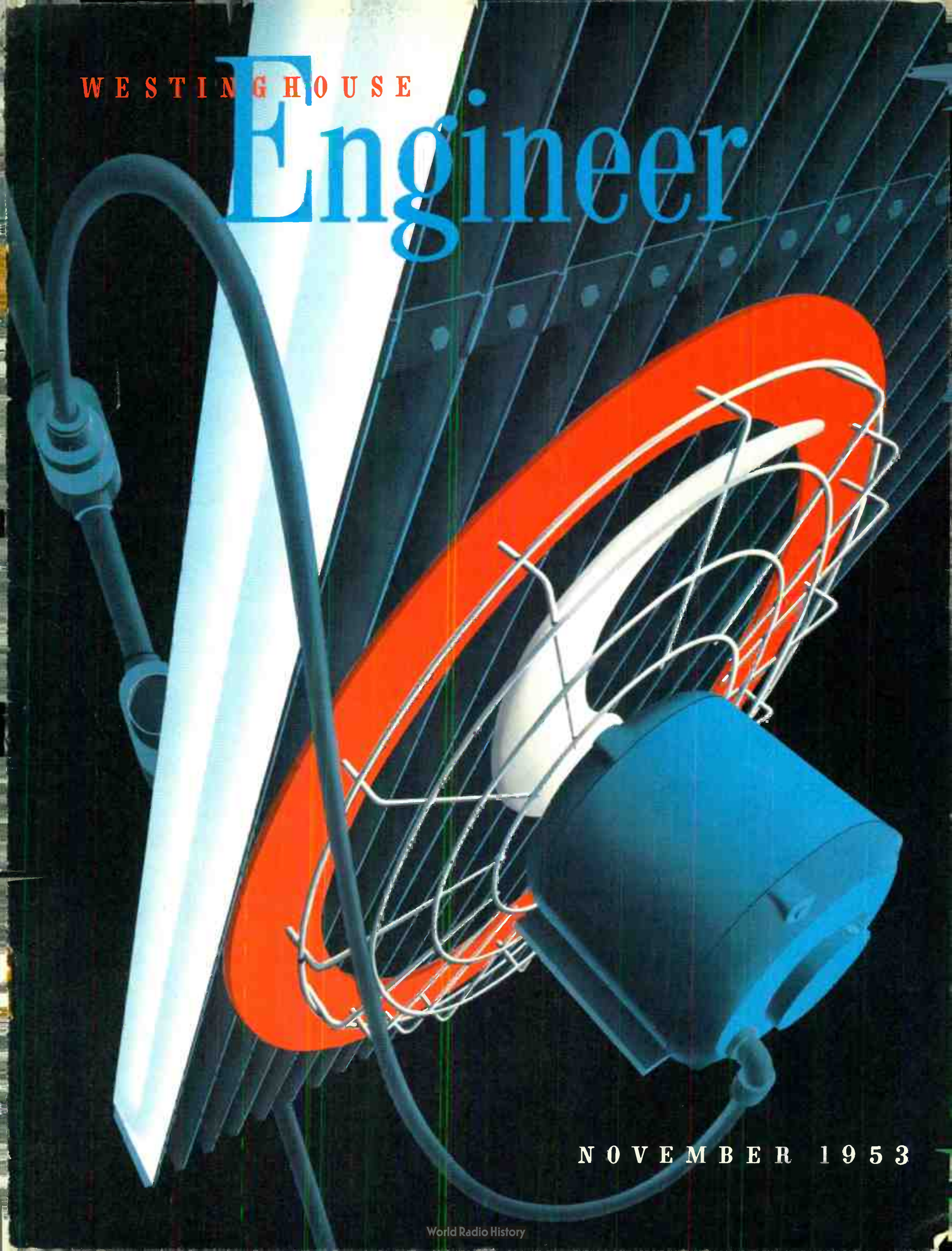
WESTINGHOUSE Engineer



NOVEMBER 1953

progress in Atomic Power

The following paragraphs are excerpts from testimony presented earlier this year by Gwilym A. Price, President of the Westinghouse Electric Corporation, and Charles H. Weaver, Manager of the Atomic Power Division, before the Joint Committee on Atomic Energy, Congress of the United States.

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"Before the outbreak of World War II, some of the original basic nuclear-fission research, upon which the Government later drew, was accomplished by Westinghouse at company expense. We built one of the first particle accelerators. Thereafter, we performed work for the Manhattan Engineer District. From the early days we have felt strongly that atomic energy would become, in time, a great source of power; and the modern world has an almost insatiable power hunger.

"It was natural for us, therefore, to be interested in possibilities of manufacturing and selling the equipment that would harness this new resource to power production—whether our customers might wish the power to turn a ship's propeller or to drive a dynamo making electricity. When, in late 1948, the Atomic Energy Commission asked us to build a power-plant prototype for the first atomic submarine, such a task seemed a local extension of our prime activities in the past; and we accepted the responsibility.

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". . . There is indeed one over-riding practical problem which we should like to emphasize—the sheer, stubborn, time-consuming difficulty of designing and engineering in detail and putting together any reactor that will do what one wants. . . .

"Where the scientist leaves off and the engineer takes up, and especially where their work overlaps, is the point at which problems become intense. Except for the genius of the scientist, there would, of course, be no such thing as a reactor. But this very fact has tended to divert from the painful, creative role of the engineer who must, in one sense, bring a scientist's dream down to earth and make it into a real structure of fuel elements, control mechanisms, moderator, shielding, pipes, pumps, pressure vessel, heat exchangers, and all the specially adapted gear that comprise an atomic power plant. Building such a plant on paper is one thing. Building it in fact is a very different matter. As the only company that has actually built a large atomic power plant designed to produce substantial quantities of useful power, we must state that developing and constructing a still larger and longer-lived advance-design reactor would remain a most arduous task, even given the type of complex facilities and going organization which have been built up. . . .

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"From the beginning, our atomic assignment has had first call upon all company personnel, and its problems have regularly received priority attention from top management. Considering the task force of experts trained over the years that we could and did assemble from Westinghouse ranks, I think it fair to say that if any company had credentials to do this job cheaply and effectively for the Government, it was our own.

"Yet we went through a series of reactor fuel-element troubles. We were forced to learn how to manufacture unprecedented quantities of the metal zirconium, and in unprecedented purity, because the unforeseen requirements of our reactor gave us no choice. We were forced to develop an entirely new type of pump, because leakage of radioactive liquids into the hull of a submarine would be intolerable and because only a radical pump development could meet necessary standards. We encountered other road-blocks and detours, and we suspect these are inherent in the still primitive reactor art.

". . . Our experience makes us sharply aware of the mass of problems, but still firmly optimistic. The constructive atomic power uses that everyone wants can indeed be realized—and they can be realized fastest in full knowledge that success is far from easy.

"Guided by such an evaluation, Westinghouse recently reached a decision which, so far as we know, commits more private money to the future of atomic power than any other company has yet determined to risk. I speak of the new Westinghouse Atomic Equipment Department. We founded this department on our own initiative and at our own expense to supply specialized equipment for use in conjunction with atomic reactors. The department's work at the start will be almost entirely nonsecret. . . .

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". . . We have been working for a year or more upon a power plant having implications not only for the propulsion of large naval vessels but also for the generation of central-station electrical power. The submarine power plant we now have behind us represents a striking advance in undersea propulsion and meets the unprecedented requirements which the Navy laid down. But it has two important limitations from the viewpoint of uses other than in a submarine. First, it simply does not put out the power needed to propel a big ship moving on the surface. Second, it does not give the long life—or the power—essential for central-station generation of electricity.

"The problem we have been studying, then, is how to take a second step forward into power uses—a step just as big or bigger than the step already taken through the submarine plant. . . . Once again, we think, actual construction of a prototype would be the comparatively easy part. The hard part would be research and development.

"As you see, despite my basic optimism, I have returned to the theme that building a reactor is no picnic. It seems to us that hammering this theme is the most useful task I can strive to perform here today. However, if there is a customer—either the Government or private utilities or a combination of both—we can go ahead and build a central-station atomic-power plant able to produce tens of thousands of kilowatts. We do not know, and no one knows, whether the first plant would produce competitively with ordinary plants. Much would depend upon conventional power costs where the atomic plant was located. Much would also depend upon the kind of bookkeeping to be used—rates of amortization and the like. This we do know: Much could be learned from the first plant that would fertilize progress. . . .

". . . We are now increasingly impressed by the need of mobilizing more minds and more resources for a broader attack upon atomic power problems. We estimate that qualified technical people working upon these problems, outside Atomic Energy Commission laboratories, are currently numbered only in three figures. Napoleon is once supposed to have said that when he had a hard job to do, he put so many men on it that the job disappeared. The time may be ripening when a similar tactic in the atomic power field could produce major technical breakthroughs. . . .

• • •

"The overall industry of the United States is basically the creation of private initiative. In the factories and production lines that give our country world leadership is evidence of what free enterprise can accomplish. But under the present atomic-energy law, enterprise is not free. We suggest it is almost academic to speculate on what enterprise might undertake if some of the curbs were lifted. So long as these remain, enterprise is severely handicapped even in thinking and planning. Relax the curbs and, judging by past experience, our economic system will find its own ways of helping to bring the promise of atomic energy to fruition."

WESTINGHOUSE Engineer

VOLUME THIRTEEN

NOVEMBER, 1953

NUMBER SIX

On the Side

The Cover—The precise rows of radiator fins and the graceful curve of the fan blades are familiar trademarks of the large power transformer. It is this combination that artist Dick Marsh portrays on this month's cover.

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The November issue—as originally planned—was to feature nuclear power: because of certain security regulations this issue has been postponed. If conditions permit, the material will be published at a later date.

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Four electric stairways will provide transportation from the 40th floor to the observation deck of a new skyscraper now under construction for the Prudential Insurance Company of America in Chicago. It is the first skyscraper in the world to have electric stairways serving its top floors. Among the advantages is the elimination of the need for an elevator penthouse on the roof.

Other electric stairways to be used in the new building include six that will serve from the first to the fourth floor, one from the Illinois Central Railroad Company platform to the ground floor, and one from the ground floor to the lobby or first floor.

These will be 32-inch electric stairways operating at a speed of 120 feet per minute, and capable of transferring over 6000 people per hour from one floor to another.

Prudential's new building in Minneapolis will also have 120-fpm, 32-inch-wide electric stairways. It will also have completely automatic, operatorless elevators.

In This Issue

High-frequency brazing of rotors—Traffic lights for steel mill—Laminated burnishing wheel—New 700-watt mercury lamp—Improved rectifier welder with Transactor—Streak photography for bearings.

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De-ion, Rototrol, Thermoguard

Published bimonthly (January, March, May, July, September, and November) by the Westinghouse Electric Corporation, Pittsburgh, Pa.

Subscriptions: Annual subscription price in the United States and possessions is $2.50; in Canada, $3.00; other countries, $3.00. Single copy, 50¢. Address all communications to *Westinghouse* ENGINEER, P.O. Box 2278, 401 Liberty Ave., Pittsburgh 30, Pa.

Indexing and Microfilm: *Westinghouse* ENGINEER contents are regularly indexed in Industrial Arts Index. Reproductions of the magazine by years are available on positive microfilm from University Microfilms, 313 N. First Street, Ann Arbor, Michigan.

THE WESTINGHOUSE ENGINEER IS PRINTED IN THE UNITED STATES BY THE LAKESIDE PRESS, CHICAGO, ILLINOIS

Synchrotie Systems

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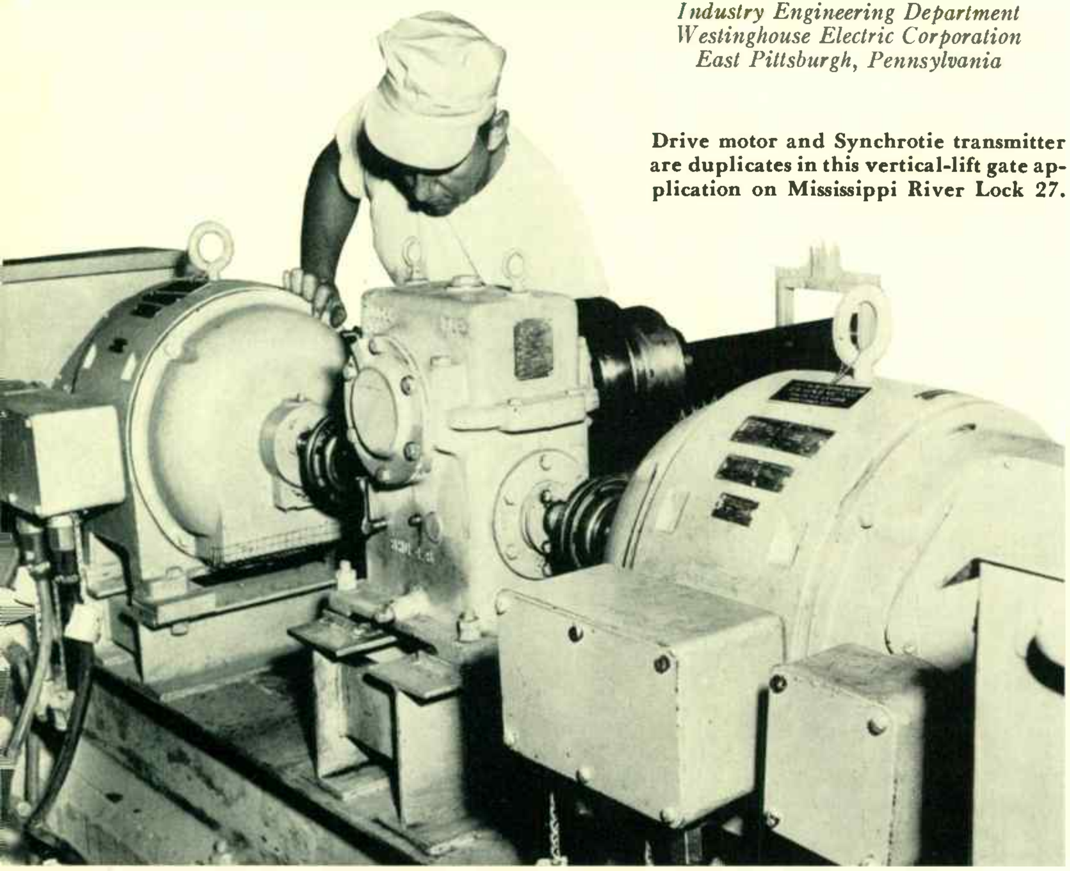
One or more parts of a machine or system of machines that must run in unison or in a fixed relation to each other can be physically connected together. Or they can be connected electrically, using Synchroties. Thus, small electrical conductors take the place of shafts, belts, or gears which, particularly when the distances are more than a few feet, become extremely cumbersome. The Synchrotie system has a long history of varied and successful application. The principles are here restated.

Basically, a Synchrotie system consists of two or more wound-rotor induction motors that have similar rotor characteristics. If the stator (primary) windings of the motors are excited from a common source, and the rotor (secondary) windings are connected together, the motors maintain a synchronized speed relation within certain limits. If the rotor of one is turned, the other automatically follows it. Speed matching of individually driven machine sections and remote position control or indication (or both) are the two main applications of Synchrotie systems.

Speed-matching Synchroties are used on coater drives for paper machines, vertical-lift bridge drives, and textile range drives in finishing and bleaching plants. Most typical of position matching applications is the use of Synchroties for remote operation of valves. But the number of different applications possible is almost limitless.

A close analogy exists between an electrical Synchrotie and a lineshaft or mechanical transmission that connects the driven sections of a machine. Both a Synchrotie and a lineshaft will transmit torque or power. Under running conditions in both cases, the receiving end of the transmission will make exactly as many revolutions as the delivery end. In the mechanical transmission, the shaft will twist under application of torque so than an angular difference between the ends of the shaft will result. In the Synchrotie also, application of torque causes an angular difference between the rotors of the transmitting and receiving motors. In the case of the shaft transmission, the amount of angular twist depends upon the torque transmitted, the shaft diameter, and the shaft length. In a Synchrotie drive, the angular difference between the rotors is a function of the size of the motors and the torque transmitted to the receiving end.

In general, where power is transmitted by any combination of shafts, gears, or other mechanical units, the same results can be accomplished by a properly designed Synchrotie. The more complicated



Drive motor and Synchrotie transmitter are duplicates in this vertical-lift gate application on Mississippi River Lock 27.

Power Flow for Various Speeds and Rotation With or Against the Field

1—*Synchrotie running at low speed in same direction as rotating field, Fig. 2.* This is analogous to induction motors operating at high slip below synchronous speed. Because the slip is high, the frequency in the rotor circuit is high, and the reactance of the rotor circuit is high with respect to the resistance. Thus the rotor circulating current lags behind the resultant voltage and is quite large. A large component of the circulating current is in phase with the receiver rotor voltage. Since the Synchrotie is running below synchronous speed with the field, the product of the receiver rotor voltage and current represents a motoring output analogous to the power that is dissipated in the secondary of an ordinary wound-rotor motor operating at reduced speed. This power is fed into the rotor of the transmitter. Thus when the Synchrotie is running below synchronous speed in the direction of the rotating stator field, the receiver acts like a motor because it takes power from the line, while the transmitter acts like a generator because it takes mechanical power from its shaft and electrical power from its rotor and returns power to the line. The component of the rotor current that is in phase with the receiver rotor voltage is larger than the component that is in phase with the transmitter rotor voltage. Thus, when running with the field, the maximum receiver torque for any given displacement angle is greater than the maximum transmitter torque.

2—*Synchrotie running at close to synchronous speed in same direction as rotating field, Fig. 3.* This is analogous to induction motors operating at low slip below synchronous speed. Since the slip is low, the frequency in the

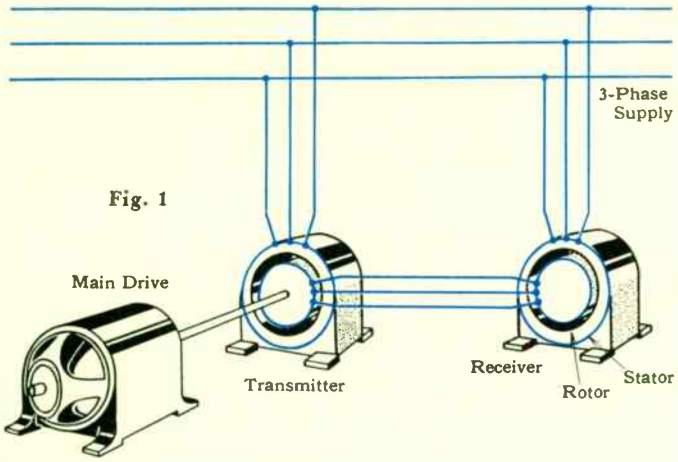


Fig. 1

Fig. 1—Two or more wound-rotor motors, excited from a common source and with rotors tied together electrically, make the basic Synchrotie system.

the mechanical drive, the more pronounced will be the advantages of the electrical system. The few copper wires that replace heavy shafting and complicated mechanical parts can turn corners, traverse any angle, or travel hundreds of feet. The machines that Synchroties connect will maintain an exactly synchronized relationship at zero speed and at every running speed up to the rated maximum value; however, some angular displacement may exist between the rotors due to friction and load torque.

Many of the problems involved in the application of Synchrotie drives are similar to those encountered in the application of ordinary induction motors, such as starting, accelerating, and maximum torques and operating speeds, speed ranges, load torques over the speed range, and motor temperatures. There are, however, additional factors peculiar to the Synchrotie system, which must be carefully considered when making an application.

Theory of Operation

For simplicity, consider a Synchrotie consisting of just two wound-rotor motors, Fig. 1. When properly connected, and with no external torque applied, the rotors of both Synchrotie units remain stationary when line voltage is applied to their stators. When no electrical angle (phase displacement) exists between the Synchrotie rotors, the rotor-induced voltages are equal and opposed. Consequently, the rotor current is zero and no turning moment is developed by either unit. When one Synchrotie unit, called the transmitter, is rotated by an external means through a small angle, the rotor-induced voltages are no longer equal and opposite. A resultant rotor current flows to develop a torque or turning moment in an effort to balance the rotor voltages and bring the rotor current back to zero. If the transmitter is rotated continuously by an external means, the receiver rotor follows at the same speed. If load is applied gradually to the receiver, the phase displacement or angle between the two rotors increases with increase in load until the maximum synchronizing torque is reached. Any further increase of receiver load pulls the rotors out of step. When this happens the Synchrotie units begin to operate independently as ordinary induction motors, each having its rotor short-circuited through the other.

With both transmitter and receiver units energized from the same polyphase source, and if the transmitter is driven by external means in the direction it would normally run as an induction motor, the Synchrotie system is said to operate *with the field.* If the transmitter is driven in the opposite direction, the Synchrotie is said to operate *against the field.* For each of these conditions the receivers rotate in the same relation to the electrical rotation of their stator fields as the transmitters, the relationship being referred to their normal direction of rotation as induction motors.

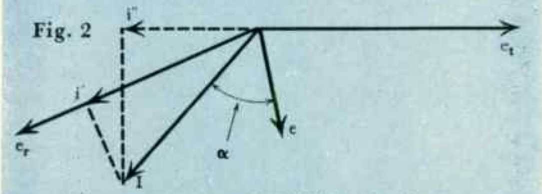
When the Synchrotie is operated in the same direction as the rotating magnetic field, the rotor of the receiver unit is retarded with respect to its electrically neutral or in-phase position. When the Synchrotie is operated in a direction against the rotating magnetic field, the receiver rotor is displaced ahead of its in-phase position.

rotor circuit is low. Consequently, the rotor reactance is low, and the angle α is much smaller than for operation at high slip. The components of the rotor current that are in phase with the receiver rotor voltage are smaller. Thus, the maximum receiver and transmitter torques decrease when the Synchrotie speed approaches synchronous speed and rotation is with the field. However, as shown by the relative magnitudes of the rotor-current components, the maximum receiver torque is still greater than the maximum transmitter torque.

3—*Synchrotie running at low speed against direction of rotating field, Fig. 4.* This is analogous to operating at a slip greater than one. In this case, a component of the rotor current is in phase with the transmitter rotor voltage, which means the transmitter is taking power from the line. Since receiver current is 180 degrees from receiver rotor voltage, the receiver is returning power to the line. The product of transmitter voltage and current exceeds that of receiver voltage and current. Thus, maximum transmitter torque exceeds that of the receiver.

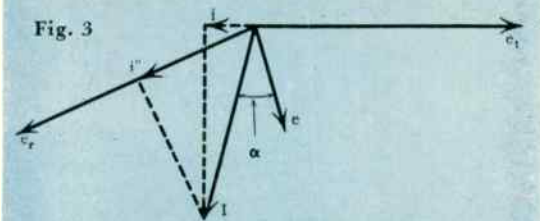
e_r—Receiver Induced Rotor Voltage
e_t—Transmitter Induced Rotor Voltage
e—Resultant Voltage
I—Rotor Circulating Current
α—Angle between e and I
i'—Power Component of I (Receiver)
i"—Power Component of I (Transmitter)

Fig. 2



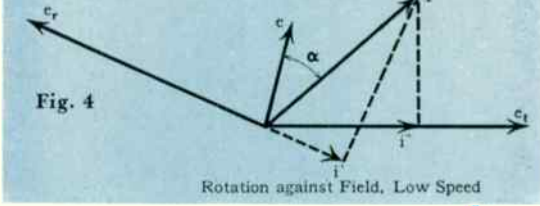
Rotation with Field, Low Speed

Fig. 3



Rotation with Field, Near Synchronous Speed

Fig. 4



Rotation against Field, Low Speed

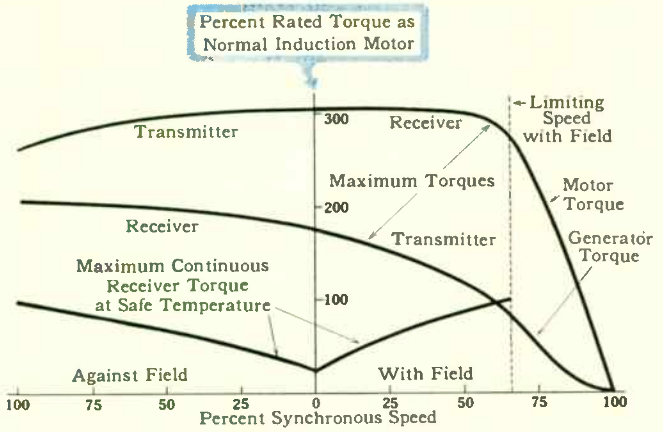


Fig. 5—Torque-speed characteristics of all two-unit Synchroties are similar, except that percent values of maximum torques over the speed range vary according to the rating. Concepts of motor and generator torques refer to power flow from stator to rotor in first case, from rotor to stator in second case.

When operating in synchronism, one of the Synchrotie units acts like a motor taking power from the line, while the other acts like an induction generator returning power to the line. Depending on whether the rotation is with or against the field, either unit can act as a motor or as a generator.

