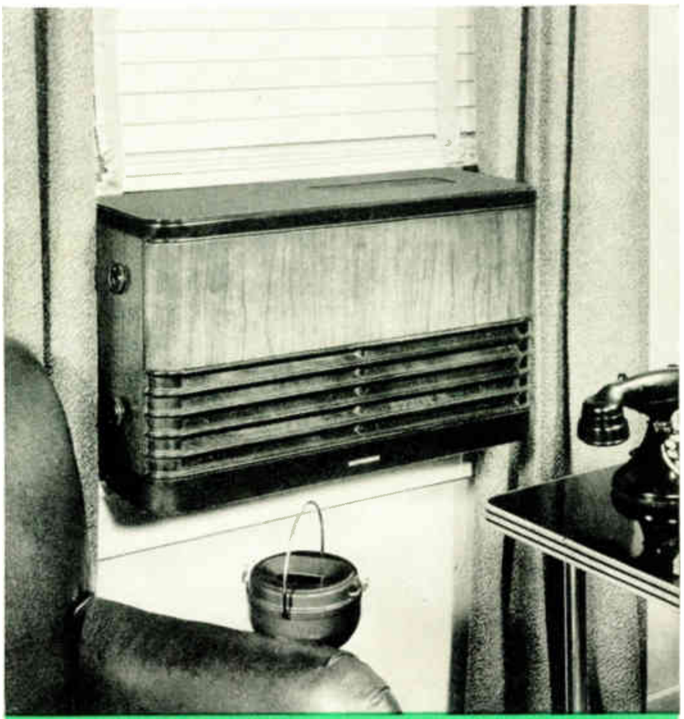


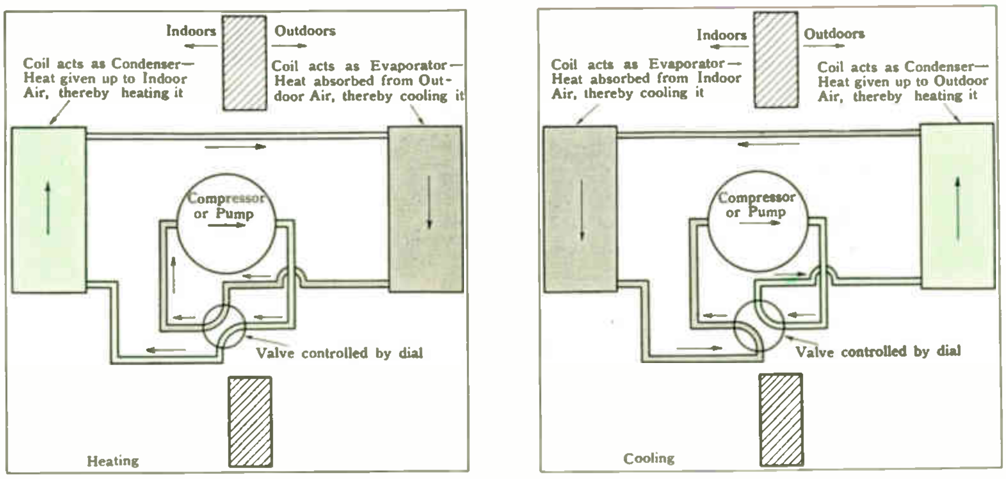
Fig. 4—*From this cabinet comes either warm or cold air as desired. Turn a knob one way and a strong stream of cold air is pumped silently into the room. Turn the knob the other way and in about twenty seconds a steady flow of warm air emerges from the unit.*

A Heat Source Is Required—Heat must not only be available in ample quantity but also the temperature of the source must exceed certain limits if the total heat gains are to be worth while. The quantity obviously depends on the size of the intended installation. The temperature, however, has strict economic limits. The theoretical lower limit for

TABLE I—THE EFFECT OF DIFFERENT CONDITIONS OF EVAPORATOR AND CONDENSER TEMPERATURE ON THE COEFFICIENT OF PERFORMANCE OF A 100-TON CONDENSING UNIT

a	b	c	d	e	f	g
Evap. Temp. Deg. F	Cond. Temp. Deg. F	Heat Absorbed at Evaporator (Cooling Effect) Thousand Btu	Motor Input Kw	Heat Equiv. of Motor Input (Col. d × 3.415) Thousand Btu	Heat Rejected at Condenser (Heat Effect) (Col. c+Col. d) Thousand Btu	Cop (Col. f Divided by Col. e)
50	96	1 430	87	297	1 727	5.80
40	96	1 185	83.3	285	1 470	5.15
34	96	1 040	80.5	275	1 315	4.78
50	117	1 290	100	341	1 631	4.77
40	117	1 055	94.5	323	1 378	4.26
34	117	920	90.4	309	1 229	3.97

Fig. 5—Flow diagrams show how, by turning a single valve, the function of the window-type unit can be changed from cooling to heating or vice versa.



water is, of course, 32°F. The practical limit is above this because, as the formula for coefficient of performance shows, the gain falls off as the temperature of the heat source is decreased. The temperature of river water, lakes, or even the city water, is usually too low in the colder regions. This then necessitates some special source of heat such as private wells. Minimum water temperatures should be between 40 and 45°F, for the coefficient of performance decreases as the temperature of the heat source drops.

Air is free in unlimited quantities and, in theory, there is no temperature too low for a heat source. But, the lower the temperature drops, the size (and cost) of the equipment increases and its gain decreases.

As the equation shows, the heat gain can be increased by decreasing the compression temperature or the temperature of the heating medium. But as this is done the amount of radiating surface necessary to transfer the heat to the room or building soon passes economic limits.

Power Costs Are a Factor—The cost of electric power, or rather the relative cost in a given locality of electric power and of competitive fuels, has a direct bearing on the economics of heating by reversed-cycle refrigeration. However, even if electric energy were free the system would not necessarily be practical or economical unless the other two requirements, a heat source and low initial investment, were satisfied.

Investment Is a Limiting Factor—It would seem that, given a satisfactory source of heat and an electric rate such that the cost of heating would compare with that of heating with coal, the installation and operation of a reversed-refrigeration plant would be warranted. There remains to be taken into consideration the capital investment and subsequent interest charges. When summer cooling as well as winter heating are required and both loads are nearly the same, the interest on the capital investment is small compared to the cost of operation. Indeed it can be argued that when equipment is needed for summer air conditioning, only that portion of capital invested for equipment over and above that needed for summer cooling should be charged to the heating cost. By such use of the summer cooling equipment the cost of installing a separate heating plant is saved. With so many summer air-conditioning installations being made, this phase of the subject merits attention.

Fig. 7—*The valve that reverses the cycle in the window-type unit.*

The valve is no larger than an automobile spark plug, yet it combines the function of two valves, has no seals or stuffing, and is low in cost, which is an absolute requisite to successful reversed-cycle refrigeration in the home. The valve is itself interesting because of the way it is made. The parts are fitted loosely together—including parts within parts—and placed in an electric brazing furnace. It comes out with hermetically sealed metal-to-metal joints, the necessary one-eighth inch movement of the valve stem being accomplished by a metal bellows.

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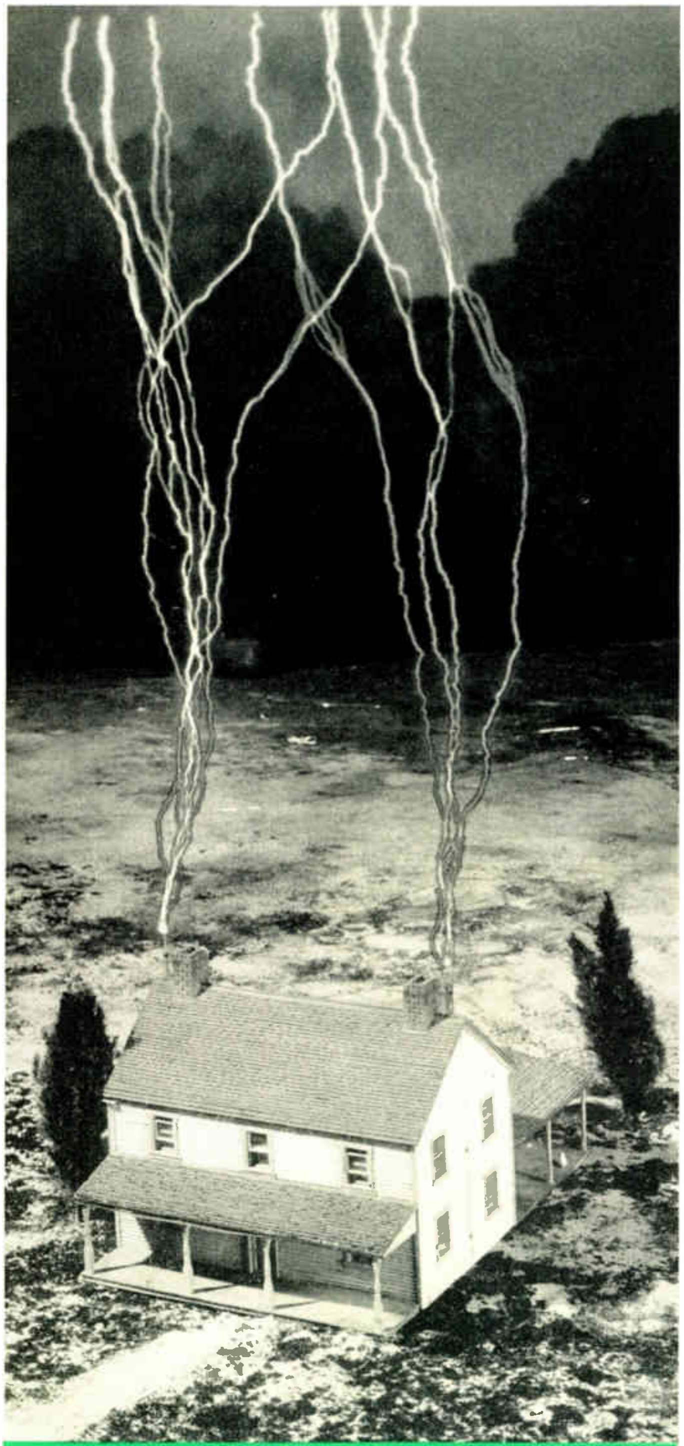

Artificial lightning tests, made in the Westinghouse High-Voltage Laboratories, help obtain added information on the shielding and protective effects of masts and lightning rods. Pictured above is a model house subjected to a succession of artificial strokes. While the rods were struck time and again, neither house nor surrounding trees were hit. Similar protection is afforded by masts to substations and transmission lines.

Corona Blackout Achieved in High-Voltage Machines

Electrical engineers have had a "blackout" problem of their own—and for much longer than the military engineers in bomb-scarred Europe. They have sought complete darkness in high-voltage machines, which spells absence of visible corona. Two of the three places in high-voltage machines where corona can appear were blacked out several years ago. For the most difficult to correct—the end turns—a treatment has been developed.

Drs. Hill and Berberich with high-voltage generator coils. The right pair has been treated to prevent the formation of corona.

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Corona has been a recognized phenomenon in high-voltage generating equipment since machines of above 10 000 volts came into use. It results from ionization of electrically overstressed gases. In the case of air the products are ozone (O_3) and nitrogen-oxygen compounds, which cause the characteristic bluish glow and odor usually associated with corona.

Corona itself is not harmful. There is a rather serious secondary effect, however, as the resulting products are powerful oxidizing agents. Furthermore, the nitrogen-oxygen compounds combine with water to form strong acids that attack organic materials and to some extent corrode metals. Organic insulation such as varnishes and cellulose are rapidly oxidized in a strong corona field, becoming weak and brittle mechanically, or eaten away gradually.

Although the main insulation of Westinghouse high-voltage generators is mica, which is unaffected by corona, it is undoubtedly desirable to protect the organic insulation present in any machine. For this reason corona elimination has long been a subject of an investigation in the Westinghouse Research Laboratories and a method of its prevention developed. Since the first work was reported by Hill[1] in 1928, much other work has been done. Out of this research has come a complete solution of the problem, now ready for commercial applications.

Corona is no problem in hydrogen-cooled machines because ozone and nitrogen-oxygen compounds are completely absent and ionized hydrogen has no effect upon organic or other insulation, as Fig. 2 shows.

Corona Appears at Three Locations

Corona may appear in any of three locations: in the slots, around coils immediately beyond the ends of the slots, and in the air spaces between various coils of the end winding. Because the conditions for its formation differ, the methods of corona elimination are different for each location.

Aquadag Eliminates Corona from Armature Slots

The laminated iron in the slot section is in actual contact with the insulation, but because of irregularities in the laminations, air gaps of from about one to fifteen mils exist between coil and slot. This results in a strong electric field in the air gaps between insulation and stator iron, and consequent ionization and corona. When air is the only insulation between conductors corona breaks down the ionized air film completely, causing an arc discharge. But, with a solid insulation in series with the air film, the air remains continuously ionized, that is, corona exists continuously as long as a sufficient voltage is maintained. Because the air gaps between coil and iron are short, corona can best be eliminated by giving the coil a partially conducting surface and providing many contacts between surface layer and grounded iron, to short circuit the air gaps.

A satisfactory means of doing this is to treat the slot portion of the coils with a conducting compound that has a surface resistivity of about 10 000 ohms per square inch, although a range of surface resistivity from 1000 to 100 000 ohms per square inch is satisfactory.[1,2] This resistivity is too high to short circuit the laminations in the stator but low enough to prevent an appreciable voltage from building up in the thin air films between coil surface and stator iron. The semi-conducting material used, called Aquadag, is a suspension of colloidal graphite in water.

This method of protecting the slot sections has been used successfully for about twelve years. The Aquadag film has excellent life properties as Fig. 3 shows.

Eliminating Corona at Ends of Slot

Corona occurs at the ends of the slot and for a short distance beyond because of the sudden transition from the conducting surface within the slot to a good insulating surface just beyond. This produces a non-uniform field at the edge of the iron or at the end of the Aquadag. As a result in either case, a ring of corona forms. In this discussion it is assumed that the Aquadag is used.

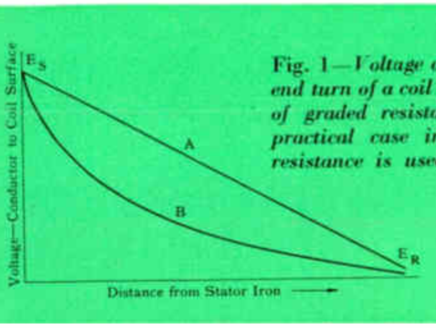


Fig. 1—*Voltage distribution on the end turn of a coil for (A) ideal case of graded resistance and for (B) practical case in which a single resistance is used on the surface.*

A satisfactory method of grading voltage stresses at ends of the slots through use of a high resistivity extension beyond the slot has also been described by Hill[1,3], in 1928. For a coil extension of about five inches a resistivity of 2000 to 3000 megohms per square inch is required to reduce the voltage sufficiently at the point where the treatment stops. This resistance is many times higher than that of the Aquadag treated slot sections. Asbestos tape is one material used to make the coil surface semi-conducting.

The treated surfaces of the slot and the semi-conducting section just outside the slot must always be in contact. The voltage gradient is reduced by the capacitance currents flowing from the copper through the high-resistance layer on the extension and then to ground in the slot.

Other methods of grading the voltage in the region where the coils leave the slots have been devised but they are not used extensively because of the difficulty of their application. Most of these make use of a compound containing a semi-conducting pigment, the resistivity of which can be altered during the manufacturing process[4]. These methods include grading the resistance in steps[5], combining a high-resistance surface layer with several embedded semi-conducting layers[6], and using low-resistance Aquadag and feathering or grading by high-resistance compounds.[7]

New Process Completely Eliminates End-Winding Corona

Since most high-voltage machines are three-phase, two adjacent coils may differ in potential by almost full line voltage. This and other considerations make corona more difficult to eliminate in the end windings than in slot sections. To extend the method used for the slot treatment to the whole end winding, namely, to treat it wholly with Aquadag, is not satisfactory for several reasons. Since Aquadag produces a low resistance path to ground, treating the whole end turn with it in effect brings the surface of the end turn close to ground potential. This impresses nearly the full phase voltage on the end-turn insulation, which, because of its bends and joints, cannot be insulated as effectively as the slot portion of the coil. Another objection to using Aquadag is that a ring of corona may appear where the treatment is ended in the phase leads, unless the resistance is feathered out to high values or a special bushing is provided for each phase connection. Finally, an Aquadag coating over the whole end winding reduces the surface flashover voltages, and may seriously interfere with overpotential testing unless the phase connections and leads are completely insulated.

An ideal solution to the problem would be to have the resistance of the end-turn insulation graded. That is, it should start at a low value, that of Aquadag, at the slot, and gradually increase to high amounts at the extremity or loop of the coil. This would result in uniform decrease in voltage as is illustrated in Fig. 1. Commercially, uniform grading of insulation resistance, or even a stepped grading is not easy to obtain. A single proper resistance value can reduce the voltage stress across the end-turn insulation sufficiently to eliminate corona. This is achieved by treating the end-turn insulation with Coronox, a new semi-conducting material, which has been considerably improved since its introduction in 1934[4]. The theoretical resistivity required to reduce the voltage in an end turn varies with the insulation thickness, coil cross section, and length of end turn. It varies in the range of 5 to 40 megohms per square inch to take care of test voltages although a single coil-surface resistivity of about 10 megohms per square inch would be satisfactory for operating voltage.

