WESTINGHOUSE

Engineer

Engineering

NOVEMBER 1951

GREAT OAKS FROM LITTLE ACORNS

As you read this, your desk is undoubtedly piled high with technical publications similar to the *Westinghouse* ENGINEER telling of new engineering advances. But, like most of us, you probably tend to take industrial progress pretty much for granted, seldom thinking about what lies behind each new product, each new manufacturing technique.

Ideas, of course, are the basic raw material of invention. But to transform ideas into products, you need people, such as draftsmen, accountants, purchasing agents, metallurgists, engineers, management. These people need power, raw materials, slide rules, machines, well-equipped factories, and scores of laboratories. If anything is to come of an idea, these many loosely related activities must be integrated. That requires planning. You have to know what people you need, and where you need them; which idea is worth ten thousand development dollars and which is worth a million. You have to know what kind of ideas you're looking for, and where you will find them.

Ideas come from many sources. An improvement may have its beginning during negotiations with customers. Or the need may show up as the result of market research. Or it may be an inspiration that comes during morning coffee, or while waiting for a bus or checking the performance of equipment. There is never a shortage of ideas.

But raw ideas are only a beginning. The good ones must be separated from the not-so-good ones. The most promising ones must be picked, those that promise returns in the immediate future, those that will be several years in development, those that will take many years.

The picking and choosing begins in the sales, engineering, and works departments of each division. If an idea has possibilities, its development is considered by management. After division approval, headquarters' management looks at the proposal in relation to the company-wide program. If it still looks promising, engineering work begins.

Designs are drawn up, and experimental models are made to test further the practicality of the idea. Throughout the various stages of development, people in the division from sales, production, manufacturing, purchasing, accounting, engineering are consulted when problems concerning their operations are encountered. They must decide how the product will be made, what manufacturing facilities are available for making it, what kind of test equipment will be needed to control quality, how the product will be packaged and shipped, what it will cost, what features it needs for sales appeal, how well it will serve the customer.

The procedure required in a large development program often must be quite formal if worthwhile results are to be obtained quickly. However, it also must be flexible enough to permit several different kinds of development. Special development, i.e., for specific orders, which, until the turn of the century, accounted for most technical advancements, is carried on to furnish a product with unusual specifications for only one customer, or just a few. There is no expectation of establishing a line of similar products that can be used by a large group of customers—the application is too limited for that. This is in contrast to standard development, which is aimed at developing new and improved lines of equipment that can be used by a great many people. Although there is still this difference between special and standard development, the difference is no longer as sharp as it once was. Turbine generators, for example, which are usually built to specifications proposed by the purchaser, are being standardized as much as possible. When several machines are ordered, often just one design is specified for the group. Accepted standard designs for turbine generators are now available in sizes up to 90 000 kilowatts. That still leaves many special designs that are applicable to only one installation; but, wherever possible, such machines are built of standard parts.

Requests for special designs can come at any time. They may require a lot of engineering or just a little; so you can't plan very well for them. On the other hand, engineering of standard lines of equipment can be planned, and usually is a major part of the development effort. This includes making major improvements to standard lines, maintaining existing lines of equipment, and planning for future radical changes. Major improvements—like the Lifeline motor and the CSP transformer—get the most publicity and are what we usually think of when we think of engineering advancements. But equally important, and a much larger part of a development program, are the constant detail improvements required to keep standard lines up to date: like decreasing the size of motors — sometimes only by inches, increasing efficiency by a fraction of a percent, or simplifying operation and control. Each step forward, when viewed individually, seems insignificant, but taken collectively these small improvements add up to impressive overall gains.

Long-range planning, the crystal-ball kind of thinking that is looking five or ten years ahead, is perhaps the most important part of the development program; it is essential to industrial progress. Without long-range planning there probably would be no Hipersil grain-oriented steel, which made possible smaller, more efficient transformers. Hipersil was ten years in development. The rectifier locomotive required more than a quarter of a century to develop. A mercury-arc rectifier was built for use on railroad cars in 1913, but it was premature. The rectifier at that time still had deficiencies that made a rectifier locomotive impractical, though workable. It was not until this year, 38 years later, that the first suitable rectifier locomotive was built.

Long-range planning also includes development of needed new materials. Discaloy is a good example, and Refractaloy, and Kovar. This work usually begins in the research laboratories, where the basic processes are developed. However, the methods ultimately used to mass-produce the product are seldom exactly the same as those used in the laboratory. Problems inevitably arise in quantity production that do not show up in the research experiments. For that reason, successful manufacture of the material in pilot-plant quantities must be achieved before large-scale production is attempted. And even then, further testing on a mass-production basis is required before full-scale production can begin.

All of these many activities are tied together through the development program. Each must receive the proper emphasis. Quick improvements cannot be bogged down in procedure, long-term projects cannot be hurried too fast. Many degrees of procedure are required, from informal discussions to formal meetings and lengthy reports. And out of this maze of details comes the steady flow of new achievements that we accept as a natural part of the American industrial scene.

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On the Side

The cover—Dick Marsh has used the spiral quite effectively on previous covers. But in working up this month's design, depicting hollow conductors, he found that generator coils just don't spiral. Undaunted, Dick still gives the feeling of the spiral while maintaining engineering accuracy.

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Last July, when the swollen Kaw and Missouri Rivers washed over the levees and into Kansas, Westinghouse was prepared for the tremendous job of reconditioning flooded electrical equipment. A plan based on experience gained in the Pittsburgh flood in 1936 was adopted.

With the cooperation of the Navy, emergency flood-repair facilities were set up in 80 000 square feet of the jet-engine plant in Kansas City. One hundred fifteen specialists were flown in from Manufacturing and Repair plants and Engineering and Service Departments throughout the Company. In addition, 100 extra local people were hired.

On Monday, July 16—just three days after that memorable Friday the 13th—the first motors were placed in the drying ovens. In the next 16 days, 1685 motors, 222 transformers, 350 pieces of switchgear, and countless other equipments were received. During that same two weeks, repairs were completed on over half of this equipment.

Most equipment could be rehabilitated. About 95 percent of all motors and 85 percent of all transformers that were flooded were cleaned and returned to service without rewinding. But most controls and switchgear required some new parts.

In This Issue

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Generator Coils Cooled Internally

—Rating Increased by One Half

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Cooling a turbine generator by blowing hydrogen through the inside of the coils is as effective as it is strikingly direct. Output for a machine of given size is increased by half. The ceiling on generator sizes is thereby raised, powerhouse costs per kw are reduced, and —very timely—less copper and iron are required.

A radically new method of cooling large turbine generators greatly increases the capacities for which these high-speed machines can be built. The practical benefits of this development also extend to smaller than maximum-size units because a machine of a given rating can be made smaller than with conventional cooling. The basis of the new ventilation technique is to cool the active conductors internally by making them hollow and blowing gas at high velocities through these ducts, thus placing the coolant in direct contact with the materials in which the heat is generated.

This method of ventilation has been carefully tested on large-size models. The results have warranted its application to two 3600-rpm generators, rated at 175 000 and 200 000 kw, which are to be completed in 1954.

The new ventilation system comes at a fortunate time. The maximum practical ratings of turbine generators has, over the years, risen steadily. By increasing hydrogen pressure, by improvements in blowers, in metallurgy, and in many construction details it has always been possible to keep pace with the demands for power-generation units. However, the need for larger and larger machines is now growing rapidly. With existing labor and materials costs, and the need to keep electric-power costs low, it becomes increasingly necessary for electric-utility companies to install the largest generating units that can be effectively utilized by the individual systems and the systems with which they are interconnected. Several utility systems in the United States are of sufficient size and closely integrated by interconnection with other similar systems to justify generating units of 200 000-kw capacity and larger. The cross-compound type of steam-turbine generating units can be built for ratings up to 300 000-kw capacity at 3600 rpm, or a combination of 1800 and 3600 rpm. Generators for this type of unit could deliver their kw output ratings at power factors of 0.8 to 0.85 and short-circuit ratios of 0.8 to 0.9 when using hydrogen pressures of 30 psig.

Since the tandem-compound turbine-generator unit has

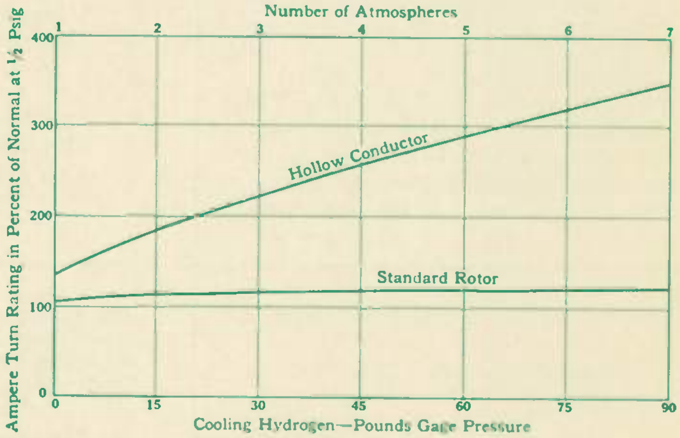

Fig. 1—Generators with hollow coils have a size advantage at low gas pressures and that advantage improves as pressures increase.

fewer bearings, higher output efficiency, lower capital and operating costs, and requires less space in the generating plant, there is an economic need to develop it for larger ratings. Although tandem-connected generators can also be built for ratings up to 300 000 kw, this type of unit would probably represent little savings or advantages over the cross-compound unit and consequently would not normally be preferred. On the basis of using available materials, present design practices, generator characteristics, and conventional construction, single-unit generators can be built at 3600 rpm for maximum rating of 200 000 kw or slightly larger at 0.85 pf, 0.8 scr, and 30 psig hydrogen pressure. The rotors of the units for these large ratings would operate above the first and probably above the second critical speed. At 0.9 pf and 0.5 scr, the maximum turbine-generator rating could be increased to 230 000 kw.

Further incremental improvements in the physical, magnetic, electrical, and thermal properties of steel, copper, and insulation, in conjunction with improved ventilation will make possible a further increase in output per unit of generator weight and ultimately result in still larger generator ratings. However, to secure a major increase, some radically new feature seems called for.

During recent years, much attention has been given to possibilities of using other cooling media as a means of overcoming this limitation but as yet none of these schemes has proved practical. The answer to a substantial improvement is believed to lie in internal cooling of rotor and stator windings with high-density hydrogen. This offers possibilities of greatly increasing the amount of copper losses that can be dissipated for a given maximum temperature rise. With the heat flow through the insulation of the windings almost completely eliminated, the temperature of the windings is determined by the temperature of the hydrogen gas in contact with the copper and the heat-transfer coefficient from the copper to the gas.

The curves in Fig. 1 show the ampere conductors per slot obtainable in the rotor members from tests on a full-size stationary model, with the average and maximum copper temperature maintained the same for the two types of construction. The lower curve is for the conventional rotor design with external cooling and shows that further increase in hydrogen pressure will offer very little increase of rotor ampere conductors. On the other hand, the benefit with hollow conductors is tremendously higher. The increase is extremely high for the higher gas pressures.

The phenomenal increase in ampere-conductor output for the inner-cooled rotor winding is obtained by passing large masses of hydrogen gas through internal passages of the conductors at relatively high velocities. It is therefore obvious that the full advantages of inner cooling are basically associated with high hydrogen pressures, which require high-pressure blowers to circulate the gas through the internal ducts.

A section view of a rotor and rotor winding, Fig. 2, shows the path of the hydrogen gas flowing through the rotor conductors for a particular type of construction. The rotor-winding insulation problems are fundamentally the same as for present conventional construction. Creepage paths of the conductors at the central discharge sections are of the same magnitude as for the end turns of present machines. Although the tapered rotor slot may prove to be more difficult to machine, its use results in a much simpler blocking for the straight portion of the rotor coil ends. The end-turn blocking is further simplified by elimination of gas flow between coil sides, and the use of a constant cross section of copper for the circumferential portion of the rotor end turns. In this type of rotor, with internal cooling, the field conductors are necessarily large in cross section and relatively few in number. As a consequence, the field current is large, and the field voltage is comparatively small. The total excitation kilowatts are approximately twice that of a generator rotor of conventional design. Large-size models of rotating coils have been built and tested to demonstrate that internal blowers mounted on the

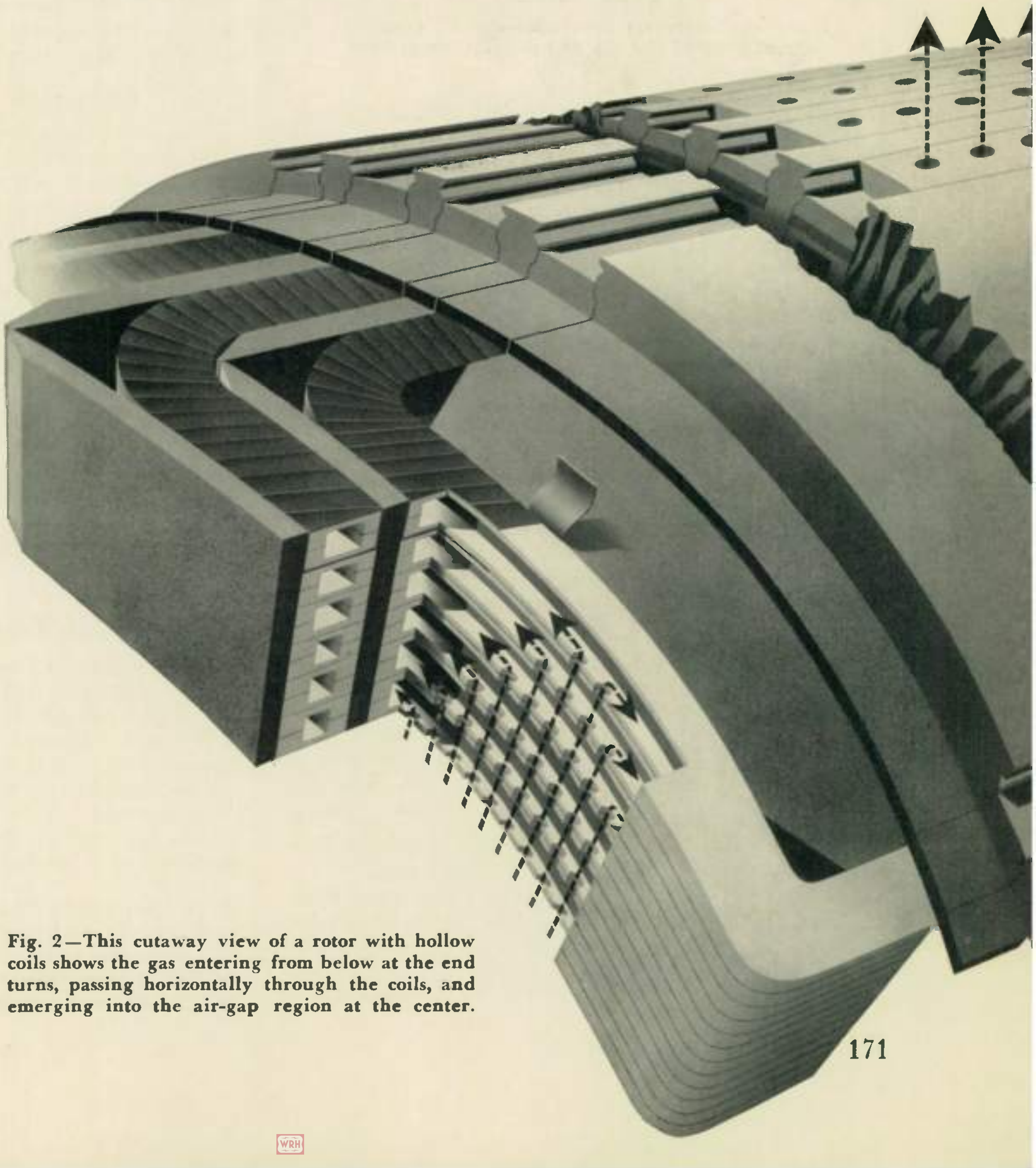

Fig. 2—This cutaway view of a rotor with hollow coils shows the gas entering from below at the end turns, passing horizontally through the coils, and emerging into the air-gap region at the center.