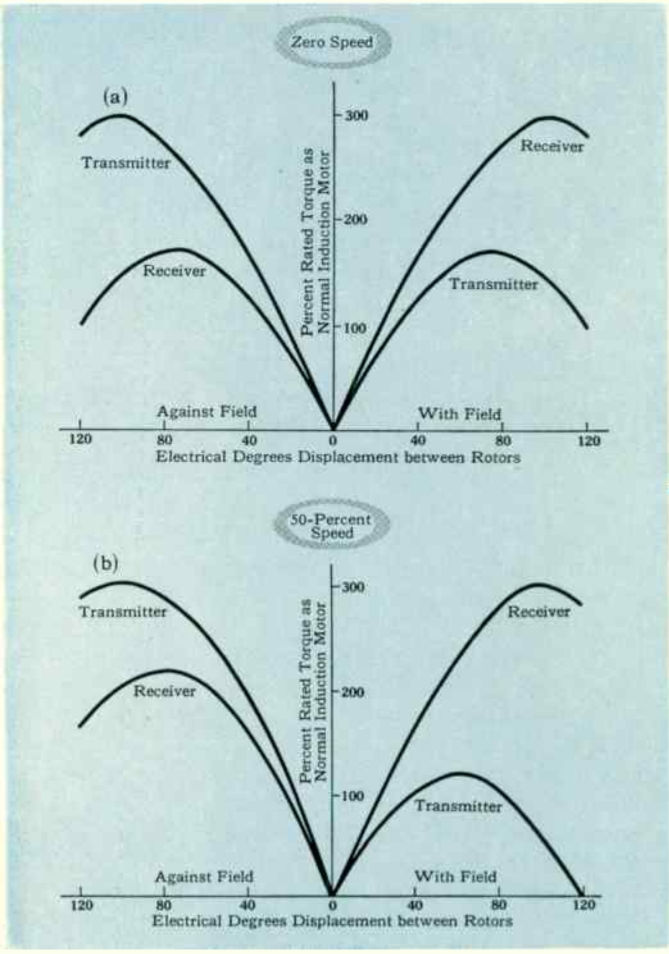
If the Synchrotie is running in the same direction as the rotating field, the receiver acts like a motor because it takes power from the line, Fig. 2. Meanwhile, the transmitter acts like a generator because it takes mechanical power from its shaft and electrical power from its rotor and returns power to the line. Under these conditions, the maximum receiver torque for any given displacement angle is greater than the maximum transmitter torque, Fig. 5. This is essentially the same when the Synchrotie is running close to synchronous speed in the same direction as the rotating field, Fig. 3. In contrast, when the Synchrotie is running in a direction opposite to the rotating field, Fig. 4, the maximum transmitter torque is greater than the maximum receiver torque.

The concepts of motor and generator torques can be visualized by remembering that motor torque refers to power flow from stator to rotor while generator torque refers to power flow from rotor to stator.

The term maximum torques refers to the maximum *momentary* torques that can be utilized to hold the Synchrotie in step at the indicated speed. The lower curve in Fig. 5 shows the maximum *continuous* torque obtainable at the receiver output shaft with safe receiver temperature rise. For example, when operating with the field at 50-percent speed, the Synchrotie will stay in step if 300-percent rated torque is required by the receiver load. However, for this particular design, the maximum continuous receiver torque at 50-percent speed is approximately 85 percent of rated torque for the machine.

Another important consideration in applying Synchroties is the limiting speed when operating with the field. Beyond approximately two-thirds of synchronous speed the maximum receiver and transmitter torques drop off rapidly to zero. For that reason, Synchroties should not be operated at more than 66 percent of synchronous speed in the direction of the field. Operation up to and beyond synchronous speed should be against the field.

Fig. 6(a) and (b)—The percentages of torque for a typical two-unit Synchrotie do not apply to all Synchroties. However, the general shape of torque-displacement curves is the same regardless of rating.



Types of Primary Circuits

In addition to Synchroties that have their stators connected to a three-phase supply, there are a number of single-phase stator connections that can be used, each having its own advantages and disadvantages. The circuit connections that give curve *A* in Fig. 7 might be used where high peak torques are encountered and where the receiver displacement angle is not critical for normal continuous running torques. Circuit connections that give curve *B* might be used where reversing service is required. In this case, the torque-displacement characteristic is the same for operation with or against the field, so it can be used in an indicating system.

Starting Methods

Synchrotie units must be synchronized or connected to the line while both units are at standstill. And even with the Synchrotie units at standstill, the application of three-phase power sometimes causes loss of synchronism and results in acceleration of one or both units to full speed as ordinary induction motors. The torque tending to turn the receiver in the direction of normal rotation as an induction motor is much greater than the torque tending to make it operate in the reverse direction (curve *C*, Fig. 7). The area under curve *C* is proportional to the energy given to the load. If the ratio of inertia to friction load is high, and if the angular displace-

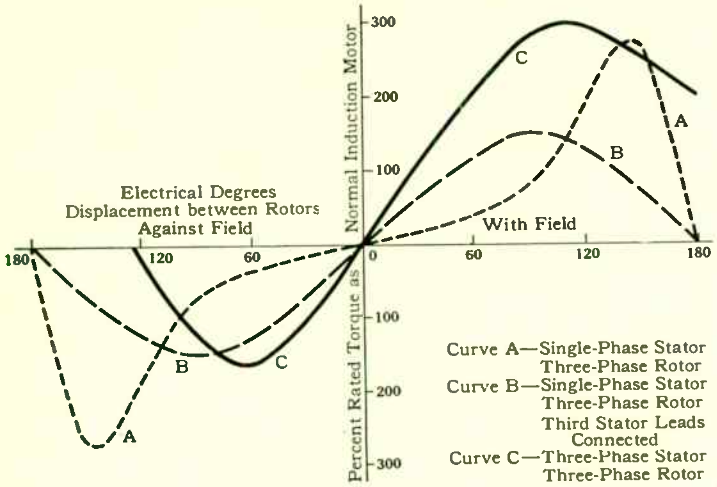


Fig. 7—Single-phase connections of stators offer advantages over three-phase for certain applications, such as indicating systems or systems requiring frequent reversals.

ment is large in the positive direction when power is applied, the receiver may accelerate toward synchronous speed and fail to pull into step.

Selection of Operating Speeds and Direction of Rotation

When the mechanical rotation is in the direction of the field rotation, the torque that can be exerted by the receiver is greatest. However, this receiver torque is available only under steady load and speed conditions. A sudden drop in speed of the prime mover and transmitter may cause the receiver to become the transmitter momentarily until the stored energy of the load has been equalized, but the equalizing torque that can be transmitted back to the prime mover is quite limited.

When mechanical rotation of transmitter and receiver is opposite to the field rotation, the receiver torque is reduced but does not fall off with increased speed. Also, there is no loss of synchronizing power when the torque is suddenly reversed without reversal of rotation. For this reason, where the three-phase Synchrotie is operated in one direction and where either the prime mover or receiver loads are fluctuating, the direction of Synchrotie rotation should be against the field.

When the system operates in either direction (with or against field) and is subject to overhauling loads, which cause a transfer of position of the receiver and transmitter, the Synchrotie units must be utilized within the torque capacity specified for the worst conditions. Thus, where reversing operation is required, the inertia of the receiver and load and the rate of acceleration and deceleration must be studied carefully to determine the torque requirements. In some cases the primary leads can be reversed when mechanical rotation is reversed. This reverses the direction of field rotation, makes the maximum synchronizing torque available in either direction, and permits the use of smaller frame sizes for the Synchroties. An example of this type of application is in synchronized hoisting when the hoisting power is applied at more than one point.

When a Synchrotie that is operating against the field pulls out of step, the receiver comes to a stop and, if load conditions permit, goes to full speed in the opposite direction as an ordinary induction motor. In some cases a control scheme can be used to shut down the drive when the Synchrotie pulls out of step and the receiver attempts to run in the opposite direction of rotation.

Effects of Number of Poles

When Synchroties are phased out, both receiver and transmitter induced rotor poles are in the same relative position with respect to their stator poles. However, in terms of relative physical position, the receiver rotor can be phased out in as many mechanical positions as there are pairs of poles on the receiver stator. Thus, a four-pole receiver can be phased out in either of two mechanical positions. Similarly, a six-pole receiver can be phased out in any of three mechanical positions. This characteristic must be considered if the receiver rotor must remain in the same mechanical position with respect to the transmitter rotor, for example, in an indicating system. This requirement can be met by keeping the Synchrotie stators excited when the drive is at standstill.

However, if there is an appreciable displacement angle at standstill, the Synchroties may overheat when the stators are kept on the line for long periods of time, unless forced ventilation is used. When overheating is a possibility, Thermoguards or timing devices should be used to disconnect the units from the line.

The transmitter and receiver need not have the same number of poles for proper operation. For example, a four-pole receiver can be operated from a six-pole transmitter, or a six-pole receiver from a four-pole transmitter. In these cases, the operating speed of the receiver is the same percent of its synchronous speed as the percent synchronous speed of the transmitter. Thus a four-pole receiver operates at 1200 rpm when connected to a six-pole transmitter that is operated at 800 rpm. This type of Synchrotie usually requires special design because of the necessity of matching electrical characteristics on two different frame sizes. In most cases, it is more economical to use units with the same number of poles and apply suitable gearing to either the transmitter or receiver to obtain the desired speed on the receiver load. An added advantage is the fact that duplicate electrical and mechanical designs can be used for the Synchrotie units.

Stability of the Synchrotie

When the prime mover is subject to sudden changes in speed, or when the receiver load is fluctuating, the Synchrotie may hunt and occasionally lose synchronism. A convenient means of reducing this hunting is to add resistance in series with the Synchrotie rotors, but this reduces the amount of synchronizing torque available between the two units. Another means involves use of V-belts between the receiver and its load to provide a damping effect between the load fluctuations and the receiver shaft.

In cases where the receiver runs at times with light loads and little inertia, a flywheel on the receiver will keep the system in synchronism.

Adjustable Speed between Receiver and Transmitter

In a simple Synchrotie, the only way to change receiver speed is to change transmitter speed. However, use of a frequency changer (sometimes called a phase advancer or electrical differential) will give adjustable speed of the receiver itself, in effect, a gear change that is infinitely adjustable. In this case the frequency changer is inserted in the rotor circuits of the Synchrotie, Fig. 8. To illustrate, assume for simplicity, that the three units—transmitter, receiver, and frequency changer—are of four-pole design. If the trans-

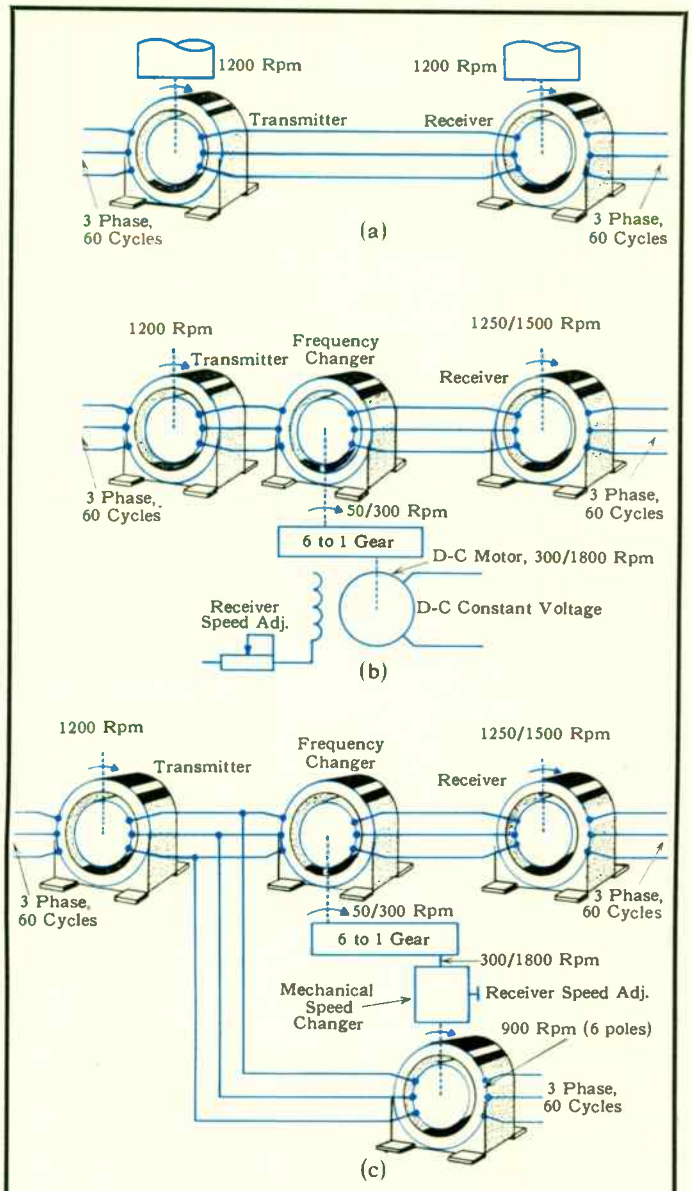
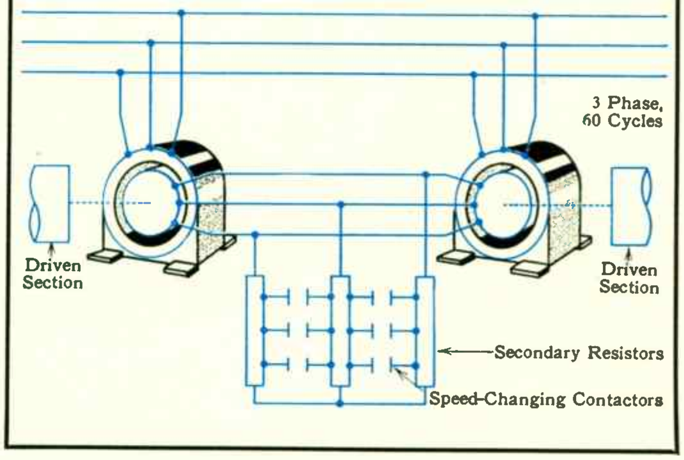


Fig. 8—A frequency changer connected electrically to the rotor circuit provides the most suitable method of obtaining adjustable-speed operation of the receiver unit.

Fig. 9—Adjustable synchronized speeds from standstill to operating speed are possible with a common adjustable secondary resistance. This is called a semi-Synchrotie.



mitter is driven at 1200 rpm with 60-cycle voltage on the stator, the frequency of the transmitter-rotor induced voltage is 20 cycles. If the frequency changer is at standstill, this 20-cycle voltage is induced in the frequency-changer rotor and appears on the rotor of the Synchrotie receiver. Thus, the receiver has a 60-cycle stator frequency and a 20-cycle rotor frequency, which cause it to operate at 33-percent slip or 1200 rpm. So when the frequency changer is at standstill, the receiver operates at the same speed as the transmitter.

In contrast, if the rotor of the frequency changer is driven at a speed of 50 rpm, and the 20-cycle voltage from the transmitter rotor is impressed on the frequency-changer stator, the frequency-changer slip is 92 percent because its synchronous speed at 20 cycles is 600 rpm. The frequency of the induced voltage in the frequency-changer rotor is 20 times 0.92 or approximately 18.3 cycles. The Synchrotie receiver now has a 60-cycle stator frequency and an 18.3-cycle rotor frequency. This corresponds to a slip of 30.5 percent for the receiver. The receiver now operates at a speed of 1800 times 0.695 or 1250 rpm. When the Synchrotie units and the frequency changer all have the same number of poles, the speed of the receiver is the sum of the speeds of the rotors of the transmitter and frequency changer. This is true when the rotors of the receiver and frequency changer are rotating in the same direction as their stator fields. If either rotor were to rotate against its stator field, the Synchrotie receiver speed would be the difference between the transmitter speed and the frequency-changer speed.

A typical application of a frequency changer is found on a paper-coating machine. Here the Synchrotie is used to match the speed of the coater section to the drying roll. Use of the frequency changer makes possible draw-speed difference adjustment as well as a speed adjustment to match roll-diameter variations due to repeated grinding.

Several methods of obtaining speed adjustment with a frequency changer are possible. Typical is the use of a small d-c motor, Fig. 8(b). Changing of its speed from 300 to 1800 rpm with a field rheostat changes the receiver speed from 1250 rpm to 1500 rpm. Using a speed reducer between the frequency changer and the d-c motor gives what might be termed a "mechanical amplification" between the d-c motor and the frequency changer. For example, with a 6 to 1 gear ratio, a speed change of three rpm in the d-c motor due to a load swing will give a one-half rpm change in the Synchrotie receiver speed.

Another method involves the use of a mechanical speed adjuster, Fig. 8(c). In this case the frequency-changer speed reducer is driven by a constant-speed Synchrotie receiver through the mechanical speed adjuster. This scheme is used when very accurate speed matching must be maintained in the drive from standstill to top speed, regardless of the setting of the receiver speed-adjusting dial.

Semi-Synchroties

Two wound-rotor motors that have their secondaries connected to a common secondary resistance will, within limits, maintain a synchronized speed relationship. This type of circuit arrangement is called a semi-Synchrotie, Fig. 9, and is used when the receiver and transmitter units must also serve as the drive motors. Typical examples are the drives for large cranes and vertical-lift bridges.

The semi-Synchrotie provides adjustable as well as synchronized speeds from standstill up to the desired operating speed by adjusting the common secondary resistance. The effect of the secondary resistance with regard to speed control is similar to that obtained with external resistance in the external rotor circuit of a single wound-rotor motor. However, since operation is with the field, the available synchronizing torque reduces sharply as the operating speed approaches approximately two-thirds of synchronous speed. Also, for fluctuating loads on either unit, the available synchronizing torque is limited in the same manner as discussed previously for Synchroties that operate with the field.

When a semi-Synchrotie must be operated up to the normal induction-motor speed, an auxiliary Synchrotie can be added to the system to provide the necessary synchronizing torque at the higher speeds, Fig. 10. The auxiliary Synchroties must be connected for operation against the field.

When a drive requires adjustable as well as synchronized operation over the wide speed range, it is usually more economical to apply a d-c motor to one of the machine sections and use the d-c motor as a prime mover for a straight Synchrotie drive for the other machine sections.

A-C Requirements of Synchroties

The question of what is required of the a-c supply for Synchroties often must be considered. This problem arises when it is necessary to have an auxiliary power supply for the Synchroties only.

At first glance, it appears that the a-c supply need only have capacity for the stator excitation losses. This is true *only* during steady-state conditions and for relatively small displacement angles. As the displacement angle increases, the excitation and I^2R losses increase, Fig. 11. Since the purpose of a Synchrotie is to maintain a speed match by providing synchronizing torques, the a-c supply must have sufficient capacity to provide the large stator currents that are required during synchronizing action.

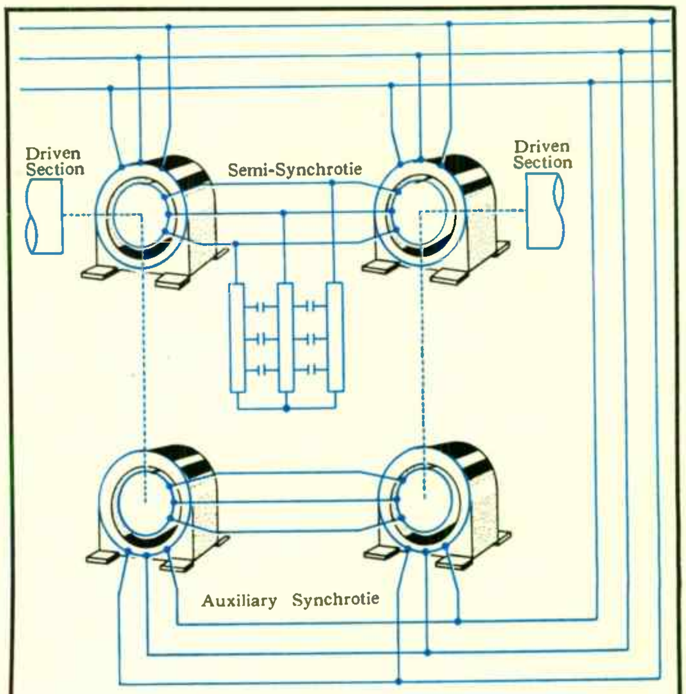


Fig. 10—An auxiliary Synchrotie must be added to a semi-Synchrotie if synchronizing torques at high speeds are desired.

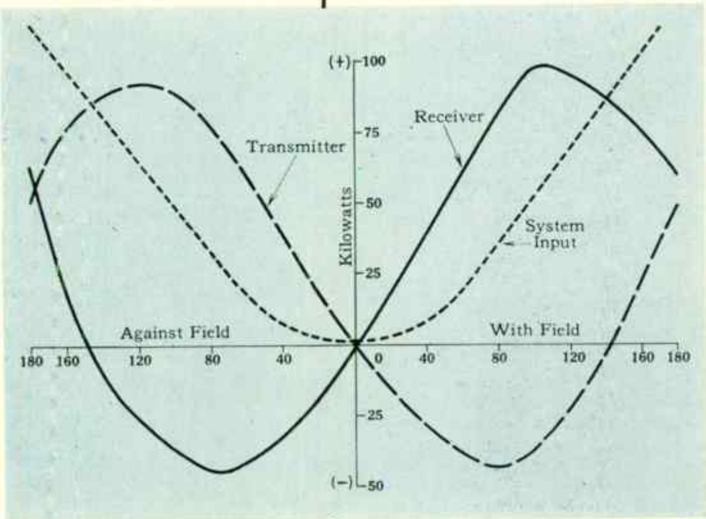


Fig. 11—Although net power required from the a-c source is low during a steady-state condition and for small displacement angles, the source must have enough capacity to supply the large stator currents during synchronizing.

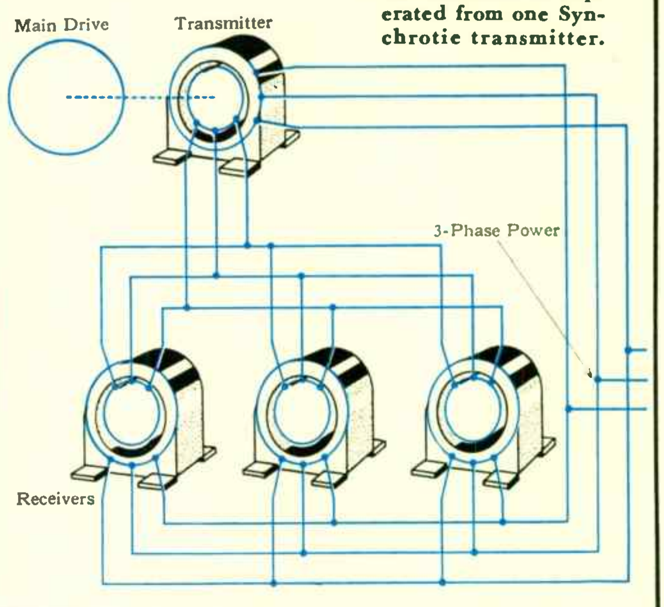


Fig. 12—To hold sections of a paper coater machine together, several receivers are operated from one Synchrotie transmitter.

Ratings and Frame Sizes

Since Synchroties usually operate over a speed range, they are rated on a torque basis rather than horsepower, as is the case with an induction motor that runs at constant speed.

Although varying with individual designs and ratings, most Synchrotie units transmit continuously the normal rated motor torque at speeds as low as 50 to 75 percent of synchronous without reaching unsafe temperatures. When the Synchrotie operates continuously at reduced speeds, rotor iron losses increase because of the high induced frequencies. Similarly, operation against the field induces high frequencies, which result in greater heating.

Peak-load and accelerating torques also must be considered. For example, the rating of a receiver that is to drive a high-inertia load may depend almost entirely on the required accelerating torque and the peak torques encountered during momentary speed changes imposed by the main drive.

If dynamic braking and quick stopping are used on the transmitter prime mover, this should also be considered, because during rapid decelerations, the receiver may act as a transmitter, and the torque then available (rotation with field) for synchronizing is much less than for acceleration.

Precise Control for Lock 27

Raising and lowering a massive 110-foot-wide lock gate with no skewing or jamming is a man-sized job. On the largest lock in the country this is accomplished by a special system of a-c driving motors and Synchroties, which moves the gate precisely in all operations.

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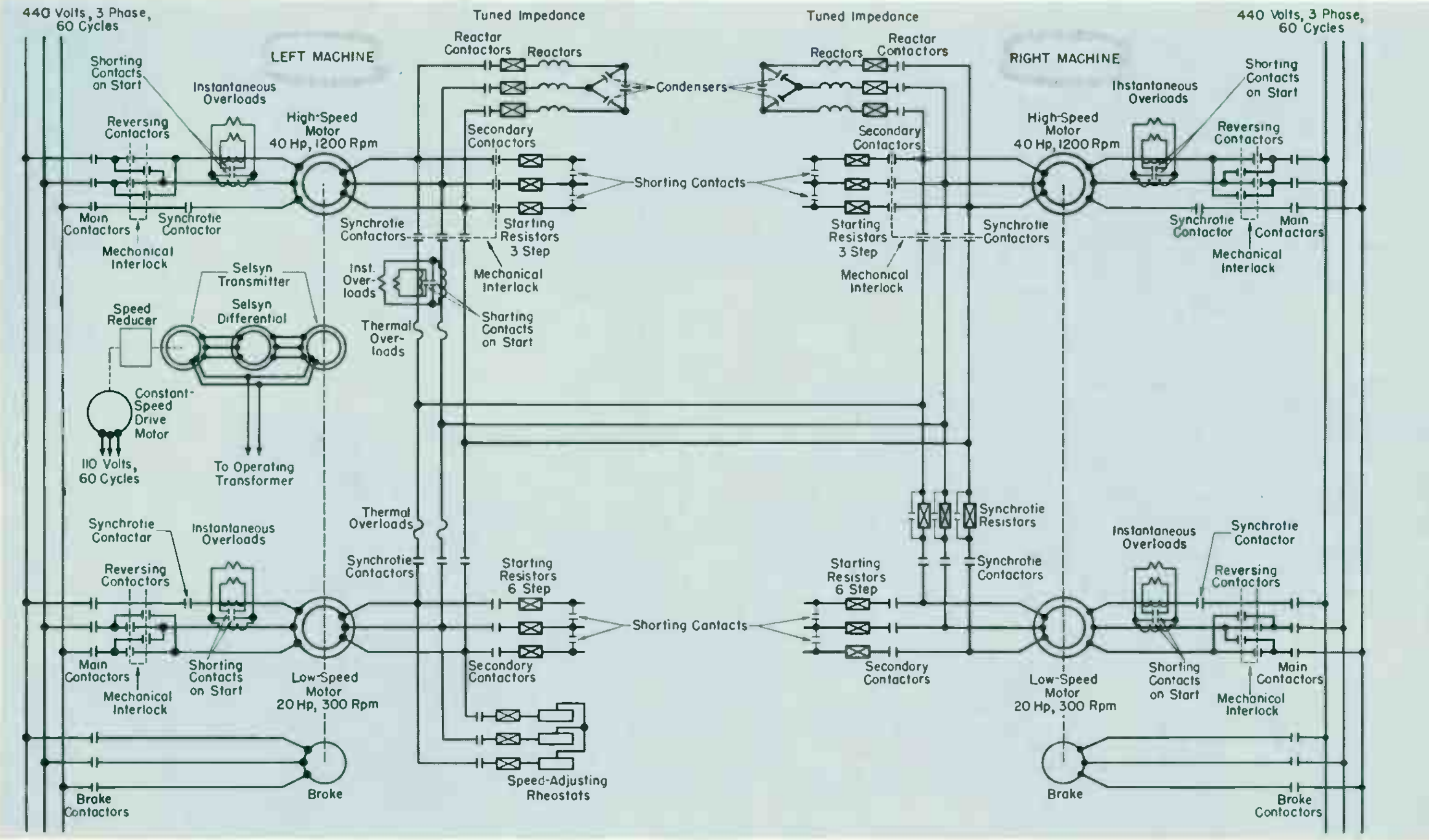
View downstream of main lock during first lockage.