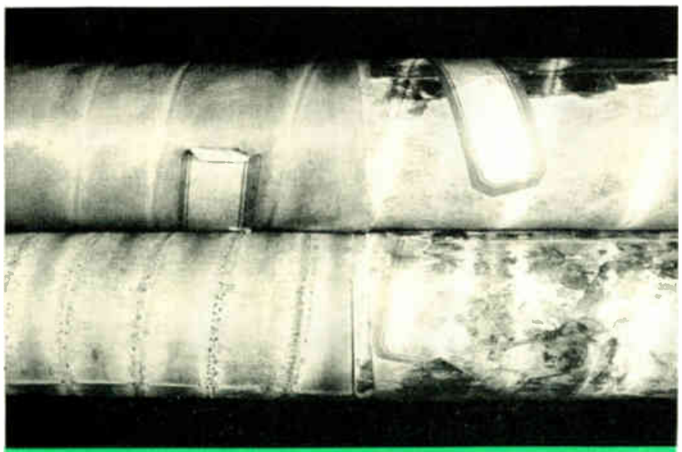


Fig. 2—*This shows the relative effect of corona on insulation in air and in hydrogen. Two tubes were wrapped with varnished cambric (left) and with mica folium on which the paper backing was exposed (right). They were exposed for three weeks to strong corona. The insulation in hydrogen (upper tube) was undamaged.*

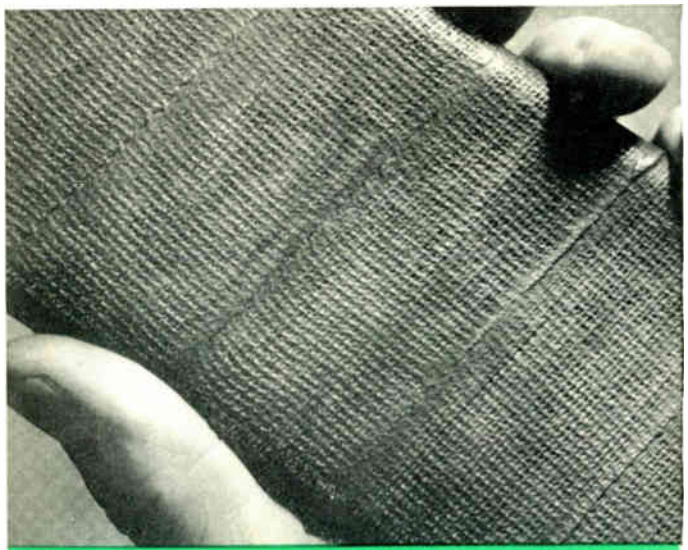


Fig. 3—*After ten years' service the Aquadag-treated slot portion of this coil from a 13.8-kv generator showed no deterioration.*

One of the most important points in the use of a semi-conducting material for the complete elimination of corona from end turns, is electrical cross-tying the coil surfaces at intervals, particularly between different phases. This is accomplished by treating all of the lashing and bracing blocks with semi-conducting compound and adding extra semi-conducting lashing where necessary.

The distance between cross-lashings is important. It is a function of the resistivity of the coil treatment used. For a highly conducting material, such as Aquadag, no cross lashing would be necessary because all coil surfaces, even those of different phases would be nearly at ground potential. But, using Coronox, which has much greater resistivity, the number of cross lashings must be increased to keep the voltage on the air spaces between coils too low to start corona. The proper spacing of lashings is easy to compute, knowing the voltage difference between two adjacent coil end turns, the thickness of the air space, the thickness and dielectric constant of the solid insulation, and the resistivity of the coil treatment. After a little experience, the number of semi-conducting cross lashings required for a winding can be readily estimated. The estimate can be checked visually by applying voltage between phases of a completely wound machine in a darkened room. Additional lashings can be placed to correct offending spots.

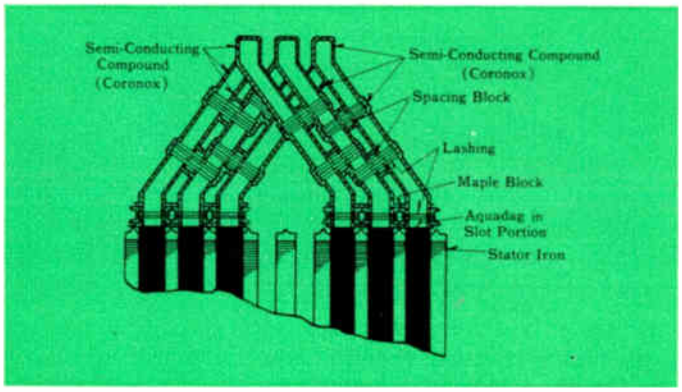


Fig. 4—*Generator end windings coated with semi-conducting compound.*

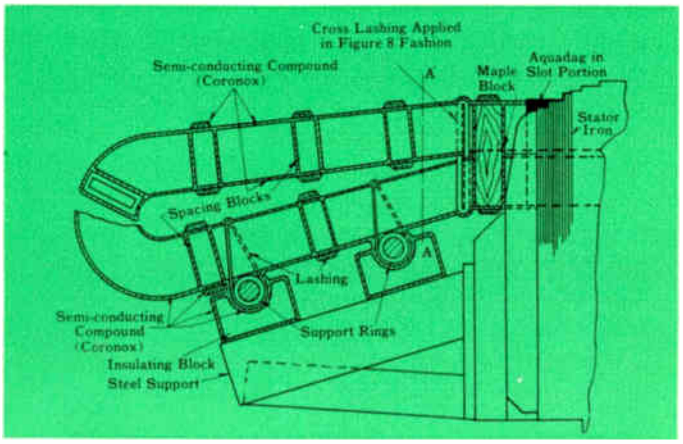


Fig. 5—*Side view of end winding completely covered with semi-conducting compound, Coronox. Shown also is a special lashing applied in figure eight fashion between the top and the bottom coil in a slot.*

The end winding of a high-voltage machine given the semi-conducting Coronox treatment is shown in Figs. 4, 5, and 6. All coil surfaces, support rings, parallel connecting rings, coil-to-coil connections, bracing blocks, and lashings are treated with Coronox. Actually, the coils within a phase group would not require such complete treatment, but with the grouping of coils in a modern winding such a large fraction of the total number of coils is involved that it is easier to treat them all than to try to distinguish between inter-phase coils and intra-phase coils.

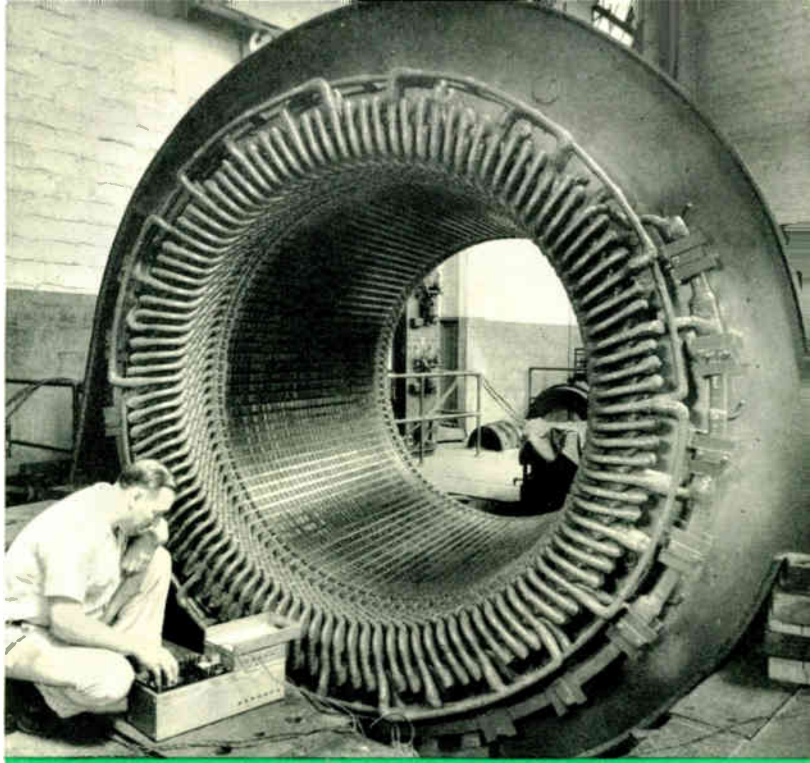


Fig. 6—*This 13.8-kv, 30 000-kva condenser stator has been in service several years in the Westmoreland station of the Philadelphia Electric Co. It has been rewound with coils completely treated to prevent corona formation, and is the first machine to be so equipped in the field.*

A special process was devised for treating the stator coils at the factory, which makes possible for the first time the use of glass binder tape. In the untreated condition, glass tape forms a coil surface too highly insulating to grade the voltage stress properly and more corona would appear than with the more conducting asbestos tape. In the new process, however, the glass tape is completely filled with Coronox which results in a thick, firmly anchored semi-conducting layer on the surface of the coil. The glass tape makes possible a smooth coil finish which has a much lower moisture absorption than the asbestos tape formerly used.

The parallel connecting rings and support rings are treated in a similar manner. The bracing blocks and cross-lashing are treated as the coils are wound into the machine. Special care and experience are necessary in applying the lashing, including that which is applied in "figure 8" fashion as shown in Fig. 5. A long-life insulating varnish of a closely controlled composition is sprayed over the whole end-winding. This protects the Coronox and increases its stability. In the slot portion the more conducting Aquadag is applied over the Coronox in order to insure further the absence of corona in the slot. This is illustrated in Fig. 7.

Corona Elimination in Old Machines

Coronox can also be applied to existing machines. Because of difficulty of applying the treatment to a machine

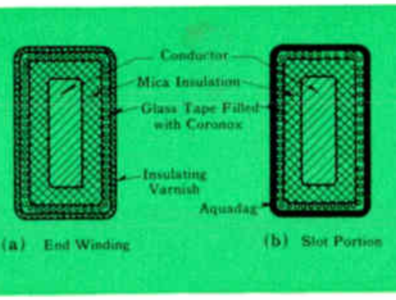


Fig. 7—*Sections of a treated coil. The small circles in the next to the outer layer indicate the fibers of the glass tape are completely buried in the compound. The treatment not only prevents formation of corona, but makes it possible to have a completely glass-covered coil.*

already wound, it has been limited to a portion of the end winding extending from the slot to the position marked by the line *A-A'* in Fig. 5 and to spot treatment where dark-room tests show excessive corona across small air gaps in other sections of the winding. The cross lashing from top to bottom coil in the same slot is applied just as is the case of a completely treated machine. Lashing is also applied across other treated areas where necessary. The treatment has been successfully applied to several machines including two 82 500-kva and three 108 000-kva, 13.8-kv, waterwheel generators. Coronox of approximately 1000 megohms per square inch resistance was used in these cases, however, because the voltage must be graded off in a much shorter distance than when the entire winding can be treated.

Coronox and Its Effect on Insulation

Coronox is a pigmented long-life synthetic resin compound, of resistivity very closely controlled in the manufacturing process. The pigment concentration in the compound is high enough to provide particle to particle contact. Unless this is done, the resistivity of the semi-conductor is unstable and erratic when subjected to high voltage stresses. A Coronox film does not change in resistivity when subjected to stresses from 500 to 16 000 volts per inch, a range far exceeding potential gradients encountered in practice.

The decrease of resistivity of a Coronox film with temperature is negligible over the normal operating range of a rotating machine, as Fig. 8 shows. This temperature-resistivity characteristic indicates that conduction through the film is largely electronic. If it had been ionic, as is the case in most insulating films, the fall in resistivity with temperature would have been far greater.

Data obtained thus far on the effect of Coronox on the dielectric absorption test (insulation resistance as a function of time), while not sufficient for positive conclusions, is summed up in Fig. 9. The insulation resistance of Coronox-treated machines is lower, and the insulation resistance-time curve flattens more quickly. This is to be expected because a treatment with a semi-conducting material like Coronox adds a definite leakage resistance over the entire surface of the end windings. This additional leakage in a machine does three things: lowers the overall measured resistance, modifies the dielectric absorption, and raises the overall measured power factor. Neither of the three effects, however, impairs the performance of the machine in any way. It must be emphasized therefore that the Coronox treatment tends to mask somewhat the resistance and power factor behavior of the insulation, but the effect of the treatment is only skin deep.

A dielectric absorption curve, such as shown in Fig. 9, describes the change of insulation resistance with time during a brief interval, say 15 minutes. The time that it takes this curve to flatten is an accepted measure of the dryness of the insulation[9]. Even though the curve is modified by the Coronox treatment, it is believed that insulation-resistance tests on Coronox-treated machines, like those on untreated equipment, will serve as successful criteria for the dryness of the insulation.

It is important to distinguish between power factor of the insulating material and that of the insulation in the assembled machine. Power-factor measurements on insulating materials give an excellent indication of their quality and suitability for use in electrical machinery. On the other hand, insulation power factor of a machine in service has not yet been shown to be a measure of its condition. Nevertheless, the effect of Coronox treatment on the power factor of insulation has been studied both analytically and experimentally. The test results for a single coil, plotted in Fig. 10, show that the power factor depends upon the resistivity of the Coronox film. The power factor increases as the resistance of the surface treatment decreases, reaches a maximum, and then falls again. The power factor at ten megohms appears to be high but it can be shown that most of this is attributable to the loss in the Coronox film. Power

Fig. 8—*Effect of temperature on the resistivity of Coronox film for two different resistances.*

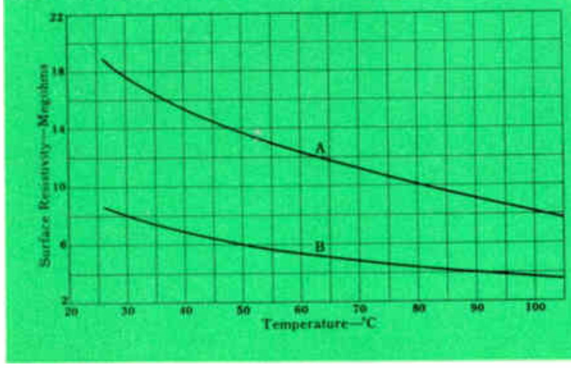


Fig. 9—*Effect of treatment on insulation resistance-time relationship in completely wound machine.*

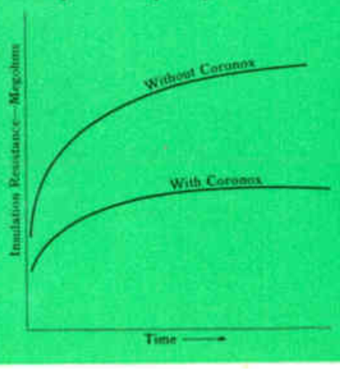
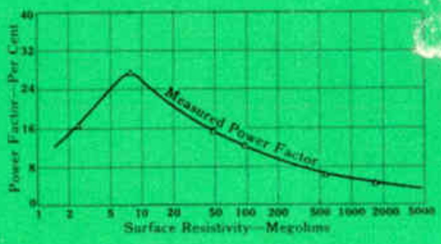


Fig. 10—*Effect of resistivity of Coronox film on power factor of a single coil.*



loss in a Coronox-treated 13.8-kv, 35 000-kva waterwheel generator has been computed and found to be less than 10 watts per coil or less than 2.5 watts per half end turn, which is considered negligible.

Two often-measured properties of electrical insulation are the flashover voltage and the breakdown voltage. The flashover voltage of Coronox-covered surfaces is actually greater than of highly insulating surfaces. The breakdown voltage for treated coils should be higher than for untreated coils, because the Coronox treatment eliminates concentrated voltage stresses at the edge of the slot. Electrically, therefore, Coronox treated coils should be superior to untreated coils. Corona elimination should have many advantages from the maintenance standpoint and the reduction of or freedom from Corona during overpotential test should tend to eliminate high-frequency resonance voltages, and transients resulting from static discharges, which may lead to failure.