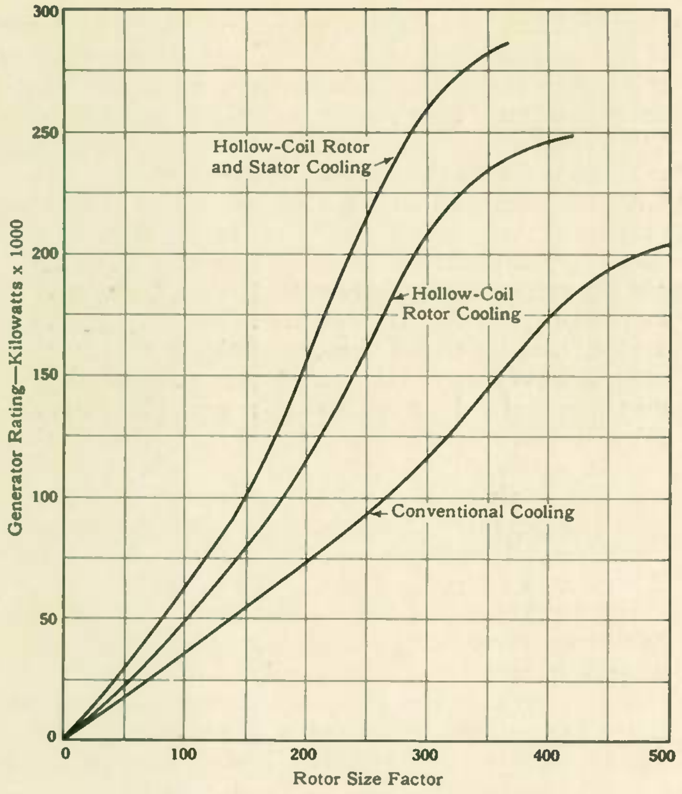

Fig. 3—These curves show what can be expected comparatively of the old and new cooling systems.

ends of the rotor can deliver the required mass of hydrogen through the rotor conductors.

These remarks have applied only to rotor cooling. Similar benefit can result from internally cooling the stator coils. The insulation problem is more difficult for stator coils due to the higher voltage involved and the need for creepage paths of greater length over that required for the rotor. With machines in which the cooling can be accomplished by passing the hydrogen gas through the full length of the coils, the creepage problems are relatively simple and no difficult mechanical and ventilation problems are involved. In the longer machines in which a central discharge is required, the creepage problems are more difficult but do not appear to be unsolvable. At present, the development of the inner-cooled stator coil has not progressed to the same stage as for the rotor, and it therefore may be advisable to apply internal cooling in two steps—the first step for the rotor alone, and the other for the stator.

The curves of Fig. 3 show what can be expected of internally cooled rotor windings and both rotor and stator windings as compared with conventional designs. The kw ratings are based on 0.85 pf, 0.8 scr, and operation at 30 psig hydrogen pressure. From a magnetic standpoint, no changes have been made in flux densities in the stator and the rotor portions of the magnetic circuit. In comparing the physical dimensions of a 200 000-kw unit for the two types of design, the size factor for the rotor with inner cooling of the conductors is only 62 percent of that for the conventional rotor. The reduction in stator dimensions is of smaller magnitude since internal cooling of the stator conductors is not used.

In the case of internal cooling for both stator and rotor windings, the rotor size factor is only 50 percent of that for the conventional machine of the same rating and performance characteristics; a similar reduction in the size factor for the stator would also be obtained.

The development of internal cooling with high-pressure hydrogen opens a new era in the design and construction of turbine generators without a wide departure from present practice and experience. The increased output per unit of generator weight makes possible smaller units for a given rating and appreciably larger maximum ratings at 3600 rpm than heretofore obtainable with conventional designs. The overall efficiency, including generator bearing losses, will then be essentially the same as for units of present conventional designs. The increase in copper losses of the stator and rotor windings due to higher current densities is more than offset by the lower bearing losses resulting from the smaller bearings required for the smaller rotors, and the reduction in rotor surface losses that follows from an increase in the radial length of the air gap and the decrease in rotor surface area. The increase in ventilation loss due to higher fan pressures is partially offset by the reduction in volume of gas to be delivered by the blowers. For turbine generators with internal cooling of the conductors, the excitation and terminal voltages are lower than for similar ratings of conventional design because of the mechanical requirement for larger overall size, and the inherent limitations in insulation surface creepage at the inlet and discharge sections for both windings.

Internal cooling of the rotor and stator windings of turbine generators with high-density hydrogen is particularly applicable for units with ratings of 90 000 kw and above. The improved cooling makes possible the construction of ratings much larger than now possible with conventional gas cooling. High-speed generators can be built in single units in ratings of 250 000 to 275 000 kw at power factors and stability characteristics suitable for the large electric-utility systems. Under present conditions, the reduction in physical size of generating units for a given rating is of paramount importance since it results in the conservation of our nation's two most necessary critical materials—copper and steel. Although the cost savings resulting from the use of less materials are more than offset at the present state of the development by the large development cost required, large capacity turbine-generator units of this type, even at present unit costs, should result in lower overall capital and operating costs of power generation without any sacrifice in efficiency performance. The reduced physical size of the rotor element simplifies the forging problem and results in improved mechanical performance and reliability. In addition to the two large machines now being constructed with internally cooled rotors, a 60 000-kw, 3600-rpm generator, using internal cooling for both stator and rotor windings, is now being designed and is expected to be available for testing late in 1952.

• • •

Teaching the Teachers

This fall, in 19 of the leading engineering colleges in the United States, prospective engineers are being lectured by professors who augmented their textbook knowledge during the summer with practical experience gained in the Industrial Experience Program conducted by Westinghouse. In this program the teachers work side by side with engineers and workmen in various Westinghouse plants. The program helps the engineering colleges develop their teaching staffs, familiarizing them with the day-to-day problems of industry.

The professors are paid a regular salary and are given assignments relating to their particular fields of study. Highlight of the program is a week-long seminar during which the teacher-workmen and other college professors meet with top Westinghouse officials to discuss the mutual problems of engineering colleges and the electrical industry.

A new adjustable-voltage cargo hoist has remarkable operating characteristics—and at the same time is more compact than previous systems. This accrues from building some of the desired characteristics into rotating machines and adding three simple control components. While a description of this new system is in itself interesting, it provides a good opportunity as well to refresh one's understanding of basic d-c machine principles.

A Simple Adjustable-Voltage *Cargo Hoist*

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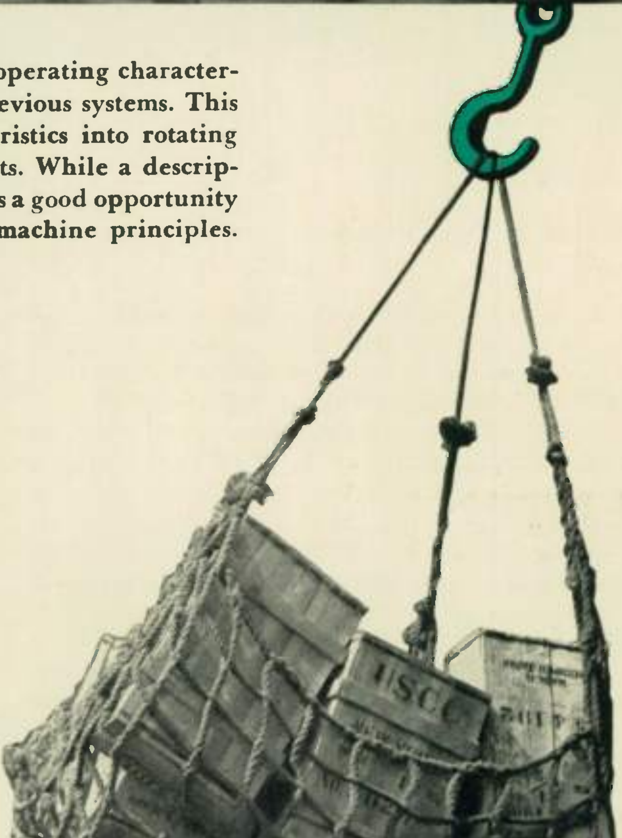


SIMPLIFICATION seldom accompanies improved performance but it has been achieved with an entirely new cargo-hoist drive. The drive employs an adjustable-voltage system and thus inherently possesses speed-load characteristics almost ideally suited to load-lifting operations. New features, however, serve the double purpose of improving on those characteristics for hoist applications and measurably reducing the number and bulk of rotating machines required. The performance abilities include high speed for light load or empty hook in both hoisting and lowering directions, low landing speeds for all loads, and an inherently safe operation to both load and personnel in even the extreme emergency of failure of both brake and primary power supply. This is accomplished with a motor-generator set that serves two winches. Therefore, it employs but a single, standard exciter. The motor-generator set and the control occupies much less deck and vertical area than any previous drives of this type used for cargo winches.

The new control was developed for loading and unloading merchant ships. However, the problem is the fundamental one of lifting and lowering a load and at the same time moving it horizontally. Thus it is probable that this scheme can be used to good advantage in other applications where the lifting problem is similar and where high productivity rate, precision handling or positioning of loads, hoisting hazardous loads, or operating reliability are important. Such requirements arise on movable traffic bridges, and various types of cranes used in pumping stations, powerhouses, foundries, shipyards, docks, etc.

The occasion for the development of this cargo-hoist drive is the new cargo-ship program of the U. S. Maritime Administration. The initial phase of the plan calls for construction of 25 high-speed vessels of the C-4 type. These in size and general characteristics will resemble the C-4 vessels built during 1941–1944 but will be much faster. They will be capable of at

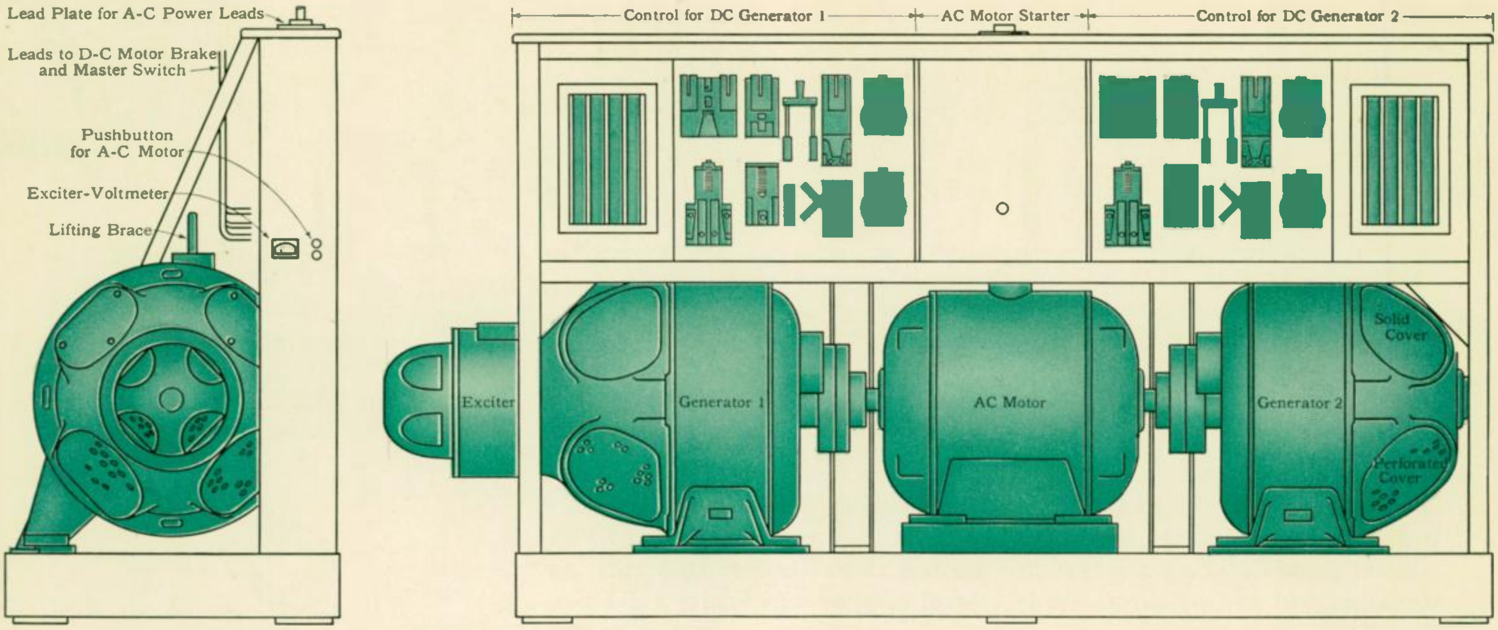


Fig. 1—Complete drive is a single, compact unit: a motor, two generators, and exciter on one shaft. Control is above the machines.

least 20 knots instead of the 14 knots previously attainable.

The Maritime Administration desired to provide vessels that are not only fast on the high seas but also can be loaded and unloaded speedily in keeping with the realization that dock-time is non-productive time. The Administration therefore instructed the shipyard acting as design agent to specify a cargo-hoist system that best combines these qualities with reasonable cost.

Because the new C-4 high-speed cargo vessels are to be equipped with a-c motor-driven auxiliaries, the shipyard made a thorough study as to the relative advantages of centrally located m-g sets in the engine room and individual m-g sets mounted in the respective winch house. In evaluating both systems, it was concluded that the adjustable-voltage type winch using individual m-g sets offers the best overall solution because of its flexibility and smoothness of operation.

The cargo-hoist system consists of one motor driving two generators (Fig. 1), each supplying adjustable-voltage power to a d-c winch motor. The two winches are customarily used together in a cargo-handling operation known as burtoning. One winch provides vertical motion while the other provides horizontal motion. The two in unison give an arc-like trajectory for the load as it proceeds from hold to dock or vice versa. Use of a single driving motor for two generators economizes on machine size because the load peaks on the two winches do not occur simultaneously. However, the motor has sufficient pullout torque to permit simultaneous loading of the generators for special service.

The best control system is one that performs all the desired functions compatible with cost, with the least equipment. With this in mind the adjustable-voltage generator and winch motors are especially designed to possess inherently as much of the desired performance characteristics as possible. This reduces to a minimum the number of contactors and relays required, by comparison with that necessary if standard rotating machines had been used.

How the System Works

The general functioning of the control and drive system is shown in Fig. 2. The three features of special significance are: (a) the rectifier, (b) the generator killer field and dynamic-braking resistor, and (c) the load relay (*LR*) and timing load relay (*LRT*).

Hoisting

During hoisting, the action is essentially that of a cumulative-compound motor supplied from an adjustable-voltage differential-compound generator. As shown in the simplified circuit, Fig. 3(a), terminal *A* of the generator is positive. Current flows from the generator through the load and overload relays, through the generator differential field, a rectifier, motor series field, and motor armature. Resistor *R* shunts part of the current from the generator and motor fields. These elements are suitably proportioned with the shunt fields to obtain a steep speed-load curve required for fast handling of the empty hook. As shown in Fig. 4, the hoisting speed of an empty hook approaches 600 feet per minute—over 250 percent of rated hook speed. The speeds for other loads on each of the five positions of the master switch are likewise shown.

Power Lowering

To lower an empty or lightly loaded hook, power must be supplied. The generator polarity is reversed by reversing its shunt field. As shown in Fig. 3(b), current flows from generator terminal *B* through the motor armature, resistor *R*, and the load and overload relays. Current cannot flow through the motor series field because of the rectifier nor through the generator differential field because it is short circuited by switch *GF*. Generator and motor both act as shunt machines.

The flux from the shunt field is sufficient for the motor to produce a torque in the lowering direction amounting to about 50 percent of the full-load hoisting torque. If it were not for the rectifier, the current would flow through the series field in reverse direction and thereby weaken the motor flux and reduce the torque.

Overhauling Load

Lowering a heavy load has a tendency to make the motor increase its speed. The motor counter-electromotive force increases because of its higher speed and the increase in field strength. As a result, the motor voltage becomes greater than the generator voltage. The current in the main circuit, Fig. 3(c), therefore, reverses, i.e., it flows from terminal *D* of the motor through the generator armature, relays, and motor series field. (The generator differential field is still short circuited by *GF*.) In effect, with overhauling load the motor acts as a cumulative-compound d-c generator feeding power to the generator, which runs as a shunt motor and drives the a-c motor as an induction generator.

The heavier the overhauling load the higher the regenerative current, with correspondingly greater motor flux and voltage. Therefore, more energy is pumped back into the a-c system. Hence, for a given generator voltage, determined by the position of the master switch, the motor flux increases as the load increases. The motor therefore runs at a lower speed to match this voltage.