A unique electrical control system that makes possible fingertip operation of an entire river lock was recently put into operation when the U.S. Corps of Engineers opened Lock 27 to navigation. Located just above St. Louis on the Mississippi, the set of locks is the largest on the river. Its main lock is 1200 feet long, 110 feet wide, and has 92-foot walls.

A new feature in the design of large locks is the use of double-leaf vertical-lift gates. Located at the upstream end of both the 1200-foot main and the 600-foot auxiliary locks, these gates submerge to allow tow boats and barges to enter the lock. Their vertical movement is also used to match the extreme changes in river level, and to eliminate undesirable



accumulations of driftwood or ice in the canal above the lock by flushing them over the gate. Water flow over the submerged gate can also be used for supplemental filling of the lock. Although walkway bridges are provided just downstream of the upper gates, they also submerge to clear the lock for traffic. Conventional miter gates are used at the downstream end of the locks.

Control Equipment

Six control houses, three adjacent to the vertical-leaf gates and three adjacent to the miter gates, contain the switchboards associated with each gate control. Each house contains a benchboard-type switchboard for control, and a special duplex switchboard incorporating the motor starting and control equipment, protective relays, and distribution circuit breakers. One upstream control house contains one switchboard for the adjacent machines of the main and auxiliary locks; another contains an engine-driven generator for emergency lighting and limited operation in the event of loss of the normal 460-volt a-c power supply.

Each benchboard has control switches, indicating lamps, and position indicators for complete control of one gate, and the associated valves used for filling and emptying the lock. Each gate except the auxiliary-lock miter gate can be controlled from either side of the lock. Both leaves of the vertical-lift gates, as well as the associated walkway bridge, can be controlled from either upstream benchboard. To make it easy for the operator to watch the movement of the gate, the vessel, and the water level, the benchboards are located in a glass-enclosed bay on the side of the control house.

Accurate indications of gate position and water level are provided by self-synchronous motor-type transmitters and receivers and, since position indication is imperative for operation of the vertical-lift gates, two sets of position transmitters are used: one from the gate-hoisting machines, the other from the gates through a wire connection. Use of either transmitter can be selected by operation of control switches.

Control for the Gates

In every detail these locks show the latest in lock engineering, but the controls of the submerging vertical-lift gates and walkway bridges represent the most important electrical design advances.

Lowering and raising of the gates, once started, must be carefully controlled. Although 110 feet wide, the 272-ton gate leaves must move over their entire vertical range with practically no skewing; torque and speed must be carefully regulated; and all controls literally must be at the operator's fingertips. These exacting requirements have been achieved by use of a special system of a-c driving motors and Synchroties.

The drives for the walkway bridge and for each of the leaves of the double-leaf gate are essentially the same insofar as they consist of one drive motor and a Synchrotie motor geared to the hoisting machinery on each side of the lock, Fig. 1. Synchronizing and starting of the motors is accomplished as follows: (1) the brakes are released and single-phase excitation is applied to the Synchrotie motors simultaneously, two steps of single-phase synchronization being used in the case of the walkway bridge and upstream leaf; (2) after a short time-delay to allow the motors to correct any position displacement, three-phase excitation is applied to each of the Synchrotie motors; (3) the drive motors are then energized and the accelerating contactors close to bring the motors up to operating speed.

The initial single-phase excitation of the Synchrotie units prevents motor action of the Synchrotie. If there is a large

Fig. 1—Simplified schematic diagram of a power Synchrotie system as applied to the lock vertical-lift gates and walkway bridge.
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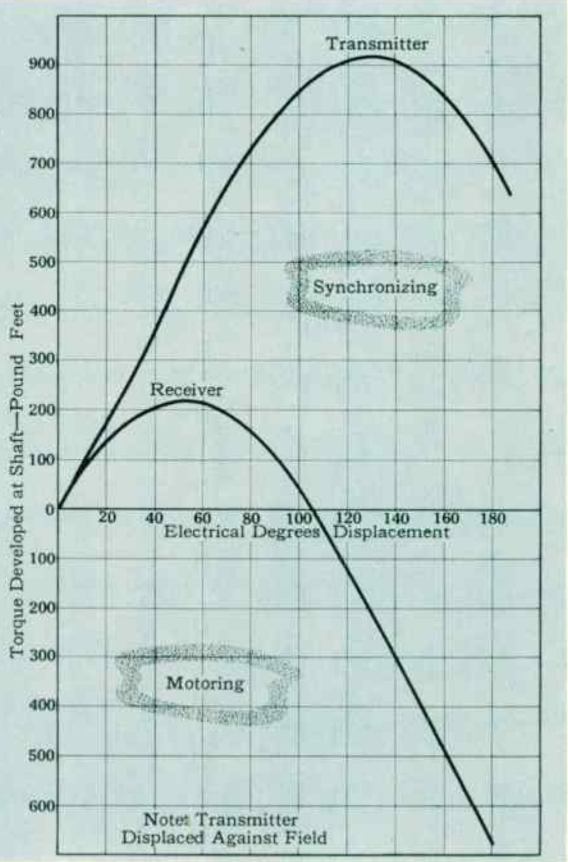
Fig. 2—The torque-angle characteristics of a 20-hp, 24-pole, 60-cycle, 3-phase Synchrotie unit with torque-limiting resistors in the rotor circuit.

Control desks in bay projections of each control house provide finger-tip regulation of speed and torque, and offer clear view of the lock.



angular displacement between the rotors of the Synchrotie units, a possibility exists that the machines will come up to speed in the direction of the field when three-phase power is applied. The torque-angle characteristics of a three-phase Synchrotie unit with torque-limiting resistors in the rotor circuit are shown in Fig. 2. Positive torques on both the transmitter and receiver units indicate that the units will tend to pull into step and not motor. At approximately 105 electrical-degrees displacement, the torque on the receiver unit becomes negative, indicating that both units will tend to motor with one unit acting as a short-circuit in the rotor circuit of the other. When single-phase excitation is applied, as in Fig. 1, the torque-angle characteristics of the motors are such that no negative torque is developed and there will be no tendency toward motor action. The angular displacement between the rotor of the Synchrotie units is reduced by the single phasing so that when three-phase excitation is applied, the transmitter- and receiver-unit torques are both positive and no motoring torque is developed. The Synchrotie units are operated against the rotating field in the stator so that maximum synchronizing torque can be developed during operation.

The complexity of a power Synchrotie drive varies with the requirements of operation. In this case, the most varied requirements exist for the downstream leaf of the double-leaf gate, as evidenced by the following requirements: (1) Raise or lower the submerged gate at a motor speed of 1150 rpm for high-speed operation and 285 rpm for low-speed operation. (2) Raise the submerged gate at a motor speed of 1150 rpm until the top of the gate is approximately 2.5 feet above the water, then automatically slow down to 285 rpm and raise until the top of the gate is three feet above the water. (3) With a water level differential of 15 feet across the gate, lower from a position three feet above the upper water level at a motor speed of 1150 rpm to six inches above upper water level, and slow to a preselected speed between 100 and 300 rpm. Continue to lower at this speed to a point of 2.5 feet below water level of the upper pool and stop automatically. As soon as the water-level differential reaches one inch, automatically continue lowering at 1150 rpm to a depth of 15 feet below water level. (4) In no case, under any operating conditions, is the torque from the drive motors and/or the Synchrotie motors to exceed 900 pound-feet. This torque limitation is approximately 490 percent of the full-load torque of the high-speed motor and 245 percent of the full-load torque of the low-speed motors. (The limitation was imposed to allow a reduction in size and cost in portions of the mechanical system between the motors and the gate.)

A schematic diagram of the downstream-leaf power system is shown in Fig. 1. For raising or lowering the gate during high-speed operation, the low-speed motors operate as Synchroties to keep the gate level. Starting resistors in the rotor circuit of the low-speed motor prevent excessive torques from being developed in the synchronizing sequence and are short circuited after the low-speed motors have been synchronized. Then the high-speed motors are energized. Torque limitation during the first step of acceleration is accomplished by the starting resistors. Approximately 12 cycles after the first step of accelerating resistance is cut out, the instantaneous overcurrent relays in the high-speed motor-armature circuit are placed in the circuit by opening the shorting contacts on the current transformers to obtain torque limitation. In case of

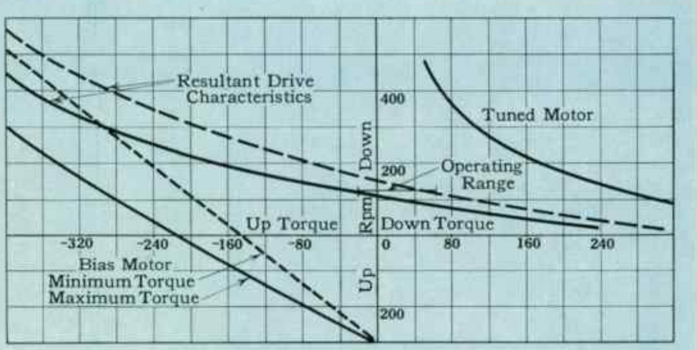
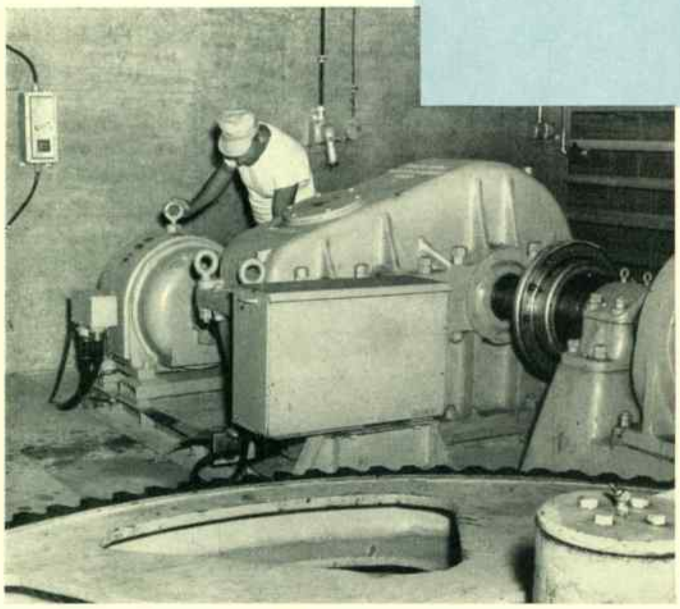
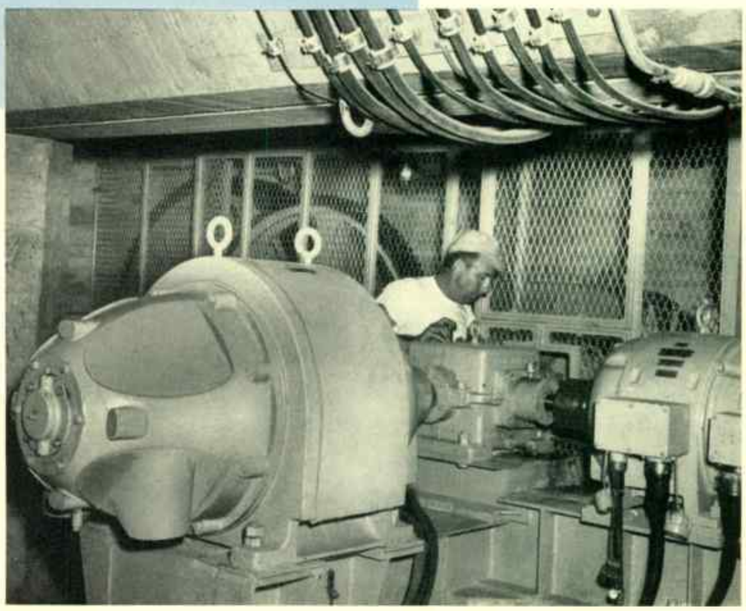


Fig. 3—Speed-torque curves of high-speed motors with the tuned circuit in the rotor circuit; low-speed counter-torque Synchrotie motor; and combined curve of two geared together for operation at 115 rpm.



High-speed motor, speed reducer and huge half-gear comprise drive for miter gates at lower end of locks.



Drive for one end of downstream leaf of the main lock.

failure of one high-speed motor, the leaf can be operated using one high-speed driving motor and the low-speed motors as a power Synchrotie, or the leaf can be operated without Synchrotie by manual synchronization when necessary.

Low-speed operation is similar to high-speed operation. except that the functions of the high- and low-speed motors are interchanged.

Operation of the Gates

The water level in the lock is raised or lowered by valves around the upper and lower gates. However, to reduce the time necessary for a lockage, the upper gate can be lowered to allow additional water from the upper pool to enter by flowing over the top of the gate. This is known as a supplemental-fill operation. To prevent excessive turbulence in the lock due to large volumes of water flowing from the upper pool into the lock, precise speed control of the leaf must be maintained during the lowering operation, and the leaf must be precisely positioned at the end of the lowering operation.

The gate is lowered at high speed until the top is six inches above the water level of the upper pool. At that time, a tuned circuit is inserted into the rotor circuits of the high-speed driving motor, causing these motors to decelerate. A contactor in the Synchrotie rotor circuit then closes to introduce resistance, which produces a counter-torque against the direction of rotation of the low-speed motors. The resultant speed of the gate is controlled by balancing the load of the gate plus the counter-torque of the low-speed motors against the output of the high-speed driving motors. In Fig. 3, the speed-torque curves of the high-speed motors with the tuned circuit in the rotor circuit are shown, as well as the speed-torque curve of the low-speed counter-torque Synchrotie motor, and the combined characteristic of the two geared together for a nominal operating speed of 115 rpm. Fine control of the speed is obtained by using a differential device, which compares the speed of the drive motors with a fixed speed obtained from a lightly loaded induction motor. The differential device operates the rheostat in the rotor circuit of the counter-torque motor and thus changes their torque within the limits shown in Fig. 3. The driving system holds the speed within ±7.5 percent of the nominal speed over a torque range of −20 pound-feet to +65 pound-feet, as shown in Fig. 3. The speed is adjustable between 100 and 300 rpm by varying the value of inductance in the tuned circuit and the value of resistance in the counter-torque circuit. The variable speed reducer is then set to operate the system at the desired speed.

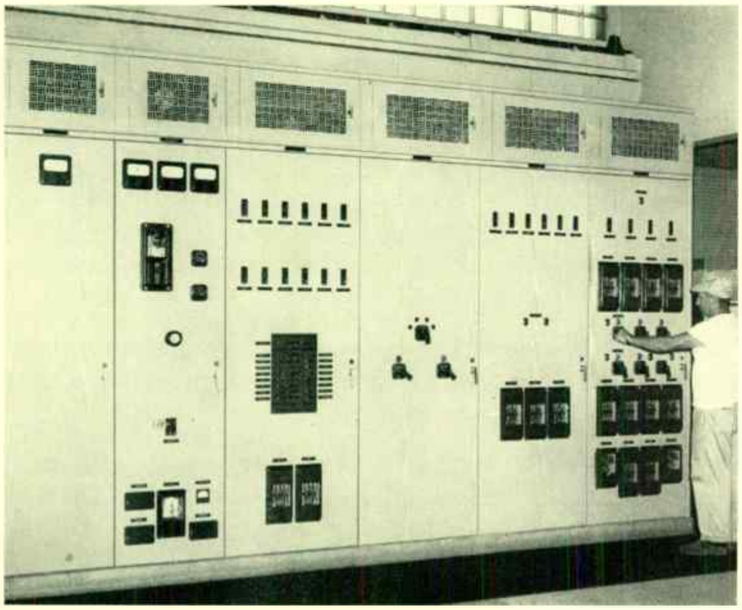
To prevent shock to the machinery, when operating on high-speed drive, the gate is decelerated as it nears the end of travel. At a point six inches from the end of travel, the tuned circuit is introduced in the rotor circuit of the high-speed driving motor, giving a smooth deceleration to a speed of travel that will not cause excessive shock to the mechanical system when the brakes are set.

The a-c drive with power Synchroties for level control requires the minimum number of rotating machines for use in moving a structure such as a lock leaf or bridge. If only one speed of operation is required, the Synchrotie and the drive motors can be of the same design. Where the Synchrotie and drive motors are duplicates, one of the drive motors can be removed, in case of failure, and replaced with one of the Synchrotie motors, and the structure moved without using a Synchrotie. With such a scheme, operation without any spare rotating equipment is possible, because the characteristics of the drive motors are so similar that very little skew will develop in normal operation with the Synchrotie motors de-energized. The leaves at Lock 27 have been operated over their entire range of travel with the Synchroties de-energized with less than three inches of skew being developed.

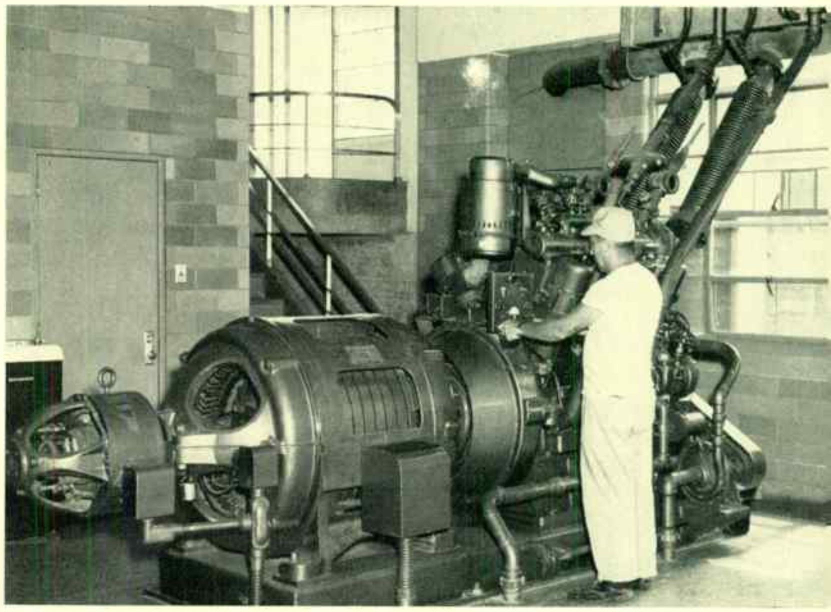
For Lock 27, duplicate motors were used for spares, a minimum number being required because only one spare is needed for the two walkway bridges and one for the two upstream leafs. The multispeed operation of the downstream leaf necessitates that two motors be kept as spares, one 40 hp and one 20 hp.

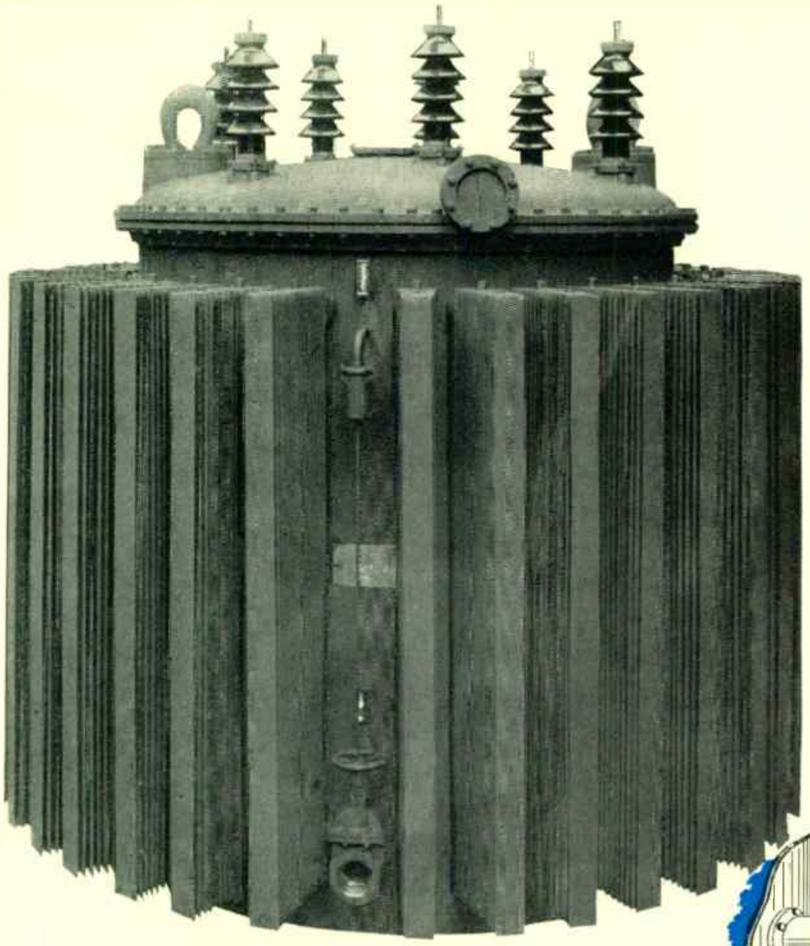
Alternating-current equipment has the advantages of providing control with a minimum number of pieces of rotating equipment and a minimum of spare parts. In addition, it reduces maintenance problems.

Vertical, tunnel-type switchboards house relays, timers, circuit breakers, contactors, and instruments.



Gasoline-engine generator set provides standby power to assure continuous supply for operation of locks.





A 200 000-kva transformer, although 99.95 percent efficient, requires more than a half acre of radiating surface to rid itself of the 1000 kw of heat losses. In the common oil-to-air variety this requires large banks of radiators, which become a major component of the transformer. An important step in the long period of transformer evolution has just been taken with a radiator capable of being tested to much higher pressure.

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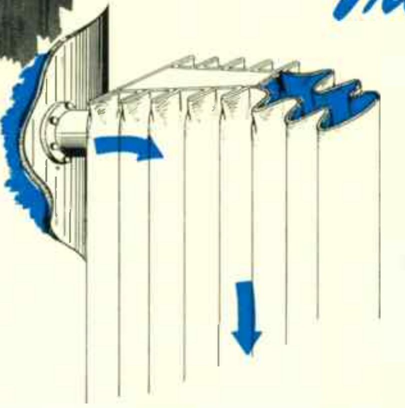
A New Milestone in Transformer-Radiator Evolution



The first demountable radiator built by Westinghouse was completed in 1915. This was a single-phase, 5000-kva, 25-cycle unit. It was made of sheet metal formed into an accordion shape, and tapered from tbe tank end.

After forty years of almost continuous development, significant improvements continue to be made in detachable radiators for power transformers. A new radiator can be factory tested against leaks to three times higher pressure than before. A new header construction, in addition to being able to withstand greater test pressure, is simpler as it eliminates connecting pipes and elbows and either one half or two thirds of the gaskets.

Detachable radiators had their beginning in 1914. Up to that time self-cooled ratings were limited by the amount of cooling surface that could be built into the tank. The larger sizes were water cooled. In the early days—the 90's—transformers of 50 and 75 kva were water cooled. This was done by placing a coiled-up water pipe in the top of the transformer, just below the oil level. As voltages increased and larger tanks were required, higher kva ratings could be made self-cooled. But it was not until detachable radiators became available that transformer men began to think of self-cooling for units of more than 3000 or 4000 kva.

Meanwhile, two other types of cooling for self-ventilated transformers were developed. One was the fluted-wall tank, which came into use in the early 1900's. The thin sheets used in the walls were folded up accordion fashion. At first these were riveted or soldered to the cast-iron top and bottom of the tank. Later the walls were supported in the molds used for casting the tanks, and the cast iron was poured in around the thin walls—hence the name "cast-in" tank. This cast-in tank continued in use for many years, for medium-sized power transformers—up to 2000 or 2500 kva. In the late 1920's cast-iron tanks could no longer compete with welded construction, and the cast-in tank was abandoned.

The second method of self-cooling for large units was the "tubular-cooler" tank. Two-inch pipes were bent at the ends, and welded directly into the tank wall. For the larger kva ratings (2000 kva) several layers of tubes were welded into the tank wall. The tanks were made of heavier plate—$\frac{3}{16}$ to $\frac{3}{8}$ inch thick—and were called "boiler-iron" tanks. The cooling tubes on these tubular tanks were much like those used on self-ventilated network transformers at present. The tubular-cooler design, with header-type tubes welded directly to the tank wall, is still the popular method of cooling for transformers up to 5000-kva rating.