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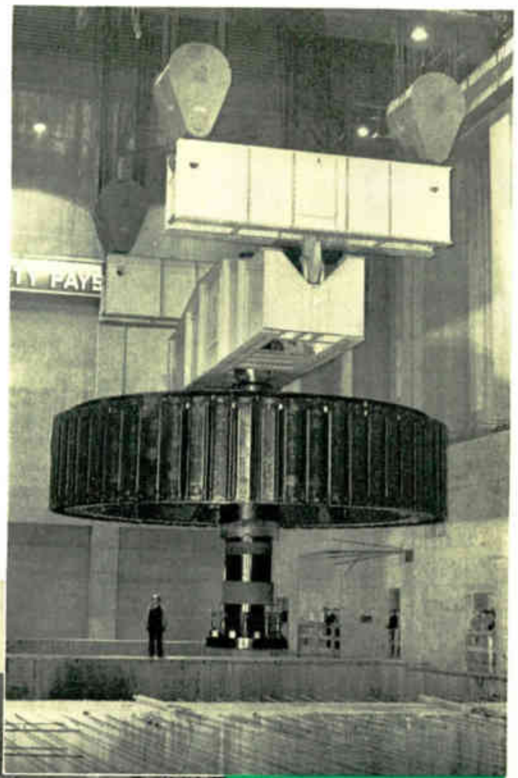
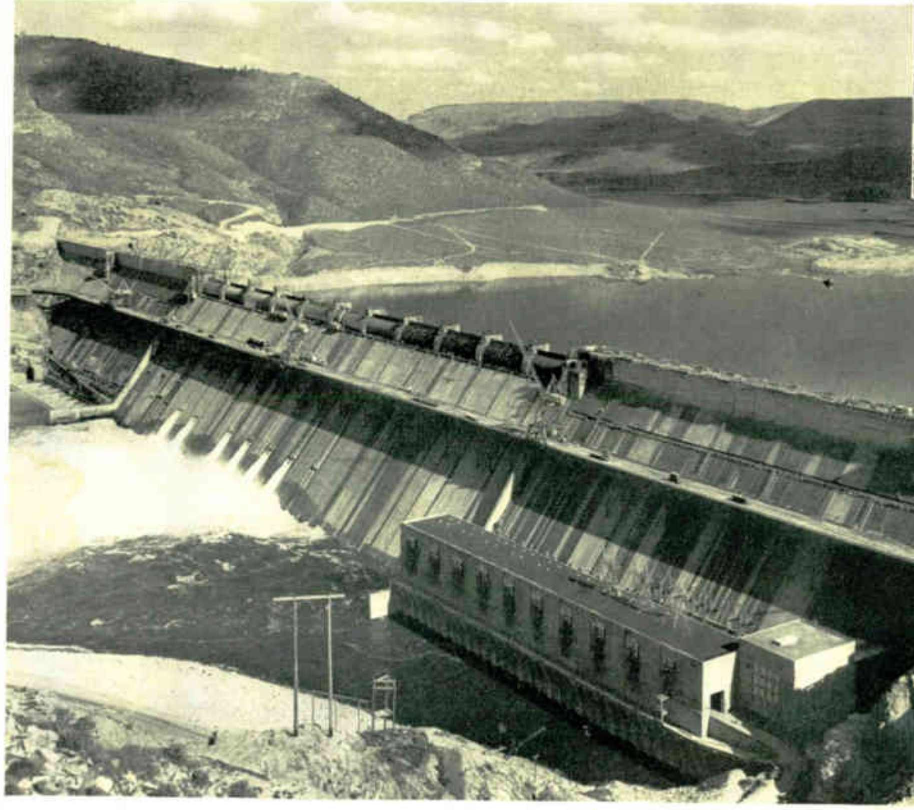
Grand Coulee Turns on the Power

GRAND Coulee Dam, colossus of man-made structures, is nearing completion—two years ahead of schedule. The first of eighteen 108 000-kva waterwheel generators is ready to deliver power, much of it for industries having key positions in the defense program. Grand Coulee takes first rank above other hydroelectric projects of the world. Not only are its generators individually the largest ever built but also it has the greatest eventual total capacity, 1 944 000 kw, half again as much as Boulder Dam with its fifteen 82 500-kw and two 40 000-kw generators, the water-power project next in size. Behind the dam will be a lake 151 miles long, extending to the Canadian border, with a storage capacity of about 10 million acre feet. Much of the power will be used later by 65 000-hp synchronous motors to pump water for irrigation to a nearby natural reservoir 280 feet higher than the lake. (Photos by Bureau of Reclamation.)



The rotor for each of the 108 000-kva generators is 31 feet in diameter and weighs 565 tons.

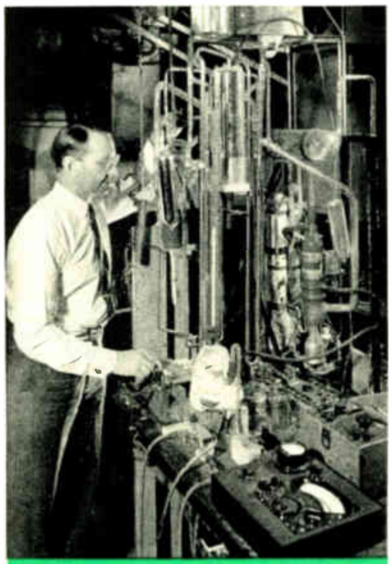


Grand Coulee Dam across the Columbia River is the largest man-made structure in the world. The largest Egyptian pyramid is surpassed for the first time—Grand Coulee Dam is three times larger. The dam is 4300 feet long at the crest, and rises 550 feet above bed rock. At each end is a powerhouse large enough for nine turbine generators.

Stories of Research

Puff of Steam Measures Iron Purity

Iron rusts because it is attacked by oxygen. To the layman this is an old story, and considering the advances in both the prevention of rust and the production of stainless steel, little sleep is lost over the matter. But Dr. T. D. Yensen, the metallurgist, has been wanting to weigh this oxygen accurately. Not the large quantities found in rust and surface scale, but the minute traces, ranging from one-tenth down to one-thousandth per cent, and remaining after other impurities have been removed.



Using this apparatus, Dr. T. D. Yensen can extract a hundred-millionth ounce of oxygen from a sample of steel. By combining this oxygen with hydrogen, enough steam is formed to increase the heat emission from a thermocouple. This gives a sensitive and exact measure of oxygen in steel.

Even the purest iron contains some oxygen, mostly as oxide of iron, silicon, and aluminum. When molten iron is mixed with other metals, the oxygen present in the iron combines with the alloying substances, forming refractory oxides—melting at higher temperatures than the alloy itself. As the mixture cools and becomes viscous, the refractory oxides, already solid, distribute themselves in fine particles among the iron crystals and affect the properties of the solid metal. Once suspended in the metal, the oxides are not readily removed.

A correctly prepared alloy, like a physician's formula, should be compounded of the purest materials available. If this is impossible, the next best thing is to know the exact amount of impurity, so that its effect on the characteristics of the alloy can be learned. An accurate measurement of an oxygen trace, heretofore a long and complicated process, has now been considerably simplified by Dr. Yensen.

He melts the iron in a vacuum, removes all surface impurities, and passes pure hydrogen over the hot melt. The hydrogen and oxygen combine into a wisp of water vapor, too tiny to be weighed accurately. But if this vapor is passed over a thermocouple (a junction of two metals capable of generating a voltage proportional to its temperature), the vapor increases the heat emission from the thermocouple—the more vapor, the more heat it takes. This lowers the potential of the thermocouple, and the result, read on a sensitive meter, can be calibrated in milligrams of oxygen.

Dr. Yensen's apparatus can be used to measure oxygen in quantity as low as 0.0005 milligram, and with a sensitivity of 5×10^{-7} (half a hundred-millionth). It takes him about an hour to perform the analysis of a sample, usually a gram of iron. In the previously used vacuum-fusion method (where carbon was used to combine with the oxygen) only a quarter of the accuracy was feasible—and it took four hours to get that.

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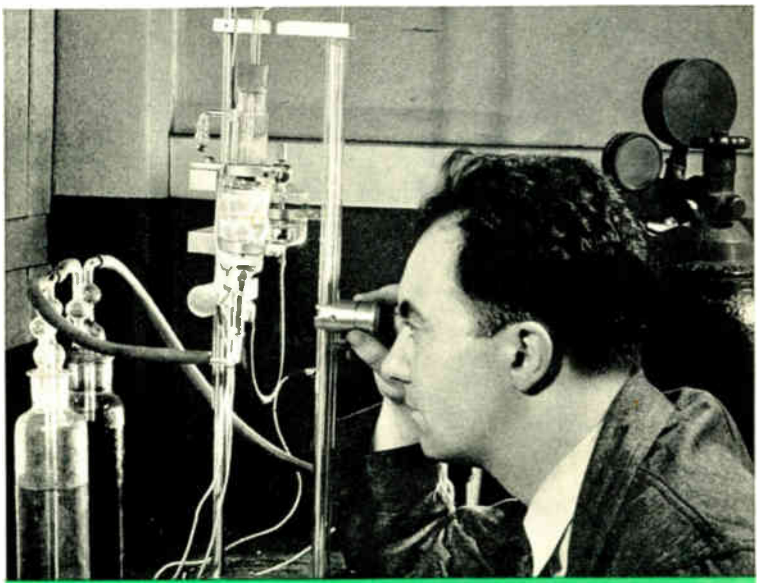
Novel Electrochemical Analysis

The interlacing of chemical and electrical principles is well known. In fact, it is almost impossible to explain modern chemistry without bringing electricity into the picture—yet it was the chemical reaction in a battery that prepared the way for modern developments in electricity. Another example of the close interrelation between the two sciences is the polarograph, invented in Czechoslovakia by Heyrovsky and used by Dr. Alois Langer at the Westinghouse Research Laboratories. Two "old-time" phenomena—polarization and the electrolytic action of electric current—are combined to produce an instrument for minute chemical analysis far surpassing any known at present. It can detect approximately a billionth of a gram of a substance in solution, but this isn't all. The analysis, which can be performed in two to fifteen minutes, is more accurate than any previously feasible, while older quantitative methods require hours for their completion.

To understand the polarograph one must first recall polarization, the phenomenon which makes flashlight batteries go dead. Polarization can be easily defined as the chemical formation of insulating layer around an electrode in a cell. It is a complex process, difficult to explain in detail, but its application in the polarograph is relatively simple. Molecules in a solution are ionized, and current passing through it will carry the negative ions to the positive electrode and vice versa. However, a polarized layer surrounding the electrode acts as a potential barrier that prevents ready passage of the ion. The charged particle needs help—in the form of higher voltage—to leap over this barrier. And just as athletes vary in the distance they can jump, so do the molecules vary in the voltage they require to assist them in crossing the polarizing layer and to obtain the necessary reduction potential at the electrode.



Dr. Alois Langer at the polarograph, a sensitive device that can measure as little as one-billionth of a gram of substance in solution. Both organic and inorganic solutions can be tested more accurately than with any other method, and an analysis can be performed in a few minutes instead of hours.

Making use of the above principles, the polarograph consists essentially of a container for the test substance, a reservoir of mercury, a d-c source, and a galvanometer or a potentiometer. Two electrodes are inserted into the test solution—one is fixed, the other is a trickle of mercury fed from a nozzle, a drop at a time. When voltage from the battery is applied to the solution, the mercury droplet becomes polarized. To measure the quantity of, say, copper in the solution, the voltage is varied within a specified range for copper. Then a meter shows the differential of current passing through the solution, which can be calibrated as a copper concentration. A new drop is formed every few seconds, to maintain a clean polarizing layer for the chemical action.

An individual voltage range corresponds to each element. So far there have been tabulated the proper voltages for about 60 inorganic and 200 organic substances. One foresees a day when a catalogue is available, giving directions for measuring any substance. Interesting possibilities that suggest themselves are quantitative investigations of hormones and detection of cancer in living tissue.

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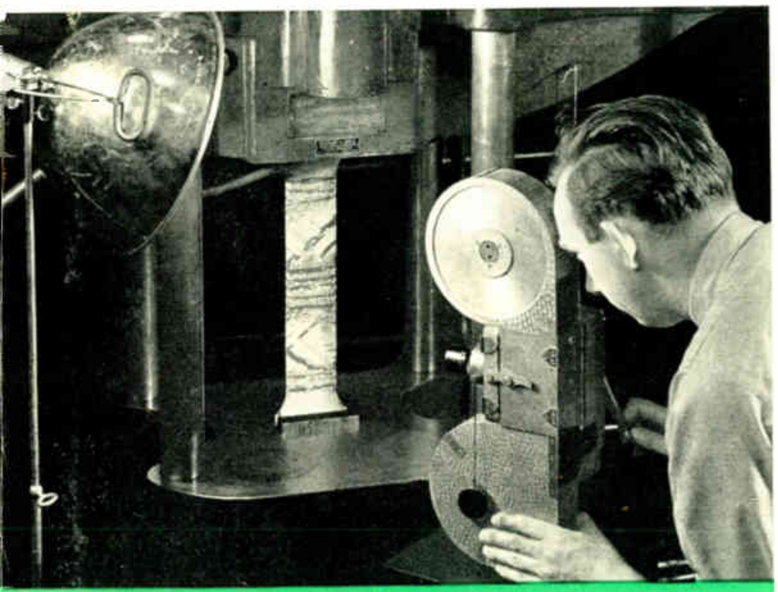
Toward a Better Understanding of Metals

RESEARCH has "gone Hollywood." A new wrinkle for demonstrating that metal becomes plastic, like clay, when stressed beyond certain limits is a "movie short" of nature's forces at work in stretching a steel bar.

Dr. A. Nadai, for years an avid investigator of plasticity in metals, has worked out elaborate mathematical means for evaluating plastic flow. But research in the modern manner is no longer symbolized by the test tube and the integral sign alone. To make things more understandable, he has prepared a series of slow-motion pictures showing how a steel sample behaves when stressed beyond the elastic limit.

What the audience sees projected on the screen is the image of a two-foot strip of steel, made white and smooth by a coating of whitewash. Tension is applied, and the strip begins to stretch like a rubber band. At first no change appears to be taking place; the metal is still in the elastic stage and will spring back to its normal position if the stress is removed.

In a few seconds the stars of the drama begin to appear. A black line shoots out from one edge of the strip and rapidly etches itself diagonally across the white surface of the metal. Soon another and still another black line appear, always at an angle of about 45 degrees to the direction in which the strip is being pulled. Before the film ends, the bar is criss-crossed by a maze of lines.



The movie set on which Dr. A. Nadai photographs a two-foot steel strip in tension. After the metal has reached its yield point, the iron crystals begin to slip, and cause a thin surface layer of whitewash to chip. The resulting network of black lines is a great help to the study of plasticity in metals.

Such slip lines appear only after the steel reaches its yield point, the stress at which iron crystals begin to change their positions. The slipping of some of the crystals of iron, like a deck of cards pushed along a table, has deformed the hard, brittle outer scale of the steel, and has traced paths by chipping off the whitewash before the camera. The whitewash itself has no body, and does not chip unless some change occurs on the surface of the metal.

All this happens very rapidly, but the slow-motion camera enables a leisurely study of this interesting and important phenomenon. Each crack can be studied separately, and its part in the failure of the whole sample can be accurately determined. An added advantage of such a motion-picture study is that the behavior of the steel sample can be observed as a function of time. With motion pictures taken at 64 frames a second, the occurrence and progress of each crack across the surface of the steel can be minutely followed.

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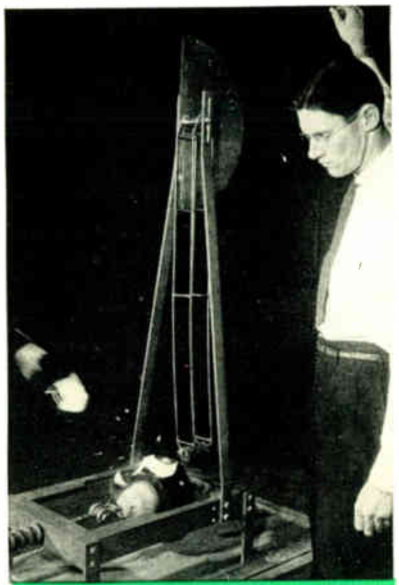
Strength on the Surface

A STRANGE thing about glazed porcelain is that its effective strength may be only skin deep. Though it constitutes only a tiny fraction of the total mass, the glaze can make an insulator either stronger or weaker than the porcelain body itself.

There are two reasons for the importance of the glaze. The first is its location on the insulator surface, where any slight defect may cause abnormal concentrations of mechanical stress. The second is that all glazes are in a state of internal mechanical stress due to the firing process.

Body and glaze are fired together at a temperature high enough to melt the glaze and to make the body slightly plastic. As both cool the body becomes rigid first, while the glaze remains a viscous film until a much lower temperature is reached. If the glaze, on cooling, tries to contract more than the body it becomes tensioned, as though it were a small rubber glove on a large hand. Conversely, if the body shrinks faster, the glaze is "crowded" into a compressive stress, the kind that ceramic materials can bear much better.



Tests like this show Dr. Ralston Russell whether the glaze over the porcelain insulator has strengthened or weakened it mechanically. By controlling the firing process the glaze on the insulator can be left either in tension or in compression, thus greatly affecting the strength of the porcelain body itself.

It is easy to see why a ceramic part coated with a compression glaze should be stronger than one with a tension glaze. The mechanical load on electrical porcelain causes only tension, which adds to the internal stress already in a tension glaze and causes quick breakage. In extreme cases a tension glaze may be sufficiently stressed to crack without external load. Such cracks in a loaded electrical porcelain insulator quickly lead to failure because of the abnormal stress that concentrates along them.

In testing glazes, Dr. Ralston Russell, Jr. has found that a coating with high inherent tensile stress actually weakens porcelain by as much as 70 per cent; also that a satisfactory way to increase strength is to apply a compression glaze. When such a surface covers the porcelain, any external tensile load must overcome inherent compression before tensile forces become destructive.

The greater strength of compression glazes has long been recognized. In fact, some insulators glazed in moderate compression had been in commercial use for a number of years. It was, however, desirable to make the most of compression glazes, and as a by-product of Dr. Russell's work it was hoped improved glazes of all types would be developed.

Finding out how to make the most suitable compression glazes proved to be an exasperating problem, even though the basic principles involved were well understood, because every simple glaze contains oxides of sodium, potassium, calcium, aluminum, and silicon, and frequently also oxides of barium, magnesium, boron, zinc, etc. To find the effect of each of these on the physical properties of the glaze meant almost endless experimentation with different mixes. In all, Russell spent more than a year studying over 500 glazes before producing the one he sought. The result was a glaze that greatly increased—in some cases almost doubled—the mechanical strength of insulators, yet had the same gloss, color, and appearance as any other glaze.

Compensation Improves Variable-Voltage Drives

The performance of variable-voltage drives, excellent at high and medium speeds, is somewhat below par at low speeds if the load is variable. Resistance-drop compensation, in several tailor-made forms, remedies this deficiency and enables the drive to carry full or light load, without speed deviation, even at less than one-twentieth full speed. Furthermore, resistance-drop compensation is as applicable to a group of motors as to one; it enables all the motors of a strip mill to accelerate synchronously from threading to rolling speed.

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Steel Mill Engineer,
Westinghouse Electric & Mfg. Co.