The extent to which a motor in this kind of a circuit automatically holds back a given load is, of course, limited by the stability of the system. Basically such a relation is unstable, since we have a cumulative-compound generator supplying power to a shunt motor. This system can be made to operate only if the motor speed can change relatively fast and therefore follow the motor flux readily. If the motor speed did not change more rapidly than flux, the voltage and current in the motor would rise to a high value before this braking action would be reflected into the load. The system under these conditions would hunt, that is, the braking action would be pulsating in nature. Expressing this relation in other words, it means that the mechanical time constant of the winch must be appreciably shorter than that of the motor field.

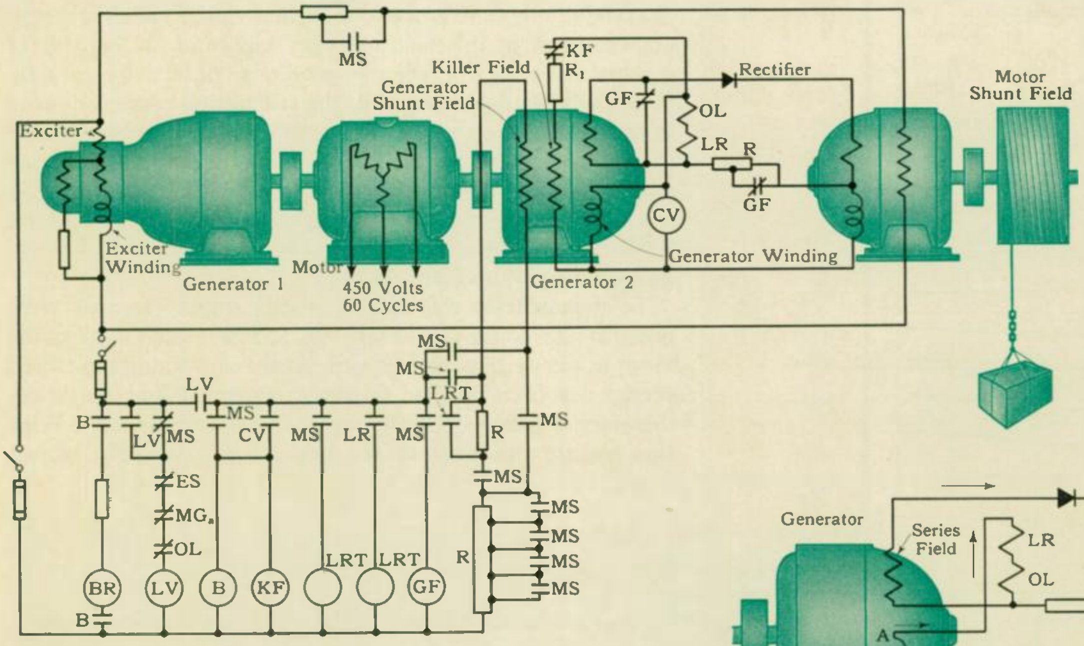


Fig. 2—Main elements of the cargo-handling control.

With the conventional adjustable-voltage winch drive, it is difficult to make this inherent rise of motor speed with decreasing overhauling loads steep enough to be satisfactory, since this rise is a function of the series field settings of the motor. Thus, to obtain this inherent rise at light loads and still have the other characteristics for hoisting would require a different ratio of shunt- to series-field strength. It should be remembered that best burtoning operation, i.e., two winches operating as a team on a single load, is obtained when the hoisting and lowering speeds are about equal.

To accomplish this, the new cargo-winch control includes a load-measuring relay LR. It is utilized on the last position in the lowering direction only. It measures the load on the hook with a current coil in the main circuit and acts to increase the generator field strength, i.e., generator voltage. To enable the current to be a true measure of the load, it is necessary that the current to which the load relay responds contain no component caused by motor acceleration. A time delay relay LRT, is inserted so that the load relay cannot act to cut out the resistance in series with the generator shunt field until a stable speed condition is reached. However, when the hook is empty or lightly loaded the time-delay relay drops out. This insures maximum generator voltage, and hence a high light-load lowering speed.

By suitably adjusting the field resistors, the light-line speed in the lowering direction can be made as high as 2.5 times the full-load hoisting speed (which, for the rated load of three long tons, is 225 feet per minute). The full-load overhauling speed is limited to about 1.5 times full-load hoisting speed. This is shown in the speed-load curves given in Fig. 4.

The control provides rapid acceleration in both hoist and lowering directions although the light-

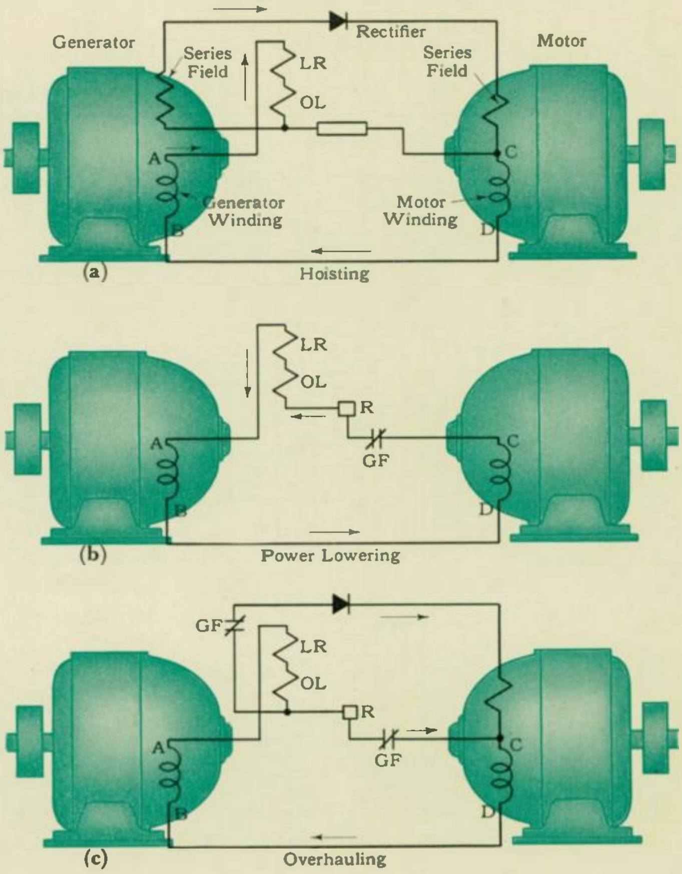


Fig. 3—The essential control circuit functioning during (a) hoisting, (b) power lowering, (c) overhauling.

line speeds are high. This results from the fact that, if high light-line speeds were obtained by field weakening, the torque available for acceleration would be low. Generator voltage increases to about 140 percent at no load and therefore permits a greater motor flux for a given speed. In other words, the system does not depend on a weak motor field to obtain a high light-hook speed. Generator voltage is increased instead.

Stopping of Motor

With constant-voltage winch-control systems, most of the stored kinetic energy of the motor has to be absorbed in the magnetic brake because there is little or no regeneration. This is particularly true when stopping a series or compound-wound motor after hoisting the light hook at maximum speed. The absence of regeneration results from the fact that the momentary reverse current caused by lowering the generator voltage reverses the ampere turns in the motor series field with consequent reduction or elimination of the motor flux. Thus, there is no regenerative braking torque (which is proportional to the product of flux and current) although a relatively large circulating current may be flowing in the main circuit.

With the new system the regenerative current cannot go through the motor series field because it is blocked by the rectifier. Thus the relatively strong shunt field maintains a substantial flux, which, in conjunction with the regenerative current in the main circuit, insures a positive braking torque. This torque is sufficient to bring the load to creeping speed without the brake.

Safety to load and personnel is further increased by the addition of a combination dynamic braking and generator "killer" field, which is applied when the generator voltage has decayed to about 40 percent of normal value. The differential ampere-turns of this field are very high and are capable of quickly reducing the generator voltage practically to zero. With the killer field energized, the circulating current flowing in the main circuit is reduced to less than three percent. This is highly desirable from a safety point of view because the magnetic brake need be adequate only to hold the load. It is not required to absorb any stored energy of the system. Furthermore, with the current low, contactors are not required to open the main circuit.

To demonstrate this feature, oscillographic records were taken of a test. One is shown in Fig. 5. The brake was adjusted to set at about 25 percent speed. At this low value the stored energy has been reduced to about 6 percent and the brake therefore is used essentially only for holding the load. With this feature the wear of the brake lining is slight, which

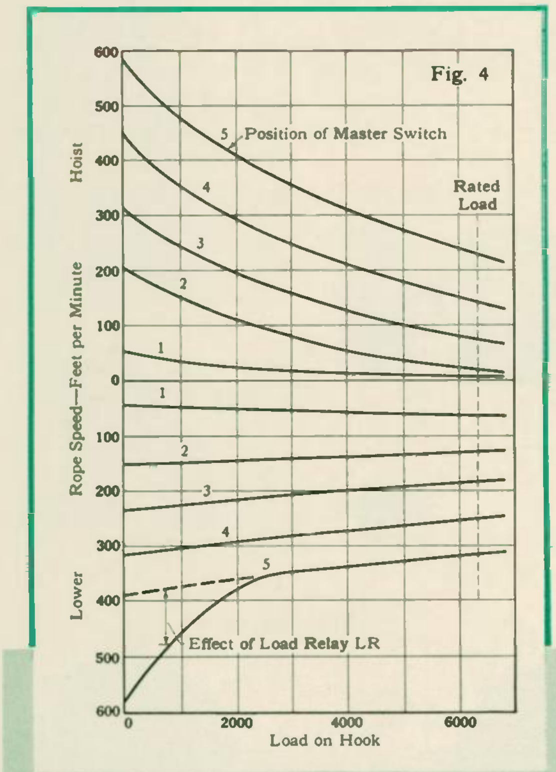


Fig. 4—The family of obtainable characteristic curves.

Fig. 5—Tracing from an oscillogram of a test to show operation during a normal braking operation.

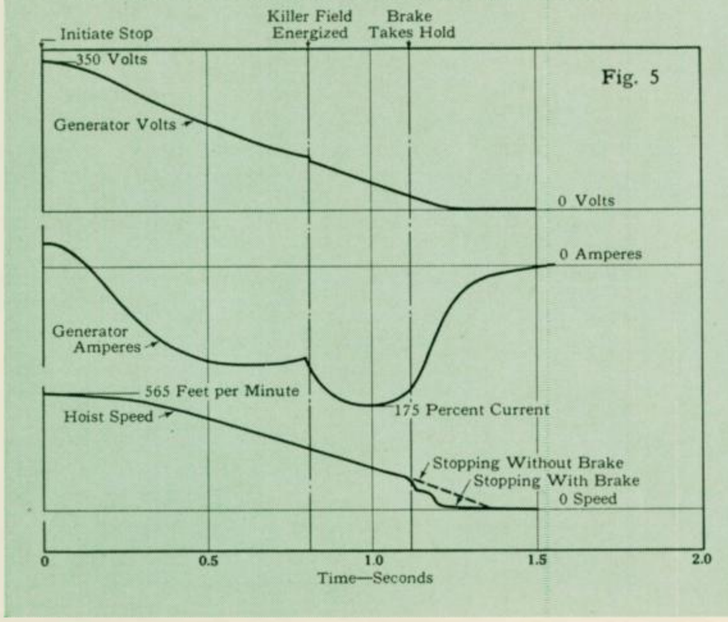
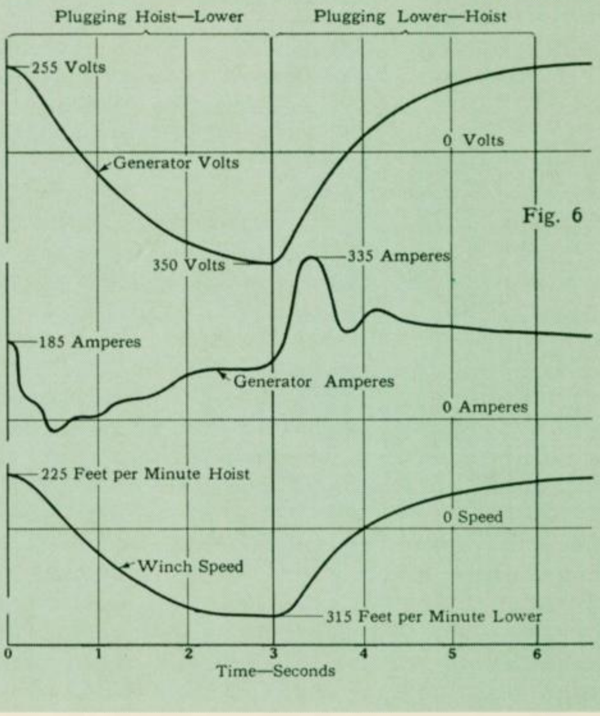


Fig. 6—Oscillogram showing operation during plugging.



naturally results in low maintenance. Also the reliability of the equipment is improved in like measure.

Plugging the Motor

Smoothness of performance is obtained basically by means of characteristics built into the generator and motor. The time delays in the various fields are selected on this basis. Moreover, the generator is provided with a differential series field of sufficient strength to keep the current peak below 200 percent of full-load current even under the most severe operating conditions.

The result of plugging the winch motor under full load is shown in Fig. 6. The master switch was moved instantly from full-speed hoisting to full-speed lowering and back again after reaching full-speed lowering. This represents a service far more severe than encountered in actual operation on board ship. Nevertheless the performance was smooth. No excessive stress was developed in any of the electrical or mechanical parts of the system. The additional stresses caused by the acceleration or deceleration forces did not exceed 25 percent of normal full-load stresses.

Effect of Brake and A-C Power Failure

Failure of any kind must not create a hazard to the operator, equipment, or load. The behavior of the new drive has been tested when the brake fails and under the extreme condition of simultaneous failure of power supply and brake.

Magnet Brake Failure

Returning the master switch to the *Off* position automatically applies the killer field and dynamic braking resistor. The generator voltage rapidly falls to zero. When handling a light line, the motor speed comes to zero in about 1½ seconds with the magnet brake blocked open. This is illustrated in Fig. 5. With full load, the stop is made in 0.9 second, which is less than for light-hook stopping because the speed, and hence the stored energy, is less.

Simultaneous Power and Brake Failure

Protection against power failure is more complex. It is necessary to prevent the motor-generator set from overspeeding when feeding power back while lowering full load. Inasmuch as the overall winch efficiency is approximately 80 percent, power failure occurring under these conditions certainly would result in dangerous overspeeds and possible damage to the motor-generator set unless suitable precautions are taken to prevent it.

As already indicated, the regenerative or overhauling current passes through the motor series field in a direction to increase the flux with increasing current, which has a tendency to slow down the motor with increasing load. If a-c power should fail, an interlock contact of the a-c motor starter opens and drops out the LV relay. This in turn applies the generator killer field and dynamic-braking resistor and thereby brings the generator voltage down to zero.

The stored kinetic energy of the winch motor and load is absorbed by the combination dynamic-braking and killer-field circuit, with little left over for driving the motor-generator set. The unit, therefore, slowly decelerates to a stop.

Because the killer field reduces the generator voltage to zero, the generator has no effect on the operation of the winch motor. The generator armature now serves only as a conductor in the main circuit. The ampere-turns of the motor series field help strengthen the motor shunt field and the high regenerative current produces a powerful decelerating torque of the winch motor so as to slow it down very rapidly. Most of the energy is dissipated in resistor and circuit resistance and some in a momentary increase in speed of the m-g set.

The Flux, Torque, Current and Speed Relationships of Direct-Current Machines

The basic formula for the voltage generated in a conductor moving in a magnetic field is $e = B\,l\,v \times 10^{-8}$ where B, l, and v are mutually perpendicular. This equation states that the voltage is directly proportional to the flux density, conductor length and conductor velocity with respect to the flux. Starting with this fundamental equation, the relationship between flux, generated voltage, and speed of a direct-current machine is:

$$E = K\,(Z)\,(RPM)\,(\phi_p)$$

Where E = Generated voltage in the armature.
Z = Armature conductors in series.
ϕ_p = Main field flux per pole.
K = Constant

Therefore, for a given machine, the generated voltage may be expressed as $E = (K_0)\,(RPM)\,(\phi_p)$.