The first Westinghouse demountable radiator was designed in 1914 and was built for three 5000-kva, 25-cycle transformers. This type of radiator was only moderately successful as it did not have adequate strength. Although more than 1000 of them were made during the three-year period of use, they have since been replaced or become obsolete.

The second period in detachable-radiator evolution covered the years from 1918 to 1930. This was a tubular radiator supplied by a company that made a specialty of radiator manufacture. It consisted of 35 to 47 oval tubes (1 inch by 3 inches outside dimensions) gas welded to sheet-metal headers. This was a successful radiator as indicated by its continuous use for 13 years. In fact, many thousands of these radiators are still in service. They were made in a wide variety of sizes from 4 to 14 feet long.

This construction, as originally made, had a weakness. The individual tubes were welded on the inside of the headers. Hence, when the header cover was welded on there was no access to the welded end of a tube in case a leak developed. Also with this construction a water pocket was created at the bottom of each tube. Frequent painting was required to prevent corrosion at this point.

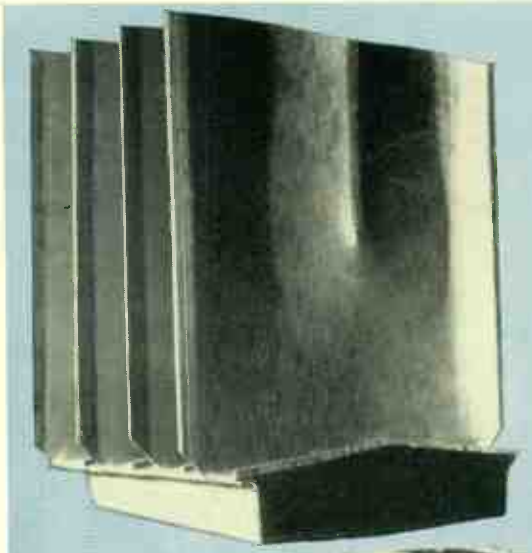
Throughout the 20's development of a sheet-metal radiator was aggressively pursued. Many designs were made and numerous samples built and tested—all of which made very clear that while a transformer radiator seems like a simple thing, the creation of an efficient, reliable, and economic one is a major undertaking.

Culmination of this effort came in 1930 with a cooler that was not only highly successful—it is still the basic design and has been built by the tens of thousands—but also it is extremely novel. This is the blown-up or inflated cooler—the cooler being a single element of a radiator assembly. Two long pieces of sheet metal are resistance-welded along the two edges. Also one or two seams are welded for most of the length of the two strips. Then the two edge- and seam-welded plates are placed in a jig and air pressure is applied through a prepared opening in one end. This inflates the radiator, forming two lobes, in the case of the single, center-seam design, or three lobes with the present double-seam. The result is a mechanically strong cooler with large surfaces and free ducts for air flow on the outside, and smooth passages for the flow of oil on the inside. One great merit of making the radiator in this fashion is that all the welding is done on two flat sheets. This is simpler than if the lobes are made in a press, or formed by rolls prior to welding. There is no distortion of the edges, and the cooler is given a good high-pressure test at the same time it is formed by inflation.

The inflated design continues with great success today. In the intervening 20 years, however, a number of important improvements have been made.

Bracing strips, to space the coolers evenly and to brace the entire assembly, were soon added. These strips were first mounted both horizontally and diagonally across the radiators, to obtain greater rigidity. Later it was discovered that certain lengths of cooler were quite resonant at 60 cycles. To keep them all the same nonresonant length, diagonal braces were omitted and only horizontal braces used.

The type of headers into which the coolers terminate and the manner of connecting the headers to the tank



Above, and at right are early versions of the inflated (twin-lobe) sheet-metal radiator units.

A radiator made of a large number of oval tubes with ends welded into headers was used for about 13 years. The tubes of this unit, built in 1930, were set in rows, each row being staggered with respect to the adjoining row.

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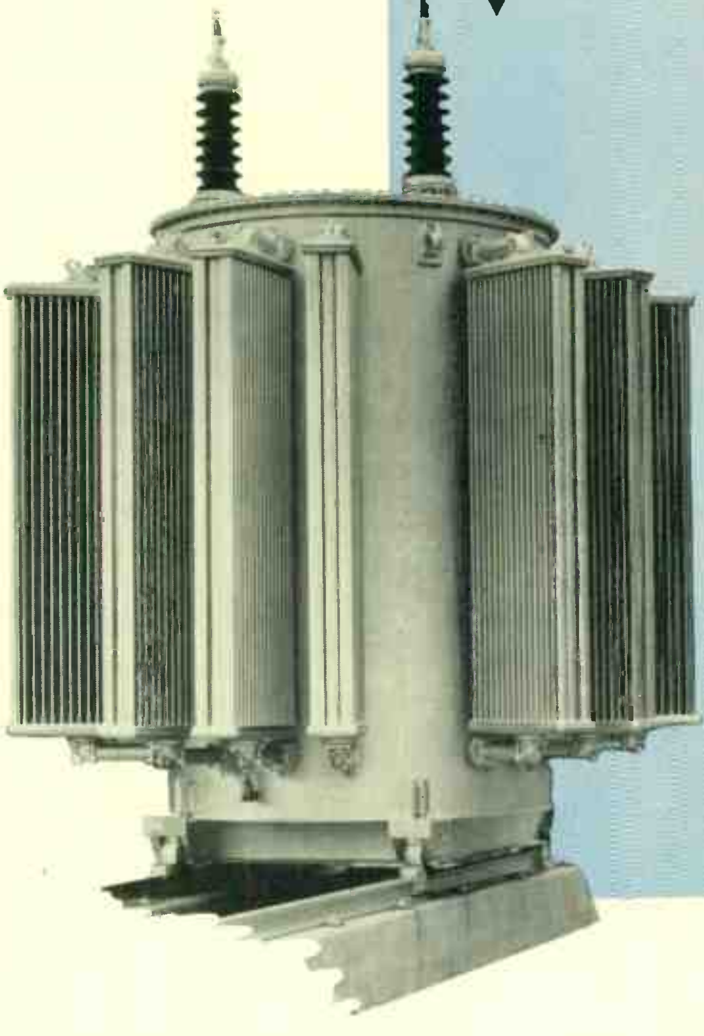
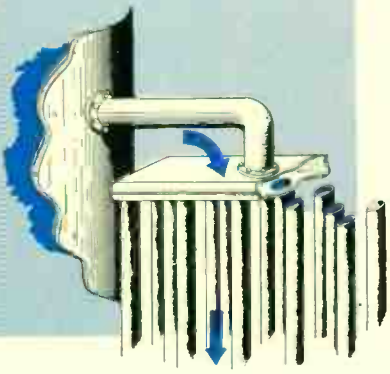




have undergone many changes. Current practice has been to flare the ends of the inflated coolers into flanges, which are edge welded. To this is welded a rectangular or box-shaped header of sheet metal. A circular opening and a flange is placed in the center of this header. This assembly is fastened top and bottom to a one-piece pipe and elbow of cast iron that extends from the tank and both supports the radiator and conducts oil to and from it.

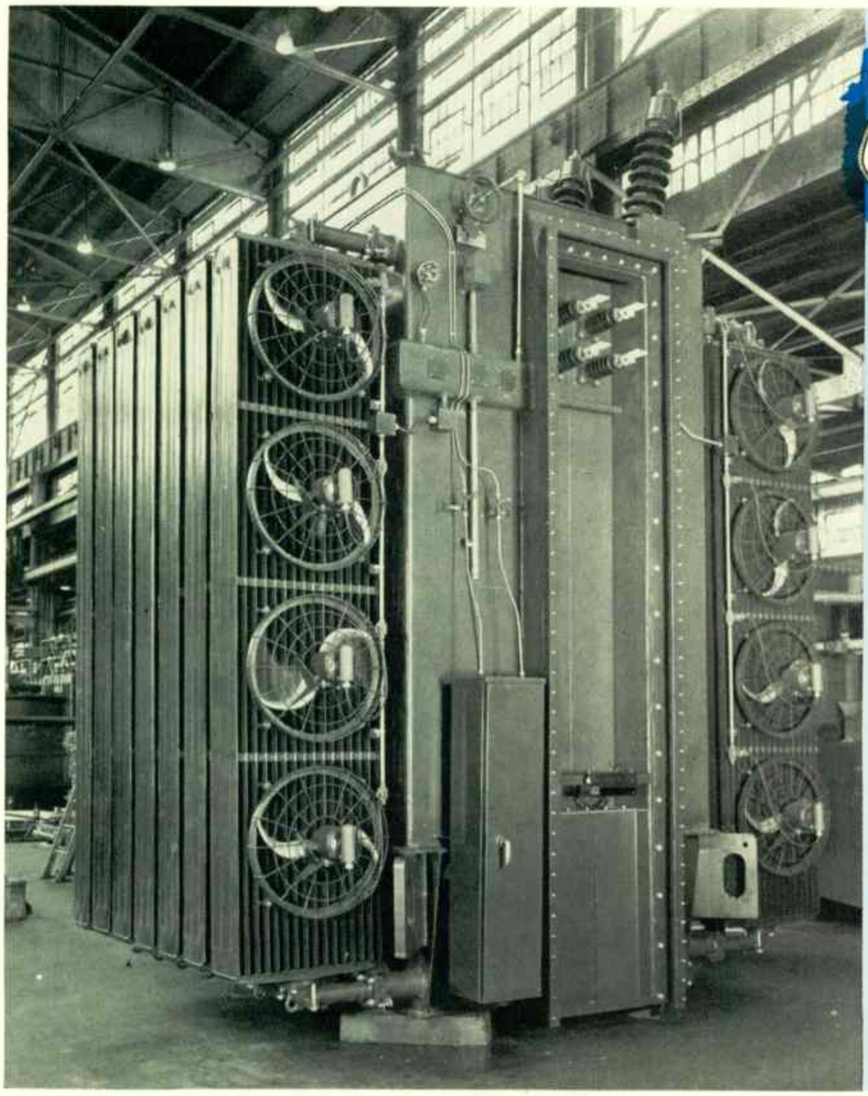
Over one-hundred thousand radiators have been built this way. Only rarely has a leak developed. However, it has been recognized that a header capable of withstanding greater pressure would be desirable as this would permit the whole radiator assembly to be tested at higher pressure and thus provide a more positive search for inadequate welds. Actually the header is the present bottleneck to test pressures. The original coolers were inflated with air pressure at 90 pounds per square inch. Subsequent improvements in welding techniques, use of thicker gauge metal, and the three-lobe instead of the two-lobe design have made it possible to raise inflation pressures to 160 psi. Except for the header, the radiator will withstand 175 psi test pressure. However, up to now test pressures have been limited to 15 or 20 psi, which is only 1½ to 2 times the pressure developed in transformer operation. This is because the rectangular section used for the header is inherently not a pressure-resisting shape.

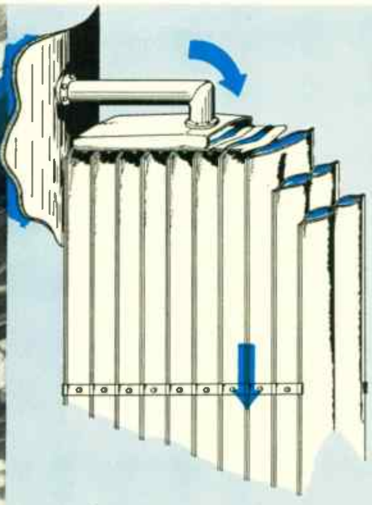
A new type of header obviates this limitation. It is formed from a single sheet of steel into a large "U". The coolers are formed and their flanges welded together as before. This welded flange section becomes the "roof" for the "U". One end of the "U" is closed with a welded plate; the other end terminates in a flange that is bolted directly to the tank opening. This construction requires no pipe to connect the radiator assembly to the transformer. Also the only gasketed joint is at the tank wall; the gasket between header and elbow is eliminated. The long, free-air ducts, so beneficial for forced-air cooling, are still a feature of the new construction. The new radiator can be tested to 50 psi. This is five or six times the operating pressure and three times the test pressures used on the previous construction.

Because the elbow and pipe connection is not needed, the space at top and bottom of the radiator formerly occupied by it can be used for coolers. Thus the coolers with the new construction are longer than with the "box" header. This increased radiating surface makes it possible for 15 coolers to do the work of 16.

Radiators, heretofore, have been made in a single size—with 16 coolers. Thus when one row of radiators did not provide adequate cooling capacity two rows were used in tandem. The pipe connecting header to tank was extended to serve both radiators. This, of course, meant two additional flanges and gaskets for a total of six for one radiator.

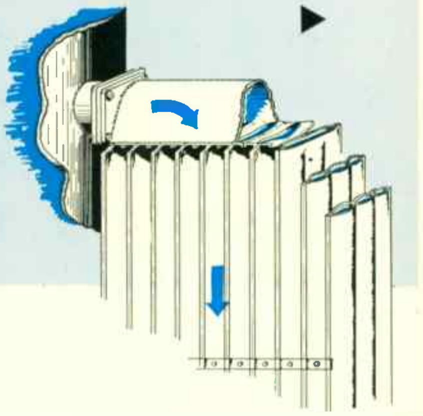
The new radiators are made in three sizes, with 15, 23, and





◀ **A modern version of the inflated radiator, with a sheet-metal header, and an elbow connection to the tank.**

The new high-pressure header formed into a U-shape of sheet metal permits testing the entire assembly to 50 psi. No pipe elbow, flange, and gasket is needed at the radiator. ▶



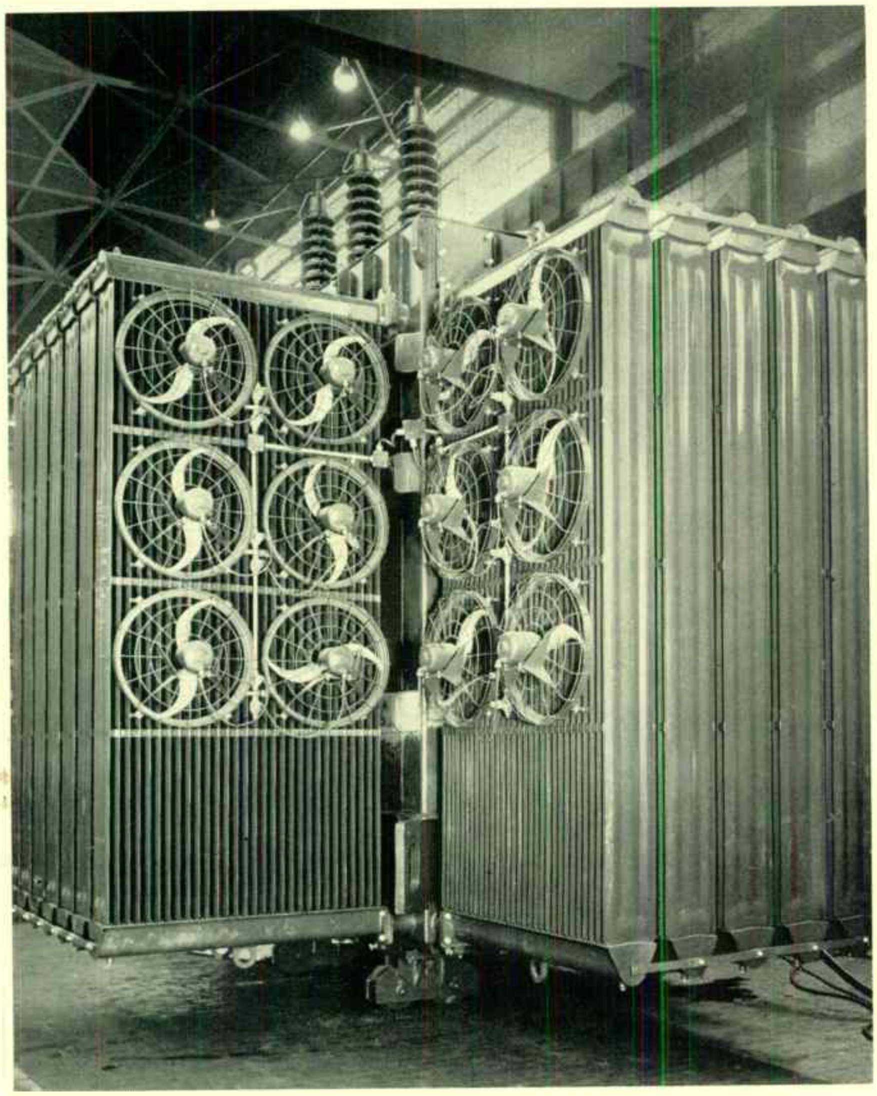
30 coolers. Each is a single unit, with but one flange at top and bottom to bolt to the tank. The choice of sizes also adds to the flexibility in selecting the most desirable amount of radiating surface for any rating of transformer.

In the previous construction the flanged ends on the outside cooler element had to be different from the others. In the new one all coolers—even including the two end coolers—are identical. A small detail, but such things conspire to make a more trouble-free equipment and one simpler to assemble.

Certain other improvements have also been made. A new and heavier forged valve has been developed. The bolt circle on the tank for mounting the radiator has been enlarged from a 6-inch circle to a rectangle 7¼ by 5¼ inches. This gives greater strength at the flange. The new and stronger radiator can be used for replacements of the older design, should this ever be required. A simple adapter flange is available for this purpose.

The finish for the radiator has been changed to the mica-flake Coastal finish developed about two years ago for use on distribution transformers subjected to salt atmospheres. This finish has been so resistant to deterioration in all kinds of atmospheres that it is being extended wherever possible. The mica-bearing paint, which is the second of three coats, is flowed on and baked with infrared heat.

This marks another step in a 40-year evolution of detachable radiators. The result is an important component that is both simple and better, and should reduce the problem of transformer maintenance even further.



Trends in Metal Production

Until a few years ago, most flat-wire products were rolled on slow-speed single-stand mills, each mill requiring an operator and considerable handling of spools for the several passes required. Recently, the trend has been toward high-speed tandem mills; in four mills that have gone into production in the past year only a single high-speed pass through all stands is required to reduce wire, or rod, to a flat or rectangular shape.

One example is a five-stand tandem mill with a maximum delivery speed of 2400 feet per minute. The principal product of this mill is 0.025 by 0.375 inch flat strip rolled from 0.25-inch-diameter steel rod.

The bull block (a die block to assure uniform entry cross section), mill, and winder motors are supplied from a common 400-kw generator, whose voltage is controlled by a Rototrol regulator. The winder-motor shunt field is controlled by a current-regulating Rototrol to maintain the desired tension over the range of coil buildup. From a single control desk one man can operate the entire line.

• • •

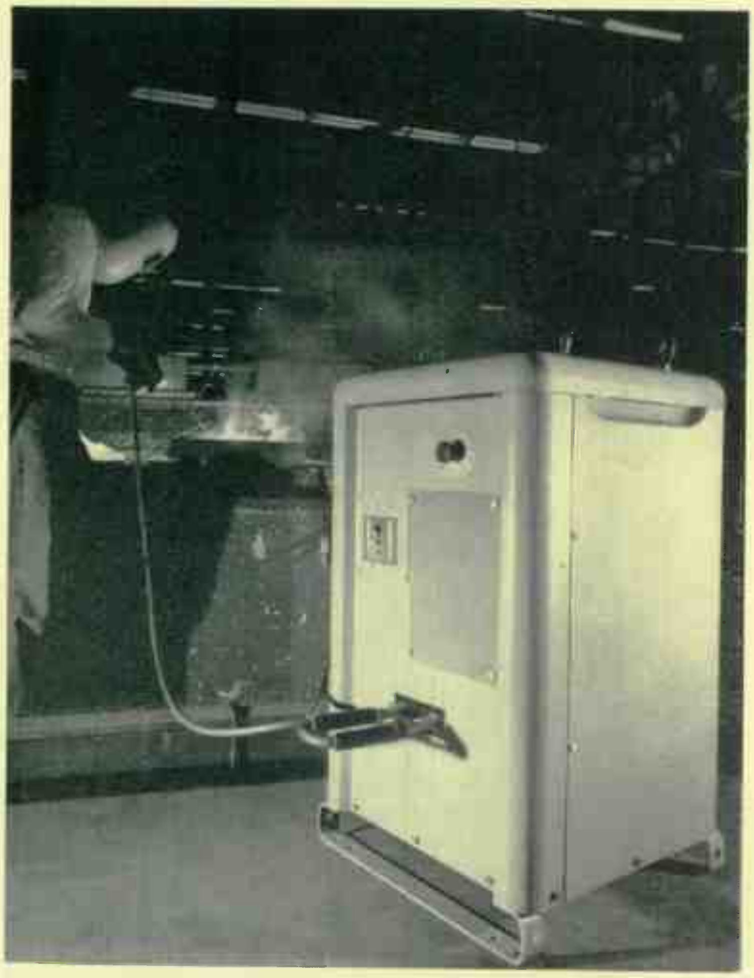
Most of the conveyors and other material-handling equipment in a new sintering plant operate in remote, unattended locations; the entire plant is under the control of a few operators at central controls.

The new plant includes two large sintering machines that convert iron-bearing materials from small particles, not suitable for blast furnace use, to the large porous lumps that are desirable for furnace charging. Mill scale and dust, fine ore, and flue dust from the blast furnace are mixed with coke and spread on a moving grate, where the mixture is ignited and sintered.

Many conveyors bring material into storage bins at one end of the sintering plant; others carry away the sintered material. They extend over a huge area but all are controlled from stations in the sintering machine building. The conveyor systems are interlocked to insure the proper sequence of starting and stopping, and to prevent pile-ups if a conveyor fails.

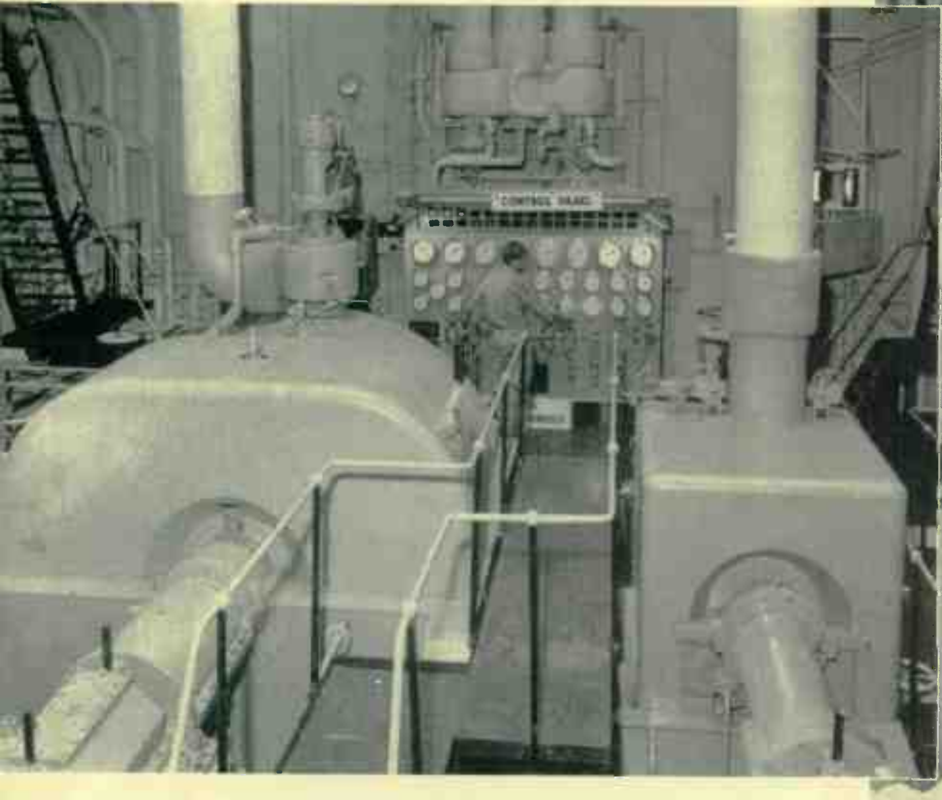
A total of 91 squirrel-cage motors, ranging from 1 to 150 hp, and totaling over 2000 hp, drive the conveyor's screens, pig mills, and pumps. All these motors are controlled from seven control centers located throughout the plant area.

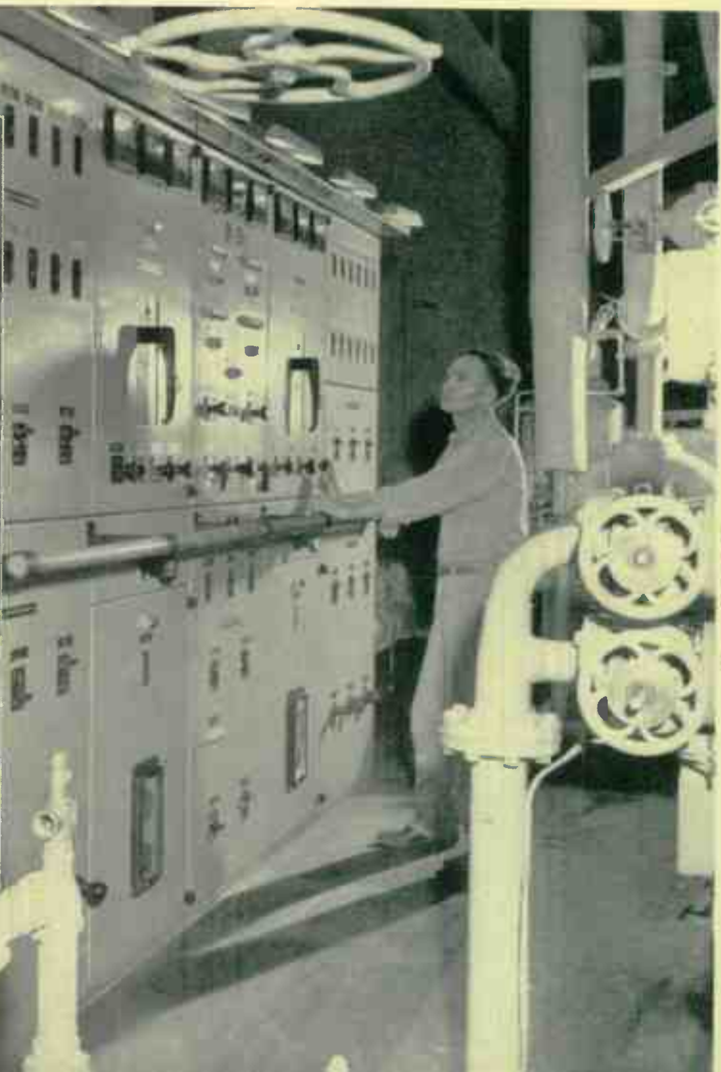
Storage bins for raw materials are fed by a complex set of conveyors, some of which can be run in either the forward or reverse direction, and can be moved on tracks to feed material to the proper bin. The operator's cabinet is equipped with push-buttons and indicating lights along with colored aluminum strips mounted to simulate the physical arrangement of the conveyors. The sintering machine operator's cabinet is similarly arranged to show the schematic location of equipment and flow of material.