AN orchestra in which the instruments play high notes in perfect tune but are off pitch at low keys, can hardly produce the best in music. Nor can a tandem strip mill with the individual rolls operating together at high speeds be satisfactory unless the same teamwork prevails among the motors at low speed. The inclusion of an adroit resistance-drop compensation in a variable-voltage drive insures that the component motors maintain accurate speed relationships at all mill speeds and with all load variations.

Smooth and accurate speed variation over a wide range, and with simple control, is generally accomplished by a direct-current drive with variable-voltage control. As used in elevators, skip hoists, reversing or adjustable-speed rolling mills, machine tools and similar applications, a variable-voltage drive is a d-c motor supplied from an individual generator. Both machines are excited from an external source. By varying the generator excitation, the voltage of the generator, and with it the speed of the motor, are altered over a wide range.

If the drive must have good speed regulation at very low speeds the conventional variable-voltage system is not suitable. The reason is easy to understand. The armature resistance drop in the generator and in the motor is proportional to the load, not to the speed of the motor. This drop consumes the lion's share of the potential in a drive running at slow speed, whereas at high speeds it barely affects the voltage of the circuit. For example, in a 250-volt system consisting of a shunt generator and motor, the resistance drop at full load may total 20 volts. This means that if the motor is running at maximum speed, the voltage is 250 at no load and 230 at full load. This reduction in potential does not affect the speed more than a few per cent. But to run the drive at, say, one-tenth speed, requires about 25 volts at no load. Obviously now a 20-volt armature drop would be so large a proportion of the total voltage in the circuit as to make operation impractical. With most of the potential spent in the resistance of the machines, speed in the lower ranges fluctuates widely with the load, and the drive may stall at torques less than the full-load torque capacity of the machine. A motor with less than two per cent regulation at 600 volts may drop one-third in speed at 60 volts. The dotted lines in Fig. 1 show typical regulation curves of a large mill motor running at slow speeds.

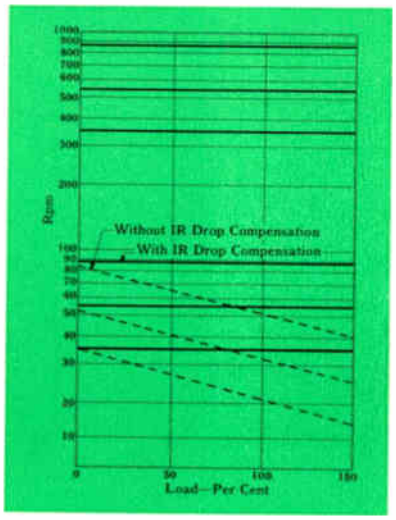


Fig. 1—*Speed-load characteristics of a 700-hp d-c motor.*

Voltage Boosted at Low Speeds

To render the drive serviceable for wide load changes at low speed two modifications are required: one to counteract the armature drop in both machines due to load, and one to provide a minimum voltage at the terminals so the motor will not stall. This latter feat is easy. A simple voltage booster is introduced into the circuit at low speed and provides a constant minimum voltage to the motor. Such a regulator enables simple drives, consisting of only a motor and a generator, to carry con-

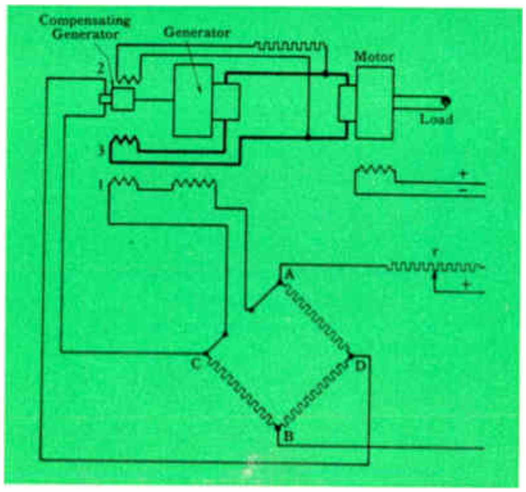


Fig. 2—*Resistance-drop compensation for single-motor drive.*

Exciting current from an external source is introduced into a bridge circuit at points *A* and *B* through the adjustable resistance *r*. The compensating generator is connected to the bridge at *C* and *D* so that its output current either adds to or subtracts from the external excitation. Field 1 of the compensating generator is in series with the shunt-field winding of the main generator. It induces a voltage that adds to that of the main generator. Field 2 assists field 1, and being in series with the drive motor, it causes the compensating generator to boost the system voltage by an amount equal to the armature drop in the two machines. Field 3 opposes fields 1 and 2 and comes into its own at low speeds and light loads, when the external excitation is low, and the residual voltage of the main generator may be too high for the desired speed. Then field 3 becomes stronger than fields 1 and 2 and reverses the compensating generator, reducing the system voltage accordingly. If the load is overhauling, the motor becomes a generator, its terminal voltage rises, and the current reverses. Fields 2 and 3 then oppose field 1 and weaken the main generator field. This increases the regenerative current and limits the speed of the drive.

stant-torque loads at low speeds. There are cases, however, where mere addition of voltage equivalent to the armature drop is not enough. For example, in elevators and various machine tools, where at low speeds the load not only varies widely in amount but also reverses, the additional regulator must do more than offset the drop in the armature. It must also follow the changes in the load and make sure that the voltage in the system matches exactly the load conditions. Furthermore, at very low speeds the generator voltage, because of residual magnetism in the poles, may be too high even without any external excitation. The function of the regulator is then to counteract the inherent generator potential. It also has to keep the system voltage within close limits in such applications as skip hoists, where the load comes to a standstill and reverses.

A compensation scheme capable of such exacting duties is shown and explained in Fig. 2. It employs a small auxiliary generator and a bridge circuit to add to or subtract from the voltage of the motor. The auxiliary generator has, in addition to its main excitation, two supplementary fields, each sensitive to a different change of the circuit. One is responsive to increases in the load, and, as soon as they occur, causes more auxiliary voltage to be generated. In this way armature drop is offset. Another field acts as a monitor to overpower generator residual magnetism when reversal of the motor is required. Once a speed is preselected by adjusting resistance r in Fig. 2 (which can be calibrated in rpm), it will stay constant for all rated loads.

Compensation Improves Operation of Multiple Drives

The advantages of resistance-drop compensation become apparent where several motors are supplied by a common generator. There compensation makes it possible to band motors of different sizes and speeds into a closely cooperating unit, automatically responding in concert to changes in the common load. An example, pictured in Fig. 3, is a tandem cold-strip mill having four roll stands and a tension reel coiling the finished strip. The reel and the stands are each driven by individual d-c motors, all fed by one variable-voltage generator. The finished strip is delivered at speeds up to 3000 feet per minute. At full delivery speed the individual motors do not run at the same speed, both because they vary in rating and because of differences in roll diameters. But the speed ratios must be maintained exactly so that the strip is under constant tension as it passes between roll stands as well as between the last stand and the coiling reel. This tension must be maintained within narrow limits at all times to avoid changing the gauge of the metal by stretching, and also to prevent accumulation of slack. However, when starting on a new coil, the strip is threaded through the stands at only about 250 feet per minute (delivery speed), roughly one-tenth full running speed. To get this low threading rate, the voltage is lowered to one-tenth normal. At this reduced potential, as well as during the intermediate steps of accelerating and decelerating the reel, the individual motors do not have the same inherent speed-load characteristics prevailing at full speed, Fig. 1. The armature IR drops must be individually compensated at low speed if the motors are to maintain their speed ratios.

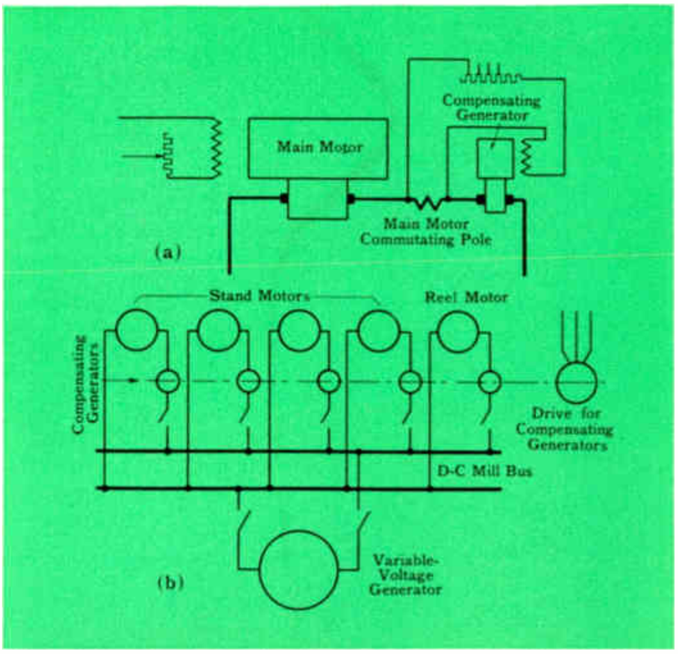
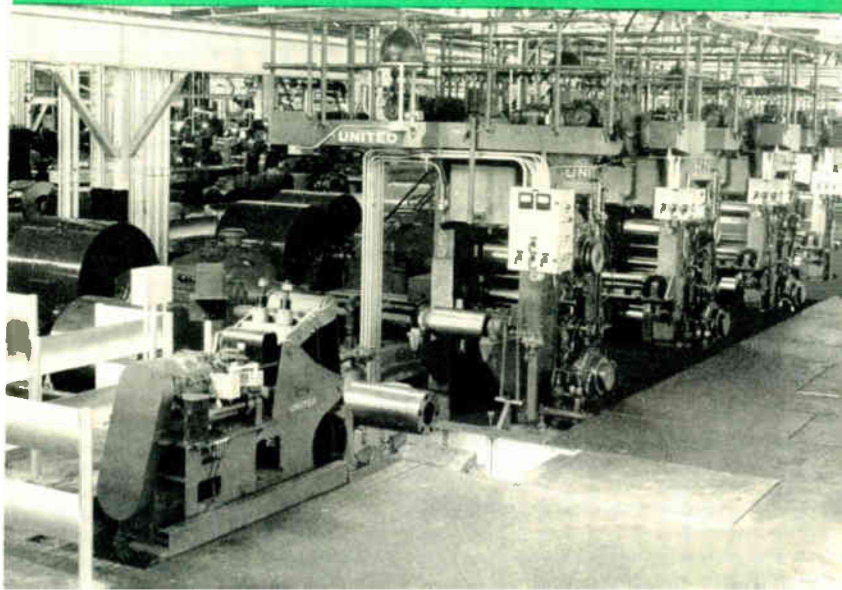


Fig. 4—*Compensation for multiple drives. (a) In each compensating generator the field is excited by the voltage drop across the commutating pole of the mill motor, and its voltage is therefore proportional to the load of the motor. (b) General connection. All compensators are mounted on one common shaft driven by a separate induction motor.*

Before multiple-drive aberrations were remedied the machine operators could thread a strip uniformly only by adjusting each motor by hand, while varying the voltage of the supply. This intricate procedure is eliminated when the armature drop is counteracted by the scheme shown in Fig. 4. As in the case of the single drive, the drop in each motor is offset by an accurately matched compensating generator, but it is efficient and simple to drive all compensating generators by a common a-c motor. Each motor is compensated to suit its own characteristics. The mill speed is varied by raising and lowering the generator voltage without having to attend to each motor separately. How the speed of each motor is maintained over the whole load range is shown in Fig. 1. Tandem mills provided with compensation of this type produce a strip with a minimum off-gauge portion.

Fig. 3—*The driving motors in the tandem strip mill of the Acme Steel Co., Chicago, may vary from 300 to 500 hp and from 600 to 1200 maximum rpm. Yet all these motors must work in close harmony at both high and low speeds, regardless of load.*



Hipersil, a New Magnetic Steel and Its Use in Transformers

Research metallurgists, working with far greater patience and ingenuity than the drill sergeant with the most awkward squad, have finally taught iron crystals to form into straight lines. After nine years' work they have a grain-oriented magnetic steel, which, because the crystals are in step, has one-third more flux-carrying capacity than previous best grades of silicon steel. Translated into practice, this means transformers can be smaller, lighter, more efficient, have better regulation, greater short-time overload capacity, or some combination of these improvements depending on the present-day need of each type transformer.

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Manager, Engineering Department

C. C. HORSTMAN
Materials and Development Engineer

Transformer Division
Westinghouse Electric & Mfg. Company

ELECTRICAL induction apparatus is composed of two active parts, the core for carrying the magnetic flux and the copper winding for carrying the current. To better the performance it is necessary to improve one or the other. Improvement of the current-carrying capacity of copper is unlikely. Hope of improving the performance of electrical induction apparatus such as transformers, therefore, lies in raising the flux-carrying capacity of the core material.

The trend of quality of high-silicon electrical sheet steel several years ago flattened out so that only minor improvements could be expected in the future. In the period from 1904, when silicon steel was introduced, to the present the core loss had been reduced to one-fourth, but during all this time there had been practically no improvement in the permeability or flux-carrying capacity. Without improvement in permeability, further reductions in core loss would have little or no effect in reducing the cost of a transformer.

Hipersil Is an Improved New Material

About nine years ago, a joint program of research was instituted by the American Rolling Mill Co. and Westinghouse to develop an electrical steel with higher permeability, which would permit redesign of transformers to take advantage of the lower core losses possible. The product of this joint program of research is Hipersil*, a word coined from the phrase "high permeability silicon steel." Although Hipersil was first produced some time ago, only recently were design methods created for using it most effectively.

Hipersil differs from Hipernik**—another magnetic material of extraordinary permeability—in that Hipernik has a high permeability at low magnetic inductions and is applicable for instrument transformers and other devices that are worked at low inductions. Hipernik, however, saturates at a much lower flux density than does Hipersil, which has a high permeability at high magnetic inductions, a fundamental requirement for all distribution and power transformers.

Hipersil differs from ordinary silicon steel in that its good magnetic properties exist only in the rolling direction of the steel. It is an electrical steel with a particular type of orientation developed by a new rolling and heat-treating technique in which the cycles and temperatures are rigidly controlled. The structure of Hipersil 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 of the sheet. This is represented diagrammatically in Fig. 1. That the cube edge in a single crystal of silicon steel is the most easily magnetizable direction has been known for some time. Because of the orderly prearrangement of individual crystals, Hipersil requires a smaller external magnetizing force to produce a given flux than an unoriented steel.

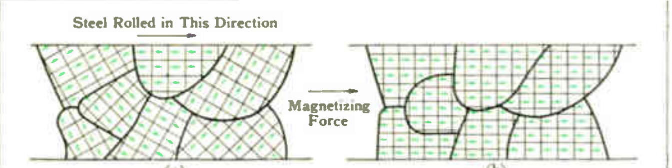


Fig. 1—Comparative grain arrangement of (a) ordinary silicon steel and (b) Hipersil. The outlines of the magnetic domains or crystal lattices are shown. Each arrow represents the direction of easiest magnetization of the individual crystals forming the steel.

*Hipersil is a registered trademark, 1934.

**A 50 per cent nickel-iron alloy described in the *Journal of the Franklin Institute*, March, 1925, by Dr. T. D. Yensen.

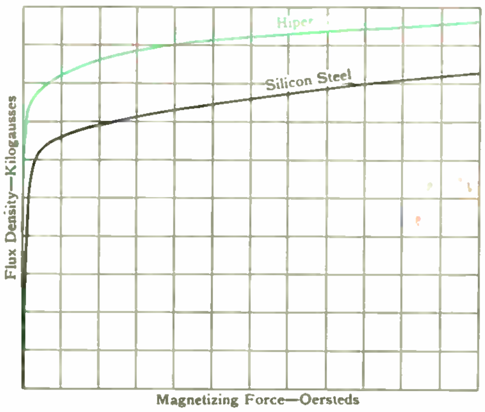


Fig. 2—*The knee of saturation curve for Hipersil is higher than for ordinary silicon iron.*

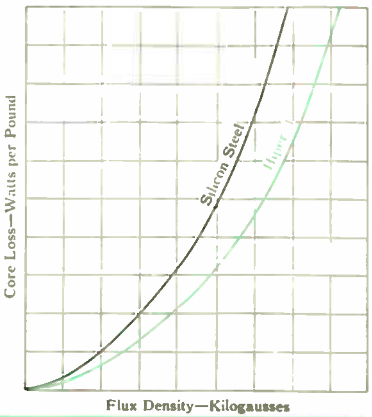


Fig. 3—*Hipersil has lower core loss than ordinary silicon iron.*

The effect of orientation is shown by comparative magnetization curves, Fig. 2. The straight part of the curve, that is, the portion of the curve from the origin up to the bend or knee, is the easily magnetizable portion. The force required for this portion of the curve is represented by the magnetization of each of the individual crystals in their most easily magnetizable direction. If the crystals are already lined up in the direction of the applied field, more flux will be carried by the steel with the same magnetizing force than if these crystals are initially at haphazard directions. In Hipersil this pre-alignment allows it to carry one-third more magnetic flux in the direction of orientation of the steel crystals than the best grades of electrical steel now available.

Along with increased flux-carrying capacity, the core loss has been proportionately reduced, as is demonstrated in Fig. 3. This is a result of controlling the composition of the steel in addition to obtaining preferred orientation. Two wound-type cores, identical as to construction and dimensions, but one made of ordinary high-grade silicon steel and the other of Hipersil, with 77 ampere-turns excitation, required 92 and 127 volts, respectively. Therefore, Hipersil carries 38 per cent more flux with the same magnetizing force applied. The alloy composition of Hipersil is also controlled so that it is essentially non-aging.