In a generator, the generated voltage is greater than the terminal voltage of the machine by the amount of the IR drop in the machine, and in a motor the generated voltage is less than the terminal voltage by the amount of the IR drop. On the assumption that the main field flux remains constant from no load to full load, the IR drop in a motor lowers the induced voltage and makes the machine slow down with an increase in load. The effect of the IR drop in a generator assuming constant main field flux is to cause the terminal voltage to decrease with an increase in load. In equation form $E = V \pm IR$ where V is the terminal voltage. The plus sign is used for a generator, the negative for a motor.

The output torque of a machine is a function of the output horsepower and the speed and is given by:

$$T = \frac{5250 \times HP}{RPM}$$

The torque produced by a given motor can also be expressed as $T = K\,\phi_p\,I$.

Where K = A constant.
ϕ_p = Main field flux per pole.
I = Armature current.

The oscillogram of Fig. 7 illustrates these conditions more in detail. It shows the events produced by a power failure while lowering full load and with the magnet brake purposely blocked open. Moreover, the motor shunt field was discon-

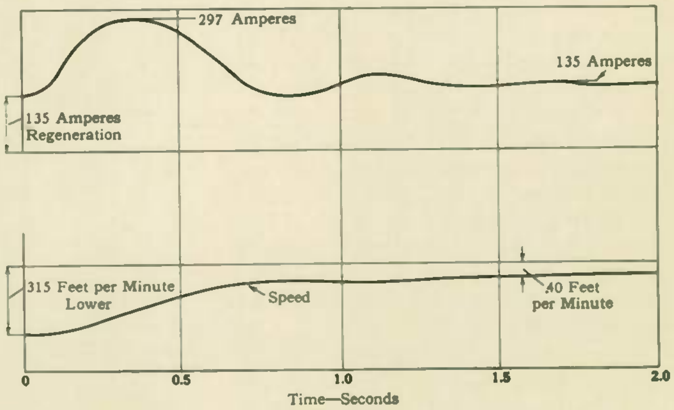


Fig. 7—Oscillogram taken during a power and brake failure.

nected to simulate extreme conditions. Within three fourths second after power failure, the speed of the load was reduced to about 12 percent of full-load lowering speed or about 40 feet per minute. This is an energy dissipation rate of 4.7 kw. Assuming a maximum elevation of full load of 100 feet, this entails the absorption of only about 200 watthours of energy.

The drifting down of the load under power failure with the brake inoperative deserves further study. Inasmuch as the induced generator voltage is practically zero, the voltage drop across its terminals is due to the *IR* drop of the circulation current generated by the overhauling motor, and amounts to about 5 percent of full-load voltage. The heating of the dynamic braking resistor R_1 therefore is negligible. In fact, energy dissipation in it does not exceed about 300 watts and it is therefore possible to insure this important protection with a small and compact resistor.

Overload Protection

An overload relay of the instantaneous type is included in the control equipment. This relay can be set to trip at any desired load. However, another protection feature is particularly valuable because it is inherent in the system. It is the stalled torque feature obtained by means of the action of the generator differential field.

The relations between generator voltage and load current for various positions of the master switch are given in Fig. 8. The maximum current with the motor stalled and with the master switch in the full-speed position is 300 percent. This drop in generator voltage permits approximately constant horsepower over a wide load range—a desirable feature because it permits a small a-c driving motor. Such a constant-horsepower curve makes the scheme advantageous for other shipboard applications. Applied to an anchor windlass, for instance, it would permit breaking away the anchor and raising it at low speed without causing undesirable overloads. As the weight of the chain is decreased, the windlass motor gains speed so that the total cycle time is not increased.

To facilitate testing the winch at the shipyard, the stalled load can be increased to 300 percent without making any special adjustments. The generator design is such that it can handle these momentary overloads without causing commutation trouble.

One feature of great importance to the ship builder and the ship operator is the unit construction of the motor-generator set and the control. All are built together on a common bedplate and installed as a unit. Special attention has been given to compactness of design and accessibility of the control parts as well as the rotating machinery. The control structure itself is a unit assembly and contains the various contactors and resistors for the respective motor, generators and exciters. The control panels are mounted directly above their respective machines in order to permit shortest internal connections and also to insure a pleasing appearance.

Personalities IN ENGINEERING

The child is father to the man. Never was that epigram more true than of Walter Schaelchlin, one of America's outstanding electrical-control engineers. The background of his unusual record of technical accomplishment was laid in the activities of his youth.

Schaelchlin grew up in Switzerland, in the very shadow of the towering Swiss Alps. Possibly the outdoors would have always had an uncommonly strong appeal for him, but the grandeur of the rugged scenery about him accentuated it. He became imbued with a zest for mountain climbing, a sport—if it can be called one—that is taken seriously there. It is a serious game with nature that requires—and this is the important part of our story—extremely careful planning as to detail. The plan must include everything essential and, equally important, be stripped of everything non-essential—simplicity, if you please. Then the program must be executed with strict adherence to plan, with each person playing his indispensable role as a team member. Mountain climbing calls for ingenuity to meet unforeseen situations, determination to reach the objective, stamina, and courage.

Asked to explain the rewards for all this, Schaelchlin squints his eyes as though to shut out the glare of a glacier, and says: "It's an indescribable feeling

All panels are of the open type and conform to marine standards for this type of application. The starter for the 450-volt, a-c drive motor, however, is of the enclosed type with the reset mechanism for the overload relays operable from the outside. The feeder breakers of the a-c power supply are mounted on a separate panel by the shipyard.

Conclusions

The performance characteristics and the design features of the new adjustable-voltage winch or hoist control are:

1—A high light-line speed up to 250 percent of full load is obtained in both hoist and lowering directions to insure a fast loading cycle.

2—The full-load lowering speed cannot exceed 150 percent. This is desirable from a point of view of safety of equipment and operating personnel.

3—Full regenerative braking of the winch motor is obtained for all operating conditions. The magnet brake, therefore, is used only for holding the load.

4—Positive insurance of slow landing speed at all loads.

5—Maximum safety to the equipment and the operating personnel in case of power failure or magnet brake failure by automatically slowing the load to a safe landing speed.

6—Protection against overspeeding of the m-g set in case of power failure when lowering full load.

7—Automatic stalling protection by limiting the winch motor torque to 300 percent. This is accomplished with the inherent generator characteristic.

8—Protection against accidental phase reversal of the driving motor because the direct-connected exciter fails to build up so that no power can be applied to the winch motor.

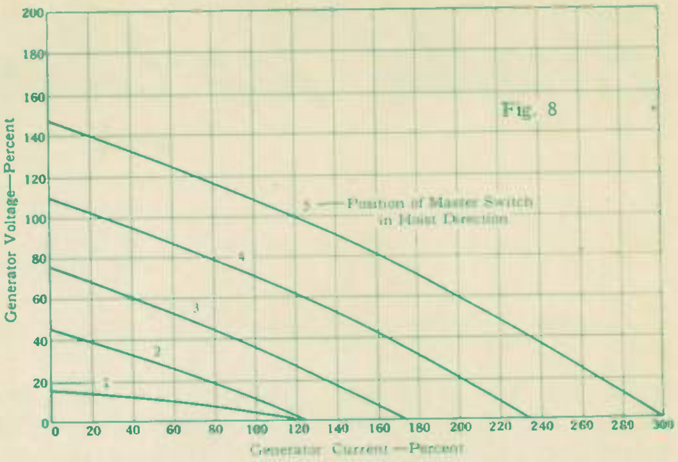


Fig. 8—Curves showing current and voltage relationships for the different master switch positions.

9—Independent and simple adjustments for the no-load and full-load speeds are available to reduce the installation time and expense to a minimum.

10—Special attention has been given to accessibility of all parts. Also the amount of apparatus has been reduced to a minimum by building the desired characteristics into the motor and generator to a large degree.

WALTER SCHAELCHLIN

of accomplishment combined with the exhilaration and humbleness that comes as one finds himself a part of the immense grandeur of nature." . . . Then, a pause, and he adds, "One wants to find out what can be seen from up there."

So Schaelchlin, with his schoolmates in Zurich, climbed mountains. Sometimes in pairs, sometimes with larger groups, never with guides. The exploit of which he is most proud is that of surveying Switzerland from .Mount Blanc, the highest mountain of the Alps.

When it came to college, it was natural that Schaelchlin should study engineering, as his father was a hydraulic engineer, associated with one of Switzerland's many hydroelectric plants. He graduated from the State College of Zurich as an electrical engineer in 1919. He first went to work for a small manufacturer of high-voltage switches and later transferred to a firm in Geneva where he spent two years on 15-kv, 16⅔-cycle traction equipment.

But he felt that the engineering horizons in Switzerland were too limited. His restless urge to climb was already showing. In 1923 he came to America and took a job as a tracer with a consulting firm in New York. But this was only a ledge for a breather. And besides he didn't like New York. Too much city; not enough country. He went to Allis Chalmers in Milwaukee as a draftsman. While this was a step upward, Schaelchlin wanted design engineering. He applied for and was given a job at Westinghouse in the section designing railway controls. Schaelchlin was at last on the main ascent.

One of his first major technical accomplishments was the design of a voltage-regulating relay (UV), specially suited to rough, heavy-traction service. Over the years Schaelchlin had a hand in redesign of almost the whole gamut of the basic control devices—standard motor starters, drum switches, motor accelerations, timing relays. One outstanding special creation was the 250 000-ampere, d-c switch used with the world's largest homopolar generator.

In the last several years Schaelchlin's talents have turned more to control systems than to devices. One was the first system for enabling the officer on the bridge to control directly a vessel's propulsion machinery.

When Schaelchlin is faced with a design problem, he plans as he would for an assault on the Jungfrau or Mount Blanc. He creates first a scheme that includes every basic requirement, then he subjects it to a simplification study to weed out every needless detail.

He has no time or opportunity now to climb natural mountains. But his zest for the outdoors has never diminished. Every possible minute is spent in his flower and rock garden, which is the envy of his friends. His home in hilly Pittsburgh was much to his liking. When Schaelchlin's activity was moved to table-flat Buffalo, he was stumped—for a time. What could he do with an uninteresting, absolutely flat plot of ground? But with traditional ingenuity and determination he obtained 15 loads of soil and rocks and now has in his yard probably the only hill in the Buffalo area. On every vacation trip, he returns with the springs of his car squashed flat with the rear end filled with flagstones and rocks for his bit of man-made Switzerland.

In recognition of his technical skill, his company last May made him assistant manager of Control Engineering. He is charged with supervising the design of control systems for the major process-line industries, such as high-speed steel mills and paper mills. Also he has participated in developing controls for maritime and naval vessels. To him comes the toughest and most complex electrical-control design problems. Some of these lately have been in connection with high-speed wind tunnels. He is approaching these problems with the characteristic vigor, imagination, and determination to reach up for something new. Schaelchlin is still climbing mountains.

Parallel Tap Changing Under Load

Another step forward has been taken in the techniques of operating load tap changers in parallel. Step-by-step switch control, used for the first time early this year, increases to seven the number of basic methods now used.

H. L. Prescott, *Instrument and Regulator Engineering, Westinghouse Electric Corporation, Sharon, Pennsylvania*

For more than 20 years, as electrical loads have steadily risen, power engineers have turned increasingly to parallel operation of transformers. With parallel operation they gain additional load capacity and provide standby capacity to insure continuity of service. Meanwhile, their use of voltage regulators and transformers with load tap changers to solve voltage-regulation and load-distribution problems has also increased. These trends have resulted in extensive application of load tap changers in parallel. As a result, steady improvements have been made in the techniques and equipments used in parallel operation. Twenty years ago only a few methods for parallel operation of load tap changers were available; but now, with the recent introduction of step-by-step control, the choice has been increased to seven.

The new step-by-step switch control has significant advantages over older techniques; however, all seven methods will continue to find use, because each has advantages.

The seven methods all operate on the same theory, and achieve the same end result, but the mechanical means by which the tap changers are controlled are quite different. The techniques can be classified according to the type of control used, of which there are two general types: the tap-changer-position and the circulating-current methods.

In the tap-changer-position methods of control the division of load current between the parallel lines depends on the circuit impedances. The circuit of lower impedance carries more current than the other circuit. Transformers and tap changers to be paralleled are designed so that the voltage ratios on the two transformers are the same when the two tap changers are set on the same relative tap positions. And the tap changers are interconnected so that they move together and are always connected to corresponding taps.

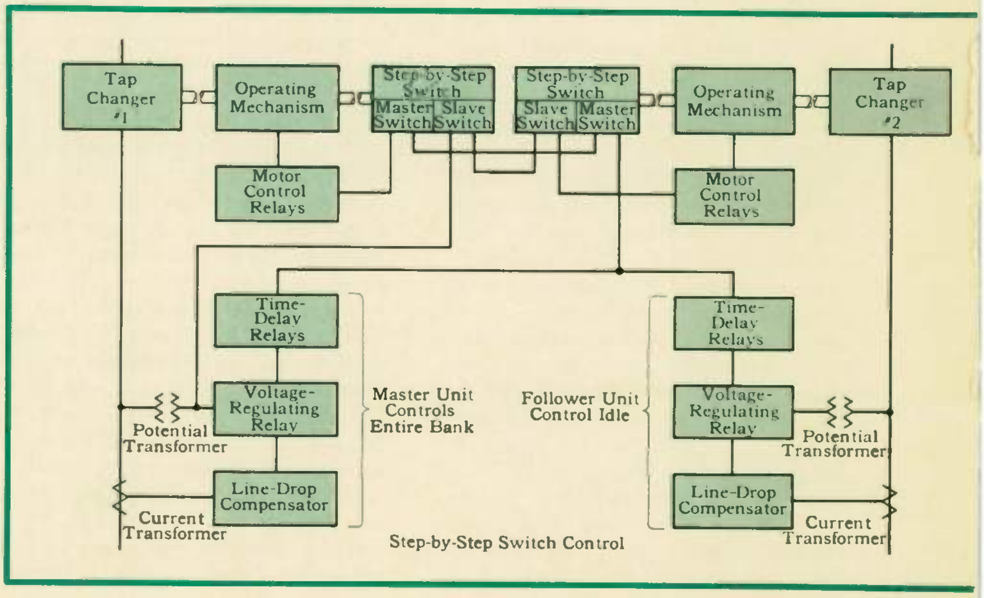
The ideal of the circulating-current methods is to make the current divide equally between the parallel circuits. However, because the impedances in the two circuits are usually different, it isn't practical to obtain exact balance. One compromise is to hold the circulating current to a minimum and let the load current divide according to the circuit impedances. Circulating-current control methods operate the tap changers to corresponding tap positions the same as the position methods. If the voltage ratios of the taps in the parallel units are not equal, the controls must be desensitized to prevent hunting.

Tap-Changer-Position Methods

The tap-changer-position methods, shown in Fig. 1, now include the new step-by-step switch control and two older methods, out-of-step switch control and control by means of a mechanical tie between units. *Step-by-step switch control* and *out-of-step switch control* are similar. Both of these schemes connect to the circuit between the time-delay relays and the motor-control relays. Therefore, these methods eliminate the voltage-regulating relay, the line-drop compensator, and the time-delay relays from the paralleling control. In both schemes, one unit is selected as a master unit by a manually operated selector switch on the control panel. The voltage-regulating relay, line-drop compensator, and time-delay relays associated with the master unit control the operation of the entire bank. A mechanically operated switch, gear-driven from the tap-changer operating mechanism, keeps all units on the same tap-changer position. A series circuit through the mechanically operated switches on all units provides a safety lockout to prevent further separation if the tap changers become displaced from each other by one or more taps.

The difference between out-of-step and step-by-step switch control is largely a matter of timing. In out-of-step switch control, the time-delay relay on the master unit checks the synchronization of all units through the safety lockout circuit. If the units are in step, all tap changers start operating simultaneously. Once started, each tap changer seals itself and completes the operation independently.

In step-by-step switch control, the time-delay relay on the master unit checks synchronization through the safety lockout circuit. If all units are in step, operation of only the master unit begins. When the sealing circuits of the master unit have closed, the mechanically operated step-by-step



Step-by-Step Switch Control

switch closes the circuit and all follower units operate simultaneously. This initiating circuit is maintained to each follower unit individually until it is opened by the step-by-step switch on the follower unit itself. With both methods, the master unit cannot start a second operation until all units complete the first one.

The out-of-step switch method, since all units are energized simultaneously and for a limited time, requires that all units be similar in operating characteristics. One of the advantages of the step-by-step switch method is that paralleling of dissimilar tap changers is possible, since each unit is energized individually. And the wider tolerance in timing makes the step-by-step method the more positive of the two, especially under adverse operating conditions.