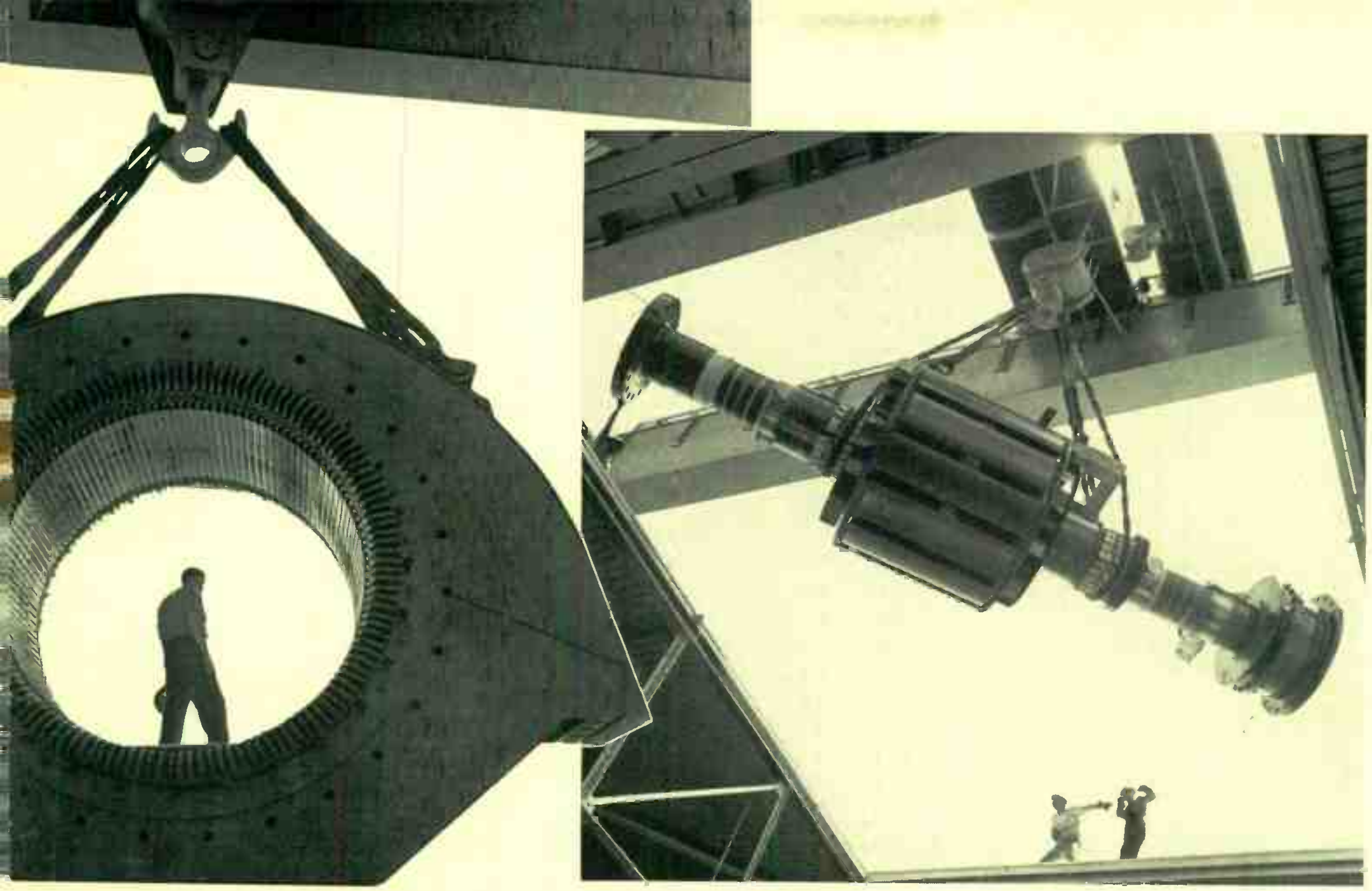


Pictures of Industry

THIS is the new rectifier welder in action. The color photograph shows the inside of the welding unit. At the top is the ventilating fan; center, the Transactor unit with aluminum coils; at the bottom, the rectifiers. (See p. 208 for further information.)







SHOWN above are the stator (left) and the rotor (right) for the 83 000-hp synchronous motor that will serve as part of the 216 000-hp electric drive for the U.S. Air Force's new transonic and supersonic wind tunnels at Tullahoma, Tennessee. A similar motor will be installed soon, along with two 25 000-hp induction motors.

THIS 150 000-kva power transformer, destined for the Appalachian Electric Power Company, is designed for 330 kv, and is one of the largest capacity transformers ever built for this high voltage. It is one of 12 such units now on order for the American Gas and Electric system. The unit is designed to operate at a river flood level of over 6 feet above the base.

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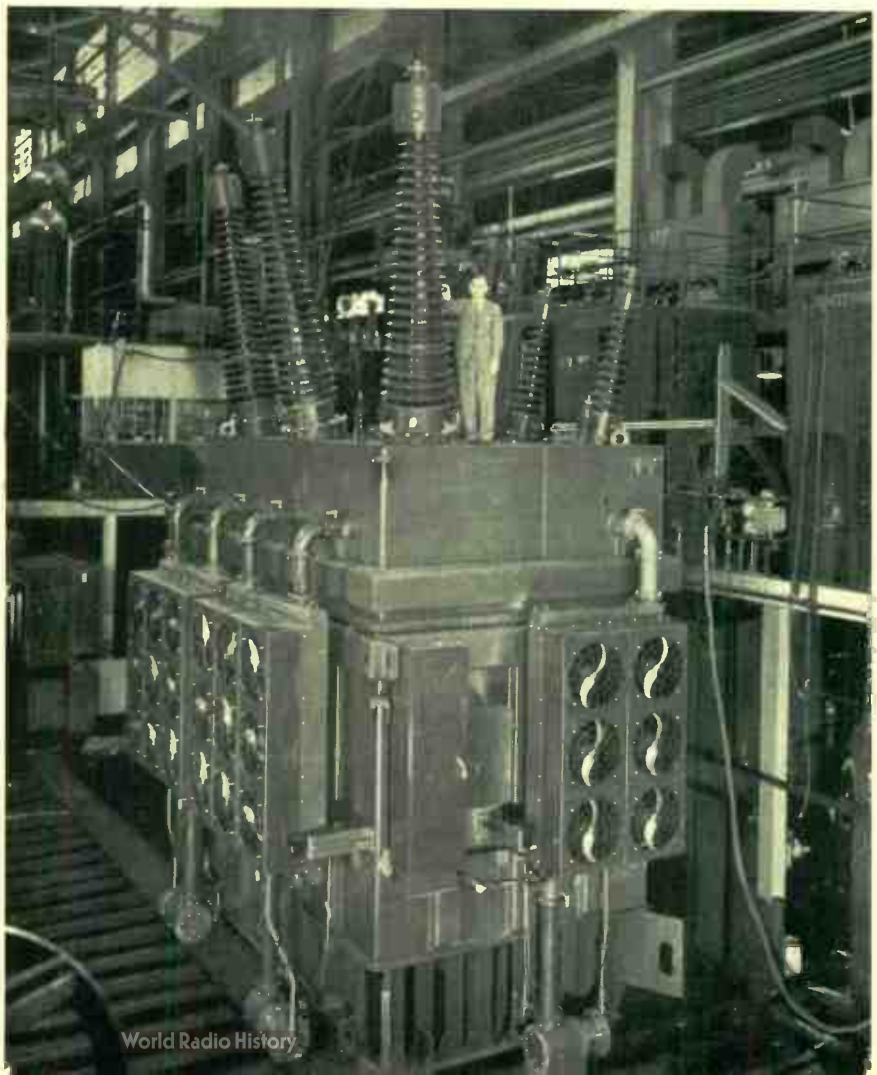
AT FAR left, the engine room of the Sun Oil Company's new tanker, the *Delaware Sun*. The low-pressure turbine is at left, the high-pressure turbine at right. In the background is the turbine control. The normal rating is 13 500 shp at a propeller speed of 100 rpm. The total shaft horsepower is equally divided between the high- and low-pressure turbines, which run at 6310 and 4230 rpm, respectively, at normal power. At left, the main generator and distribution switchboard, which incorporates the generator circuit breakers, voltage regulators, instrumentation, and distribution circuit breakers required for parallel operation of the two 500-kva ship's service generators and for distribution of power to auxiliary panels. There are 24 power and lighting distribution panels at various points on the ship.



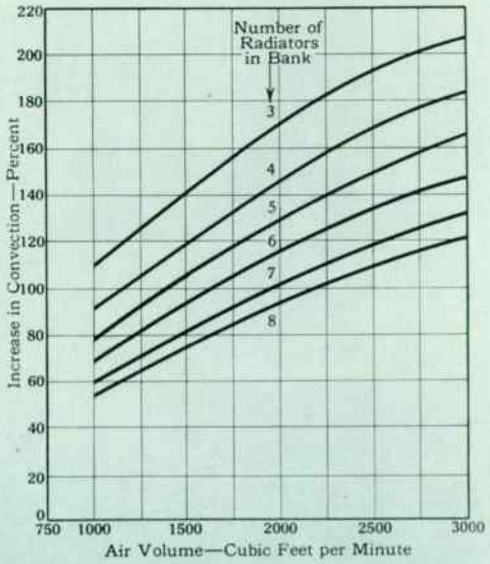


Fig. 1—The use of forced-air fans can result in more than a 200 percent increase in the efficiency of the transformer radiator surface. Air volume is in cfm per foot of radiator length.

If nature were fully cooperative, a power transformer might need no cooling fans. But until such time as a good stiff breeze is available whenever the transformer needs it, fans will continue to play their vital part in the operation of all large power transformers.

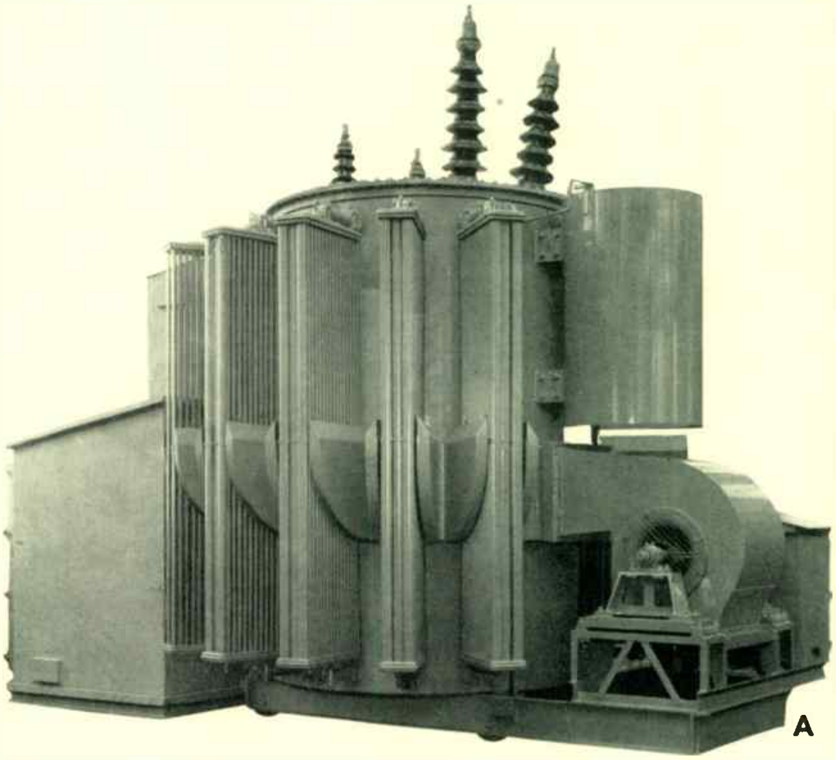


Fig. 2—Early attempts at forced-air cooling utilized a central ventilating fan and a cumbersome system of metal ducts (A). To conserve the floor space required by the fan equipment, and to

Forced-Air Cooling of Power Transformers

Nearly 75 percent of all power transformers larger than 10 000 kva are built with cooling fans, and many of the rest have fans installed later. Transformer radiator efficiency can be increased by as much as 200 percent through the use of fans (Fig. 1), and the usual design of forced-air-cooled power transformers allows for a one-third increase in load when fans are in operation.

As power transformers have grown in size, supplementary cooling has become even more important, because for the large ratings the radiators required to self-cool a transformer would be larger than the transformer itself. Radiator surface areas are cooled mainly by convection, and require a volume of cool air about equal to that of a 15- to 20-mile-per-hour natural breeze. Fans are used to supply air in this amount, and their application greatly reduces radiator size.

Fan cooling is often used only during peak-load periods, with self-cooled radiators dissipating the heat from average loads. Such an initial installation makes it a simple matter to increase the transformer rating to accommodate load growth by merely operating the fans continuously. And since peak-load periods are usually periods of higher ambient sound level, the fan sound is not as noticeable.

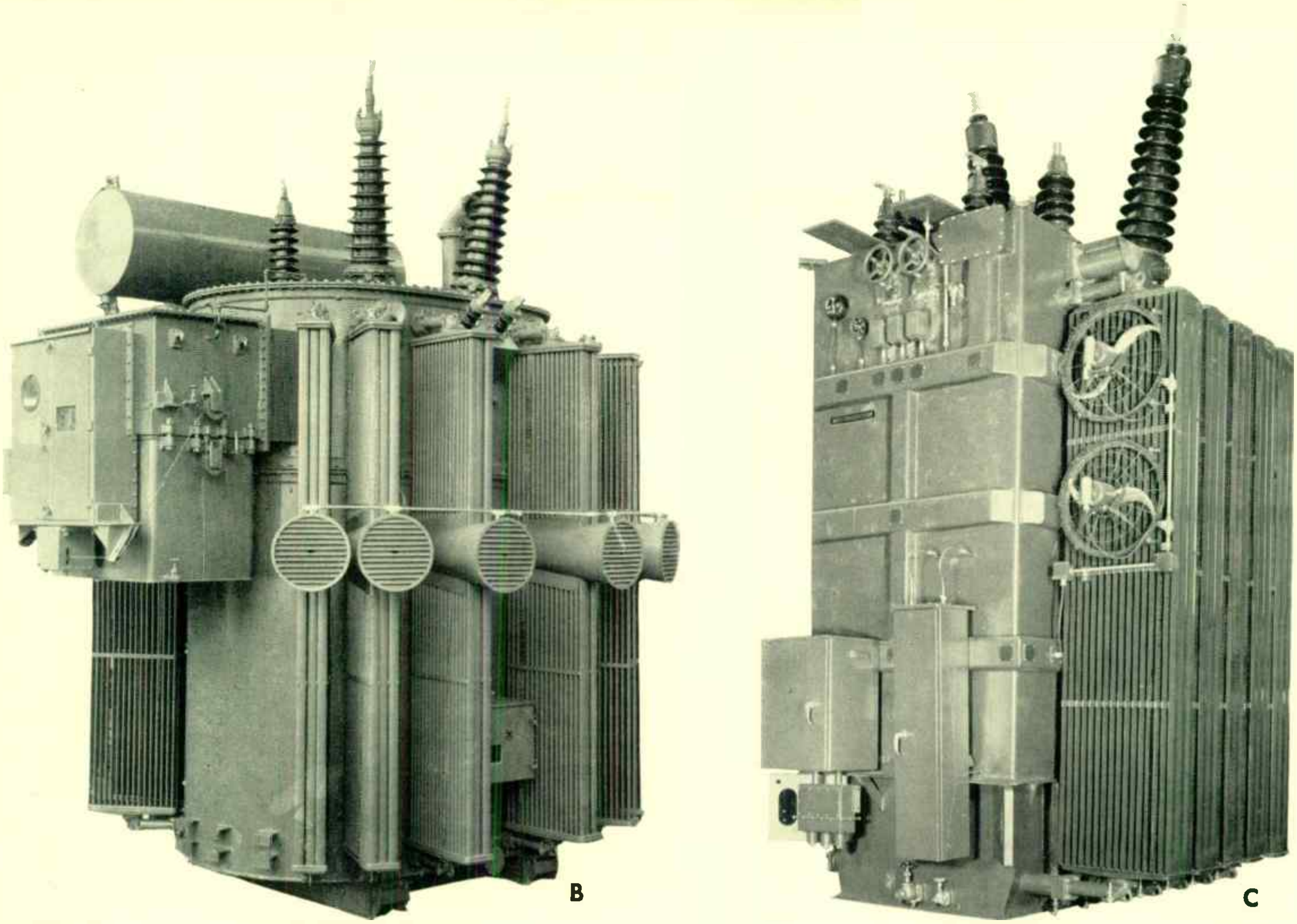
Continuous fan operation, on the other hand, permits the use of a smaller transformer, and eliminates the need for fan control. Even in times of off-peak loads, continuous fan operation will increase transformer life as a result of cooler operating temperatures.

Evolution of fan cooling has led to the present flat-fin radiator (Fig. 2). Replacing the round-tube design, the flat-fin radiators form a series of continuous air ducts, and eliminate the need for a fan on each radiator.

Factors Influencing Fan Selection

Many factors enter into the selection of the kind of fan cooling, including available space, load, both present and anticipated, and sound ambient. Obviously, the number of fans applied should be kept to a minimum, and such interrelated characteristics as fan size, speed, blade configuration and pitch can be varied to provide the needed amount of air. Since each affects the other, and all vary such things as sound level, they cannot be changed independently.

Fan sound level is sometimes the limiting consideration. Standards permit a three-decibel increase in total transformer sound level when forced-air fans are applied. Since the combination of two equal sound levels results in approximately a three-decibel increase, the sound level of the fans should not



eliminate the costly duct work, individual fan housings and ducts were applied to each radiator (B). Flat-fin radiators mounted side by side made it possible to mount fans on one end of the radiator bank to force air through the continuous ducts so formed (C). This reduces the number of fans required, and results in simpler maintenance and replacement. No additional floor space is required.

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exceed that of the self-cooled transformer for which they are to provide cooling.

Modern forced-air cooling fans deliver from 3000 to 7500 cubic feet of air per minute, at velocities of some 1000 feet per minute at the fan. Some large power transformers require as much as 300 000 cubic feet of air per minute. The relationship of air volume and sound level is shown in Table I.

Fan speed is closely related to air volume and sound level. Standard 1725-rpm motors have been used for years, and are still used in many applications. Where large numbers of fans are required, or where an extra low sound level is desired, 1140-rpm motors are used, and in a few very special cases the speed has been further reduced to 860 rpm. Since fan blade efficiency drops off below the optimum design speed, changes in pitch, blade shape, and size are necessary if low-speed blades are to be used.

TABLE I—PERFORMANCE OF TYPICAL FORCED-AIR COOLING FANS ON POWER TRANSFORMERS

Fan	Fan Diameter—Inches	Air Volume*—Percent of Fan A	Fan Noise†—Decibels (40)	Motor Input	
				Volt Amperes	Watts
A	26	100	65.5	335	227
B	26	81	58.3	286	204
C	26	61	54.6	246	148
D	26	58	51.3	139	62
E	26	50	48.3	156	64
F	18	44	56.2	234	134

*Measured with anemometer per preliminary NEMA Standards 1-FM
†Measured on six-foot radius from fan per NEMA Standards TR-130

Even though statically balanced, fans do not operate completely free of vibration. Rigid mounting is used to prevent sympathetic vibrations in radiator assemblies. Flexible neoprene connecting cable eliminates the transmission of vibrations through conduit.

Either single-phase, capacitor-start, capacitor-run, or three-phase fan motors are used. Although a three-phase motor always rotates in the proper direction, a natural breeze can cause unenergized single-phase fan motors to start in the reverse direction and continue to run reverse when energized. The cooling effects of the breeze, however, usually offset the loss in cooling efficiency that results from rotation of the fan in the reverse direction. Reverse rotation will not cause any damage to the motor.

Unit assembly, such as illustrated in Fig. 3, makes it possible to remove the fan without de-energizing the circuit. This not only simplifies any maintenance work, but limits the number of replacement fans that must be kept available.

Fan Control

Manual control is obviously the simplest, both on new transformers and on applications subsequent to initial installation. In attended stations, the operator can start and stop fans on the basis of transformer load or temperature, or any combination thereof.

Next in simplicity is hot-oil-temperature control. Where rapid load variations are infrequent, the top oil in the transformer gives a suitable indication of the winding temperature, and a thermostat can be used to actuate the fan switch as the temperature of the top oil varies.

Where operating conditions permit rapid load changes, winding temperature can be used to control fan operation. The new type TRO thermal relay not only starts the fans, but indicates visually the approach of dangerous winding temperatures, and sounds an alarm or trips a circuit breaker if the temperature rise persists.

A hot-spot thermometer is sometimes used to control cooling fans. It detects the top oil temperature, and also responds to a heating coil through which is passed a current proportional to the load current. The device is calibrated so that it measures the winding hot spot, rather than the winding temperature itself.

In combination with self-cooling and forced-oil cooling, forced-air cooling has given rise to the triple-rated power transformer. Such a transformer has one rating when self-cooled, a one-third larger rating with half the pump and fans running, and still another one-third increase with all the pumps and fans operating.

As power transformers get still larger, and 300 000 kva units are now being designed, forced-air cooling will continue to be an important factor in their operation.