High flux density, in ordinary transformers, is associated with more sound. This is due to magnetostriction, the stretching and contracting of the laminations when alternating current is applied. Fortunately, magnetostriction of Hipersil is reduced as much as its permeability is raised. This results from preferred grain orientation in combination with other factors. As a result, Hipersil transformers, although operating at considerably higher flux densities, make no louder sound than those using ordinary silicon steel.

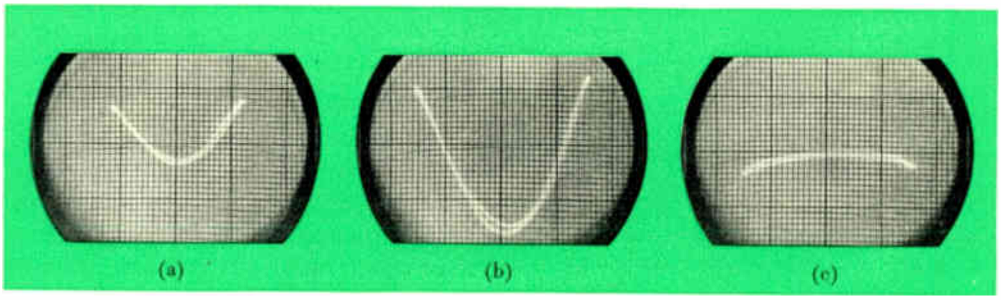


Fig. 4—*The elongation of steel as it is alternately magnetized is shown by cathode-ray oscillograms. The horizontal axis represents magnetic density; vertical axis, magnetostriction. Each vertical square is equal to a change in length of one part in four million. (a) shows a magnetostriction curve for a piece of ordinary silicon steel magnetized to a density commonly used in transformer practice; (b) the same steel when magnetized to one-third more flux density; (c) Hipersil carrying the same flux as the steel (b).*

Hipersil Makes Possible Transformer Redesign

The availability of a magnetic material of much greater flux-carrying capacity is as important as having copper capable of carrying more current. Because any well-developed engineering structure, like a transformer, represents a balance between materials, a sudden great improvement in one calls for complete redesign to utilize most effectively the new advantages. The superior properties can be utilized in various ways. They can be used solely to improve efficiency; efficiency can be held constant and weight and dimensions decreased. For transformers in which improved performance is more important the new material is so utilized; in other classes transformer weights and dimensions have been reduced. Iron losses have in some ratings been decreased.

Short-Time Overload Capacity and Regulation of Small Distribution Transformers Improved

Hipersil has, in effect, allowed a fresh start in transformer construction, from the smallest distribution unit to the power giant. An investigation of desirable improvements of each class of transformers has shown that in the small distribution transformers weight and dimensions are of minor consideration. Instead, modern requirements call for more short-time overload capacity, accompanied by better regulation so that this additional short-time overload capacity can be utilized. Because Hipersil has more flux-carrying capacity, the core is smaller, which in turn results in a smaller copper coil and fewer turns. Because this reduces the resistance and the reactance of the copper winding, better regulation is obtained. Also, with the smaller copper coils and core, more cooling duct space is provided and the volume to be cooled is smaller; therefore, the cooling gradient is reduced and the transformer has greater capacity for short-time overloads.

Temperature characteristics of the small distribution transformers are compared in Fig. 6. The ordinary silicon-steel transformer has a lower oil temperature, but because of the comparatively slower rate of heat transfer from copper to oil, the copper temperature is quite high. The Hipersil transformer has a lower temperature gradient (temperature difference between copper and oil), because the core and coils are smaller in volume and because the construction lends itself to better placement of the oil ducts. As a result, even with a higher oil temperature, the copper is cooler, and the transformer can carry an overload for a longer time without exceeding the maximum safe temperature rise of the copper winding.

The greater capacity for a short-time overload would be of no value without a corresponding improvement in regulation. Regulation at overloads limits the load-carrying capacity of a transformer to as great an extent as the thermal characteristics. The average improvement in regulation of small 2400-volt distribution transformers is shown in Fig. 7. The average effective increase in rating, based on the same regulation at 100 per cent power factor, is 14 per cent, obtained by the smaller amount of copper required in the coils and the consequent lower resistance. The average effective rating at 80 per cent power factor has been increased by 10 per cent because Hipersil carries more flux per unit area and thus requires fewer turns in the copper coil with consequent lower reactance.

Fig. 5—Demonstrations of the bearing of the greater permeability on core size and weight. The test cores at the left have the same iron loss, exciting current, and copper resistance, but the one at the left is made of Hipersil, the one at the right of high-grade ordinary silicon iron. The silicon L-plate core weighs 38¼ pounds; the Hipersil core weighs 21¼ pounds.

In addition to better performance from the small distribution transformers, Hipersil also results in an average weight reduction of 23 per cent in ratings from 1½ to 15 kva, 7200 volts and below.

In the larger sizes of distribution transformers smaller weights and dimensions are important considerations. This is especially true in the range of sizes where weight dictates the method of mounting on the pole. As an example, a power company may mount 50-kva transformers directly on the pole or suspended from the cross arm, but mounts 75 kva and larger on platforms. The latter method of mounting is considerably more costly and where existing units have to be changed to larger sizes, considerable expense is entailed if the method of installation must also be changed. Here the lighter weight Hipersil transformers offer a real advantage. In general, the Hipersil transformers are about one rating larger for the same weights and dimensions; for instance, a 50-kva, 2400-volt ordinary silicon steel transformer weighs 1130 pounds and a 75-kva Hipersil transformer weighs 1210 pounds. The 75-kva ordinary silicon steel transformer weighs 1340 pounds and a 100-kva Hipersil transformer weighs 1310 pounds. Thus one size larger rating can now be installed without changing the method of mounting.

In the larger distribution transformers Hipersil has been used not only to reduce the weight and size but also to improve the performance and reduce the losses, as shown in table I. The average reduction in weight of larger distribution transformers is 22 per cent and the average reduction in space requirements is 17 per cent. This is an important factor in industrial applications. The average reduction in iron loss is 10 per cent.

Distribution Transformer Cores Are Tightly Wound

The superior magnetic properties of Hipersil occur in the direction of rolling only or in the grain direction. It therefore demands a construction in which the flux at all times is parallel with the grain. In the small distribution transformers the method is to slit Hipersil into long narrow strips and wind these strips continuously on a rectangular mold or mandrel. This window opening is essentially as rectangular as obtained with the old L-punchings. In the next step, a strain anneal relieves all stresses produced by the winding operation. The strain-annealed core is impregnated with a plastic material. This keeps the core from spreading apart when it is cut in two pieces to permit the form-wound copper coils to be slipped into place. The two parts of the core are then fastened together, as shown in Figs. 9 and 10. The slit in the core is finished so accurately that the final joint is equivalent to less than 0.001-inch air gap, which does not increase the core loss.

TABLE I—COMPARISON OF 333-KVA, 2400-VOLT ORDINARY SILICON STEEL AND HIPERSIL TRANSFORMERS

	Weight	Iron Loss	Copper Loss
Ordinary Silicon Steel	5300	1310	3355
Hipersil	4150	1110	3355

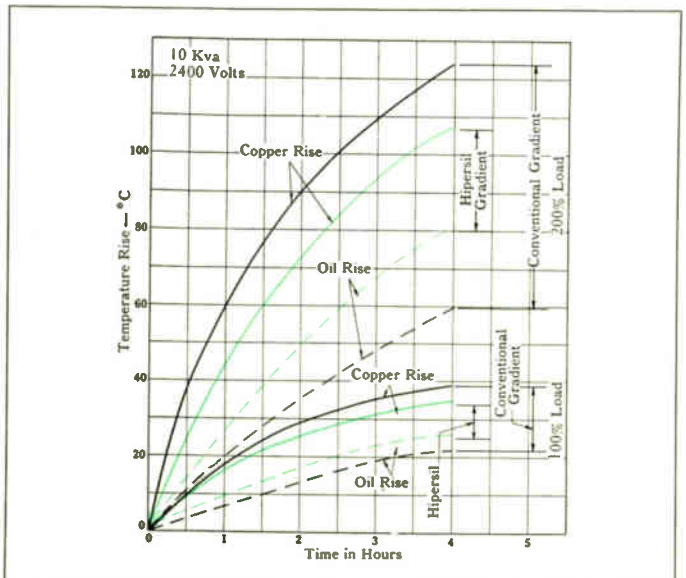


Fig. 6—*Although the oil in a Hipersil transformer is hotter than in one with the conventional core, the temperature of the copper (and hence of the insulation) is less. This fact accounts for the greater short-time overload capacity of the Hipersil unit.*

Manufacturing cores from ordinary silicon steel by such a procedure would be impractical. The material applied to insulate one lamination from the next must withstand the high temperature of the strain anneal. This insulating material must adhere tightly to the metal in order that the laminations can be bonded together successfully. With hot-rolled silicon steel the oxide films on the surface, generally used for insulation on small transformers, are too loosely adherent to permit adequate bonding. The plastic bonding material will successfully stick the oxides together but the oxides themselves strip from the steel. Any organic material such as is generally used for inter-lamination insulation is destroyed at annealing temperatures.

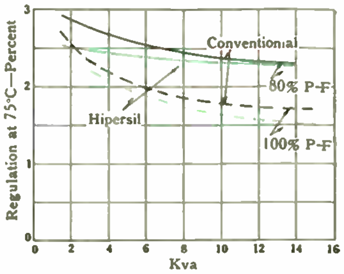
The surface insulating film on Hipersil is a silicate glass. This film is integral with the surface of the steel and does not peel off. Being a silicate glass, it will withstand temperature of strain annealing without deterioration.

Larger Transformers Have New Style Laminations

For larger distribution transformers, another type of construction is used in which the flux is always parallel to the grain direction of the steel. This method uses an alternate butt and lap joint with the ends of the laminations butting together at a 45° angle as shown in Fig. 10. It is adaptable for both single-phase and three-phase transformers. This type of construction was especially applicable in that it could be put into practice immediately without considerable tool expense.

For large transformers Hipersil has interesting possibilities. With the smaller core area and the resultant smaller copper coils, it is possible to reduce the size and weight of large transformers substantially. With the same losses in the core and the copper windings, the volume of these materials is greatly reduced and thus lends itself readily to artificial cooling. A 40 000-kva Hipersil forced oil-cooled transformer has recently been built in which the weight of copper was reduced 10 per cent and that of the core 25 per cent compared with that of the equivalent ordinary silicon-steel transformer. The use of Hipersil in large power transformers permits such reductions in size and weight that a 40 000-kva transformer, complete with bushings, can be shipped in its own tank on a flat car ready for installation without field assembly. This, of course, results in a significant saving in expense of installing the transformer.

Fig. 7—*The new small distribution transformers have better regulation at both unity and 80 per cent power factor.*



The Significance to System Investment

Consider a system requiring a capital investment in distribution transformers of $1 600 000, with an average load of 50 per cent.* Increasing the average load to 60 per cent decreases the investment to $1 335 000; an average load of 75 per cent decreases the investment to $1 065 000. This is a strong reason for loading transformers to their limit.

In the average installation one of two factors limits the degree to which a transformer can be loaded: thermal characteristics or regulation. Suppose Hipersil transformers were applied to the above $1 600 000 system with 50 per cent average load. If regulation were the limiting factor the improvement of 10 to 14 per cent in the smaller sizes would

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*This case is discussed in Edison Electric Institute Bulletin H-6.

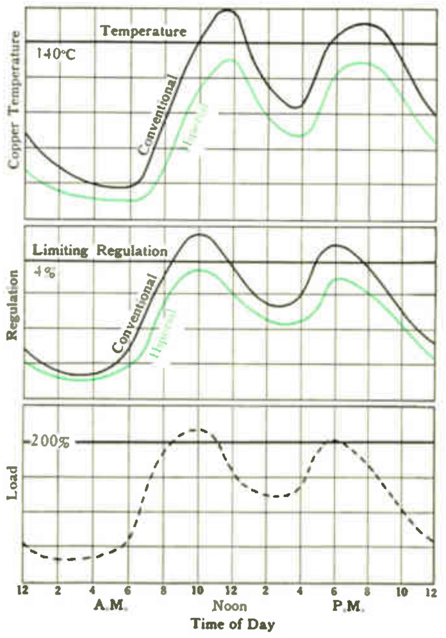


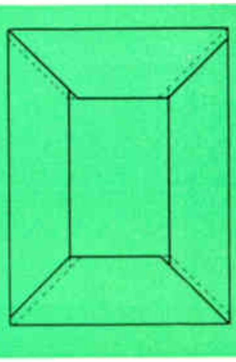
Fig. 8—*Transformers with Hipersil cores are better able to follow the average load cycle on distribution transformers. Data taken under actual conditions on a winter day in Pittsburgh, Pa.*

Fig. 9—For small distribution transformers the core is made of wound Hipersil instead of stacked laminations. After impregnating with a bonding material the core is cut in two so the machine-wound core can be slipped over the iron. The core halves are again joined and held in position by straps, as can be seen on the core and coil assembly in the lower left corner.

allow a saving of from $267 000 to $350 000 in investment. If thermal capacity were the limit the increase of 17 per cent in short-time overload capacity would mean a saving of $400 000 in investment in transformers. The use of the completely self-protecting transformer with inherent thermal protection would allow taking full advantage of these improved thermal characteristics.

There has been much study of methods for extending the network system to lower density areas such as high-class residential areas, business districts in small communities and the like. The Hipersil transformer has characteristics that adapt themselves well to such a system. Assume a system with a total peak load of 200 kva and an average load of 100 kva. If the simplest network design were made on the conservative basis of being able to carry full peak load with one feeder out of service, 100 per cent spare capacity would be necessary or total transformer capacity of 400 kva would have to be installed to carry the 200 kva peak. If the design were based on the primary feeder being open not more than one or two hours and full advantage of the overload capacity of transformers were taken, the transformer capacity could be reduced to 210 kva for overloads of one hour or 267 for overloads of two hours with the older design of transformer. This effects considerable saving in investment but even greater saving can be made with Hipersil as the capacity necessary when this transformer is used will be 177 or 238 kva for overloads of one hour or two hours respectively. This is an important saving in system investment when it is considered that the saving is not only in transformer capacity as considered in the first example but is also now in network protectors and other equipment that go into the system. By taking full advantage of this method of loading a much greater use of the network system can be expected.

Fig. 10—For larger transformers, which use the stacked-lamination construction, a new method of cutting the laminations has been devised so the flux path is always in the direction of the grain in the steel.



The completely self-protecting transformer fits well into such a program as the inherent thermal protection does safeguard the transformers under the emergency condition of one feeder being out of service. Should the trouble not be cleared up on the faulty feeder in one hour or two hours, depending on the basis of design, the transformers on the good feeder would be cleared before they overheated. Thus the network system in combination with the completely self-protecting transformer gives a thoroughly protected power-distribution system.

Hipersil as a new magnetic material again presents a starting point for further improvement in transformer iron. Perfect orientation has not been reached commercially as yet even in Hipersil. Doubtless, therefore, improvements can be expected, that will lead to better transformers.

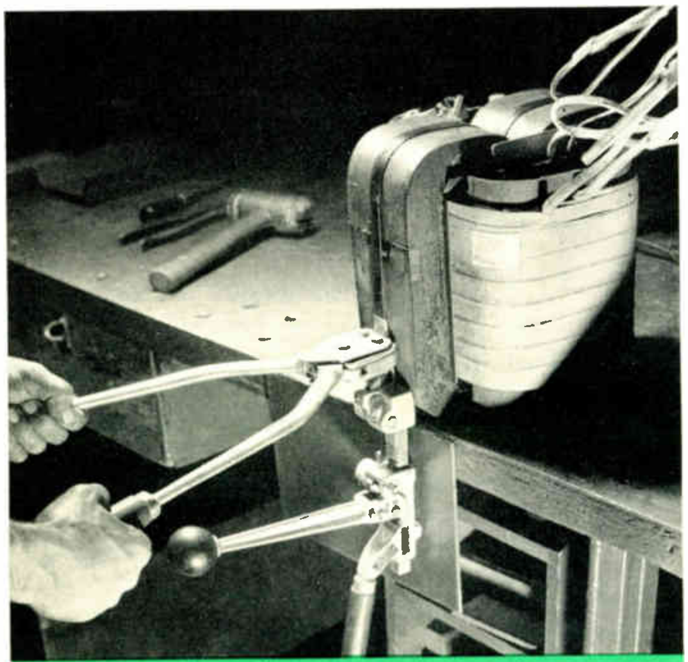


Fig. 11—The cores are fastened together by steel straps.

Line Constants and Circle Diagrams—Simplified

A novel approach to the calculation of transmission-line performance eliminates the tedious work necessary to evaluate line constants and the difficulty in construction of circle diagrams. The simplified method presented is not merely time saving. Through familiarity with a few elementary ideas and equations, it is now easy to visualize the transmission line as an equivalent circuit, which is as readily represented by circle diagrams as it is easy to calculate.

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THE standard classroom introduction to transmission-line problems has usually been rigorous. The exact equations for most problems involve hyperbolic functions, and their calculation is somewhat laborious. Furthermore, circle diagrams, so valuable in the study of power-system performance, have also been considered complicated, and for this reason not used frequently. It is much easier to represent the lines by equivalent circuits. Reasonable approximations in the constants of such a circuit not only facilitate computations, but also reduce the construction of circle diagrams to a few simple steps. If the simplicity and usefulness of the circle diagrams are better understood, they may be used more frequently for both transmission and distribution problems.