The third of the position methods, the use of a *mechanical tie* between tap-changer operating mechanisms, provides the greatest insurance of in-step operation of parallel tap changers. The possibility of a relay failure causing the units to get out of step is eliminated. However, this advantage is offset by the difficulty and inconvenience of installing and operating gearing and shafting between the units. The use of a mechanical tie requires obtaining and maintaining proper alignment of the connecting shafts, protecting the operating parts from the weather and from accidental contact with personnel, and keeping the exposed parts properly lubricated and free from corrosion, dust, and dirt. A mechanical tie is used only for applications where the line impedances are very low or the tap-changer steps are unusually large, conditions under which the possible circulating currents may be excessive.

Circulating-Current Control Methods

Circulating-current control includes four methods: reverse-reactance, cross-current, difference-current, and current-balance control. These are illustrated in Fig. 2. *Reverse-reactance control* is the simplest. It requires only that it be possible to reverse the polarity of the reactance element of the line-drop compensator. In a typical transmission or distribution circuit, the line impedances are largely reactive. Therefore, the circulating current is reactive and primarily affects the reactance element of the line-drop compensator. The normal polarity of the reactance compensator is such that increased reactive current causes the tap changer to raise the output voltage, which increases the circulating current. However, if the polarity of the reactance compensator is reversed, increased reactive current causes the tap changer to decrease voltage and circulating current.

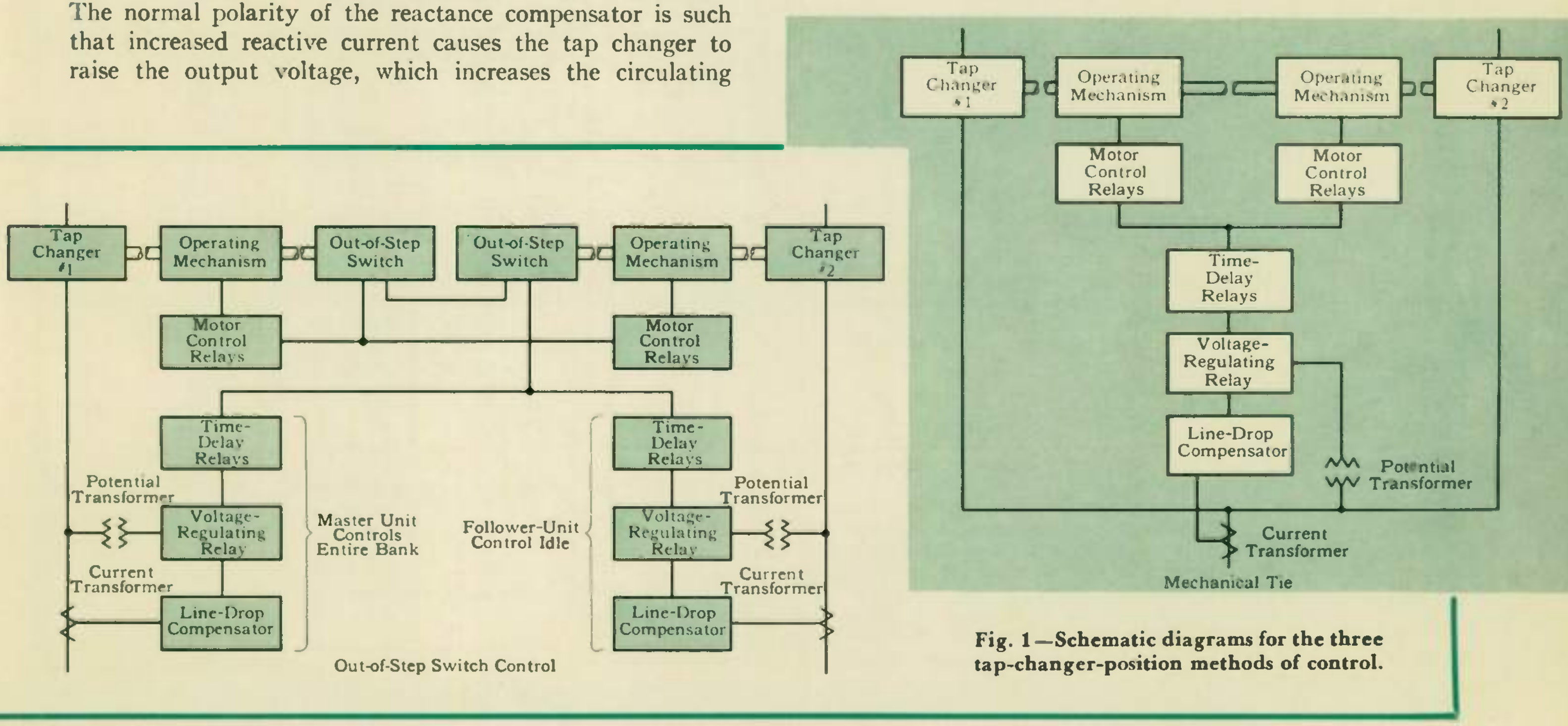
Reversing the reactance compensator has the disadvantage of making line-drop compensation for load current incorrect, but this often can be overcome satisfactorily by using greater resistance compensation than normal. Because no control wiring is required between units, this method is particularly useful where tap changers are a considerable distance apart.

Cross-current control can be used when two parallel units are close enough to be connected by control wiring. The control circuits are interconnected so that the current of one unit flows through the line-drop compensator of the other unit, and vice versa. With these interconnections, an increase in current in one unit causes the tap changer on the second line to raise the output voltage of the line-drop compensator on the second line.

This method has an advantage over reverse-reactance paralleling, since normal line-drop compensation is not limited. It has two principal disadvantages: if one unit is removed from service, the remaining unit has no line-drop compensation; and line-drop compensation and sensitivity to circulating current cannot be adjusted independently.

Difference-current control is also limited to two parallel units. Control-circuit networks, using auxiliary current transformers, segregate load current from circulating current. The load-current component is directed through the line-drop compensators of both units so that normal line-drop compensation is obtained. The circulating-current component passes through paralleling reactors that apply voltages in the voltage-regulating relay circuit. The polarity of these voltages is such that increased circulating current causes the tap changer to reduce the output voltage.

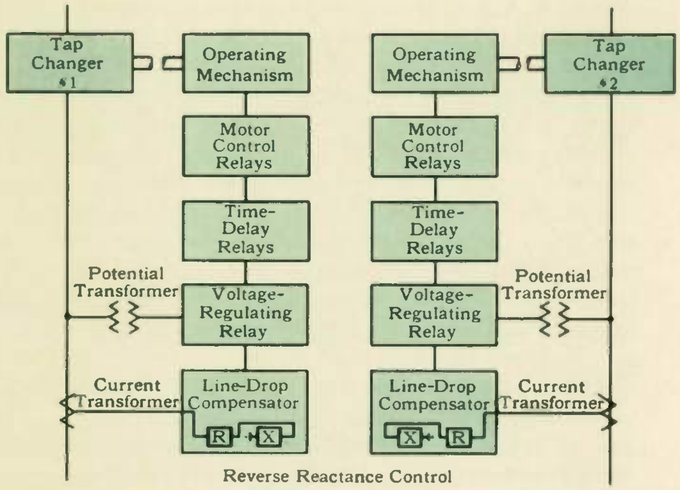
Like cross-current control, this method permits normal line-drop compensation; but unlike the cross-current method, it also permits one unit to be removed from service without loss of line-drop compensation. And it provides independent adjustment of line-drop compensation and sensitivity to circulating current.



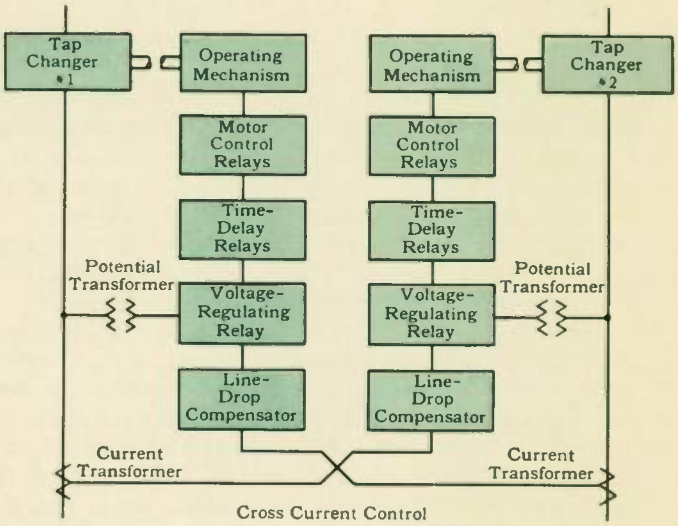
Out-of-Step Switch Control

Mechanical Tie

Fig. 1—Schematic diagrams for the three tap-changer-position methods of control.



Reverse Reactance Control



Cross Current Control

Current-balance control extends the benefits of difference-current paralleling to more than two units. Like difference-current control, it uses auxiliary current transformers to establish control-circuit networks that direct load-current components through the line-drop compensators and circulating-current components through the paralleling reactors. Depending upon the design of the load-current networks, the line-drop-compensator currents may be proportional either to the load current of the particular unit or to the total load on the paralleled bank. Paralleling reactors are connected so that the tap changers reduce the total amount of circulating current.

The operation of current-balance control of two parallel units is equivalent to difference-current paralleling, but it is more complicated and requires more interconnecting control wiring between units. Therefore this method is used with two units only if later expansion to more units is contemplated. For more than two units, it has several advantages over reverse-reactance control. It permits normal line-drop compensation and independent adjustment of line-drop compensation and sensitivity to circulating current. Also, one

Comparison Chart of Various Methods For Parallel

Method	Circulating-Current Methods			
	Reverse Reactance	Cross Current	Difference Current	Current Balance
Point of Interlock	Line-Drop Compensator	Line-Drop Compensator	Voltage-Regulating Relay	Voltage-Regulating Relay
Basis of Operation	Polarity of response to reactive current is reversed so that output voltage decreases with increased circulating current.	One unit responds to change in current in opposite unit.	Circulating current segregated and used to operate voltage-regulating relay.	Same as Difference Current.
Advantages	1. Exactly corresponding taps on all units not required. 2. Attachments on operating mechanism not required. 3. Tap-changer mechanism may have different operating characteristics. 4. No control wiring between units. 5. The only special control is a reversible reactance element in line-drop compensator. 6. Can be used with any number of units.	1. 2. Same as Reverse Reactance. 3. 4. Does not limit line-drop compensation. 5. No special control equipment required.	1. 2. Same as Reverse Reactance. 3. 4. Same as Cross Current. 5. Provides independent adjustment of line-drop compensation and paralleling sensitivity. 6. Removing a unit from service does not require changing line-drop compensator setting.	1. 2. Same as Reverse Reactance. 3. 4. Same as Cross Current. 5. Same as Difference Current. 6. 7. For any number of units.
Disadvantages*	1. Safety lock-out requires auxiliary overcurrent relaying. 2. Depends upon correct operation of all control equipment on all units and upon properly correlated settings of line-drop compensators, voltage-regulating relays, and paralleling reactors. 3. Limits line-drop compensation available. 4. No independent adjustment of line-drop compensation and paralleling sensitivity.	1. Same as Reverse Reactance. 2. 3. Limited to two units. 4. Same as Reverse Reactance.	1. Same as Reverse Reactance. 2. 3. Same as Cross Current.	1. Same as Reverse Reactance. 2.

*All methods except Reverse Reactance require

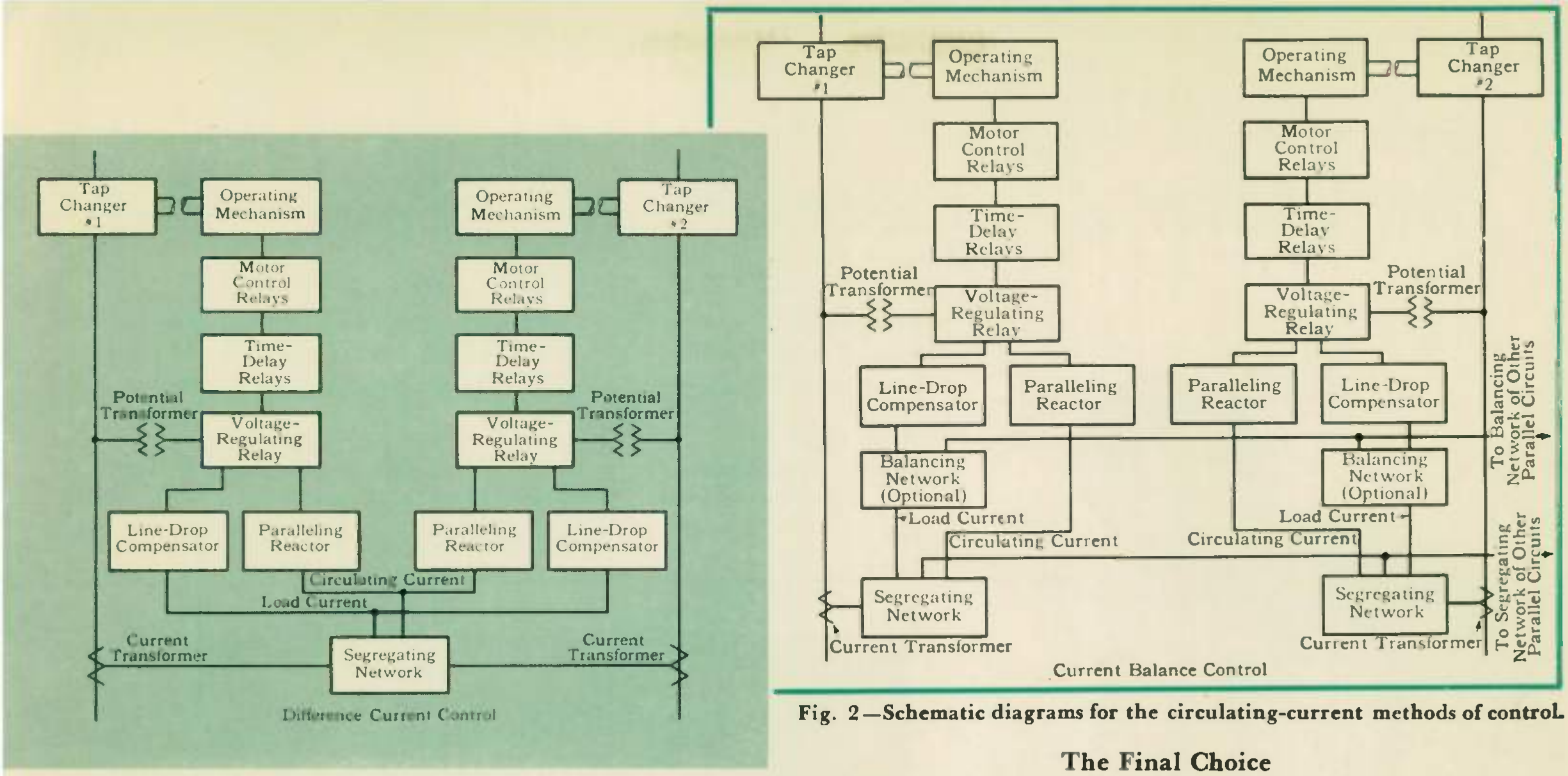


Fig. 2—Schematic diagrams for the circulating-current methods of control.

or more units can be removed from service without disturbing the operation of remaining units.

In all four circulating-current schemes, the paralleling controls operate in the voltage-regulating relay circuit. The chain of control is from the paralleling circuits through the voltage-regulating relay, the line-drop compensator, the time-delay relay, the auxiliary or motor-control relay, and the tap-changer operating mechanism to the tap-changer contacts. In the tap-changer-position methods the paralleling controls are electrically closer to the tap changers.

The Final Choice

Successful parallel operation of tap-changing-under-load equipments requires careful study. The operating conditions to be met must be compared with the advantages and disadvantages of the possible methods of control. Consideration must be given to number of units and their relative location, the flexibility of operation desired, the insurance against out-of-step conditions required, the similarity or dissimilarity of the tap changers being paralleled, and the impedance characteristics of the circuits. Each of these seven basic paralleling methods, summarized in the comparison chart, below, can be modified to adapt it to particular requirements.