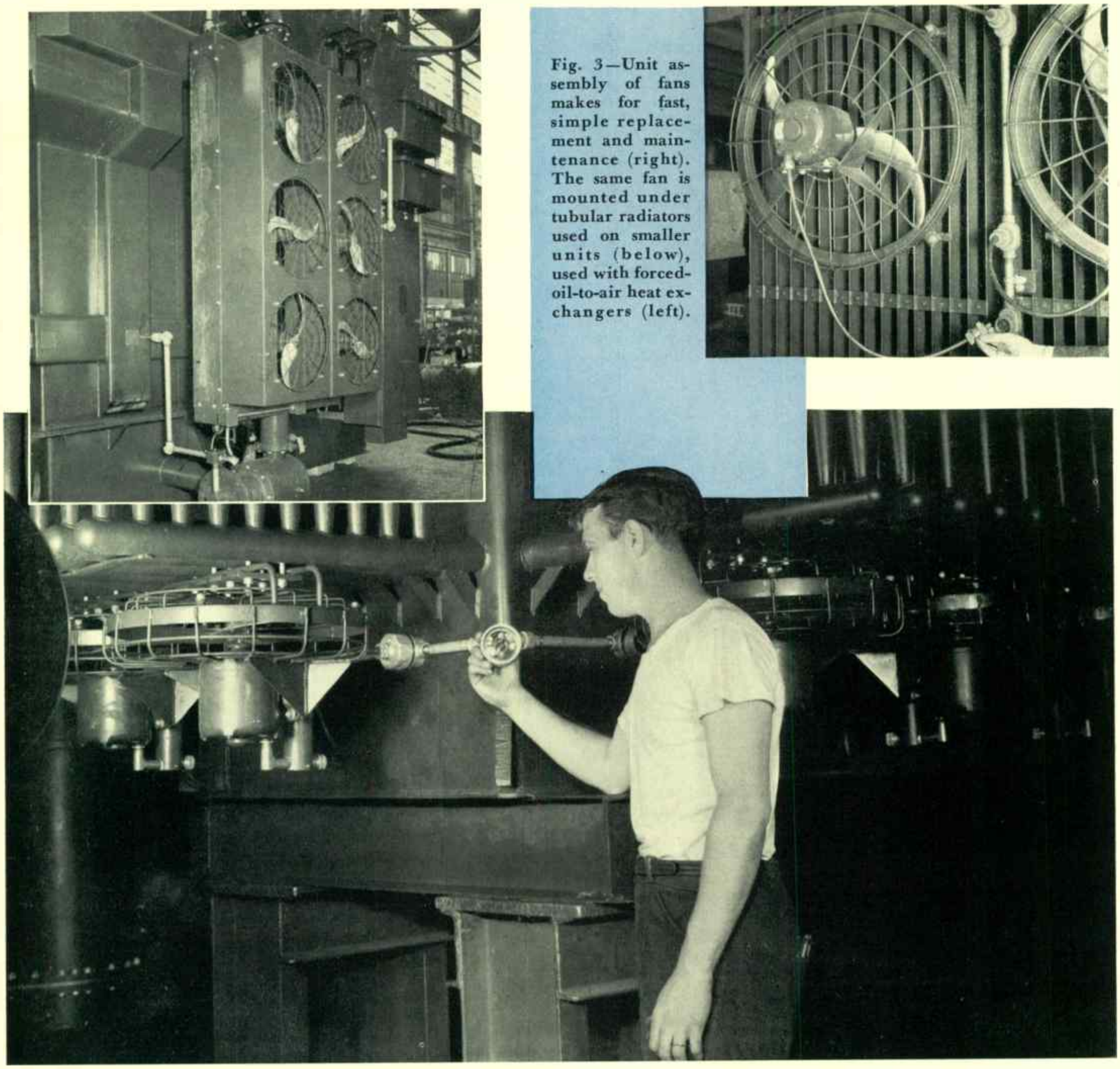
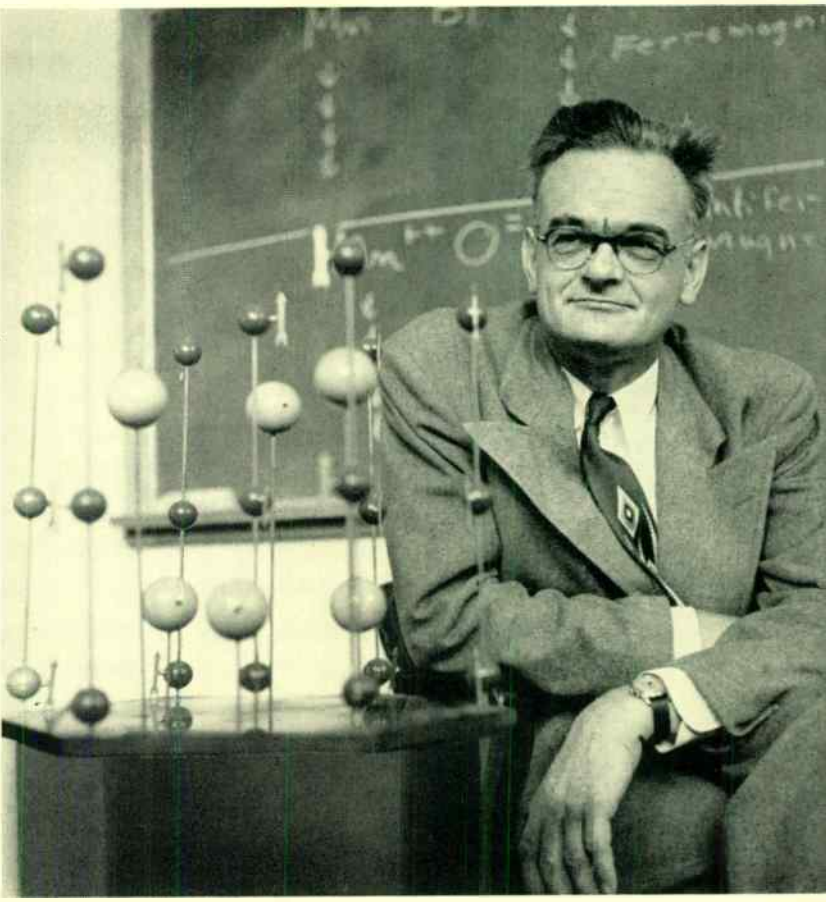


Fig. 3—Unit assembly of fans makes for fast, simple replacement and maintenance (right). The same fan is mounted under tubular radiators used on smaller units (below), used with forced-oil-to-air heat exchangers (left).

Personalities in Engineering

Dr. Clarence Zener



"Most scientists are pleased if they produce one idea a week, or even a month. He turns them out by the dozen. And many of them prove to be sound, useful ideas; all of them are thought-provoking."

This sincere compliment to Dr. Clarence Zener was volunteered by one of his associates, himself a recognized authority in his field. It is a belief expressed by many of his other scientific colleagues. Had Dr. Zener heard this statement personally, the part he would have appreciated most would have been the reference to his ideas as being "thought-provoking." For this, as he sees it, is one of his major aims as an Associate Director of the Westinghouse Research Laboratories—to serve as a sort of spark for his team of scientists. Ideas beget ideas, and if one of his thoughts strikes a resonant note, it may produce an avalanche of totally new information.

Zener is a relative newcomer to the industrial laboratory. And his presence there indicates a certain change in his personal philosophy of research. Most of his career to date was spent as a college professor. And in the classroom and laboratory he built a considerable reputation as a theoretical physicist. As he puts it, "I really was—and am—a theoretical physicist. I never was much of a hand at actual experimentation with equipment."

Zener has gained nationwide professional recognition for his work on metals, particularly on internal friction and diffusion of metals. Several years ago, he proposed an entirely new theory for the causes of ferromagnetism; this has since provoked considerable discussion both in this country and abroad.

During World War II, Dr. Zener carried on research and development work on projectile design and armor penetration at Watertown Arsenal. It was here that his views on the methods of doing research began to change. As he puts it, "The presence of a practical objective to our work—for example, better armor plate—made us ask questions we would have never thought of in an academic environment. This helped to convince me that research proceeds at a more rapid rate if we have some ultimate practical goal, or goals, in front of us."

Zener's early life was spent in Indiana; he was born in Indianapolis and spent his youth in Vincennes. About his choice of a career, he says, "I never really did *decide* to become a scientist. I just sort of veered in that direction from the time I first became engrossed in the family encyclopedia." That direction turned out to be physics. In 1926 he obtained a B.A. from Stanford, then enrolled at Harvard, from which he earned his doctorate in 1929. From there his quest for knowledge led him in a zigzag path to several parts of the world. First to the University of Leipzig, where he spent a year in study; then back to the United States, where he became a National Research Fellow in Physics. In 1932 he began specialization in solid-state physics at Bristol University in England, where he remained for two years, following which came a period at Washington University in St. Louis as an instructor in physics. In 1937 he moved to a similar post at City College of New York; and three years later he became an associate professor at Washington State College.

After his wartime work at Watertown Arsenal was concluded, Dr. Zener became a professor in the Institute of Metals and the Department of Physics at the University of Chicago. It was here that much of his work on metals was done, and where his theory of ferromagnetism was conceived. From this post he came to Westinghouse in 1951.

Cartoonists often portray scientists as preoccupied, absent-minded, and somewhat antisocial individuals. Zener bears no resemblance to this popular but fallacious concept. In conversation you gain a distinct impression that his entire concentration is directed toward the discussion at hand. His manner is direct, helpful, and pleasant.

Even in the short space of two years, Zener has made a lasting impression upon his research colleagues. One characteristic that helped accomplish this is a certain basic optimism combined with an unwillingness to admit defeat where a research problem he believes in is concerned. If, for example, a laboratory experiment appears to prove a new theory wrong, Zener refuses to become discouraged. He insists on a complete and careful review of both the theory and the experiment to find the error. Until such time as it is found, he maintains a completely open mind on the subject. Back of this, of course, lies a scientist's desire to see a fair and thorough test of any theory. Nevertheless this tenacity of purpose is a trait that stands any research scientist in good stead.

In trying to make a point, Zener often resorts to analogies. He also has a favorite and somewhat versatile humorous anecdote that tells a story in itself. It concerns a slightly inebriated gentleman discovered searching the sidewalk under a lamppost by a curious minion of the law. The officer watched for a few moments and then inquired if he could be of help. The tippler replied that he had lost his key, whereupon the officer offered to help. After several minutes of joint effort had failed to turn up the missing key, the officer asked politely if the man was sure he lost the key there. "Oh, no, officer, I lost it over there in that dark alley—but there's more light over here."

The lessons contained in the story are several, but one in particular applies to Zener himself. Everything about his past and present efforts suggests that he will be found looking in the right place for the key, regardless of the surrounding difficulty.

Insulation Coordination

—A Problem in Probabilities

If a person insured himself against every possible contingency he would have no substance left for other of life's activities. So one must decide what is a reasonable amount consonant with his own situation. There is a fair parallel with the problem of determining the amount of apparatus insulation and lightning protection for high-voltage power systems. Various elements of experienced judgment and records of past performance can be established as guides.

C. F. Wagner, *Consulting Engineer*
Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania

The coordination of insulation and the determination of basic impulse insulation levels must be approached from a rational and economical basis. From the economic standpoint, it is desirable to keep the insulation level as low as possible commensurate with safety to the insulation to be protected.

One way to attack the problem would be to consider the worst theoretical case, in which all of the unfavorable factors are permitted to pyramid on each other. This involves numerous possibilities: the existence of no margin in the impulse strength of the protected equipment above the specified values; an arrester discharge voltage at the maximum value permitted by the manufacturer's tolerances; a considerable separation between the arrester and the apparatus to be protected; and a particularly severe arrester discharge current, in magnitude or rate of rise, or both, resulting from a nearby direct stroke or from the failure of the shield-wire system. The simultaneous occurrence of all of these pessimistic factors obviously would lead either to higher insulation levels than now in use, or to more elaborate protective systems. Good engineering dictates some sort of compromise in the probability of occurrence of all of these factors. The occurrence of these elements must be considered as a statistical phenomenon. While the pyramiding of all of these factors might be possible, it is unlikely. The problem is to seek a satisfactory and economical compromise.

In approaching the problem, one might attempt to analyze each factor independently with regard to its magnitude and the probability of occurrence of each of the magnitudes, and then to choose judiciously a magnitude whose frequency of occurrence appears reasonable. This is difficult, first, because in many cases there is insufficient data to perform such an operation, and, second, because of the interrelation of the factors. Thus, one might obtain a certain probability of occurrence for the magnitude of the discharge current through an arrester and another probability of occurrence for the rate of rise of this discharge current. There is no evidence of the existence of a direct relationship between the magnitude of the discharge current and its rate of rise. It becomes difficult, therefore, to attack the problem from this fundamental point of view. Fortunately, another approach is available. This is to use the operating experience obtained with transformers protected with arresters according to what is considered today as good practice. This has the advantage that *all* of the factors have been taken into account; those that are evident and analyzable as well as those of a more intangible character. There is just a sufficient number of failures to indicate that the present methods of applying arresters are neither too liberal or too skimpy.

The problem of setting insulation levels in the first place, or the converse problem of choosing an insulation level from those already established, involves three major steps. These procedures are:

1—The rating of the arrester must be established from a determination of the maximum voltage to ground that can appear on a sound phase at the arrester location during fault conditions. This step of the problem is straightforward and does not, in general, involve the question of probability. One merely assumes that the worst fault can occur, which would give the highest voltage to ground regardless of its character or location.

2—The conditions of arrester discharge must be assumed. This will depend on many factors and involves a large measure of probability. These assumed conditions will determine the arrester discharge voltage or the maximum voltage to which the arrester limits the voltage across its terminals.

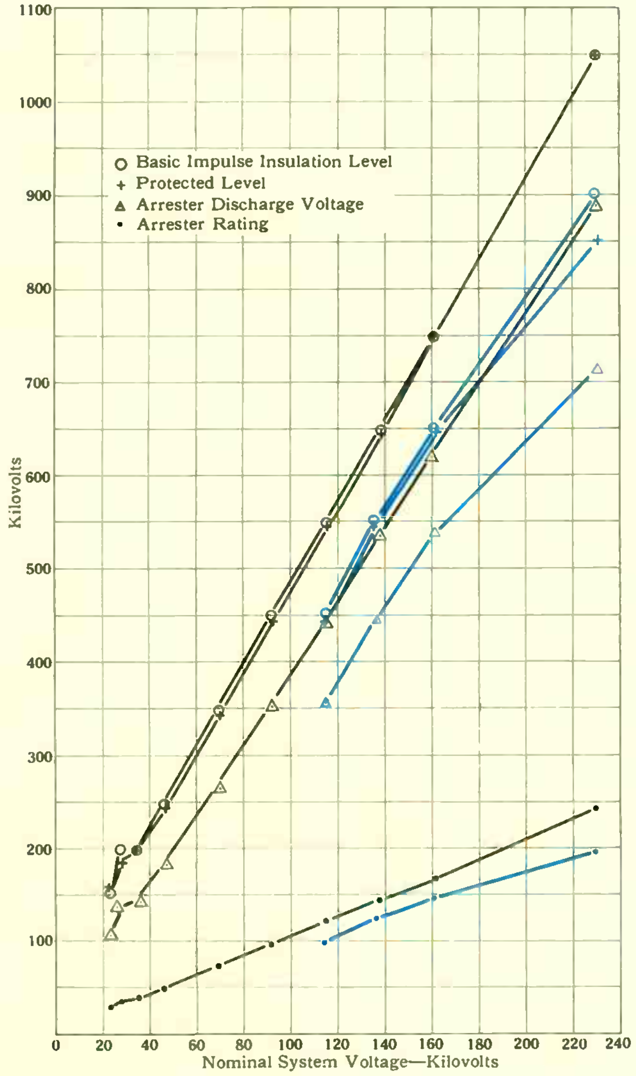
3—One must assume a certain margin over and above the crest of the arrester discharge voltage. This margin, when added to the arrester discharge voltage, determines the "protected level." This is to take care of such factors as departures from assumed discharge currents in the arrester, separation between the lightning arrester and the protected equipment, and the probabilities that occur in the manufacturing tolerances of arresters.

As will be shown later, the factors involved in the choice of the discharge conditions for the arrester and in the margin are so numerous and vary over such wide limits, that it is difficult to choose a set of numbers applicable to all cases. Since it is one purpose of this discussion to point out the wide variation in these conditions, this end will be served sufficiently if the discussion be limited principally to the protection of substation equipment.

In order to orient oneself with regard to some of the possible conditions that might be assumed for the lightning-arrester discharge current and reasonable values that might be used for the margin, examine Fig. 1.

For both grounded and ungrounded systems the curve indicated by triangles represents the crest voltage across the arrester (station-type assumed) when discharging a 5000-ampere, 10×20 microsecond wave. This includes the plus 10-percent tolerance reported by the manufacturers for station-type arresters. With this assumed arrester discharge current, a value for the margin was adjusted so that the computed values would fall just below the corresponding basic impulse levels (BIL's) in common use for these system voltages. The formula found to be satisfactory is to take 15 percent of the crest voltage across the arrester plus a constant value of 30 kv. The protected level, which includes both the arrester voltage and the margin, is plotted by the crosses and the BIL's are plotted by circles. The relationship between the protected level so computed and the corresponding BIL's clearly is close. Arresters applied according to these values have given good performance both as to failures of arresters and as to protection afforded to the protected equipment. It would appear, therefore, that this combination of arrester discharge current and margin is one of a number of possible combinations that can be counted on to give good results.

Fig. 1—The curves in black refer to ungrounded systems in which so-called 100-percent arresters must be applied; the curves in color are for grounded-neutral systems in which 80-percent arresters can be applied. In both figures the abscissas are plotted for the nominal system voltage and the lower curve shows the arrester voltage rating. For the 100-percent system, the arrester rating was taken as equal to "the maximum voltage in the tolerable zone" or the next higher standard rating. This in most cases is equal to 105 percent of the nominal system voltage. For the 80-percent case, the lightning-arrester rating was taken as about 80 percent of that of the corresponding ungrounded systems.



With the foregoing basis of discussion established, some of the factors involved in the insulation-coordination problem can be considered.

Maximum Arrester Discharge Current

A considerable amount of field data has been obtained with magnetic links concerning the maximum discharge currents in arresters. Analysis of the experimental data obtained by different investigators on actual systems shows that for discharges through station-type lightning arresters, only 4 percent exceed 5000 amperes crest and only 1 percent exceed 10 000 amperes crest. The probability of occurrence of these discharges for each lightning arrester is one every 14 years for 5000 amperes and one every 58 years for 10 000 amperes. It must be remembered, however, that in most cases the records were obtained at locations considered high in lightning severity so that data could be obtained quickly. Therefore, these values probably represent more severe duty than for the average location.

One might argue that, since an arrester is a protective device, the most severe condition should be accepted. Actually, if this philosophy were followed, one might even consider a 20 000-ampere or even a 35 000-ampere discharge, as this is the maximum that has been recorded. It is a fundamental precept in planning protection that all of the most severe conditions for application will not be imposed simultaneously. Because of the probability nature of most of the factors to be discussed, a reasonable condition should be chosen and this correlated with the actual overall service performance of the arrester and the protected equipments. One might very well have chosen a 10 000-ampere, 10×20 microsecond wave to fix the arrester performance. For station-type arresters this gives a crest value of discharge voltage that is 8 percent higher than the 5000-ampere discharge current. Therefore, other conditions remaining the same, the margin would have had to have been reduced from 15 percent to 6.5 percent to result in the same protected level.

Other factors affect the discharge current to be expected in arresters. Shielding is important. In a well-shielded substation or a well-shielded transmission line, 99.8 or 99.9 percent of all the discharges are diverted harmlessly to ground, and an even higher percentage might apply to substations where special precautions are made to obtain good shielding. Closely associated in its effect upon the diversion of current to ground is ground resistance. Substations, of course, always have relatively low resistances, but the first and second tower out on the line might have high footing resistances so that even if a stroke does strike the ground or shield wire on the first few spans, a significant portion of the current might be discharged through the arrester. The type of line construction, whether steel tower or wood poles, and the amount of insulation also affect the discharge current.

Wave Shape of Discharge Current

During the past 25 years, the 10×20 microsecond discharge current has been used as the standard wave to determine the discharge characteristics of a lightning arrester. It approximates the most severe condition that can be obtained in laboratories without undue expense and effort. Also the wave shape of the discharge voltage approximates a 1.5×40 microsecond wave. It does not represent the most severe condition that can be encountered in practice. A record of a discharge current that approximates a 5000-ampere crest with a 5000-ampere rate of rise has been obtained. It might be argued that a system with a ground wire might receive such a discharge in case of a direct stroke to the conductor when the shielding function fails, or in case the line insulation fails when an exceptionally severe stroke strikes the ground wire. This is quite true, but the probability of occurrence of such a condition must also be considered. Some substations are not provided with shield wires as the designers feel that the calculated risk of mechanical failure of the shield wire is greater than the protection afforded. Without shield wires, the probability of occurrence of steeper waves is somewhat greater than with shield wires. It is my belief and that of my associates that the probability of occurrence of a 5000-ampere rate of rise is not sufficient to justify its use as a basis of arrester application.

The wave shape of the voltage across an arrester when discharging a 10×20 microsecond wave approximates, but is not exactly the same as, the 1.5×40 microsecond voltage wave that is used as a basis of insulation coordination and for the testing of the impulse characteristics of equipment. It has been argued that quite apart from the occurrence of a 10×20 microsecond current wave, in practice a current discharge wave should be chosen that would give as close as possible a 1.5×40 microsecond discharge voltage wave. This argument would be fallacious if the current wave to produce such a voltage wave form never occurs in practice. A more theoretical approach might be to choose a reasonably severe wave that might occur in practice and to determine then the actual wave shape of the voltage wave across the arrester value corresponding to this current. Then by a method such as developed by Witzke and Bliss, the volt-time characteristics of insulation with this type of voltage wave form applied could be determined. Actually, this would become rather involved and the extra complication is probably not warranted. In recent years the suggestion has been made to use a current wave having a 5000-ampere crest and a 5000-ampere per microsecond rate of rise. The crest value of the discharge voltage with this type of wave is 17 percent greater than the discharge voltage for a 10×20 current wave having a crest value of 5000 amperes. As stated previously, the crest value alone does not reflect the effect upon the insulation. It so happens that practical laboratory limitations make it difficult to obtain a current wave having a 5000-ampere crest and a 5000-ampere rate of rise, and at the same time a long tail.

Even though a 1.5×40 microsecond voltage wave form appears across the arrester, the same voltage wave would not appear across the protected equipment if it is separated appreciably from the lightning arrester. Only when the arrester is located directly across the terminals of the protected equipment would the protected equipment be subjected to the 1.5×40 voltage wave.

At least 80 percent of all transmission lines above 100 kv are either equipped with ground wires or have ground wires extending for a mile from each substation. It is in this range of voltages that significant economies result from reducing the insulation of transformers on effectively grounded systems. In 34.5-kv and 69-kv systems, use of ground wires is not so prevalent, but, on the other hand, it is not customary to use reduced insulation even if the system is well grounded. In the systems of these two voltage classes, particularly when the system is grounded and reduced rated arresters are used, the protection problem is not so severe. It would appear, therefore, that for systems having a voltage of 100 kv or greater, the steep current discharge can be neglected and for substations on 34.5-kv and 69-kv grounded-neutral systems, the inherent margin is sufficient to obviate this refinement.

It appears from the foregoing that in view of the little data available on the wave shape of the discharge arrester currents, the wide variations in the conditions of application, and the enormous amount of laboratory data collected to date on the characteristics with a 10×20 microsecond discharge wave, it would be unwise to use any other than a 10×20 microsecond discharge current wave for coordination.

Separation between the Arrester and the Protected Equipment

The voltage across the lightning arrester can be considered in two parts: first, the voltage that appears before breakdown, and, second, the voltage during discharge. The voltage before breakdown rises at a rate determined by the incoming surge. Upon breakdown of the arrester gap, the current begins to discharge and the voltage across the arrester becomes the discharge voltage. Only when the arrester and the protective equipment are immediately adjacent will their discharge voltage be equal. Determination of the voltages within the substation structure is quite complicated and depends upon such factors as the length of the downlead from the bus to the arrester, the electrical distance horizontally between the arrester and the protected equipment, the presence of stub-end feeds and, even more important, the number of lines emanating from the substation. The conditions are so variable and complex that unless one makes a rather detailed study of the station, it becomes impossible to do otherwise than make a general allowance for these effects. Thus, unless the arrester is located on the transformer case, it is well to include the effect of separation as one of the factors entering into the margin mentioned previously and to limit the separation to certain prescribed maximum distances.

Probability of Lightning-Arrester Manufacture

In the standards for lightning arresters, the crest value of the discharge voltages are given for different values of 10×20 microsecond current waves (5000, 10 000, and 20 000 amperes crest). These values represent the average of a large number of arresters. A tolerance of 10 percent above these average values is then provided, which represents the maximum voltage that must not be exceeded to meet specifications. It has been found that in the probabilities of manufacture, half of the arresters fall within the average value and 95 percent within a tolerance of 6⅔ percent above the

TABLE I—VARIOUS LIGHTNING-ARRESTER CHARACTERISTICS AND MARGINS THAT PRODUCE THE SAME OVERALL PROTECTION

Lightning-Arrester Characteristics	Crest of 10 × 20 Microsecond Discharge through the Lightning Arrester	
	5000 Amperes	10 000 Amperes
Average + 10 percent tolerance	15 percent + 30 kv	6.5 percent + 30 kv
Average + 6⅔ percent tolerance	18 percent + 30 kv	9.0 percent + 30 kv
Average	27 percent + 30 kv	17.5 percent + 30 kv

average value. It has been suggested that the probability factor in the manufacture of arresters be recognized in the application of lightning arresters by using for this purpose a value equal to 6⅔ percent above the average value. Thus, there exist three possible bases for coordination. One might use the average value, a value 6⅔ percent greater, or a value 10 percent greater. In the values used in computing the discharge voltages in Fig. 1, the author preferred to use the maximum value, that is, the value 10 percent higher than the average. It is recognized that this is largely a matter of judgment and preference. However, whatever value is used, a corresponding adjustment must be made in the margin so that the overall performance of the arrester characteristic and the margin remain the same. Several combinations of assumed lightning-arrester characteristics and discharge currents through the arrester that give the same overall protection are shown in Table I.

Insulation Characteristics

The major insulation of transformers is such that for chopped waves (3 microseconds for 25-kv insulation and above) the withstand voltage is about 15 percent in excess of the full-wave test value. For shorter times of application, the insulation has an even higher strength. This is fortunate as the voltage across insulation at points other than the arrester location has superimposed upon it an oscillation of short duration. This overvoltage nests in with the upturn characteristic of the insulation for short periods of application. Closely associated with this question is the wave form of the discharge voltage of the lightning arrester previously discussed. Mention is made of the upturn characteristic of the insulation at this point merely to draw attention to this factor, which is of a compensating character as regards oscillations within the substation and the peaking effect of the arrester discharge voltage with high rates of rise of discharge current.

Probability of Manufacture of the Protected Equipment

Although the insulation of the protected equipment is rated on a minimum basis, certain margins are involved in the variabilities of manufacture and in the necessities of design. These margins exist with even more reason than the lightning-arrester margins, as the lightning-arrester probability can be controlled by tests in the course of manufacture. It is not suggested that this region be encroached upon, but the fact that this region does exist, and for sound basic reasons, must be recognized.

Choice of Application Conditions

Choosing conditions of application from a consideration of each individual factor and the probabilities with which these factors occur becomes quite involved. It should also be apparent that from the excellent operating service, any combination in Table I shows the same satisfactory coordination. Other information must be available to choose from Table I the most reasonable set of conditions. The margins given are based upon the characteristics of station-type arresters. Line-type arresters whose average discharge characteristics are 25 percent greater than station-type arresters and whose tolerance is 15 percent have also given tolerably good service, but not as uniformly good as station-type arresters. Using the higher average discharge voltage and incorporating the higher tolerance of line-type arresters, one must use a margin of 10 percent plus 30 kv to obtain the same protective level for a discharge current of 5000 amperes. This appears to reflect reasonably the somewhat inferior protection afforded by line-type arresters as compared to that given by station-type arresters.