Equivalent Circuits for Short Lines

The distributed capacitance of three-phase lines shorter than 30 miles can usually be neglected, and their impedance can be represented by the equivalent "per phase" or single-phase circuit of Fig. 1a in which

$$Z = R + jX = zs = rs + jxs$$

where z, r, and x are, respectively, the series impedance, resistance, and inductive reactance in ohms per mile, and s is the length of the line in miles.

The vector relation between the line-to-neutral terminal voltages in terms of the impedance and line current is

$$E_s = E_r + ZI \qquad (1)$$

where E_s, E_r are the sending- and receiving-end voltages, I is the line current and Z the line impedance.

Two-wire, single-phase lines can be represented by the same circuit and equations by doubling Z.

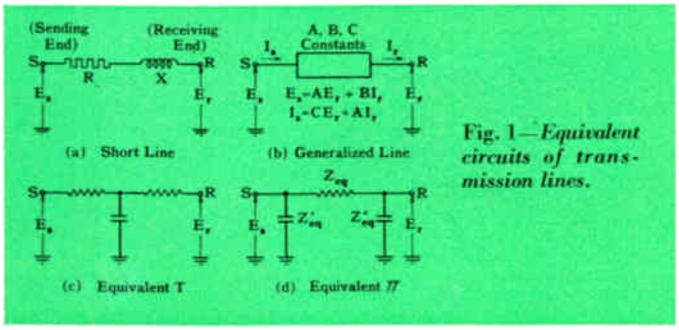


Fig. 1—*Equivalent circuits of transmission lines.*

Equivalent Circuit for Long Lines

Transmission lines of such length and voltage that the effect of distributed capacitance need be taken into account can no longer be pictured as the simple series circuit of Fig. 1a. Such lines are commonly represented by the conventional ABC constants of Fig. 1b, the equivalent T circuit of Fig. 1c, or the equivalent π circuit of Fig. 1d. Rigorous equations for such circuit constants involve hyperbolic functions which do not permit of rapid evaluation.

An equivalent circuit has several advantages over the ABC constants. It not only provides an actual circuit to be set up on the network calculator, but also affords a better picture of transmission-line performance. The equivalent π is preferable to the equivalent T, because it helps develop circle diagrams simply and clearly.

Circuit Constants for Long Lines

The exact equations for the branches of the equivalent π circuit are:

$$Z_{eq} = \sqrt{ZZ'}\,\sinh\sqrt{\frac{Z}{Z'}} = Z\left(1 + \frac{Z}{6Z'} + \frac{Z^2}{120(Z')^2} + \cdots\right) \ldots\ldots\ldots\ldots (2)$$

$$Z'_{eq} = \frac{\sqrt{ZZ'}\,\sinh\sqrt{\frac{Z}{Z'}}}{\cosh\sqrt{\frac{Z}{Z'}} - 1} = 2Z'\left(1 + \frac{Z}{12Z'} - \frac{Z^2}{720(Z')^2} + \cdots\right) \ldots\ldots\ldots (3)$$

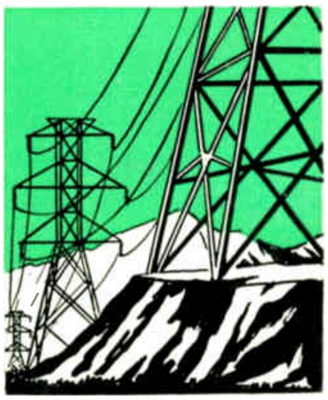
where

$Z = R + jX$ as in the short line

$Z' = z'/s$

$z' = -jx'(10^6)$

$x'^* =$ capacitive reactance, megohms per mile.



Because of conductor sag, its variation with different spans, diversity in conductor spacing, and effects of temperature upon conductor resistivity and sag, the resistance, inductance, and capacitance of an actual line can rarely be known with greater accuracy than three or four per cent, and probably never within one per cent. Equations expressing them within 0.5 per cent should therefore be serviceable.

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*This is commonly given in megohms in tables as it then becomes numerically of the same order as the inductive reactance.

For lines up to 300 miles in length the constants given by eqs. (2) and (3) can be determined to an accuracy of a few tenths per cent by using only their first two terms. The third term in these series may in extreme cases, for a line 300 miles long, introduce an error of as much as 0.5 per cent. However, varying with the fourth power of the length of the line, the third term diminishes rapidly as the line becomes shorter. Thus, for the same conductors and equivalent spacing, the error in the constants of a 150-mile line is only one-sixteenth that of a 300-mile line.

Using only the first two terms and separating the real and imaginary parts, eqs. (2) and (3) become:

$$Z_{eq}=R\left(1-\frac{xS^2}{300x'}\right)+jX\left[1-\frac{S^2}{600}\left(\frac{x}{x'}-\frac{r^2}{xx'}\right)\right]\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$Z'_{eq}=2Z'\left[\left(1-\frac{xS^2}{1200x'}\right)+j\frac{rS^2}{1200x'}\right]\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

where S = length of line, hundreds of miles.

Inspection of eq. (4) reveals that the equivalent impedance of the line, Z_{eq}, can be obtained from the lumped impedance of the line, Z $(=R+jX)$ by applying correction factors to the real and imaginary parts of the latter. Thus, by defining

$$K_r=1-\frac{xS^2}{300x'}\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$K_x=1-\frac{S^2}{600}\left(\frac{x}{x'}-\frac{r^2}{xx'}\right)\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

the equivalent impedance can be expressed as

$$Z_{eq}=RK_r+jXK_x\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Similar examination of eq. (5) shows that it is possible to express the equivalent leakage impedance of the line, Z'_{eq}, as twice the sum of the distributed capacitance, multiplied by correction factors. Letting

$$k_x=1-\frac{xS^2}{1200x'}\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

$$k_r=\frac{xS^2}{1200x'}\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

TABLE I—MINIMUM CONDUCTOR SIZES AND SPACINGS FOR WHICH THE MEAN CORRECTION FACTORS APPLY WITHIN ONE-HALF PER CENT

(Conductor sizes are in circular mils or AWG.)

Length of Line, Miles	50	75	150	200	300
G. M. D. (ft.)	3	6	6	10	14
Copper Cable	6	2	0	300 000	500 000
A. C. S. R. Cable	1	1	000	500 000	795 000
Anaconda Hollow Copper Cable	00	00	00	300 000	500 000
General Cable Co. Type HH	000	000	000	300 000	500 000

TABLE II—EQUATIONS FOR THE CORRECTION FACTORS FOR EQUIVALENT π IMPEDANCES

(S is length of line in hundreds of miles.)

Correction Factors	Values for Line Lengths up to				
	50 Mi.	75 Mi.	100 Mi.	200 Mi.	300 Mi.
K_r	$1-0.0141S^2$				
K_x	1	$1-0.0069S^2$			
k_x	1		$1-0.0035S^2$		
k_r	0				

the equivalent leakage impedance becomes

$$Z'_{eq}=2Z'(k_x+jk_r)\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Equations (6), (7), and (9) show that for a given line, the factors K_r, K_x, and k_x differ from 1 by a term that is proportional to the square of the length of the line. However, a study of lines which have been built economically in the United States reveals that, for any given length, these correction factors are approximately equal for all lines. Only in lines with uneconomically small conductor sizes and equivalent spacings do the factors vary appreciably.

A list of minimum sizes and spacings for which the use of mean correction factors is sufficiently accurate is given in table I. For lines up to 300 miles with conductor sizes and spacings equal to or greater than given by this table, the mean values for K_r, K_x and k_x are accurate within 0.5 per cent. The correction factor k_r is never greater than about 0.005 and can be neglected; thus, the shunt impedance Z'_{eq} can always be considered as a pure capacitance.

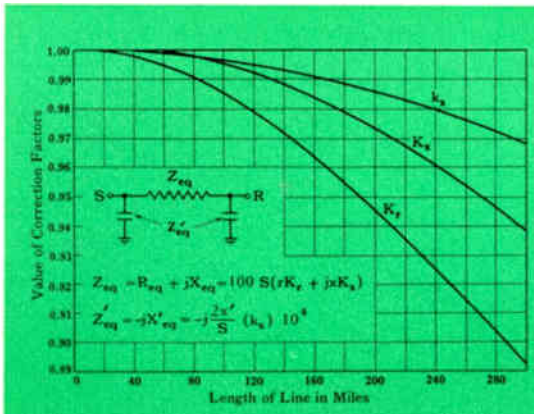


Fig. 2—*Correction factors for equivalent π transmission line impedances.*

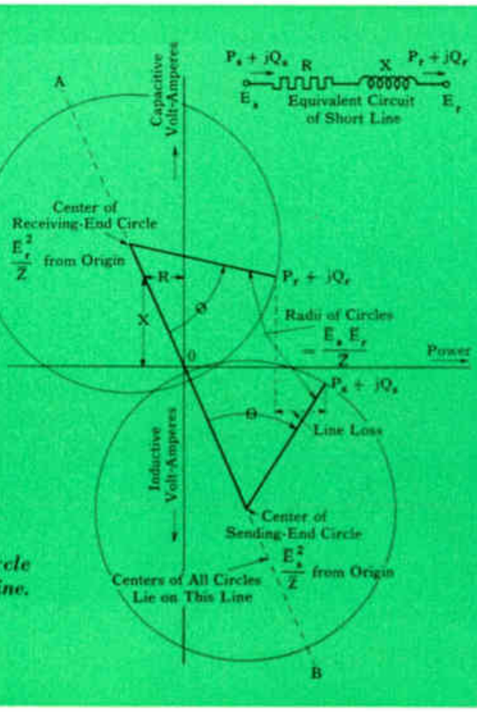


Fig. 3—*Power circle diagram for a short line.*

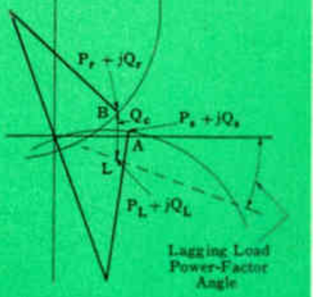


Fig. 4—*Relation between sending-end and receiving-end loads.*

The mean values of K_r, K_x and k_x as functions of line length are listed in table II, and the corresponding curves are plotted in Fig. 2. The factors can also be expressed to sufficient accuracy as parabolic equations of the type $(1-kS^2)$, and listed in this form in table II. Curves constructed from table II conform closely to those of Fig. 2. Table II shows that it is correct to consider K_r as 1 up to 50 miles, K_x as 1 up to 75 miles, and k_x as 1 up to 100 miles. Since individual sections of the lines are seldom longer than 100 miles, the correction factors can be neglected entirely if an error up to 1½ per cent is permissible. The largest deviation from unity is in K_r, which at 100 miles is only 1.4 per cent.

Power Circle Diagrams

To calculate the constants of a transmission line is usually only a step in the solution to the more general transmission problem, namely to supply a given load without exceeding a predetermined voltage drop. A graphic answer to this problem, in the form of a circle diagram, is preferable to an analytic one, for it is not only simple, but also shows readily and clearly the effects of changes in the load and the operating conditions. It is easy to see, for example, without any computations, the effect of a change in either the magnitude or the power factor of the load, or what would happen if a portion of the equipment such as a synchronous condenser were to be put out of service.

There is nothing mysterious about the construction of circle diagrams. It is particularly easy first to understand how to apply them to short lines. The extension of the method to long lines becomes then very simple.

Circle Diagrams for Short Lines

As its name implies, the circle diagram consists of one or more circles drawn for either the sending or receiving ends of the circuit, voltages at the two ends remaining constant. The circles are drawn on a coordinate system in which the abscissa denotes power and the ordinate indicates reactive volt-amperes. Any point on the circle represents the volt-amperes that must be delivered in order that a given amount of power be available at a chosen voltage. Two such circles are shown in Fig. 3, the upper for the receiving end and the lower for the sending end. The positive flow of power is indicated by arrows on the insert, being "in" at the sending end (P_s+jQ_s) and "out" at the receiving end (P_r+jQ_r).

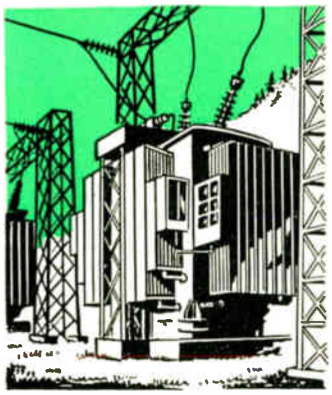
To construct these circles only the following simple rules need be observed.

1—Draw the line AB through the origin, inclined to the horizontal axis at an angle with tangent X/R, as shown in Fig. 3.

2—Locate the center of the sending-end circle along the line AB, in the fourth quadrant, a distance $\bar{E}^2_s/\bar{Z}$ from the origin.

3—Locate the center of the receiving-end circle along the line AB, in the second quadrant, a distance $\bar{E}^2_r/\bar{Z}$ from the origin.

4—The radii of the sending- and receiving-end circles are each equal to $\bar{E}_s\bar{E}_r/\bar{Z}$.



5—The angle θ by which the sending-end voltage leads the receiving-end voltage is measured from the line AB for both circles. To obtain simultaneous operating points at both ends, this angle must be equal for both circles.

6—The horizontal component of the distance between two simultaneous operating points, such as P_s+jQ_s and P_r+jQ_r shown in Fig. 3, is equal to the loss in the circuit, P_s-P_r.

If the voltages at both ends are fixed, there is a definite limit to the amount of power that can be delivered at the receiving end of a particular line. It can be shown that when maximum power is transmitted over the line, θ is equal to the angle between the horizontal axis and line AB.

Geometric consideration of Fig. 3 shows that the power at the two ends can also be calculated from the following expressions:

$$P_s=\frac{E^2_sR}{Z^2}-\frac{E_sE_r}{Z^2}(R\cos\theta-X\sin\theta)\ldots\ldots\ldots\ldots(12)$$

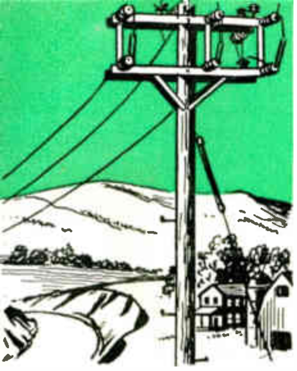
$$P_r=-\frac{E^2_rR}{Z^2}+\frac{E_sE_r}{Z^2}(R\cos\theta+X\sin\theta)\ldots\ldots\ldots\ldots(13)$$

The value of Q at each end represents the volt-amperes that must be supplied to the line (in the case of the sending end) or drawn from it (in the case of the receiving end) to maintain the chosen terminal voltages. If, at the receiving end, the reactance of the load alone is not enough, a synchronous condenser must draw or supply the remaining reactive volt-amperes. For example, if it is desired to deliver the load P_L represented by the point L on Fig. 4 at the lagging load power factor given, it is necessary that the negative (or inductive) reactive volt-amperes indicated by Q_C be supplied by the condenser. This machine must be operating over-excited drawing capacitive volt-amperes from the line and thus supplying the necessary inductive volt-amperes to the load.

Family of Circle Diagrams

In the usual transmission-line problem the receiving-end load and voltage are both selected in advance and it is desired to select a practical sending-end voltage and an economical regulation. For this choice, only the receiving end diagram is needed, comprising several circles corresponding to various fractions of the operating voltage, i.e., to various values of regulation. A graphic solution to such a problem is shown in Fig. 5. The location of the center of the circles depends only on E_r, which is fixed; all the circles are therefore concentric. The radii correspond to the different sending-end voltages.

This figure shows, for example, that the maximum line load at 0.9 lagging power factor and 5 per cent regulation, without capacitive kva correction, is that represented by point A or about 2600 kw. A load of 5000 kw, indicated by point B, can be transmitted without kva correction with



a regulation of 11 per cent. To reduce the voltage drop for this load to 5 per cent requires that the receiver end load be represented by the point C, directly above B, and that about 2400 kva capacitance be added.

Power Circles for Long Lines

Power circle diagrams for long lines differ from those for simple series impedances only in that the effect of the distributed line capacitance must be included. For the equivalent circuit shown in Fig. 6, it is clear that the circle diagrams for the points just inside the capacitances, namely $P'_s+jQ'_s$ and $P'_r+jQ'_r$ are exactly the same as those for a simple series impedance. P_s+jQ_s differs from $P'_s+jQ'_s$ by the leading reactive volt-amperes, $\bar{E}_r^2/\bar{Z}'_{eq}$, required by the capacitance Z'_{eq}. This fact is included in the circle diagram by simply raising the center of the circle for $P'_s+jQ'_s$ by the amount $\bar{E}_s^2/\bar{Z}'_{eq}$. Similarly, P_r+jQ_r is less than $P'_r+jQ'_r$ by the amount of the leading volt-amperes required by the capacitance.

To meet this simple requirement, the power circle diagrams are constructed as follows:

1—Draw line AB through the origin, inclined to the horizontal axis with a slope X_{eq}/R_{eq}.

2—Locate O'_s along AB in the fourth quadrant a distance $\bar{E}_s^2/\bar{Z}_{eq}$ from the origin.

3—Locate O'_r along AB in the second quadrant a distance $\bar{E}_r^2/\bar{Z}_{eq}$ from the origin.

4—Center for sending circle is a distance $\bar{E}_s^2/\bar{Z}_{eq}$ vertically above O'_s.

5—Center for receiving circle is a distance $\bar{E}_r^2/\bar{Z}_{eq}$ vertically below O'_r.

6—The radii of the sending and receiving circles are both equal to $\bar{E}_s\bar{E}_r/\bar{Z}$.