Operation of Tap-Changing-Under-Load Equipment

Tap-Changer-Position Methods		
Out-of-Step Switches	Step-by-Step Switches	Mechanical Tie
Motor Control Relay	Motor Control Relay	Operating Mechanism
All units operated simultaneously by parallel circuits to motor control relay; interlocked by mechanically operated switches.	Controls operate master unit; mechanically operated switches operate follower units.	Operating mechanisms are mechanically synchronized by shafts between the units.
1. Eliminates voltage-regulating relay, line-drop compensator, and time-delay relays from paralleling controls. 2. Does not restrict line-drop compensation. 3. For any number of units. 4. Mechanically operated switches provide safety lock-out at one step difference in tap-changer positions. 5. Only one voltage-regulating relay and line-drop compensator needed to control entire bank; but, if desired, all units may be supplied with these devices and the master unit selected by switch on control panel.	1., 2., 3., 4., 5. Same as Out-of-Step Switches. 6. Tap-changer mechanisms may have different operating characteristics.	1., 2., 3. Same as Out-of-Step Switches. 4. Paralleling is independent of the auxiliary and motor control relays. 5. Only one set of automatic and manual control is required.
1. Requires units designed with corresponding taps. 2. Requires mechanical attachments to operating mechanisms. 3. All units must have similar operating characteristics.	1., 2. Same as Out-of-Step Switches.	1., 2. Same as Out-of-Step Switches. 3. Requires shafts between units.

control wiring between units.

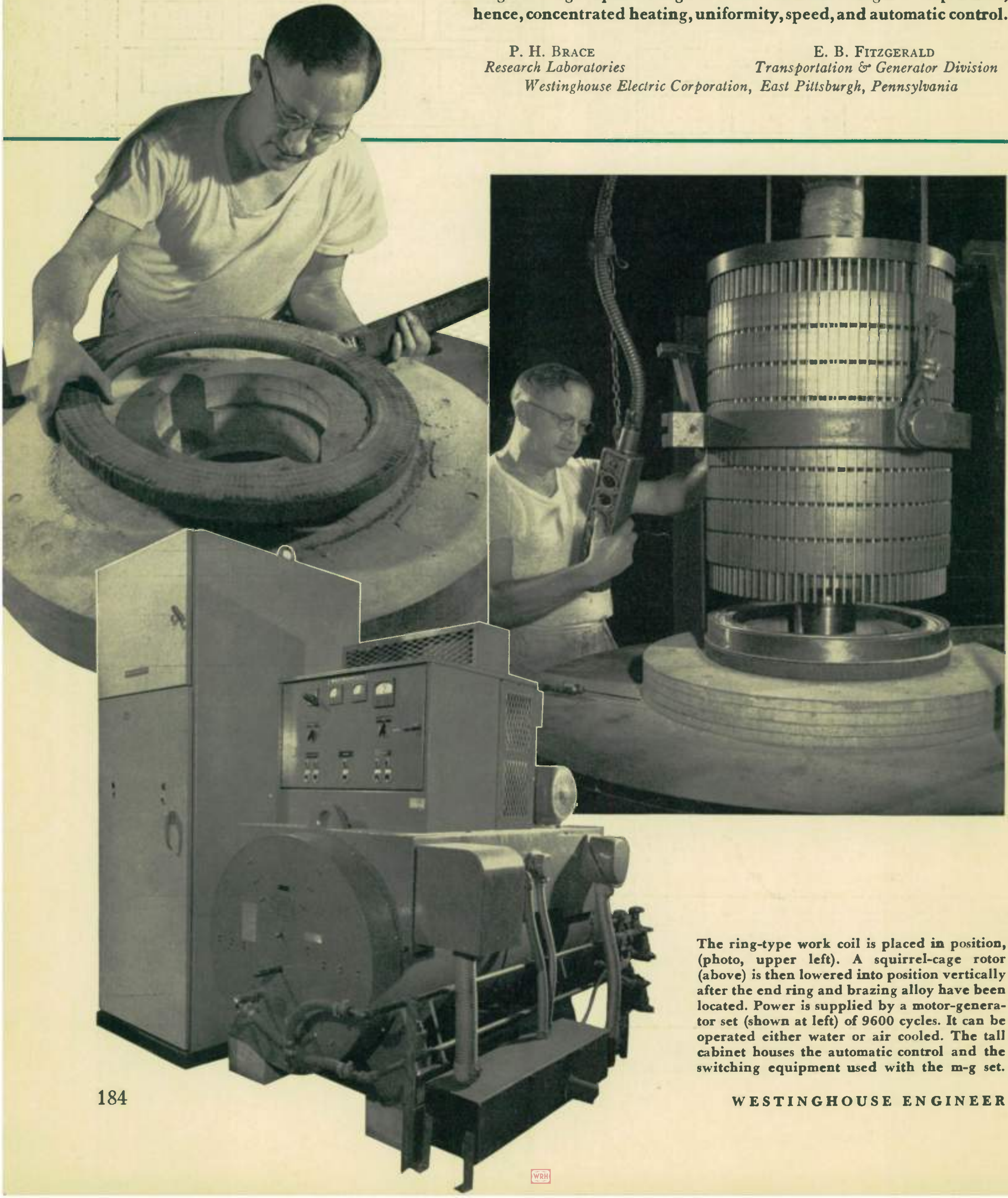
Induction Brazing of Large Rotors

Induction heating using 9600-cycle energy applied to brazing of end rings of large squirrel-cage motors offers advantages of rapid and, hence, concentrated heating, uniformity, speed, and automatic control.

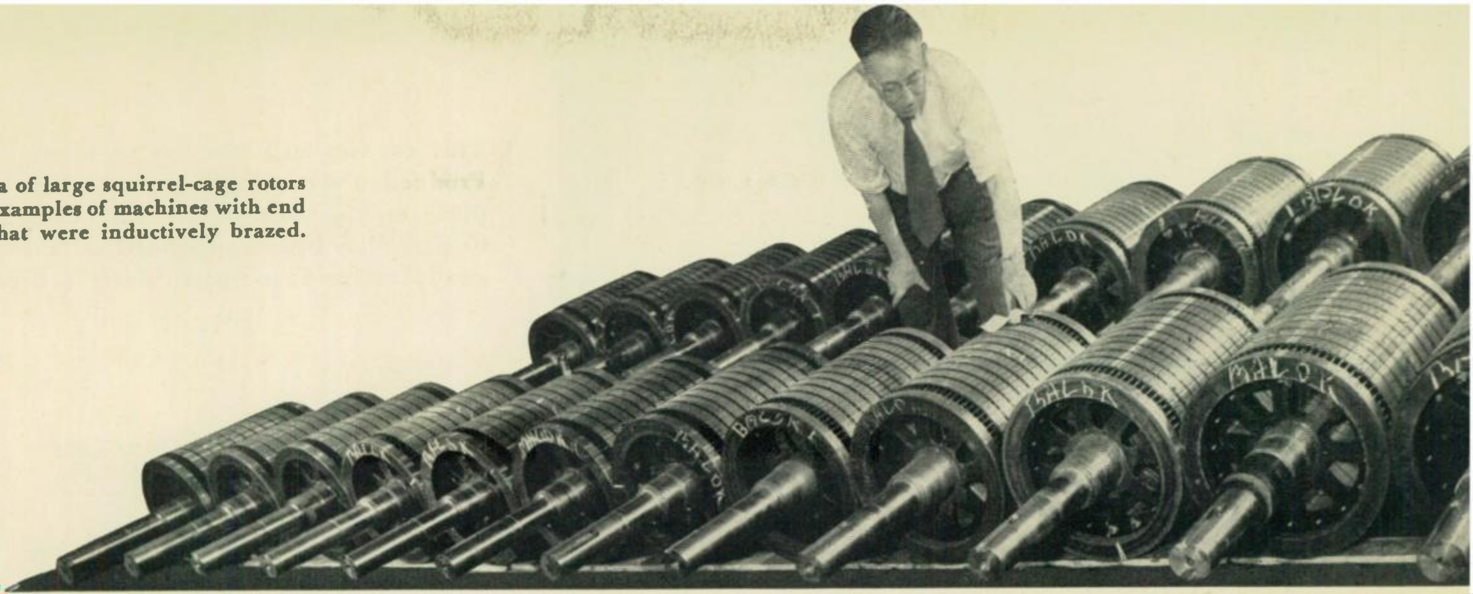
P. H. BRACE
Research Laboratories

E. B. FITZGERALD
Transportation & Generator Division

Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania



The ring-type work coil is placed in position, (photo, upper left). A squirrel-cage rotor (above) is then lowered into position vertically after the end ring and brazing alloy have been located. Power is supplied by a motor-generator set (shown at left) of 9600 cycles. It can be operated either water or air cooled. The tall cabinet houses the automatic control and the switching equipment used with the m-g set.



This sea of large squirrel-cage rotors shows examples of machines with end rings that were inductively brazed.

INDUCTION HEATING is being used to braze end rings to large squirrel-cage rotors. The result is a great saving in time and a large improvement in quality. The technique has been worked out with conspicuous success on a production run of several hundred squirrel-cage, 600- and 700-hp induction motors destined for a class of service where the highest order of reliability, uniformity, and efficiency is required. The method is generally applicable to a wide variety of motor sizes, and to other applications as well.

Brazing the end ring to the rotor bars has long been considered a difficult, troublesome task. The problem is to braze each of many—sometimes over a hundred—closely spaced copper bars, extending beyond the stator iron, into a copper short-circuiting ring. The conventional method has been to braze the bars individually to the ring using electrically heated carbon-tipped tongs. This is time consuming and offers the possibility of variation or inconsistency between bars, which can lead to trouble in service. With the induction method, brazing of an entire cage winding to a ring is accomplished at one time—in a matter of three or four minutes, with energy supplied from a 9600-cycle generator. All brazed connections are, of necessity, alike.

Extensive tests were made to arrive at the best method of applying high-frequency heating for this type of brazing work. For the preliminary tests the inductor coil available spanned only a part of the rotor ring circumference. Results of these tests demonstrated that heat can be very rapidly generated in the ring. It also became apparent that adequate power must be available to do the job quickly if excessive temperature rise and consequent buckling of the rotor iron by heat transferred from the rotor bars were to be avoided. After trying various arrangements of the induction coil, the one most suitable proved to be a simple "pancake" inductor coil placed as close as possible to the end plane of the rotor ring and designed to supply sufficient power to heat the entire ring quickly. The basic elements of a practical routine were established whereby the brazing of a rotor ring to the rotor bars is accomplished in less than six minutes.

It is of paramount importance to provide a strong axial force for holding the ends of the rotor bars parallel. This is accomplished by a rig operated by an air-actuated cylinder located beneath the rotor brazing table. This applies an axial compressive force of a few thousand pounds between an aligning plate bolted to the top end of the rotor and a steel foundation platen that carries the inductor coil and insulating rings of Transite. These rings separate the coil and the platen to avoid inductive heating of the latter.

To reduce the brazing setup time and to avoid using unnecessarily large amounts of brazing alloy, the alloy is applied in the form of one-piece rings of correct weight pre-placed in the channel machined in one face of the rotor ring. Thus, all the rotor bars make thermal contact with the rotor ring through the brazing alloy ring. As the temperature rises, the alloy yields under the compressive force. In so doing it establishes intimate thermal contact and the heat flows rapidly into the ends of the bars so that the joints are wetted quickly after the brazing alloy has melted. This scheme permits the use of high-power inputs without overheating the rotor rings, and limits the heat flow into the bars.

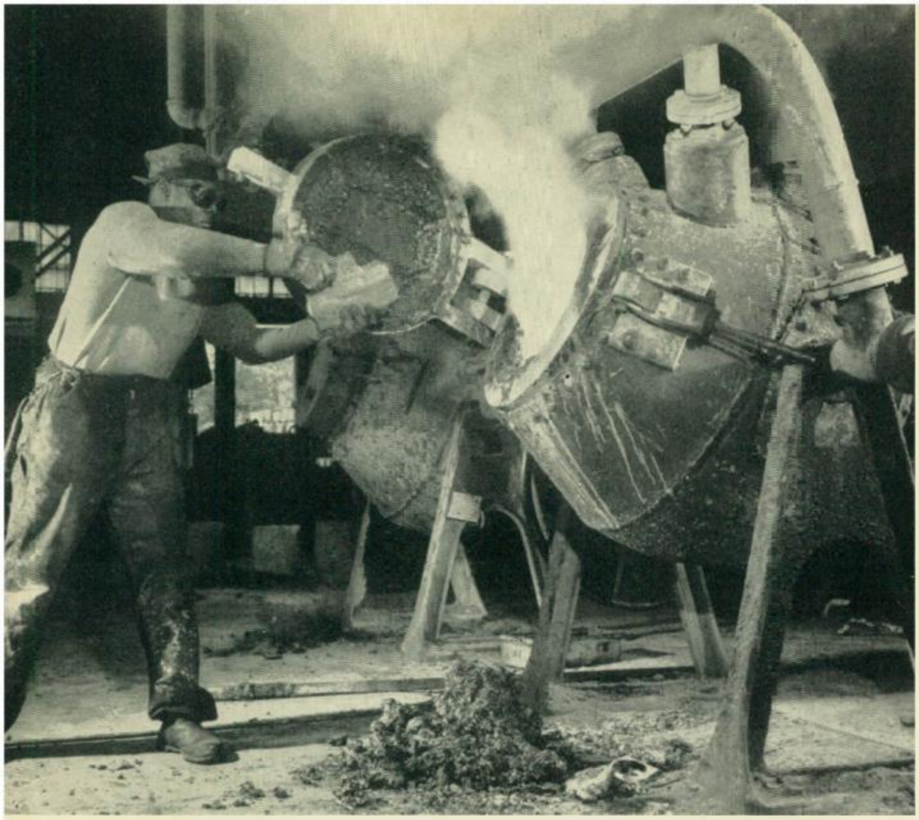
A new flux that is far superior to ordinary fluxes has been developed for this purpose. The usual alkaline-borate flux, having water as a vehicle, foams as the water is driven off during fusion. The foam becomes an inch or more deep and remains as an undesirable deposit on the rotor bars. Also, the foam prevents visual observation of the progress of the brazing operation. The new flux employs essentially the same ingredients but is processed in a way that leaves only traces of water. The result is a crystal-clear, pale green, dry granular powder. It is entirely effective insofar as fluxing action is concerned and does not foam. Thus, the progress of fusion of the brazing alloy and its action as it wets the submerged ends of the rotor bars can be clearly observed. This allows opportunity to correct any occasional minor irregularities. There is thus greater assurance of high-quality brazed joints.

During the preliminary development work, temperatures were controlled by observation. However, it soon became evident that the process can be performed with such regularity that it can be made automatic. A thermocouple placed in the ring in conjunction with simple instrumentation controls the power input automatically and maintains a pre-determined temperature as long as desired.

Because of the high thermal-expansion factor of copper, the diameter of the rotor ring in these large rotors changes by a quarter of an inch during heating and cooling. This has not proved to be troublesome, however. By adequate design of the ring this expansion is readily accommodated.

The generator used is a 150-kw, 9600-cycle machine with a 2300-volt, 60-cycle, three-phase driving motor. It has been found useful for a variety of other work, such as armature brazing, stator-winding brazing, etc.

The technique of unbrazing joints has been developed, utilizing the same equipment that is used for brazing, with a tremendous reduction in the time required as compared to previous methods. In actual production, rotor rings are being applied to rotor bars with a total elapsed time of between three and four minutes.



SOURCES AND USES OF ZINC

This country still has lots of unmined zinc. Production capacity is high. The metal wins a place on the short-supply list because a war demand has been superposed on a long-term steady increase in use, particularly for die casting.

ZINC IS NOT a spectacular metal. It does not have the popular appeal, either inherent or by virtue of glamorous applications, of other metals such as copper, aluminum, and magnesium. Neither does it make the headlines as an international political issue, as does tin. Zinc is, instead, a workhorse metal and one of the most indispensable. How much so is indicated by the fact that it stands fourth among metals in amount used by the world each year. In tonnage it is surpassed only by iron, copper, and lead. Its importance is further suggested in that since August 1, 1951 every pound of it used in the United States is under Government control.

Zinc, also called spelter, has had a long history. Museums display brass (zinc-copper alloy) objects known to have been made before 500 B.C., although zinc was probably not then known as a separate metal. Probably that distinction goes to the Chinese, who in spite of recent Soviet claims, seem to have had everything first. Portuguese mariners brought zinc objects from the Orient in the 16th Century. The modern zinc industry began with the development of smelting in Belgium in 1806 and the United States got into the act in a serious way in 1858, using New Jersey ores. The United States has been the world's leading zinc producer since 1909.