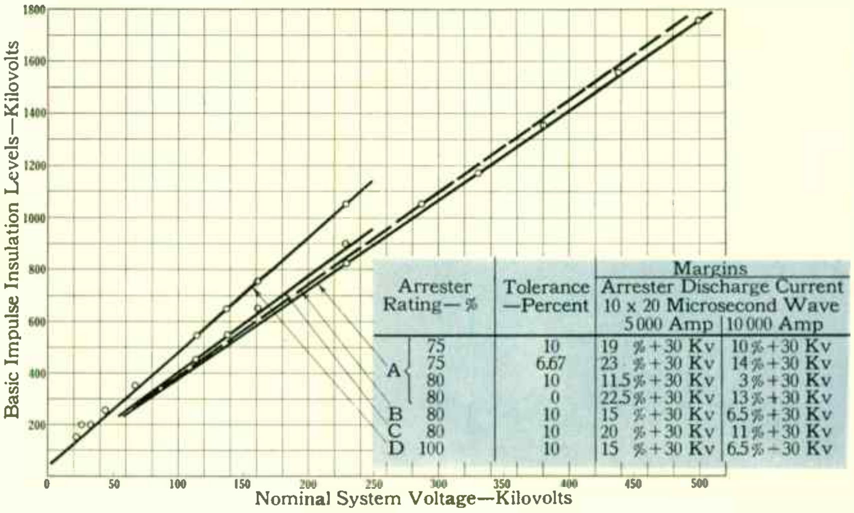
On distribution circuits, the absence of ground or sky wires, particularly in rural applications, increases the exposure to the effects of lightning. This is substantiated by data obtained by means of magnetic links, which indicates that a higher arrester discharge current, of the order of 20 000 amperes, should be used for this type of application. On the other hand, since arresters in this voltage class are usually connected directly across the transformers, no margin need be included. Using the assumption of a 20 000-ampere discharge current without margin appears to give protective values that reflect the quality of the service obtained from actual operating experience. With this additional data as a background, 5000 amperes appears to be a reasonable compromise for shielded-substation arrester discharge currents.

When viewed with the operating experience of substations protected with line-type arresters and with the assumptions necessary to reflect the performance of arresters on distribution circuits, it appears that the choice from the different possibilities enumerated in Table I centers around the use of a 5000-ampere discharge and the use of the maximum tolerance for the protection of substations.

BIL's for Extra-High Voltages

Standardizing bodies in the United States have under consideration at the moment the standardization of BIL's for systems above 287.5 kv. It is basic to this work that the maximum system voltages in the tolerable zone be 5 percent higher than the nominal system voltages. In Fig. 2 are plotted BIL's for different nominal system voltages, the four highest ones being new ones now being given consideration for standardization. The upper curve is for systems utilizing 100-percent arresters. Below this curve are shown the BIL's, one class lower, which are used on grounded-neutral systems that can utilize 80-percent arresters. The five highest BIL's are plotted against the corresponding nominal system voltages which

Fig. 2—Basic impulse insulation levels for different system voltages.



Arrester Rating—%		Tolerance —Percent	Margins Arrester Discharge Current 10 x 20 Microsecond Wave 5000 Amp	10 000 Amp
A	75	10	19 %+30 Kv	10%+30 Kv
	75	6.67	23 %+30 Kv	14%+30 Kv
	80	10	11.5%+30 Kv	3%+30 Kv
	80	0	22.5%+30 Kv	13%+30 Kv
B	80	10	15 %+30 Kv	6.5%+30 Kv
C	80	10	20 %+30 Kv	11%+30 Kv
D	100	10	15 %+30 Kv	6.5%−30 Kv

are 287.5, 330, 380, 440, and 500 kv. To illustrate the degree of coordination of the higher BIL's with their corresponding system voltages, the table in the figure is arranged for different assumptions. If coordination is based on a 5000-ampere, 10×20 microsecond current discharge through the arrester and maximum tolerance in the arrester characteristic, then the resultant margin with a 75-percent arrester plus 10-percent tolerance is 19 percent plus 30 kv. If, on the other hand, a 10 000-ampere discharge is assumed, the margin would be reduced to 10 percent plus 30 kv. If the system grounding conditions are such that a 75-percent arrester cannot be used but an 80-percent arrester can be, then the margin with an arrester of standard characteristics becomes rather low; for whether a 5000-ampere or a 10 000-ampere discharge is assumed, the margin is either 11.5 percent plus 30 kv or 3 percent plus 30 kv, respectively. Special arresters are available for which the 10-percent manufacturing tolerance is eliminated. If such special arresters are used, then the margins become 22.5 percent plus 30 kv and 13 percent plus 30 kv for the 5000-ampere and 10 000-ampere discharge, respectively. Regardless of the tolerance in the arrester or the assumed discharge current, substantially the same coordination with system voltage is obtained with the four upper points with a 75-percent arrester as is obtained with 115-kv and 138-kv systems with 80-percent arresters.

Discussion of insulation coordination would not be complete without mention of the effect of normal voltage, and such abnormal voltages either of system frequency or slow transient nature as are associated with switching surges. For a particular type of insulation a rather definite ratio exists between the full-wave impulse test value and the 60-cycle test value. The BIL's assigned to systems of 287.5 kv and higher are now so low that most insulation engineers are fearful that any further lowering of the impulse characteristics might endanger the life of the equipment under normal operating conditions. While arresters are now available that protect equipment having lower values of BIL's than those indicated, advantage cannot be taken of their availability because of the hazards introduced under normal conditions and switching surges. Some engineers feel that further reduction would be admissible. Again, this involves a great element of judgment. The risk involved in going to lower values of insulation is great, as equipment in these higher voltages is usually associated with transmission lines carrying large blocks of power. A failure of the equipment would not only be costly in repairs, but might hazard disuse of other important equipment. These BIL's in themselves already represent a reduction as compared to practice in the lower transmission voltages. Before further reductions are made, it would be well to await the results of operation of equipment with the present values. The deleterious result of a further reduction might not be apparent for many years, and it is therefore desirable to go slowly.

It is hoped that the point has been made that the arrester operating conditions and the margins should not be viewed too strictly. All of the most severe operating conditions cannot be expected to occur simultaneously. The range of operating conditions are so wide that one can only choose a reasonable set of conditions to impose upon the arrester and then choose a corresponding margin so that the combination satisfies the current applications which have been found by experience to be satisfactory. Emphasis should not be placed upon one particular extreme operating condition. This is not to say that particular phases of arrester applications should not be analyzed separately, as this constitutes the most fruitful means of adding to our understanding of the problem. My preference in the application of arresters to substation protection is to use a 5000-ampere, 10×20 microsecond discharge current and include the full 10-percent tolerance permitted the manufacturer. Over and above the crest value of voltage so fixed, a margin of 15 percent plus 30 kv should be used. This provides acceptable coordination except in extreme cases.

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Heat Pump for Home Use

Our most abundant resource—air—will soon find itself with another big job on its hands—providing home heat as well as cooling. That this possibility is now close to reality is suggested by the increasing interest in the heat pump.

While neither the heat-pump principle nor its commercial application are brand new, a home unit has been slower in arriving, partially because of the problem of size, and the high initial and operating cost. Extensive development and field testing have now reduced these problems.

A new Westinghouse heat pump for home use is a typical example of what can be done by this device. It is an air-to-air unit, which means no water connections are necessary; its operation is entirely automatic, even including the switching from summer to winter operation; and it occupies only about ten square feet of floor space.

Essentially, the heat pump consists of a closed circuit in which is a refrigerant, such as Freon. This liquid Freon absorbs heat from the air, becomes a vapor, is pumped through a compressor where it absorbs more heat; the refrigerant gives up its heat as its pressure is allowed to decrease and it reverts to a liquid again. If heating is desired, the refrigerant absorbs heat from an external source—in this case the outside air—and delivers it indoors. For cooling, the cycle is the exact opposite, heat being picked up from the indoor air and released outdoors In addition to heat picked up from the outside air, the heat of compression is also utilized in this new unit.

An important new engineering feature is a simplified transfer valve for refrigerant flow control; this device is connected to a wall thermostat, and automatically switches the unit from heating to cooling or vice versa.

The new heat pump is made in three- and five-horsepower sizes. The smaller unit occupies only 10 square feet of floor space, the larger one 14.5 square feet.

The coefficient of performance, i.e., the efficiency, is three, which in effect means that the system produces three times as much heat as is available in the electrical energy required to operate it. This efficiency value is the same for both units, and is for an outside temperature of 50 degrees F, inside temperature of 70 degrees. In sections where extreme cold is encountered, accessory strip heaters are provided, in 2-kw increments.

Field trials conducted in various parts of the country indicate that the comparative cost of operation of the new unit, as related to fuel-burning equipment, is a matter of the local cost of electricity. In general, where the electric rate is less than two cents per kilowatthour, the heat pump is fully competitive with other methods of heating.

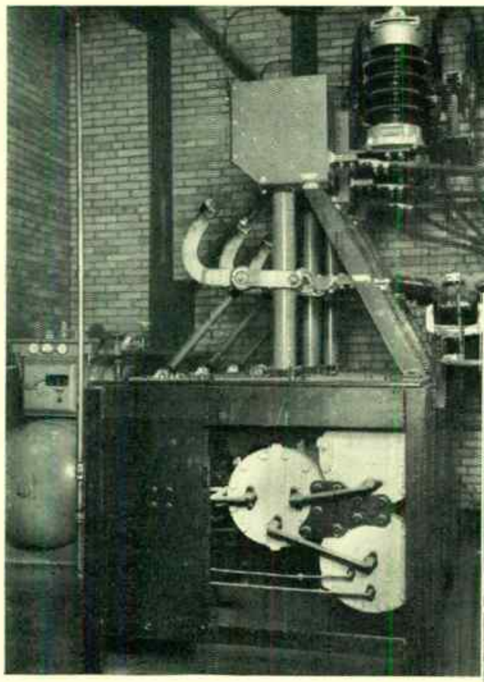
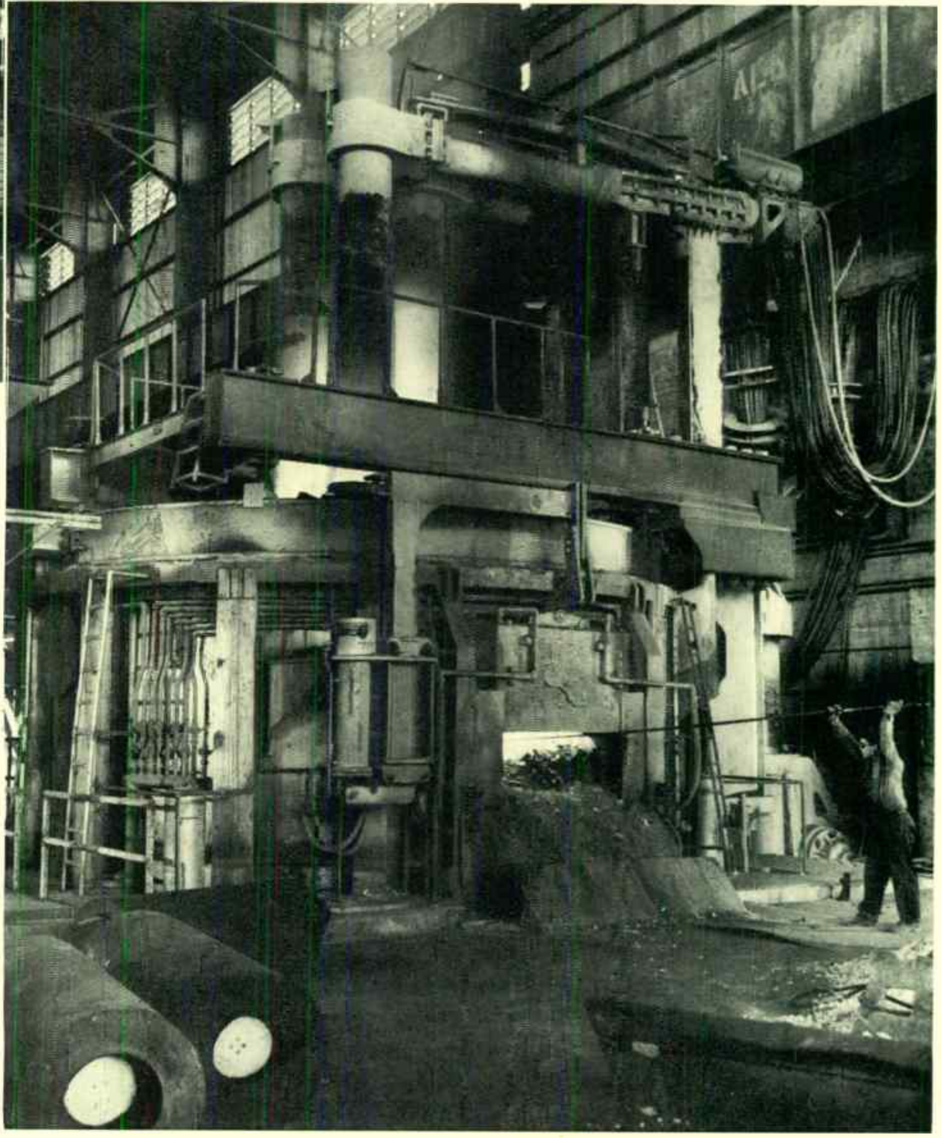


Fig. 2—Installation view of a 230-CAF air-insulated, air-blast circuit breaker. This breaker is suitable for use in 13.8-kv and 22-kv furnace circuits and is rated at 1200 amperes. Surge suppressors for minimizing overvoltages caused by switching are shown mounted on the terminals. The breaker is of rugged construction and was specially developed for arc-furnace switching.

Fig. 1—A large 150-ton, 22-foot shell-diameter electric-arc furnace. This furnace is supplied by a 25 000-kva, 13.8-kv 3-phase furnace transformer.



Electrical Equipment for Large Arc Furnaces

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Electric-arc furnaces are hard to beat in quality and consistency of product. Certainly part of the credit for this reputation goes to the electrical equipment that supplies and controls their operation. This continues to be improved.

While the basic principle of the electric-arc furnace has remained virtually unchanged in over a half century, much progress has been made in the design and application of electrical equipment, especially in the last decade. Notable among these improvements are those involving higher secondary voltages, circuit interruption, regulating equipment, and means for minimizing voltage fluctuations.

Higher Secondary Voltages—The use of secondary voltages as high as 445 volts was unknown but five years ago, the usual voltage being approximately 300. However, the three electric-arc furnaces in the Sterling, Illinois plant of the Northwestern Steel and Wire Company are supplied by a 25 000-kva, 13.8-kv primary, 3-phase, forced-oil-cooled furnace transformer; taps on these transformers assure that the highest secondary voltage obtainable is 445 volts at full capacity. This use of high secondary voltages is one important step that has been taken to obtain high power input to electric furnaces and the short melting times required to increase production.

The furnace transformers employed in this installation are of the shell form,

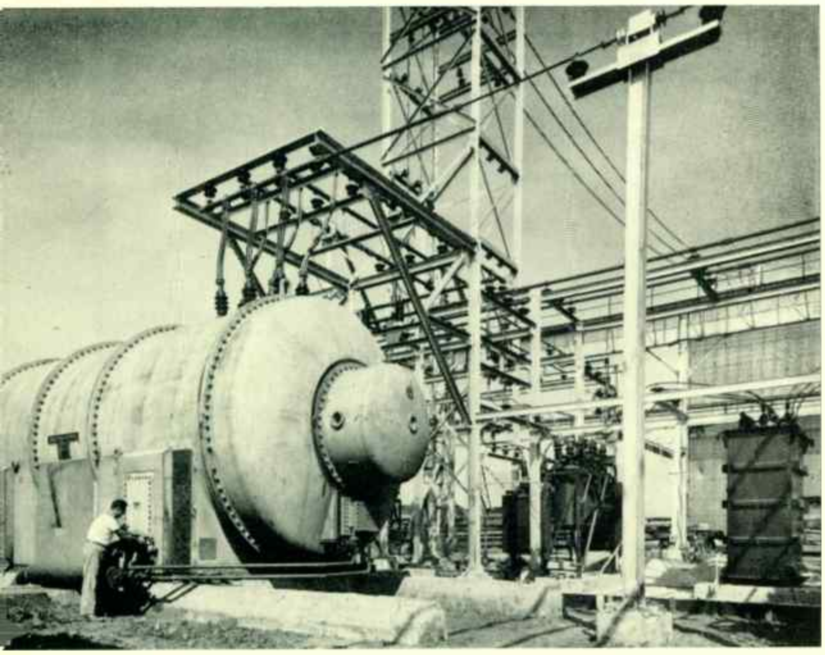

Fig. 3—A 60 000/70 000 kva hydrogen-cooled synchronous condenser used for minimizing power-system voltage fluctuations on arc furnace supply buses. Use of such equipment reduces light flicker.

because such construction has proved to be effective in carrying the large secondary currents. Shell-form construction provides a well-braced transformer that can be easily and adequately cooled. Presently, these transformers are the largest used in the United States for steel-melting electric-arc furnaces.

Circuit Interruption—One important consideration in the supply of power to large electric-arc furnaces is the type and design of the operating breaker in the primary circuit to the furnace transformer. This breaker must be rugged and suitable for highly repetitive operation at normal and light loads as may be required for operation of the furnace. It also must be capable of interrupting fault currents due to cave-ins inside the furnace.

For circuit interruption at Northwestern, specially developed compressed-air furnace breakers (230-CAF) were used. Back-up breakers are used in the circuit to protect against primary circuit faults, should such occur. Such a furnace circuit breaker is shown in Fig. 2. This breaker is air insulated and air operated and employs an air blast for interruption of the arcs drawn. The breaker is characterized by rugged mechanical construction and has been designed to facilitate inspection and maintenance.

Surge suppressors are used with the breaker to reduce the surges normally inherent in arc-furnace switching. A recent improvement in the design of the compressed-air furnace breakers makes them capable of interrupting primary circuit faults of 500 000 kva at service voltages of 15 and 34.5 kv.

Furnace Regulators—All of the large electric furnaces at the Northwestern Steel and Wire Company's plant are regulated by means of Rototrol arc-furnace regulators. This equipment maintains constant power input to the furnace for each of the various taps used during the melting cycle. The input to the regulator consists of a signal of arc current and arc voltage, which are then compared by means of the Rototrol fields. The output of the regulator is supplied to an electrode motor that positions the electrode winch mechanism to maintain the desired power-input conditions to the furnace for each tap voltage employed. The rotating-type furnace regulating equipment is used extensively in industry and has fully demonstrated its capacity for excellent regulation.

Reduction of Voltage Fluctuation—Of particular importance today is the increasing use of synchronous condensers in conjunction with power systems supplying large electric-arc-furnace loads. Because of the violent operation that characterizes the melting of steel in these furnaces, many cases demand the use of equipment to minimize fluctuations in voltage that can occur in the power supply system. The synchronous condenser has been successfully used for keeping these fluctuations within desirable limits. A 60 000/70 000-kva synchronous condenser for this purpose is shown in Fig. 3. This is a hydrogen-cooled unit rated to supply the reactive kva required when the furnace surges, and in so doing lessen the reactive kva that must be supplied by the power system. The net result is that other loads located near the furnace installations are not adversely affected by voltage fluctuations caused by the furnace.

As the use and size of electric-arc furnaces increase in the steelmaking industry, electrical-equipment designs now available will find continued use and undoubtedly new forms of equipment will be developed and applied.

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The Re-rating Program—
More Motor in Same Space

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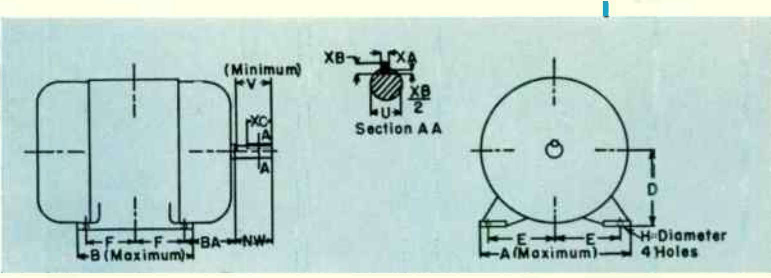
Four questions arise in any discussion of the present Re-rating Program involving 1- to 30-hp a-c motors: (1) how is it possible to double horsepower output of a motor, yet keep physical dimensions essentially the same? (2) what are the advantages to the machinery manufacturer who incorporates the motor into his product? (3) how does it benefit the user of motor-driven machinery? (4) just what are these suggested standards and when will the new motors be available?

The a-c motor dimensional standards now used were established in 1938, and thus have been in effect over a quarter of the alternating-current age. The fact that the life of the present standards has spanned a period during which the electrical capacity of this country has doubled, has lasted through two war periods of accelerated technological develop-

Speed—Rpm	60-Cycle Polyphase Horsepower						Frame	A	B	D	E	F	BA	H	N-W	U	V	XA	XB	XC
	3600	1800	1200	900	720	600														
Dripproof and totally enclosed fan-cooled	1.5	1	0.75	0.5			182	9	6½	4½	3¾	2¼	2¾	13/32	2¼	7/8	2	3/16	3/16	1⅝
	2, 3	1.5, 2	1, 1.5	0.75			184	9	7½	4½	3¾	2¾	2¾	13/32	2¼	7/8	2	3/16	3/16	1⅝
	5	3	2	1, 1.5	1		213	10½	7½	5¼	4¼	2¾	3½	13/32	3	1⅛	2¾	1/4	1/4	2
	7.5	5	3	2	1.5	1	215	10½	9	5¼	4¼	3½	3½	13/32	3	1⅛	2¾	1/4	1/4	2
	10	7.5	5	3	2	1.5	254U	12½	10¾	6¼	5	4⅛	4¼	17/32	3¾	1⅜	3½	5/16	5/16	2¾
	15	10	7.5	5	3	2	256U	12½	12½	6¼	5	5	4¼	17/32	3¾	1⅜	3½	5/16	5/16	2¾
Dripproof only	20	15	10	7.5			284U	14	12½	7	5½	4¾	4¾	17/32	4⅞	1⅝	4⅝	3/8	3/8	3¾
	25	20		10	5	3	286U	14	14	7	5½	5½	4¾	17/32	4⅞	1⅝	4⅝	3/8	3/8	3¾
		25	15		7.5	5	324U	16	14	8	6¼	5¼	5¼	21/32	5⅝	1⅞	5⅜	1/2	1/2	4¼
	30						324S	16	14	8	6¼	5¼	5¼	31/32	3¼	1⅝	3	3/8	3/8	1⅞
		30	20	15	10	7.5	326U	16	15½	8	6¼	6	5¼	21/32	5⅝	1⅞	5⅜	1/2	1/2	4¼
	40						326S	16	15½	8	6¼	6	5¼	21/32	3¼	1⅝	3	3/8	3/8	1⅞
Totally enclosed fan-cooled only		15	10	7.5			284U	14	12½	7	5½	4¾	4¾	17/32	4⅞	1⅝	4⅝	3/8	3/8	3¾
	20	20		10	5	3	286U	14	14	7	5½	5½	4¾	17/32	4⅞	1⅝	4⅝	3/8	3/8	3¾
			15		7.5	5	324U	16	14	8	6¼	5¼	5¼	21/32	5⅝	1⅞	5⅜	1/2	1/2	4¼
							324S	16	14	8	6¼	5¼	5¼	21/32	3¼	1⅝	3	3/8	3/8	1⅞
		25	20	15	10	7.5	326U	16	15½	8	6¼	6	5¼	21/32	5⅝	1⅞	5⅜	1/2	1/2	4¼
	25						326S	16	15½	8	6¼	6	5¼	21/32	3¼	1⅝	3	3/8	3/8	1⅞

TABLE I—PROPOSED RATINGS AND DIMENSIONS FOR A-C MOTORS



ment and a post-war period of tremendous business activity is a miracle in itself.

What has this high-pressure period of the past 15 years brought forth in the way of new or improved materials for the design and building of motors? Basically, the design engineer has four broad categories of components to work with to improve his motor designs. They are conductor, insulation, magnetic steel, and mechanical parts.

The most important, the conductor, is still the same copper that was available in 1938, and no one has found a more economical substitute or devised a method to increase the current-carrying capacity. However, the insulation, the magnetic steel, and the mechanical parts play a large part in the utilization of the basic conductor. The changes made in these other materials tell the story.

In 1938, varnish-covered wire of the Formvar or Formex type had just been developed. It was new and untried but potentially a revolutionary tool for the motor-design engineer. There was some reluctance to accept motors built with this wire. There were even motors shipped back to the manufacturer because the wire was "bare." Several demonstrations had to be put on to prove the effectiveness of the new wire. Even then, some users still asked that end turns be taped for extra protection, which actually shortened the life of the motors by making them harder to cool.

Varnished wire has been improved considerably in the past 15 years. Paralleling the wire-coating techniques, slot-cell and phase insulation have made comparable improvements. An excellent example of this is the hermetic refrigeration motor. In 1938 the hermetic motors had double cotton-covered wire, and the design engineer used every mechanical type of insulation available to assure reasonable life. Today 5- and 7½-hp hermetic motors are being built by the thousands with enameled wire in the dimensions formerly used by fractional-horsepower units, yet they run in Freon 22—an excellent solvent. In addition, some manufacturers weld the entire housing closed and guarantee them for five years of trouble-free service.

By taking advantage of the much smaller space required for 1953 insulating materials, the useful copper that can be put in a given area has been greatly increased. This not only saves space, but the motor gets insulation that will withstand its enemies—such as oils and chemicals—many times better than its older counterpart.

Electric-steel development has followed almost a parallel course. The sheet metal of 1938 has been improved many times. Due to the growth of the electrical industry, lamination steel has grown from a specialty-mill product to a major product of most steel companies. The amount of copper and steel required to get given field strengths for specified ratings of motor has been improved continuously. Treatments of the lamination to give more perfect interlaminar resistance has also added to the effective use of a given amount of steel.

Die casting of the aluminum squirrel-cage of the rotor was in its infancy in 1938. The pressures used today, along with methods of insulating the bars, give rotors of far superior quality.