7—The lines of reference from which to measure the phase angle between the two end-voltages of the line are obtained by drawing O_sM and O_rN parallel to AB.

Since the only difference between this problem and that for short lines is in the addition of the capacitive branches, the expressions for power are the same as eqs. (12) and (13), except that the equivalent impedance Z_{eq} is used instead of Z.

Power Circle Diagrams for General Systems

Circle diagrams are equally applicable to the performance study of a general system, which can always be represented by an equivalent π circuit shown in Fig. 8. For such a circuit, however, the shunt impedances usually are not equal and include the resistance components of the various machines in the system. The construction of the diagram is shown in Fig. 8 and differs from that for a simple series impedance in that the real and reactive power at the sending-end branch must be added to $P'_s+jQ'_s$ in accordance with the voltage at that end. The diagram has been drawn as though Z' at the sending end has a positive resistance and an inductive reactance component. At the receiving end the volt-amperes delivered to the shunt impedance must, of course, be subtracted from $P'_r+jQ'_r$ to obtain the delivered volt-amperes.

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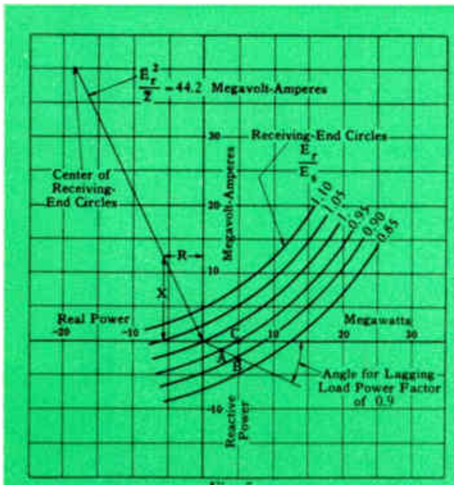


Fig. 5

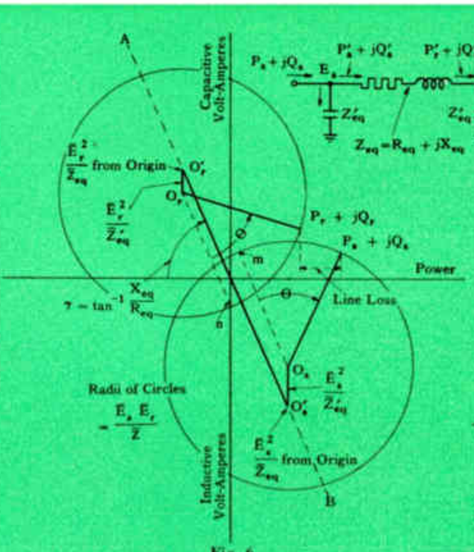


Fig. 6

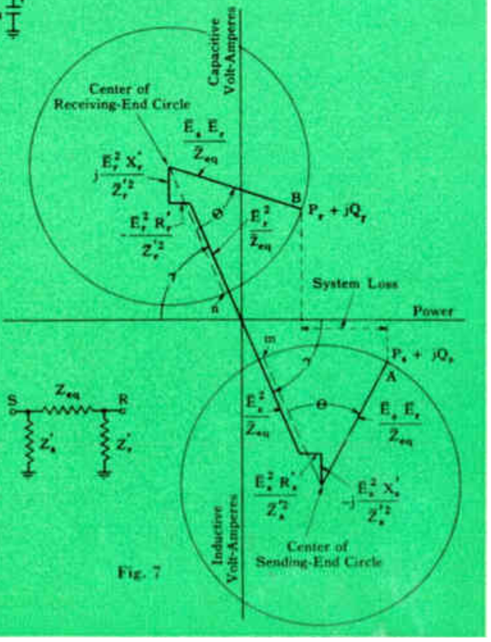


Fig. 7

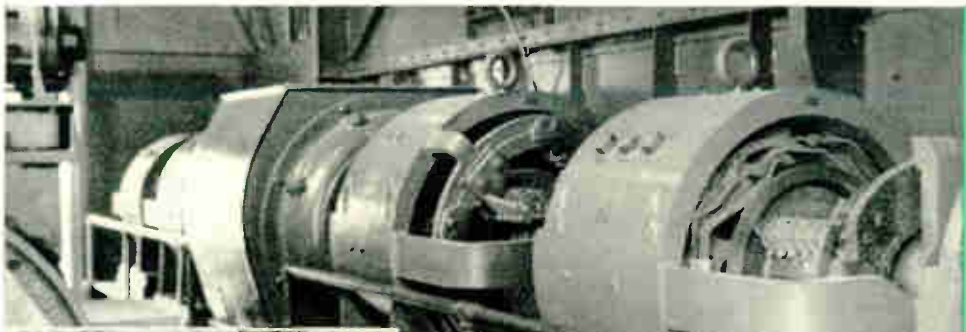
Fig. 5—Family of power circles for the receiving-end of a typical short line.

Fig. 6—Power circle diagram for a long line.

Fig. 7—Power circle diagram for the general equivalent circuit of a system.

Digging Colossus Takes 30-Yd. Bites

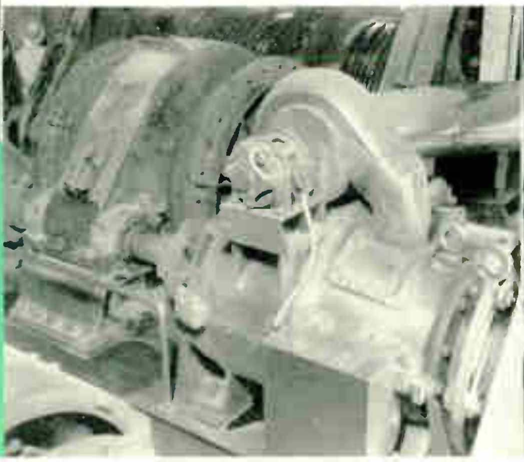
Electric shovels are coming big these days. Latest type Bucyrus-Erie shovel at work removing the overburden of dirt from a coal seam at Cuba, Ill., mine of the United Electric Coal Co. has a 30-yard dipper, equivalent in volume to a single-car garage. The shovel has a long reach, too. It can dig to the top of a 100-foot bank and with its 73-foot dumping height it can fill a gondola on top a six-story building. From one position it can dig in an area nearly equivalent to that of a football field, and dump its load anywhere in a 114-foot radius. The dipper handle is 70 feet long, and the boom, 108 feet.



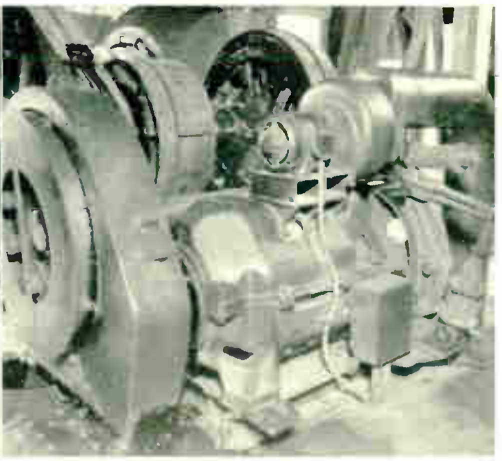
Variable-voltage power for the electric shovel's five main motors is supplied by a 1000-hp synchronous motor driving five generators: two of 225 kw for the hoist motors; two of 112.5 kw for the swing motors; and one of 112.5 kw for the crowd. In addition there is a 35-kw, 125-volt exciter. The rotor of each machine in the set is carried on two sealed ball bearings, and the shafts are joined by flexible couplings. The generators have horizontally split frames, and all working parts are accessible for maintenance.

The shovel, for all its size, is very easy for the operator to control. Before him are two pedestal-mounted master switches for hoist and crowd, and a foot switch for the swing. A thumb-operated switch in the crowd pedestal controls the dipper trip motor. The master switches operate magnetic contactors that control direction of excitation and field resistances.

The counterbalanced hoist is operated by two motors, each having a continuous rating of 250 hp, 230 volts, 410 rpm. The motors have cast-steel frames and are forced-ventilated. Each motor is supplied by a generator that delivers 550 volts at no load. At 1650 amperes, which is the stalling current, the voltage is just equal to the resistance drop through the two armatures.



The crowd, which holds the dipper in the bank during digging, and which extends or withdraws the dipper handle as required, is driven by a forced-ventilated motor with a continuous rating of 125 hp, 230 volts, at 475 rpm. Its generator provides 600 volts at no load, and a stalling current of 900 amperes. Swing motors are similar to the crowd motors, but are vertically mounted.



What's New!

High-Frequency Capacitors for Low Voltages

A ton of steel weighs no more than a ton of feathers; but the latter is much more difficult to handle. Similarly two high-frequency capacitors, rated at the same kva, differ greatly in design if one is for 1250-volt and the other for 300-volt service. Lower voltage means higher currents; limitations in terminal size and excessive heating of current-carrying parts have heretofore prevented the design of capacitors for low voltages. This bottleneck has now been eliminated and it is possible to build a 230-kva, 300-volt capacitor for continuous service at 11 520 cycles. Such a unit draws 766 amperes—far beyond previous limits.

This capacitor, the size of a 15-kva 60-cycle unit, can handle continuously 230-kva (766 amperes, 300 volts) at 11 520 cycles.

Recent developments in high-frequency heat treating have created a demand for new capacitors, not only for higher frequencies, up to 12 000 cycles, but also for direct connection to low-voltage furnaces, as low as 300 volts. These low-voltage ratings call for high currents in the capacitor terminals and working elements. It is this problem of dissipating the heat in the terminal studs, case parts, and internal current-carrying parts, that has bottlenecked the design of capacitors at kva ratings that the insulation can carry safely.

Previous increase of kva rating of capacitors had been made possible through the development of efficient internal water cooling. This removed the dielectric loss from the insulation and kept it within a safe operating temperature. Water cooling had made it possible to build 230-kva units for 625 to 1250 volts, 2000 to 3000 cycles.

Further increase in the current-carrying ability of the capacitor is made possible by water-cooling not only the working elements, but also the case and terminals. The higher frequency rating is achieved through metallic shields that prevent magnetic fields from inducing eddy currents in the housing and spread the heat over a larger area, for easier cooling.

The availability of a low-voltage, high-frequency capacitor is of great importance to induction heating. High-frequency furnaces operate at low power factors, approximately ten per cent. It is therefore important that the corrective capacitors be placed close to the furnace, to eliminate excessive voltage drop in the leads. But efficient design of furnaces calls for low voltage, to permit the use of small induction coils. Providing a capacitor of low enough voltage to be placed at the furnace, and of high kva rating, is sure to simplify furnace installations.

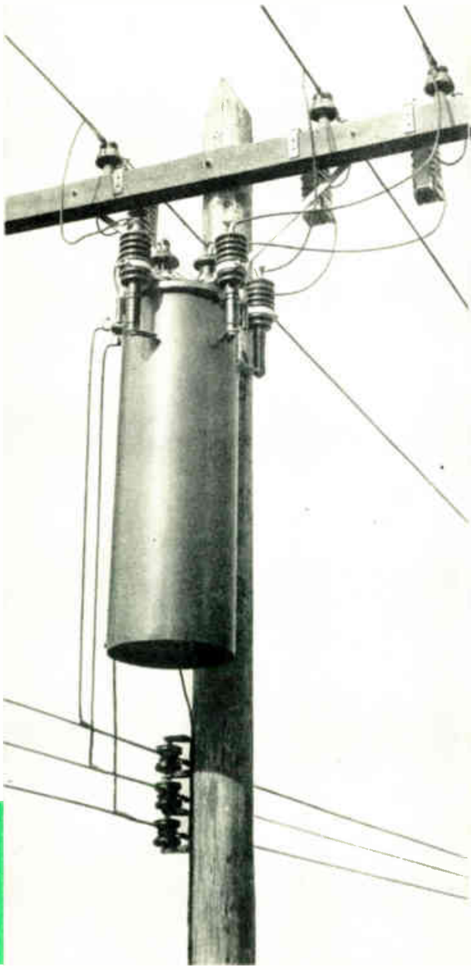
Three-in-one Transformer Saves Space

A single three-phase transformer is light and compact—certainly! But in many installations the demand for reliable service dictates the bulkier use of three single-phase units. In case of failure in one phase, it is cheaper to replace one-third of the equipment than it is to get a whole new unit. Two single-phase transformers can also be operated in open delta and thus supply a major portion of the load while the faulty transformer is being replaced.

Combining the reliability of three transformers with the compactness of a single unit, the Triplex Distribution Transformer houses three single-phase transformers in one oil-filled tank. Designed to be mounted on poles, the slender housing conforms to the shape of the pole, to which it can be readily fastened. This unobtrusive appearance is particularly desirable in fine residential areas. The transformer can also be used in vaults of substations or underground distribution systems, effecting, thereby, savings in floor space up to 66 per cent.

The complete unit comes filled with oil, and ready to use. All high- and low-voltage leads come to marked studs on terminal boards under oil. Electrically speaking, the three transformers are separate. Although no external connections are required between single-phase units, it is unnecessary to disturb any one winding to change connections. Each single-phase transformer is readily removable, in case of burnout or short-circuit.

Triplex transformers, rated up to 150 kva and 13 200 volts, incorporate the most modern materials and design, such as non-aging silicon steel or Hipersil, wound cores, vacuum impregnated insulation, up-to-date bracing and ventilation of coils, and coordinated insulation between windings and bushings. They may also be protected against surges by means of De-ion gaps.



15-kva, 13 000-volt, three-phase transformer is mounted on a pole conveniently and unobtrusively.

Inexpensive Meter Indicates Both Energy and Demand

A PRINCIPLE of operation cannot become obsolete; it can only be relegated to future applications. Thus in attempting to develop a low-cost demand meter, Westinghouse engineers recalled their pioneer work of a generation ago, the Lincoln thermal demand meter. Twenty years ago, demand rates were applied primarily to large loads, for which more efficient meters were later developed. The application of the thermal principle was therefore shelved.

The modern trend is to extend the advantages of demand metering to lower loads, but the cost of a separate demand meter is seldom justified in smaller installations. This objection is now eliminated by incorporating a thermal demand element into a conventional single-phase watthour meter.

The watthour meter proper is of the usual induction type, complete with the normal watthour register. The thermal unit, which operates the demand indicator, is entirely independent of the other meter except that its voltage component is supplied from a secondary winding located over the potential coil of the watthour meter. This novel arrangement obviates the need for potential transformers, an expensive part of the original thermal meters. Further maintenance economy is achieved by encasing the bimetal heating element in a thoroughly electrically and thermally insulating plastic compartment. This reduces the energy required to expand the bimetal strips. The combination demand and energy meter is as simple to install as the usual watthour meter, and takes no more room.

The thermal demand element has not only a low first cost, but is also inherently inexpensive to maintain, because it eliminates many of the maintenance problems usually associated with motor-operated demand mechanisms. However, on larger loads, the higher accuracy required warrants the installation of modern, mechanically operated demand meters.

More Transformation per Cubic Foot

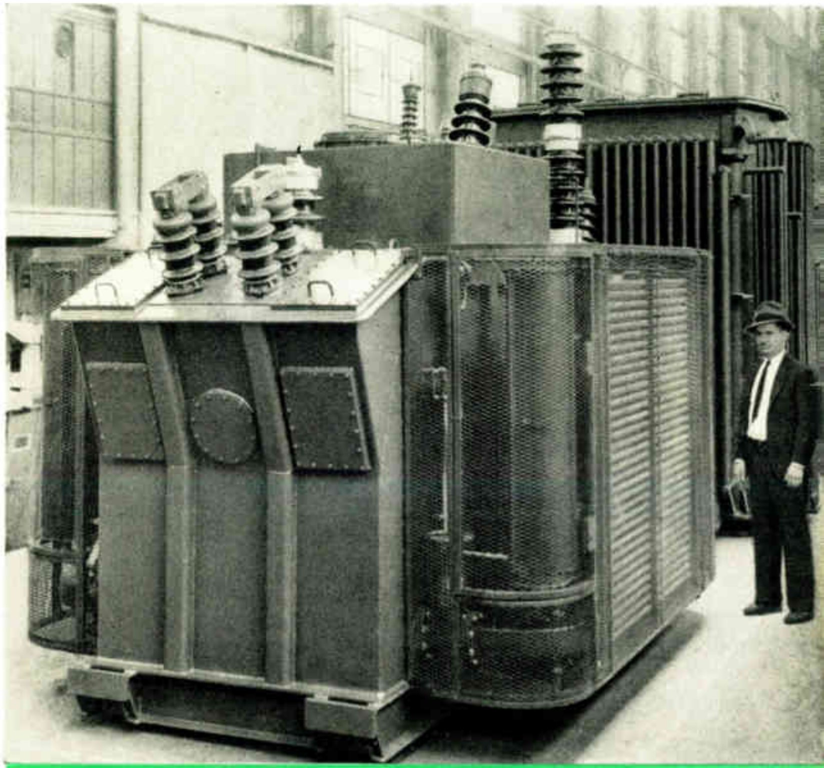
IN merchandising it is "turn over," in engines it is speed. The principle is the same, it is means of accomplishing more with a given investment or material; materials are worked harder or more often to give a better result. This idea has been applied to produce a wholly new kind of power transformer. One rated at 40 000 kva weighs but approximately half as much as a standard self-cooled unit of the same rating, is eight feet shorter, covers only about three-fourths as much ground space, uses less than half as much oil, and can be shipped on a flat car complete with oil and bushings, ready for immediate service when placed on the foundation. The labor of erecting and connecting in the field is obviously reduced to a minimum.