Nature was both generous and impartial when she laid down the earth's concentrations of zinc ore. Last year 17 nations some in every continent, each mined more than 10 000 short tons of zinc yearly. The total world production amounted to about two million tons. This does not count the Soviet Union and her satellites. Russia is believed to be producing about 120 000 tons of zinc yearly and Poland about 90 000.

Of total world mine production, North America turns out more than half (57.5 percent) taking the four postwar years, 1946 through 1949, as representative. Of the North American output, the United States has in that period accounted for more than half (57.5 percent) or almost exactly one third (33.1 percent) of the world total. The United States' output of zinc is more than twice that of the second largest producer, Canada, which contributes 15 percent, and has good reserves. Mexico follows with nearly 10 percent, but its reserves are more limited. Then comes Australia with 9 percent. The world sources of zinc are listed in table I.

Just as zinc is mined on a substantial scale in many parts of the world, so it is produced in widely separated areas in the United States. There are some 750 operating zinc mines in this country, of which several hundred are small ones—even one-man operations. However, 60 percent of the total comes from 25 of the larger mines.

The United States has several major zinc-producing regions. As might be expected, the western states produced the bulk of the national total (about 55 percent in the 1946–49 period). Idaho, Arizona, Montana, Colorado, Utah, New Mexico, Nevada, Washington, and California—in that order—are all important producers.

Several widely scattered states east of the Mississippi River have a combined output that in the four postwar years, 1946–49, accounted for a little over one fourth of the national total. These states, in order, are New Jersey, New York, Tennessee, Virginia, Illinois, and Wisconsin.

The third major zinc-producing region is the so-called Tri-State area about 30 miles across, where Kansas, Missouri, and Oklahoma join. In the four years after World War II, the Tri-State region was responsible for roughly 17 percent of the nation's zinc-mine output. (The wartime average production was 225 000 tons yearly. Since 1945 the average has been less than one half that and in 1949 amounted to only 80 000 tons.) At one time (1921) the Tri-State area produced two thirds of the nation's zinc. The area hit its peak of zinc production in 1926 with 424 000 tons (and 100 000 tons of lead). The reason for the decline is the exhaustion of the higher grade ores. A decade ago the tenor of combined lead-zinc Tri-State ores (as mined) stood at 6.12 percent. Now it is 3.4 percent. However, there is probably nearly a million tons of zinc (and 165 000 tons of lead) left. How much will be recovered is a question.

In general the ores of the Tri-State area are low grade (recovery of zinc is 1.66 percent; lead, 0.69 percent). They are characterized by simple mineralization and lend themselves to larger scale, lower cost mining than the eastern zinc ores, which are of higher grade, but metallurgically more difficult

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Prepared by Charles A. Scarlott from information provided by the U. S. Bureau of Mines, American Zinc Institute, U. S. Geological Survey, St. Joseph Lead Company, and Westinghouse.

of treatment. The deposits of the western states are higher grade and, unlike eastern and Tri-State ores, they usually contain worthwhile quantities of gold and silver. But these advantages are offset by complexities of the ores, generally higher production costs, remoteness from markets.

The United States and the world still have lots of zinc, as table I shows. Statements of mineral reserves must always be hedged with qualifications, many contingent on price level, state of mining and ore-dressing technology, extent of exploration, and character of the deposits. This is particularly true of zinc, which occurs, in general, in two types of deposits. In one, zinc is found in more or less vertical veins in the rock and, in the other, in sloping limestone beds into which the sphalerite (zinc sulphide) has been carried and precipitated from solution in the earth waters. In both cases the zinc ore bodies are often discontinuous, and the boundaries are extremely difficult to delineate except by expensive drilling. In this respect zinc deposits are more difficult to estimate than, for example, those of porphyry copper, which, by comparison, are uniform and have more definite boundaries.

With these qualifications, the proved and indicated (but not inferred) zinc reserves of the United States, in terms of gross content of zinc workable under conditions similar to those prevailing in 1949, are estimated by the United States Geological Survey as 8.5 million tons. Of this, about three fourths or something over 6 million tons should be recoverable. If one were to divide this figure by the 1950 rate of production one would come up with the startling figure of ten years. However, we can be sure that zinc mines will be producing in this country many years hence, as probably the total zinc yet to be developed by exploration and brought out of mines in this country will total several times 6 million tons. It is simply not good economics to invest money in proving up zinc ore many years in advance of the need for this information in planning for mining.

Although the proportion of the world's zinc that the United States provides is interesting, two other matters are more important: (a) how much of what we need do we produce, and (b) what is the quality and quantity of our reserves. The answer to one is easy to set down; the other is not.

Whereas the United States produces a third of the world's zinc, it normally consumes a little over 40 percent (1946–49, 42.6 percent). Clearly this leaves a deficit that must be made up by imports and scrap. In the last five years this has amounted to a net average importation of 315 000 tons of contained zinc per year, or about 38 percent of our consumption. Furthermore, demand for zinc, particularly since July, 1950, is rising faster than the ability to produce it. The supply of secondary (reused) zinc has been small, less than 10 percent of the total consumption, largely because when zinc is used for galvanizing—the largest application—it is never recaptured. However, with the increase in zinc die casting, the amount of zinc returned in the future as scrap will increase.

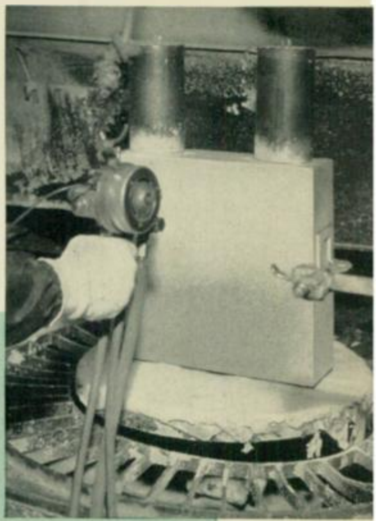
As matters stood at the beginning of this year, based on figures for the first five months of 1951, United States' mines were producing at the annual rate of 690 000 tons. (Previous mine production peaks were 775 000 tons in 1926 and 768 000 tons in 1942.) Consumption for 1951, if the January-April use rate continues, will be about 900 000. Consumption, while the emergency lasts, will be federally controlled.

Vigorous efforts are being made to increase production. The Government is lending encouragement and financial assistance for exploration, allowing rapid amortization of the cost of new production facilities, and facilitating the obtaining of loans for expansion of mines and plants. Once abandoned and now flooded mines may be pumped out and zinc and lead mining resumed with federal aid. It is believed that by these measures the quantity of zinc produced from United States' ores this year will be 10 percent more than last, and in another two or three years mine output will have increased another 10 to 15 percent. This would bring this country's mine output by 1954 to between 735 000 and 770 000 tons, taking declining grade into account. There is no prospect, short of a major industrial depression, that the United States will become wholly self-sufficient even temporarily as to zinc.

Most zinc ore produced in the United States goes chiefly to smelters in Texas, Oklahoma, Illinois, Pennsylvania, Montana, and Idaho. A small quantity of ore is reduced to pigments directly. In addition to importing slab zinc, the United States also receives zinc-sulfide concentrates from foreign sources. These must be processed in United States' smelters. Hence smelter capacity exceeds mine capacity by about a third. The smelters of this country can now turn out about a million tons of slab zinc annually. Mines and imports have represented the bottleneck to zinc production, not United States' smelter capacity.

The curve of zinc consumption in the United States since 1900 is both smooth and steeply rising, with no hint at leveling off. Most old uses are growing and new ones are continually being added.

The largest single use of zinc—hot-dip galvanizing—arises out of zinc's unusual anti-corrosion properties. Applied as a surface layer to steel, it prevents corrosion in two ways. Zinc exposed to normal atmospheres forms an insoluble, adherent, impervious layer of zinc carbonate that resists further attack. Also in the electrochemical series, zinc is positive with respect to



Zinc, vaporized by heat, is sprayed onto a capacitor case, giving good weather resistance.

TABLE I—PROVED AND INDICATED ZINC RESERVES OF THE WORLD WORKABLE UNDER 1949 CONDITIONS

	Gross Zinc Million Short Tons
United States	8.5
Other North America	8.0
South America	12.0
Western Europe	8.5
Eastern Europe	11.0*
Africa	4.0
Asia	4.0
Australia	14.0
World Total	70.0

*Of which about one half is estimated for U.S.S.R.

TABLE II—U. S. CONSUMPTION OF SLAB ZINC. ANNUAL AVERAGE—SHORT TONS

	Galvanizing	Brass	Rolled Zinc	Die Casting	Other	Total
1926–1930 Prosperity Era	273 600	163 800	70 720	23 800	51 500	583 420
1931–1935 Depression	154 400	93 600	45 600	30 100	36 340	360 040
1936–1940 Recovery	251 600	168 600	55 800	81 600	34 000	591 600
1941–1945 World War II	290 780	338 680	71 520	99 320	23 040	823 340
1946–1950 Postwar	366 939	118 259	72 526	228 016	22 387	811 127

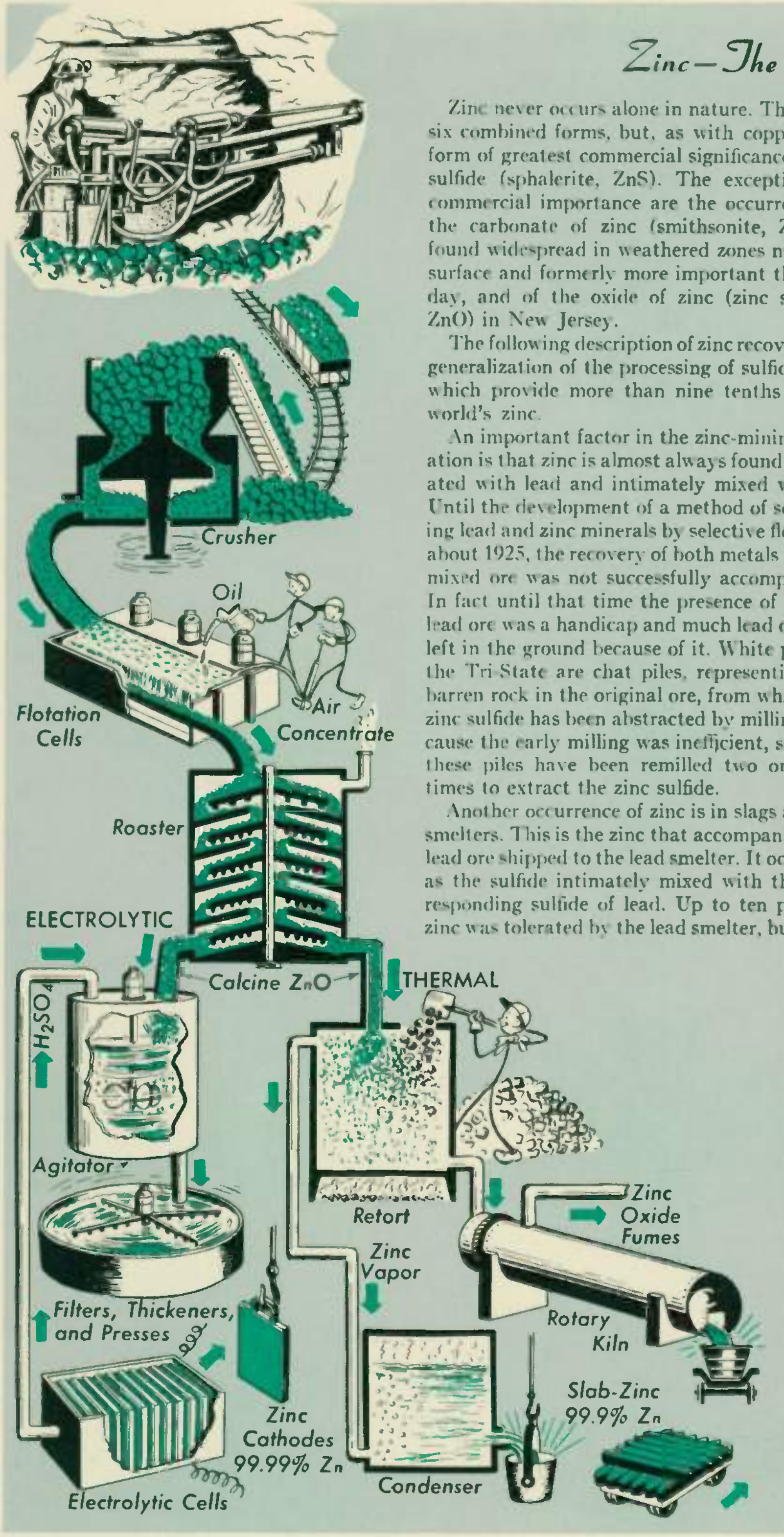
iron. Hence when a galvanized article is subjected to electrolysis the zinc is sacrificed for the iron. Even if spots of bare metal are exposed the nearby zinc will protect against consuming galvanic currents.

Galvanizing absorbs about 45 percent of the total slab zinc consumption. Galvanizing is one of the long-established zinc uses. In the first four postwar years consumption of zinc for galvanizing averaged 350 000 tons yearly. In 1950 the total so used was 434 000 tons.

The second largest class of zinc usage is for die castings. This is the most rapidly growing use for zinc, particularly since the war. Since 1946 it has totaled a little more than 200 000 tons per year, or a little over one fourth of the total consumption.

Zinc die casting began coming into its own 20 years ago when special high-grade (99.99+percent) zinc was developed. Zinc of this high purity makes possible die-casting alloys of controlled quality. Die casting requires a good structural metal that can be melted and used at low temperature, has little shrinkage, is dimensionally stable, freezes to a smooth

Zinc—The Route from Ore to Slab



Zinc never occurs alone in nature. There are six combined forms, but, as with copper, the form of greatest commercial significance is the sulfide (sphalerite, ZnS). The exceptions of commercial importance are the occurrence of the carbonate of zinc (smithsonite, $ZnCO_3$) found widespread in weathered zones near the surface and formerly more important than today, and of the oxide of zinc (zinc silicate, ZnO) in New Jersey.

The following description of zinc recovery is a generalization of the processing of sulfide ores, which provide more than nine tenths of the world's zinc.

An important factor in the zinc-mining situation is that zinc is almost always found associated with lead and intimately mixed with it. Until the development of a method of separating lead and zinc minerals by selective flotation about 1925, the recovery of both metals from a mixed ore was not successfully accomplished. In fact until that time the presence of zinc in lead ore was a handicap and much lead ore was left in the ground because of it. White piles in the Tri-State are chat piles, representing the barren rock in the original ore, from which the zinc sulfide has been abstracted by milling. Because the early milling was inefficient, some of these piles have been remilled two or three times to extract the zinc sulfide.

Another occurrence of zinc is in slags at lead smelters. This is the zinc that accompanied the lead ore shipped to the lead smelter. It occurred as the sulfide intimately mixed with the corresponding sulfide of lead. Up to ten percent zinc was tolerated by the lead smelter, but anything in excess of that was heavily penalized. This zinc was converted into a silicate in the lead smelting and left in a solid solution in the slag. Only in recent years has it been recovered, by fuming the hot slag, and by adding cold slag to hot slag and fuming this brew.

Most of the zinc in old slag piles was in higher grade lead ore that could be mined and shipped directly to the smelter without a mill concentration.