The advance in the art of metal fabrication is probably as big a factor in the new standards as all of the other improvements combined. During the war, great advances were made in the fabrication of steel, with the result that much greater strength can be obtained from an equivalent mass of metal. Clever engineering in applying these advances in metal fabrication has changed the motor housing from a necessary evil to a precisely designed housing that protects the electrical parts and gives needed mechanical strength.

In the casting arts, shell molding has come along to give perfection in form and appearance. Nodular iron, with its desirable casting and working characteristics, is now a common commodity. Thus new and better materials are making possible an increase in capacity for a given frame size.

Reduction in the physical size of motors has always been desirable. But one important thing to remember about this suggested standard is that the minimum performance standards now established are to be maintained. Temperature rise, pull-out torques, starting torques, and speeds that now define a specific rating are not to be changed. Dripproof motors will still be 40 degrees C rise; fan-cooled motors will still be 55 degrees C rise, and the 5-hp motor of the new design will do everything the 5-hp motor of the old design would do.

In effect the present re-rating program is making the motor bigger on the inside, and smaller on the outside. It will be every bit as big in performance on the inside, and will be physically smaller on the outside.

From 1938 to 1953, there has been a big change in the pattern of motor purchases. For example, when the present standards were established in 1938, the single-phase motor for refrigeration service was a high activity item in 1- to 3-hp ratings. Today, practically all refrigeration motors are the hermetic type, and due to the extension of three-phase power lines, the activity on single-phase motors is becoming less and less, except on rural lines. Also, machinery manufacturers are now applying a greater percentage of standard motors and realizing the subsequent economies.

The re-rating program will have the following benefits to the user: (1) the increase in horsepower per given size will bring motors in line with the changes in their application, especially in applications such as machine tools; (2) the motor will be a better product, because the standard line will incorporate all of the improvements made in the past 15 years; (3) economically, this re-rating should reduce the tendency of electric motors to follow the basic inflationary curve, because superfluous metal that produces no horsepower will be eliminated.

An electric motor by itself is of no value. It must be incorporated into another product and provide driving power to some piece of machinery before it produces anything. As motors cut across our entire economic structure, they are basic components. They fall in the same class as bearings, bolts, nuts, and screws which, by themselves, are of no use. But without these, our entire economy would come to a standstill. Therefore, the standardization of motors and the economic gain from such standardization are as important to a user of motor-driven machinery as the standardization of nuts, bolts, and screws.

If through technological advancements a standard becomes obsolete, it is either time to change or abandon it. That is the point now reached. The art of design and manufacture has advanced to a point where the present standard is obsolete. Those who argue that the present standards should be maintained are in effect arguing that standards should be abandoned. Economics would soon force all motor manufacturers to design and build larger horsepower rating in present dimensions. If new, realistic standards are not set, a hodge-podge of ratings would be the result.

The fourth question was, "What are these new standards and when will they be available?" The critical dimensions appear in Table I. All details are not yet available, so these are limiting dimensions. On the left side of the drawing, the horsepower assignments are shown for each set of dimensions. Actually the adopted standards to date are only on 1800 rpm double-pole motors and a few dimensions. The rest of the information is close enough to adoption to be used for preliminary work. Fine details should wait for final adoption of all standards.

To cause minimum inconvenience, a suggested time table has been set up that will make the first diameter, 182 and 184, available by the first of January, 1954, and one diameter like the 214–215 available every five months thereafter.

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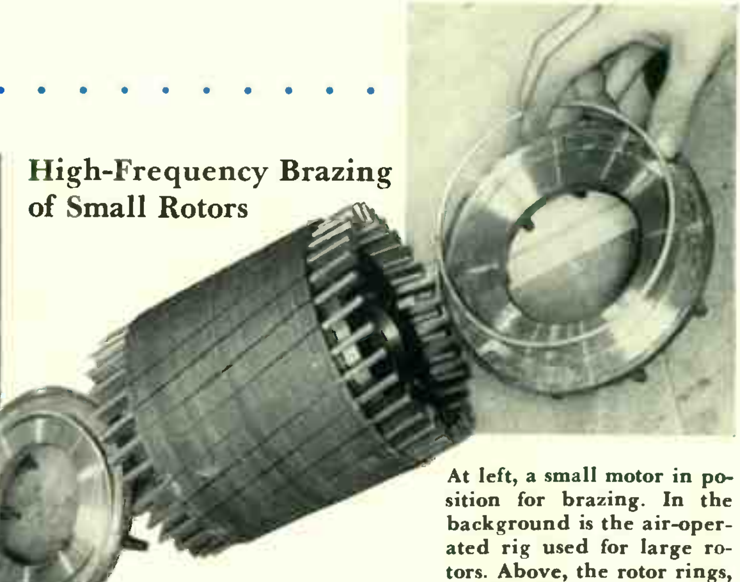
What's NEW

High-Frequency Brazing of Small Rotors



At left, a small motor in position for brazing. In the background is the air-operated rig used for large rotors. Above, the rotor rings, brazing alloy, and the rotor.

The engineering ideas conceived for one specific application often "fan out" and prove useful in similar developments. Such has been the case with a new method for induction brazing end rings to large squirrel-cage motors. Two years ago the use of a 9600-cycle induction-heating technique for brazing rotors of 600- and 700-hp motors—with rotor diameters of approximately 18 inches—was announced.* Later this same technique was applied to 2000-hp, 1800-rpm motors, where the rotor diameter is over 2½ feet. Now it is being extended in the opposite direction, i.e., to small auxiliary units (3 hp, 1800 rpm), where the rotor diameter is less than six inches (see photograph).

The rotor rings for the 3-hp motors present a more difficult brazing problem, in that they have integrally cast fan blades. This was solved by mounting the rotor ring on nonmagnetic pin supports with the inductor coil interwoven around the supports and vanes in such a way that the induced high-frequency magnetic field provided a uniform heating effect. Preformed rings of silver brazing alloy weighing less than 1½ ounces were used, with the flux preplaced as is the case with the larger units. For the larger rotors an air-operated rig is necessary to provide the force for holding the bars and rotor ring in compression during brazing.* However, in the case of the smaller rotors, a piece of heavy shafting slotted at one end to fit the rotor vanes is suspended from a crane and suffices to give the follow-up force required during the brazing operation. The brazing time required for both small and large motor end rings is essentially the same, i.e., 3 or 4 minutes.

Again, on these small high-efficiency rotors the induction-brazing method of attaching the end ring to the rotor bars has given much more satisfactory levels of quality and cost than were attainable by other procedures, such as torch brazing. In less than three years a total of more than 1500 induction-brazed rotors have been supplied for 600, 700, 900, and 2000 hp motors; rotor performance has been flawless.

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*"Induction Brazing of Large Rotors," by P. H. Brace and E. B. Fitzgerald, *Westinghouse* ENGINEER, November, 1951, p. 184.

This article was written by P. H. Brace of the Westinghouse Research Laboratories and E. B. Fitzgerald of the Transportation and Generator Division.

Traffic Lights for a Steel Mill

ELECTRIC-FURNACE operators at the Newport Steel Company now have an unusual "traffic-light" system to help them make maximum use of available power. When no signal lamp is lighted the furnace operator can use as much power as is needed. Green signals the approach of a plant demand peak; yellow warns the operator to make no further increases in power consumption; and red requires that a reduction in power consumption be made.

Because the company is a large power consumer, the problem of controlling plant demand during peak periods is an important one and warrants close consideration. A previous metering system measured the 15-minute demand for the entire plant and operated control relays in the furnace department to raise furnace electrodes whenever the allowable peak demand was reached. While this system was effective in limiting peak demand, furnace operators had no indication of how much below the peak they were operating. Thus, for example, if the hot mill were shut down for a roll change, the furnace department could not take advantage of the extra power available.

To simplify a solution to this problem it was assumed that, while the currents in each phase were seldom balanced, the effect of the furnace regulators over a long period of time would be to balance the line currents. Voltage changes on the supply line were also assumed to be small, since the plant received power directly from the generating station. Thus the current in one phase averaged over a short period was taken as a satisfactory index of the overall plant demand.

Three induction-disc current relays (type CO) were installed, calibrated for 86, 91, and 96 percent of the allowable peak demand. These relays control green, yellow, and red lamps respectively in the furnace department. This signal system has proved effective in assisting the operators to make maximum use of available power and at the same time maintain the desired power demand limit.

The above material is a condensation of an article by R. L. Klar, Engineering and Service Dept., Westinghouse Electric Corporation. Cincinnati, Ohio.

The new laminated burnishing wheel being used to finish the edges of a helmet liner. Grinding is done in the grooves of the wheel.

Burnishing Wheel for Finishing Plastic Edges

THE EDGES of many plastic products require a final finishing to render a smooth, nonporous edge. This is particularly true of cotton-fabric-filled phenolic-resin parts, where the excess flash must be removed and the edge polished. A new laminated burnishing wheel, constructed of glass-fiber cloth impregnated with resin, is proving highly successful in finishing such edges. It has proven especially valuable where irregular contours are involved.

The previous method was a two-stage process. Flash was removed on abrasive-covered belts, and the final finishing was done with a cotton wheel, on which alternate coats of cement and abrasive were applied. This wheel required constant attention and frequent redressing of the abrasive coating.

The new burnishing wheel has parallel grooves—cut with a carbide-tipped tool—in which the grinding is done. The abrasive action is accomplished by a combination of the glass material and high speed, removing the flash and polishing in one operation.

One proven application of the new wheel is in finishing the edges of Army helmet liners. These irregular contours were easily contacted with a minimum of effort. Over half a million of these liners were finished with little or no attention to the burnishing wheel.

This new 700-watt mercury lamp was developed to fill the need for a size between the 400- and 1000-watt lamps. It is especially well suited to medium mounting heights; minimum recommended height is 24 feet. The bulb has the now-familiar isothermal shape, which provides approximately even temperatures over the entire bulb wall. The lamp has an average rated life of 4000 hours, and operates from a 460-volt circuit with a simple choke, or from other voltages with suitable ballast. The new lamp is suitable for street lighting, flood lighting, or general uses. Initial output is 35 000 lumens.

Rectifier Welder Gets Design Improvements

Significant design improvements have been achieved in a new d-c rectifier welder. The new welder uses plate-type selenium rectifiers to convert a-c power to d-c—as did its predecessor—but by careful design the new version has been made even smaller, lighter, easier to maintain, and more convenient to operate.

Much of the weight and size reduction was accomplished by combining a three-phase transformer and a movable-core reactor into one unit—called a Transactor—and utilizing aluminum coils. The Transactor accomplishes both voltage step-down and current control. It consists of two 3-phase laminated cores; one is a fixed core, on which are wound the primary and secondary coils, the other is divided into two parts—a stationary core, and a movable core. The legs of the movable core are linked by the common secondary and reactor winding. Current is controlled by moving the core in or out of the Transactor unit cores. When the movable core is at maximum distance from the stationary core, the welder output current is at maximum. Through proper design, the class-B insulated aluminum conductors produce operating characteristics equal to copper. As example of the weight reduction, the 300-ampere unit weighs 400 pounds instead of 510.

The ventilating fan is located at the top of the new welder, the air intake at the bottom. The upward flow of air follows natural convection and results in maximum cooling with minimum-sized cooling fan and motor. The rectifier unit is located at the bottom of the unit where it is ventilated by the coolest air. Coils of the Transactor unit are wound with large ventilating ducts to permit maximum cooling.

Overloading, and thus overheating, is always a possibility on arc welders. To protect the new unit against overload, a temperature-sensing Thermoguard unit is wound into one of the coils of the Transactor unit. If the coils overheat, the Thermoguard closes, activating a shunt-trip mechanism on a De-ion circuit breaker, thus shutting off the welder. When the temperature again reaches a safe value, the circuit breaker can be reset and welding resumed.

Arc-drive control—a system that supplies instantaneous surges of current if the arc starts to short circuit—simplifies the job of vertical, overhead, or deep-groove welding.

The new welder is built in three standard units—of 200-, 300-, and 400-ampere rating. Duplex units, consisting of two single units mounted in a single case are also available.

This rectifier welder is particularly well adapted to parallel operation. Any number of units and any combination of ratings can be combined to make any desired size welder merely by paralleling the secondary output leads. The current output of any machine in a paralleled group will be that for which the machine is set.

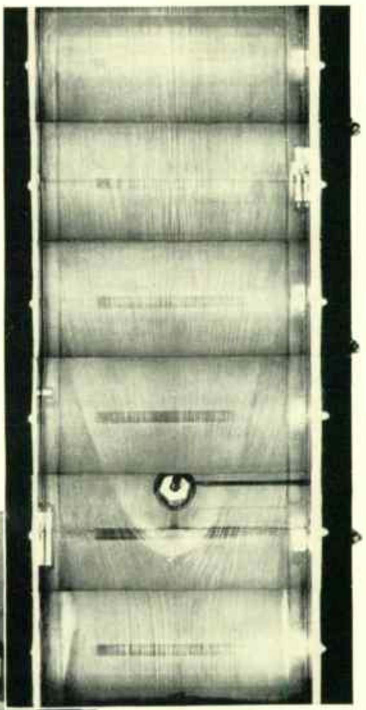
Many items—such as structural parts, fan and motor, and mechanical parts—are interchangeable between units of different rating, thus simplifying maintenance.

Streak Photography for Bearings

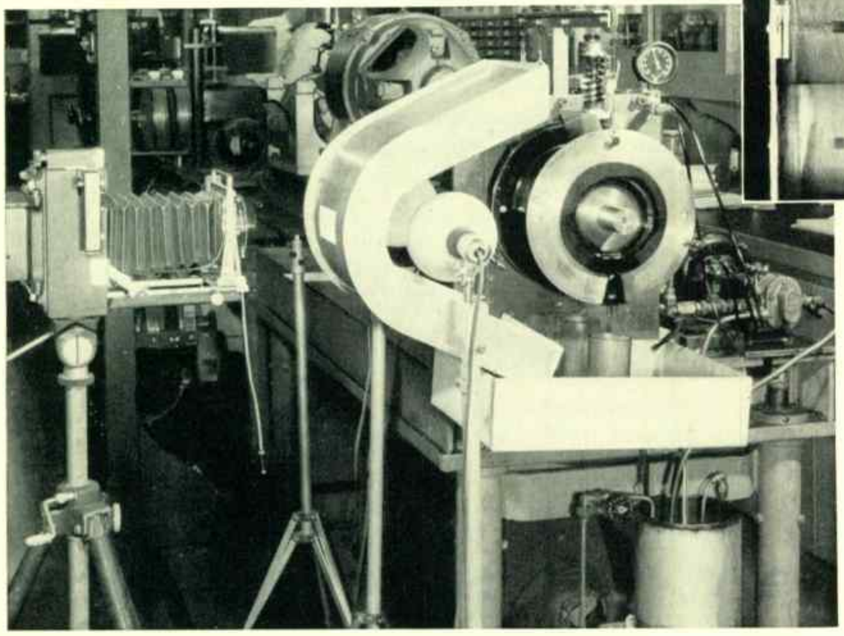
Oil is used in bearings both as a lubricant and a cooling medium. As a lubricant, it reduces the friction between rubbing parts by forming a film between them; as a coolant it carries heat away from the points at which it is generated. Both functions are important in many bearing designs.

In studying the use of oil as a bearing coolant, a clear picture of the path it follows through a bearing is an invaluable aid toward improved designs. This can be accomplished by adapting a method called "streak photography" to bearing studies.

If finely divided solids are introduced into a fluid flow, they are carried along by the stream; a series of short time exposures give photographs containing streaks indicating the path of these solids, and thus of the fluid. In bearing studies, however, solid streak-producing materials large enough to be seen easily are impractical; they may clog small passages, and perhaps damage the test apparatus or change the flow pattern.



A new method eliminates this difficulty by substituting finely divided fluid in suspension for the solid particles; the droplets merely flatten at constricted locations and pass on with the main flow.



Far left, test setup for making streak photographs. In the photo at left, lubricant flow is upward. The streamlined shape at bottom is the line between incoming oil and that which has circled the test bearing.

A small laboratory model of a bearing is used; to obtain operating conditions comparable with a large bearing, kerosene is used instead of oil. The kerosene is dyed a dark red, and a clear solution of glycerin in water is the streak-producing medium. The mixture is passed through fine screens in the lubricant supply line, where the glycerin-water solution is broken up into fine droplets.

The fluid flow is then photographed through a plastic bearing shell. Only 60 degrees of the bearing arc is recorded in a single photograph; the bearing shell is rotated 60 degrees between photographs so that the full 360 degree flow pattern is recorded. Adjacent photographs are then matched, giving a complete picture of lubricant flow in the bearing.

The above material is a condensation of an article by Frank J. Kolano, Westinghouse Research Laboratories, East Pittsburgh, Pa.

Personality Profiles

A year after he joined Westinghouse in the Switchboard Engineering Department, *S. S. Browne* was loaned to the Navy Department to help in the huge shipbuilding program. This was in 1941. He spent the next five years with the Bureau of Ships, engineering switchboards for every class of ship from PT boat to battleships.

Despite his brief stint with Westinghouse before "joining the Navy," Browne was well versed in switchboard design; even before his graduation from Virginia Polytechnic Institute in 1932 he had designed his first switchboard. And just prior to his arrival at Westinghouse he spent six years with the Bureau of Reclamation, helping to engineer the switchboards at Boulder Power Plant.

After his hitch with the Navy, Browne returned to Westinghouse; in 1947 he was made engineering supervisor in the Manufacturing and Repair Department at St. Louis, the job he now holds.

Browne's coauthor of the article on Lock 27, *Burke Frick*, is a graduate of Oklahoma University, class of 1947. Frick's first assignment at Westinghouse was in the Insulation Design Section, where he was concerned with developing insulation for large generators and motors. This was followed by a two-year assignment in the turbine-generator design section. With this experience in hand Frick was made consulting and application engineer in the St. Louis Office in 1951.

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When *H. L. Cole* was a small boy in Plymouth, Mass., he earned pin money showing tourists famed Plymouth Rock and other sights reminiscent of Pilgrim days. Now Cole is becoming a tourist himself. He has just wrapped up nearly 40 years of accomplishment with Westinghouse—retiring a bit early at his request—and embarked on several projects, one of them being to see the world.

Cole graduated from Worcester Tech in 1914 and came directly to Westinghouse, beginning in the Research Department. For about a year under Dr. C. E. Skinner, he measured dielectric losses in insulating materials. He likes to point out that power-factor testing is not new, that in 1916 he made a large Kelvin electrometer, immersed it in oil in a wooden washtub, and measured the power factor of 110-kv condenser bushings at their normal operating voltage.

Came the war and Cole went into the Navy. When he returned in 1919 he decided that transformer design work would be to his liking. Must have been a good choice because he never left it for 35 years. When he entered the field the tops in rating for self-cooled transformers was 5000 kva. Cole recalls, with understandable pride, that he designed the first "five-figure"—i.e., 10 000 kva—self-cooled transformer ever built. That was in 1920. He is now closing his career with work on elements for a 300 000-kva unit.

Cole has had much to do with every aspect of power transformers—core and coils, insulation, terminal bushings, valves, pumps, radiators, and so on. From 1930 to 1952, when he became Advisory Engineer, he was head of the Power Transformer Development Section.

But now, he is anxious to get on to other things—to engage, in a more serious way, in projects he has had scant time to do justice: still and motion photography, music and tape recording, metal and wood working. And, oh yes, he wants to see the world.

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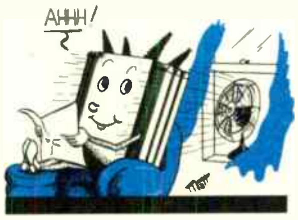
William D. Albright didn't find it necessary to travel far to seek his fortune. A native of Pittsburgh, he got his electrical-engineering education at the University of Pittsburgh, graduating in 1935. He first gave the steel business a try, working as a production clerk for Weirton Steel Company for nine months. Early in 1936 he went to work for Westinghouse in the High-Voltage Impulse Test Laboratory at the Sharon plant.

In 1940 he had a brief turn in power-transformer design, followed by a period with distribution transformers. With the war at its height he was pressed into service in the Ordnance Section, working on the then new electric torpedo. This business finished, he returned to the Power Transformer Section. There one of his outstanding assignments was to design an 83 333-kva unit for installation in a residential area that called for an uncommonly low noise level. He is now engaged in transformer development work.



C. F. Wagner needs little introduction to many of our readers. He is already well known for his many contributions to power-transmission theory and practice, and as the coauthor of "Symmetrical Components," the widely used book on unbalances in polyphase circuits.

Wagner is a graduate of Carnegie Tech, in 1917, and has been with Westinghouse for all but the first of the ensuing years. His time has been well spent in the study of all phases of transmission-system performance. This varied and solid background in all phases of electric-utility problems fits him admirably for his present position as consulting engineer assigned to that industry.

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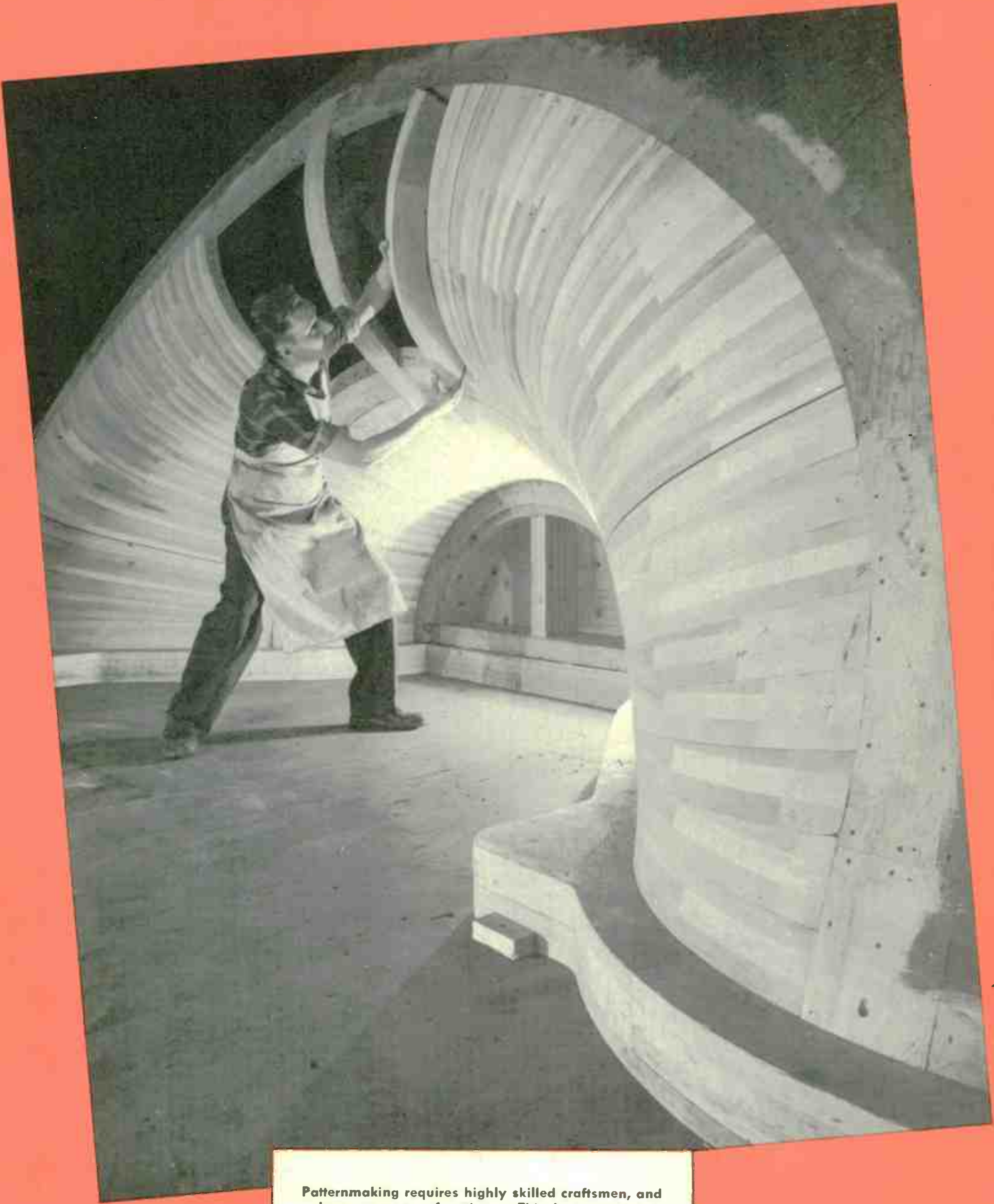
In the Wisconsin town where *S. J. Campbell* grew up, papermaking and lumbering were the two main industries. Presently, his specialty is application of electrical equipment to paper mills and lumbering operations. One might draw the conclusion that his present work was the result of boyhood interest or ambition—but nothing could be further from the truth. Campbell admits that, "In all those years I never even saw the inside of a paper mill."

A bit of advice offered by a high-school physics teacher helped steer him toward his profession. Noting Campbell's facility with circuitry, he insisted that he should take nothing but electrical engineering. During the war he served as a radar technician in the Marine Air Corps; this experience, plus an aptitude test given by the Veterans Administration finally decided the matter.

Shortly after his discharge Campbell enrolled at Superior State College; the next year he transferred to the University of Wisconsin, from which he earned his electrical engineering degree in 1950.

Campbell came to Westinghouse via the Graduate Student Course; during the course he spent one of his assignments with the General Mill Section of Industry Engineering, and eventually became a permanent member of the group. Other than paper- and lumber-mill applications, another interest has been the Synchrotie, about which he writes in this issue.



Patternmaking requires highly skilled craftsmen, and a large measure of patience. This large pattern is for part of a turbine cover. When finished, literally thousands of hours will have been expended in its creation, as well as a proportionately large number of board feet of lumber, all precisely cut and fitted.