The new type of transformer represents the summation of several new ideas and materials, although the basic principle of the construction has been used successfully in many portable units in ratings up to 5000 kva. Its core is made of Hipersil. This new magnetic steel has a flux-carrying capacity one third greater than previous best grades of silicon steel. The use of Hipersil and of forced oil cooling instead of a self-cooled airblast produces a reduction of one fourth in core weight and one-tenth in copper weight. The shell form of construction is utilized with the oil ducts running horizontally through the winding to reduce the height. The higher rate of dissipation of heat from the windings by continuous circulation of oil permits working the copper at higher densities and keeping temperature gradients normal, reduces the space occupied by the core and coils, and reduces the amount of oil required. It is estimated that a drop of oil makes the round trip with a load of heat from coil to cooler and back to the coil in 80 seconds. The radiators on either side of the tank are cooled by 16 motor-driven fans. These fans are controlled automatically to start and stop as needed to keep the temperature of the oil in the transformer below prescribed maximum safe limits.

To prevent excessive copper temperatures from developing on failure of the cooling system, relays actuated by copper temperature are provided in each unit. When the copper in the coils reaches a resistance corresponding to a temperature of 105°C, a warning signal urges the station operator that reduction of load is in order. Should the copper temperature continue to increase and reach a dangerous point, a second set of relay contacts actuates another signal for immediate shutdown. It is not likely for the transformer to become actually overloaded, because it usually matches the station's generating capacity, but it is possible that failure of the fans or pumps on one side of the transformer may cause the copper temperature to become excessive even under normal full load for which the entire cooling system must operate.

The cover of the transformer is welded in place. The small size of the unit and the small quantity of oil permit the tank to be sealed tightly, eliminating breathing entirely. This results in excellent preservation of the oil.

This type of transformer will probably have an extensive application at base-load stations where relatively little overload capacity is required. The first unit of this new construction will consist of a bank of three, 40 000-kva, single-phase, 138-kv transformers soon to be installed at the Philo station of the Ohio Power Company, a subsidiary of the American Gas and Electric Company.



This transformer is unique both in appearance and in performance. Although rated at 40 000 kva, single phase, 138 kv, it is but 160 inches high, weighs about 92 000 pounds, and uses only 2530 gallons of oil.

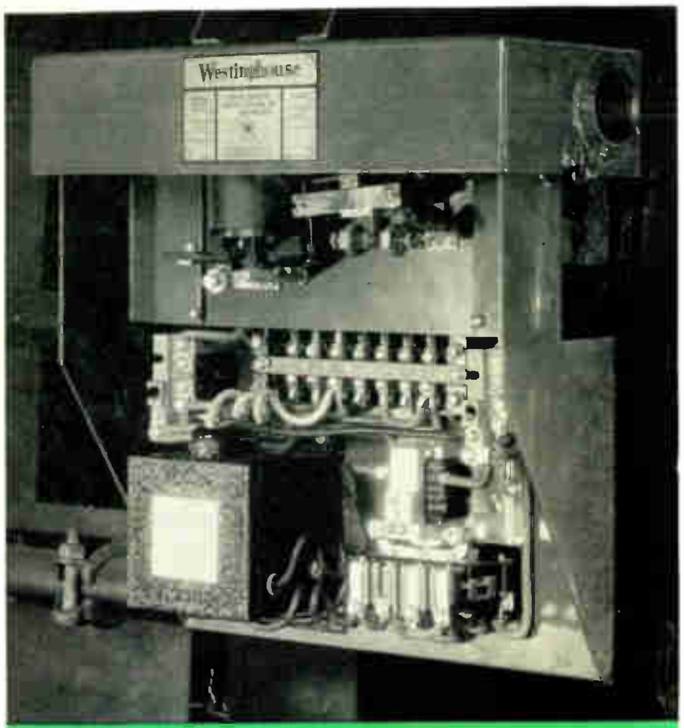
Automatic Switching Control for Capacitors

EVERY glamorous discovery is accompanied by many simple, everyday kinks and gadgets that neither stir the imagination, nor perform stupendous tasks. One of them, an automatic switching contactor for distribution capacitors, is a prosaic but new device, designed for a particular job and doing it well. It controls the electrically operated oil contactor usually employed to add capacitors to a distribution line whenever the circuit voltage drops below a specified value. When the potential rises above an upper limit, the condensers are automatically disconnected.

Essential to the successful performance of such an automatic control must be a relay sensitive to small changes in voltage. Such a relay must have positive-make contacts, which do not arc when the line voltage persists at approximately the contact setting. Furthermore, the voltage relay must not be instantaneous, to insure that the capacitors are connected and disconnected only if the rise and fall in voltage are sustained. This prevents transient voltage fluctuations from operating the controller.

All these requirements are incorporated in a compact unit, about the size of the standard 15-kva capacitor, that mounts readily on the same distribution pole as the capacitor bank. It performs a task not economically justified by previous equipment. True, automatic switching of capacitors has been possible for some time, but only to provide multistep control for large banks, to fit load conditions at substations. The new control is primarily a single-step device for capacitors located along the distribution lines.

Usually distribution capacitors are permanently connected to the circuit, in banks sufficient to counteract the reactive component of an



Automatic switching of capacitors for power-factor correction now becomes economically justified in distribution circuits by means of this compact control unit.

average load. During peak conditions it is desirable to increase the power limits of the line by adding more capacitors, but these must be switched off when the load returns to normal. The installation of the additional capacitor banks can be justified now that an economical control for automatic switching is readily available.

Welder Has Face Lifted

Just because welding machines are useful, they need not necessarily be large and clumsy. There are many applications—garages and small shops are but two—where occasional welding operations can be easily performed with a small, portable unit. The illustrated compact welding motor-generator set is rated at 150 amperes, and in a pinch can deliver 200. This current capacity, high for a machine this size, is achieved by running the generator at 3500 rpm, twice the speed used on larger machines. As an aid to simplicity in operation, a single preset dial indicates both the welding current and the corresponding no-load voltage. The unit is horizontal, has half the weight of a standard welding set, and is equipped with a full-size four-wheel moving gear that makes it easy to wheel it around and put it out of the way. An outstanding feature of its design is the attractive, streamlined enclosure that contains all the parts. There is even a tool compartment inside the cover, making the machine completely self-contained.

What looks like a typewriter case, or a toy tank, is a real portable welder. Small in size, it is nevertheless capable of performing work comparable with its big brothers.

Capacitors on the Bandwagon

The trend in present-day additions to power-distribution systems is to unit constructions. Capacitors have fallen in step with this idea. A bank of 540-kva of capacitors now rolls on wheels. This mobile unit can be drawn by a truck to any power location and be quickly placed in service by simply connecting the leads to the three-phase line, unblocking the relays, and making the proper relay adjustments for that locality. The trailer has its own oil circuit breaker, protection equipment, and automatic control. The three banks of standard 15-kva Inerteen capacitors, 90, 180, and 270 kva, are arranged so that any capacity up to 540 kva can be obtained in steps of 90 kva. An important feature of the mobile unit is the short time required for the addition or removal of a bank in response to voltage variation. The automatic control makes the transition from one step to another in less than five cycles. This assures a minimum of transient disturbance.

The mobile capacitor can be used for temporary power-factor correction, for use during transformer repair, or for preliminary field checks of proposed permanent capacitor installations.

This is not a streamlined mobile circus cage for wild animals. Instead it contains capacitor units with which distribution engineers can set out on a safari for lurking low power factor. This one is for the Allentown district of the Pennsylvania Power and Light Company.

PERSONALITY PROFILES

The interest of *REGIS D. HEITCHUE* in air conditioning possibly had its beginning when, as a lad of six, he swiped a cake of ice from an ice wagon and tried to cool the house by putting it in the furnace. A young man, he is already a veteran air-conditioning engineer. From 1935 to 1939 he was in charge of the Westinghouse experimental laboratory in which air-conditioning equipment was developed and tested. For the past two years he has been active in the design and development of the apparatus itself. He has had a variety of experience in reversed-cycle refrigeration, having been in direct charge of the installation of the 320-ton heating and cooling system in New Haven, Conn. He also has assisted in developing the window-type heating and cooling air conditioner.

Johns Hopkins University is noted, among other things, for the large number of its graduates specially trained in insulation and dielectrics. *DR. L. J. BERBERICH* is one of these. A student of the eminent Drs. Whitehead and Kouwenhoven, he obtained his bachelor degree in 1928 and followed it with a doctorate in engineering in 1931. Even while at the university he seemed headed for research, having been associated with the National Bureau of Standards.

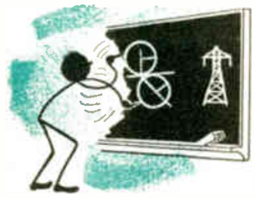
From 1931 to 1937 he was research engineer in the Research and Development Division of the Socony-Vacuum Oil Co., Inc., where he was placed in charge of a phase of insulating oil research. He joined the Westinghouse Research Laboratories in 1937 where he assumed charge of the physical section of the Insulation Division. He has helped solve many problems of electrical insulation, of which the latest is the elimination of corona from end windings of generators.

"When we run into something we don't understand we take the problem to Kroon," one of his associates in the Westinghouse Steam Division was heard to say. *R. P. KROON* does have the enviable ability to visualize phenomena ordinarily expressed in complex mathematical form. Many contributions to steam-turbine practice have resulted from his clear material concepts of abstract calculation. A native of Holland, he obtained his engineering education at the Technical Academy of Zurich, Switzerland. He joined Westinghouse in 1931, and in 1937 was placed in charge of the Steam Experimental Division. Tall, quiet, unassuming, he has a talent for personnel work. Each spring he is a familiar figure on college campuses, interviewing graduating engineers and assisting them plan their future work.

RALPH WRIGHT is a modest fellow. When we asked him some questions about himself, he replied somewhat apologetically, "I'm not an inventor, like lots of engineers; I simply try to apply electric machinery to the solution of steel-mill problems—and make 'em work." [Note: Wright does hold a dozen patents. His little black book, which lists all the steel-mill electrifications he has dealt with, reads like a roll call of the steel industry.] Since entering this work for Westinghouse in 1917, on graduating from Purdue as an E.E., he had much to do with planning the electrical equipment for many now famous installations such as the Homestead Beam Mill, the first electrically driven beam mill. There many ideas, then thought revolutionary, were first tried, such as automatic screwdown, separate edging-roll motors, and preset rolling schedules. He helped develop the first twin-motor drive in which two 5000-hp motors individually drove the two rolls of a beam mill, the synchronous-type speed regulator, means of operating reversing-mill generators in parallel, automatic screwdown for beam mills, excitation systems for reversing equipment, synchronous ties for power transmission, and all sorts of regulators for both speed and current.

Of *C. C. HORSTMAN* it was said, "He is the only man who has been able to make Hipersil sit up and behave." Which is to say, to Horstman fell the big problem of guiding Hipersil through the maze of difficulties that for any new material lie between the research stage and consistent performance on the production line.

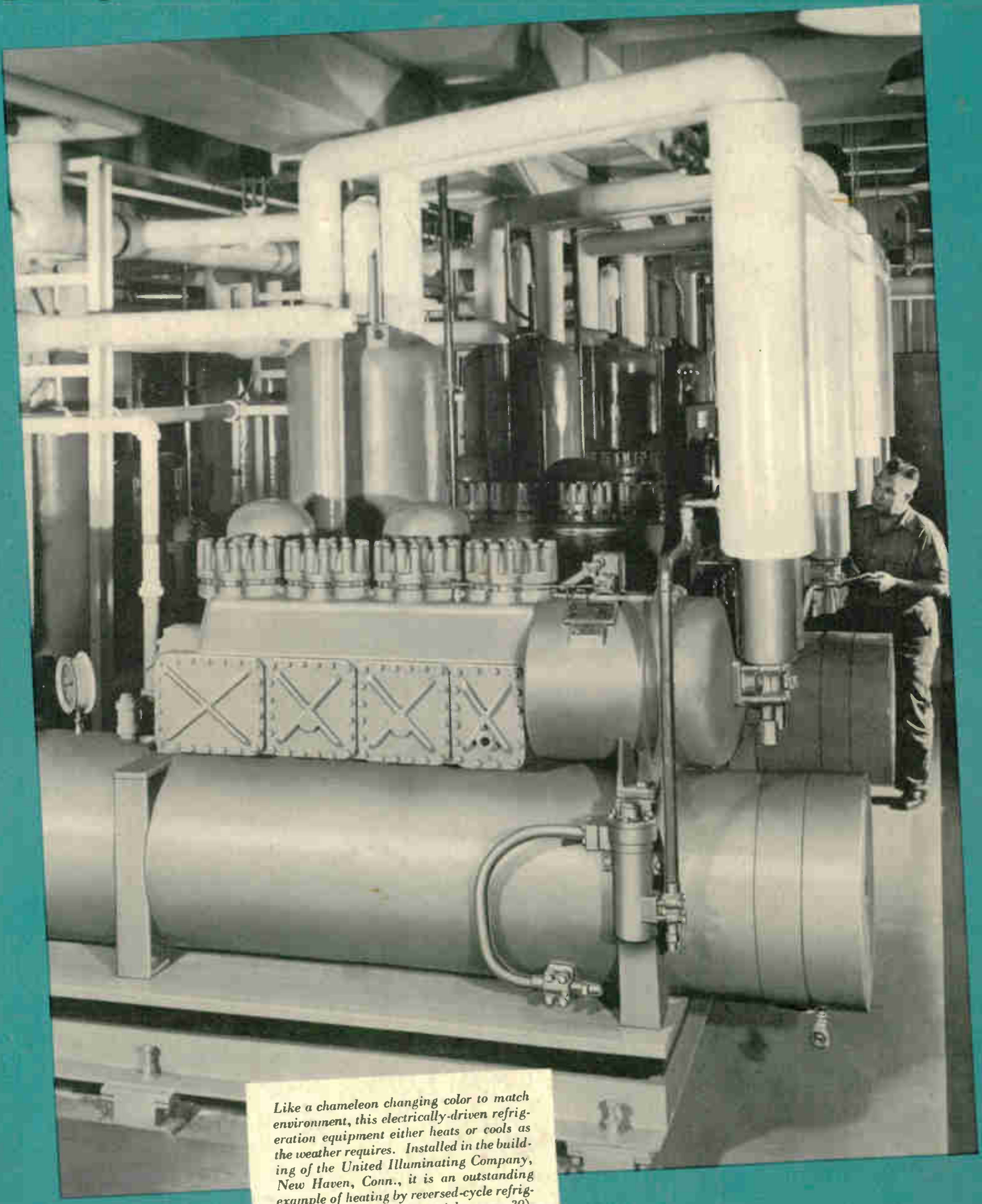
On leaving Washington University, St. Louis, as an Electrical Engineer in 1930 he went to Westinghouse Research Laboratory to work with tube-circuit problems and on noise measurements, thence to Gulf Refining Company for five years to deal with power-layout and illumination problems—with instrumentation thrown in for good measure. In 1937 he assisted at Westinghouse in the design of metal-clad switchhouses. In 1938 he moved to the feeder division, to help develop and apply magnetic materials. It was there that he was introduced to Hipersil—or perhaps we should say Hipersil was introduced to Horstman. He has also been largely instrumental in the development of the new method of winding transformer cores. His "way" with Hipersil led to his present position as Materials and Development Engineer, Transformer Division.



"Positive sequence" is an apt designation for the array of contributions to engineering theory and practice made by the co-author of "Symmetrical Components." Ever since his first article was published in 1922, *C. F. WAGNER* has been progressively busy explaining things, particularly power transmission. He has been recently promoted to Manager, Central Station Engineering Department. And rightly so, for most of his professional life (he came to Westinghouse in 1918, a year after graduation from Carnegie Tech) has been spent in the study of transmission system performance; he is a recognized authority on the effects of lightning on transmission apparatus. Transmission-line stability, machine behavior under short-circuit conditions, high-voltage and lightning phenomena—there's enough in these problems to fill many longer careers (he is only 46). But not Wagner's. In 1933–35 he digressed enough from transmission to collaborate in the development of the Ignitron. And one can hardly dismiss as "zero sequence" authorship of some forty technical papers, possession of over thirty patents, and the widespread fame of "Symmetrical Components" as *the* text on unbalances in polyphase circuits.

Although a graduate mechanical engineer, *J. K. HODNETTE* has won distinction for many improvements he has made in transformers. He was named a Pioneer Inventor during the nation-wide selection last year of outstanding living inventors and the Westinghouse Company gave him the Silver Award for Merit for his many transformer improvements. To him goes principal credit for the completely self-protected distribution transformer. He also made significant achievements in the shielding of power transformers. While manager of Distribution Transformer Engineering, he led the work of redesigning distribution transformers to use the new magnetic steel of which he and Mr. Horstman write. He has recently been elevated to the managership of the entire Transformer Engineering Department. Hodnette is a tall, slender southerner with a crisp humor. He believes—and practices—that one's planned educational program does not end with graduation. He received his degree from Alabama Polytechnic Institute in 1922, and on coming to Westinghouse the following year, registered for engineering classes in the night school of Carnegie Institute of Technology, and later took additional work in mathematics by extension courses. He likes to hunt deer, and says he has just as much fun as if he shot one.

New tasks FOR ELECTRICITY



Like a chameleon changing color to match environment, this electrically-driven refrigeration equipment either heats or cools as the weather requires. Installed in the building of the United Illuminating Company, New Haven, Conn., it is an outstanding example of heating by reversed-cycle refrigeration (described in an article on p. 39).