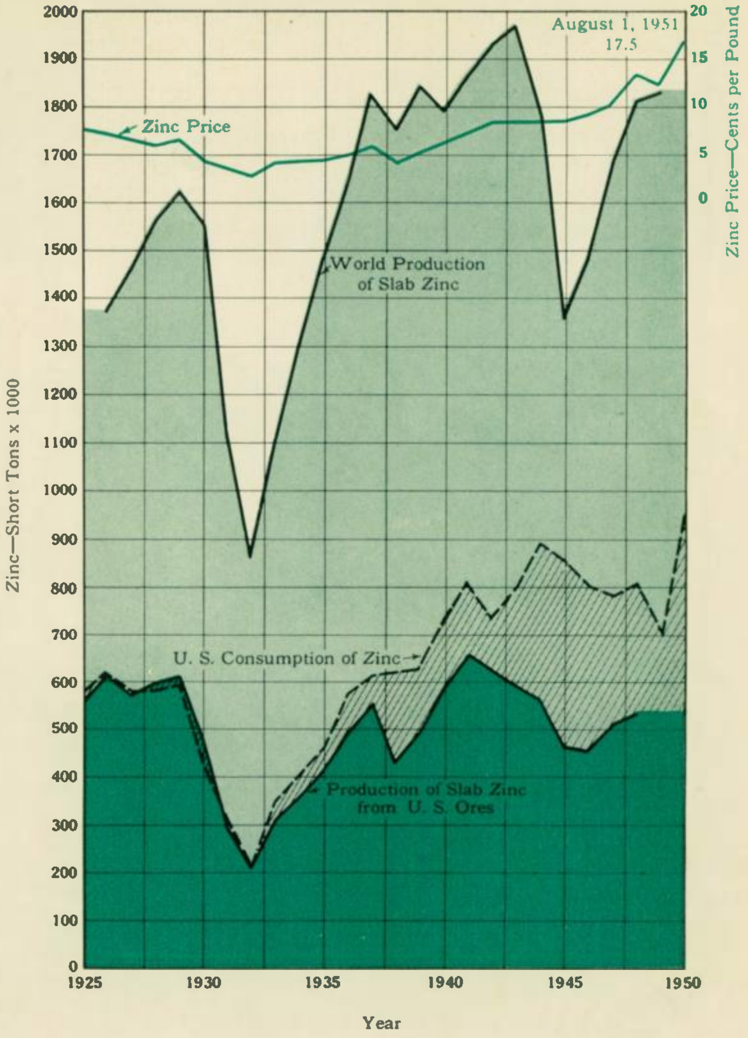
Most zinc ores are mined underground. The ore must first be crushed and pulverized, and the zinc sulfide concentrated, because the grade of zinc is always low—usually less than 10 percent with 2.6 percent a United States' average in 1949. Sulfide ores fortunately lend themselves to concentration by the flotation process (see May issue, p. 78 for flotation description) and even the lead sulfide can be separated from zinc sulfide by remarkably sensitive differential flotation. The result is a zinc sulfide concentrate that varies from 48 to 60 percent contained zinc. The concentrate is roasted to convert the sulfide to zinc oxide, drive off moisture, sulfur dioxide, and any other volatiles.

The resulting calcine, ZnO, now may proceed to slab zinc by either of two routes—one thermal, the other electrolytic.

In the thermal process the oxygen molecule is persuaded, by heat, to give up zinc for carbon. This is done either in the batch-type horizontal retort or the newer, and more efficient, continuous vertical retort. In either case the zinc calcine and coal (or coke) are charged as a loose mixture or combined as briquettes into the retort furnace and heated. Heat is provided either by burning gas or coal outside the retort or by passage of electricity through the mass.

The zinc, now freed from the oxygen, emerges as a gas and passes to a condenser. In one type of condenser the zinc vapor is bubbled through a bath of molten zinc which condenses it; the surplus is drawn off at intervals and cast into slabs for market. Meanwhile residue from the retort is routed through a rotary kiln where a large portion of the zinc that escaped gasification in the retort is separated as a zinc-oxide fume and trapped as a dust.

If the zinc is to be won electrolytically, the calcine from the roaster is stirred with sulfuric acid, and the resulting zinc sulphate, water, and residue is sent to a series of filters and thickeners. It is further purified of copper, cadmium, and other elements by the addition of zinc dust and filtered again to provide a clear neutral solution of zinc sulphate. This solution is dripped as feed into the electrolytic cells. Zinc is deposited on aluminum cathodes and subsequently stripped off, melted, and poured into slabs.



finish without gas inclusions. Zinc die castings—which are at least 94 percent zinc—are used to provide parts as small as zipper elements (sometimes cast directly onto the fabric) or as large as automobile radiator grilles. Castings can be made of complex shapes, such as gasoline-engine carburetors, requiring close and exactly held tolerances and requiring little or no subsequent machining. Literally thousands of parts of everyday articles are made of die-cast zinc: automobile door handles, washing-machine parts, building hardware, tools, toys, novelties, parking meters, typewriters, cameras, frames, etc.

Brass making has taken large quantities of zinc, but this demand has fallen off sharply since the last war. Brass, on the average, is 30 percent zinc, 70 percent copper; red brass is 15 percent zinc, 85 percent copper. Prewar zinc used for brass ran to about 150 000 tons or nearly a fourth of the total consumption. World War II, with its demand for brass cartridge and shell cases and other military articles, skyrocketed the need for brass. However, zinc used for brass has dropped steadily from 120 000 tons in 1946 to 85 000 tons in 1949*, the consumption for brass averaging about 15 percent of the total. The new defense program will, of course, reverse this trend.

The low strength of zinc limits its use unalloyed, except in sheet and rolled forms. This use amounts to less than 10 percent of the total. Such uses include the cases (and negative terminal) of dry cells, fruit-jar caps, weather stripping, photoengraving plates, and salt-resisting plates on vessels.

Zinc compounds, of which the chief is zinc oxide, have literally hundreds of uses. Although the average consumption of zinc oxide made from metal came in the four postwar years to only about 16 000 tons or roughly 2 percent of the total in average years, over 100 000 tons of zinc in concentrates are converted by the American process into zinc oxide. Few are aware of the variety of everyday uses of zinc compounds. Take zinc oxide itself. Its principal uses are in rubber, paint, ceramics, coated fabrics, textiles, floor coverings, pharmaceutical chemicals, printing ink, dental cement, soap, glue, matches, and tailor's chalk. Zinc chlorides are used as preservatives and for flame-proofing of wood poles and railroad ties. Lithopone, a mixture of zinc sulphate and barium sulphate, is used because of its higher hiding power in interior wall paints of many types, including resin-oil emulsion and the newly popular latex paints, industrial enamels, road-marking paint, and in inlaid linoleums. Zinc sulphate, made directly from sphalerite concentrate, is used in glue, rayon sizing, electrogalvanizing solutions, insecticides, fungicides, soaps, salts, fertilizers, pigments, dry colors, and as a preservative in casein products.

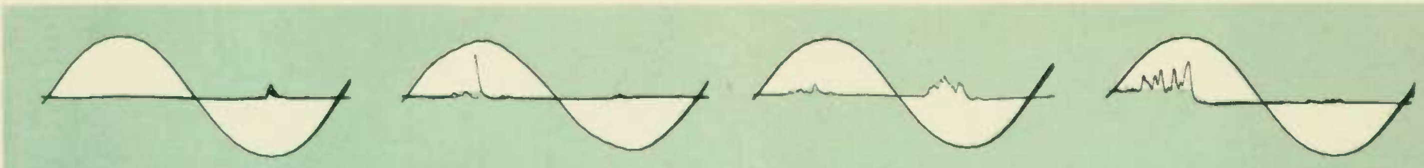
Since the birth of the ready-mixed paint industry, sparked by the prior pioneer production of zinc oxide about a century ago, that zinc pigment has continued through the years to serve as a major constituent of outside house paint. Today, in the average white or tinted exterior paint it constitutes about one third of the total pigment content, a quantity larger than any other white pigment. To those coatings it imparts such important properties as self-cleansing, controlled chalking, resistance to ultraviolet rays, whiteness, hiding power, tint retention, mildew-resistance, toughness, and durability. To enamels, traffic paints, industrial finishes, and interior paints, zinc oxide contributes many of the above properties as well as gloss and gloss retention, washability, and resistance to wear and yellowing.

Zinc oxide of exceptional purity, smoothness, and whiteness adds special benefits to various health and beauty products. Its nontoxic, protective, and mildly astringent qualities are useful in zinc ointments and other pharmaceutical items. In face powders, deodorants, and similar cosmetics, it provides covering, anti-acid and adhesive properties.

Zinc dust has some use directly. In sherardizing, for example, a metal part to be coated is heated with zinc dust in a revolving closed chamber. Zinc vapor, given off below the melting point, condenses on the article forming a uniform, adherent protective coat. Zinc dust imparts highly desirable rust inhibition properties to paints for iron and steel surfaces.

There are but a few adequate substitutes for zinc and mostly they too are currently in short supply. No metal has yet been substituted for zinc in galvanizing; some other bare metal, such as aluminum or magnesium, must be resorted to in peacetime for coating metals if one is not willing to put up with frequent painting. Aluminum and magnesium are competitive to brass in solid articles. Also aluminum die casting has been making great progress. Any long sustained differential of about three cents or more per pound in favor of aluminum over zinc would undoubtedly throw a large share of die casting to aluminum. Magnesium could quite possibly be used, perhaps with advantage, in place of zinc, for photoengraving plates.

Zinc, in our present industrial economy, is well-nigh indispensable. Unfortunately reserves are not inexhaustible.



A- Dry Weathered Conductor at 178 Kv (RI Starting Voltage)

B- New Conductor in Rain at 65 Kv (RI Starting Voltage)

C- Dry Weathered Conductor at 228 Kv

D- Weathered Conductor in Rain at 166 Kv

Radio Influence from Transmission Lines

In the last issue we presented a discussion of "Corona Loss at Extra-High Voltages." Another significant feature of corona is radio influence, which is an important consideration in the design of transmission lines.

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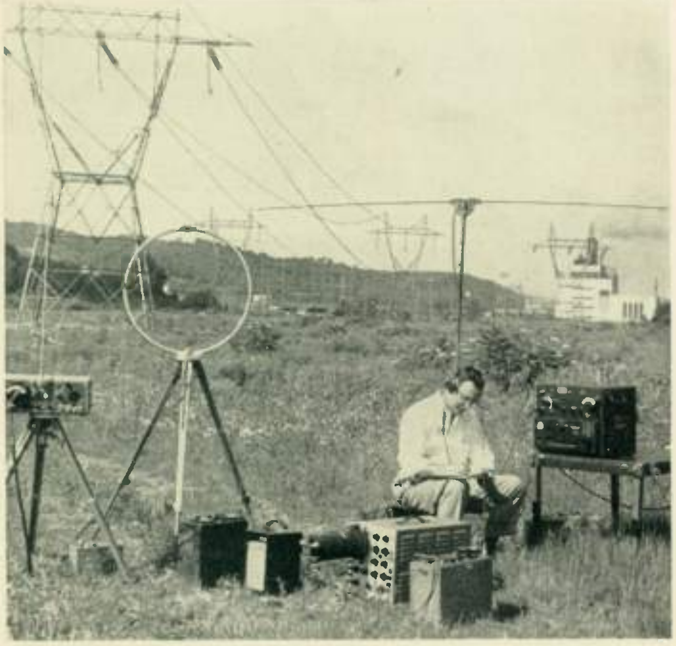

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Fig. 2—The instruments used in RI investigations are shown here near the 500-kv Tidd test line. The instrument mounted on the tripod at the far left is a radio noise meter. Both the rod antenna, mounted on the meter, and the large loop antenna are used with this meter. On the ground are several noise meters, a graphic recorder, and a cathode-ray oscilloscope. The dipole antenna is used with the noise meter on the table. During tests, these instruments would be installed at scattered locations along the line.

Interest in transmission of electricity at extra-high voltages has led to investigations of corona and radio influence (RI) jointly by Westinghouse and the American Gas and Electric Company. Studies of the RI characteristics of various types of transmission-line conductors have been made at the Tidd 500-kv Test Project and the Westinghouse High-Voltage Laboratory. The purpose of these studies was to provide data to be used in the selection of conductors and general designs for high-voltage transmission lines.

At the Tidd test site there are three 3-phase lines, one 800 feet long, one 1.36 miles long, and the third 1.39 miles long. Tests were made on these lines and also on a number of long transmission lines operating at 138 and 230 kv. Samples of all conductors tested in the field were also tested at the Westinghouse High-Voltage Laboratory to obtain a correlation between the tests on operating lines and the lines at Tidd. The data obtained and the measurement techniques developed can be used to predict the RI characteristics of transmission lines.

Characteristics of Radio Influence

Radio influence on transmission-line conductors is the result of corona.* Radio influence starts on the negative half cycle on new, dry conductors, and for usual operating voltages occurs only during the negative half cycles of the voltage wave, as illustrated in Fig. 1. On wet conductors, either new or weathered, it occurs at lower voltages during the positive half cycle, appearing first at the crest of the voltage wave. On dry, weathered conductors corona and RI appear on both half cycles. As the applied voltage is increased, the duration of the RI also increases, but RI always stops soon after the crest of the voltage wave is reached.

Oscillograms show that a corona pulse on the negative half cycle rises very rapidly. This results in shock excitation of any radio receiving system located near the conductor in corona. The disturbance in the receiving system lasts much longer than the corona pulse, and the duration of the output or noise depends upon the number and characteristics of the tuned circuits in the receiving system. Corona pulses on the positive half cycle rise more slowly than they do on the negative half cycle of the voltage wave.

Since the RI of a conductor results from corona, it was expected that the factors affecting corona would also affect

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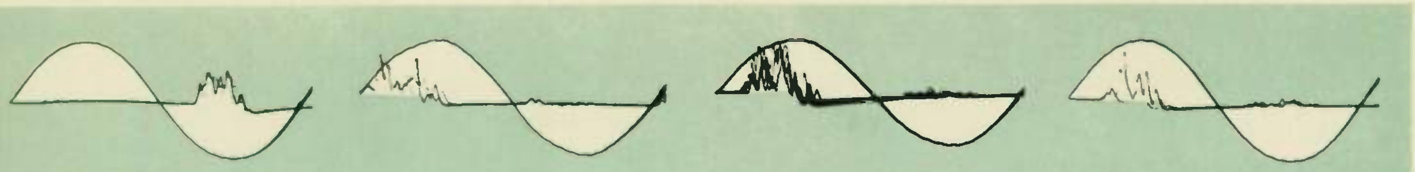
*See "Corona Loss at Extra-High Voltages," by R. L. Tremaine, A. R. Jones, and Otto Naef, *Westinghouse* ENGINEER, September, 1951, p. 144.



E-New Dry Conductor at 228 Kv

F-New Conductor in Rain at 166 Kv

G-Weathered 1.65-Inch H-H Conductor in Rain at 177 Kv

H-Weathered 2-Inch ACSR Conductor in Rain at 177 Kv

I-Fair-Weather RI 40 Feet from Three-Phase Tidd Test Line for 2-Inch ASR at 400 Kv

J-Fair-Weather RI 40 Feet from Windsor-Canton 138-Kv Operating Line—0.5-Inch Stranded Copper

Fig. 1—These oscillograms show the occurrence of RI with respect to the voltage wave. First six are for a 556 500-CM ACSR conductor. These and the next two oscillograms were made during single-phase laboratory tests. The last two are three-phase tests at Tidd and on an operating line, where RI occurred three times every 360 electrical degrees, compared to only once for the single-phase laboratory tests.

RI. Therefore, during many tests corona loss and RI, the two principal effects of corona, were measured simultaneously, but there was no consistent relation between them. Radio influence of significance occurs at voltages where corona loss is negligible; however, corona loss increases more rapidly than RI as the operating voltage is raised.

At the test lines RI field intensity was always higher in the vicinity of a pronounced audible corona burst. To simulate a line conductor with a single local corona source, a small sphere was attached to the line conductor. In the vicinity of this local corona source the measured value of RI was considerably higher than that caused by a number of sources distributed along the conductor. This result indicates that the measured value in the vicinity of the local source is the resultant of two components: one, the RI due to a large number of sources adding at random, and the other, that due to the local source. It is believed that the local source produces a vertical current flow to ground through ionized space, thereby causing a strong field in addition to and superimposed on the field of the current flowing in the conductor.

Instruments Used in Tests

In studies of this type, the instruments used should give results comparable to those obtained by other investigators and also to results that may be obtained in the future with improved instruments. Recent improvements in RI meters made it necessary to repeat many tests to obtain a correlation between the data obtained with the different instruments. The instruments used in these investigations are shown together (for photographic purposes) in Fig. 2. Most of these instruments were constructed according to the specifications listed in the references [1, 2]. The latest specification [2] requires that the instrument be capable of measuring three characteristics of radio noise: average, quasi-peak* (weighted detector circuit), and peak values. With meters designed to the new specifications, much more information than that provided by the old instruments[1] can be obtained, but the noise characteristics still are not completely defined. Tests were made with an oscillograph connected to the output circuit of the noise meters in order to determine the 60-cycle polarity of the pulses and their variation in magnitude and repetition rate.

Radio-influence meters with graphic recorders were used at the test lines and near a two-circuit 138-kv line that had the highest RI of any of the 138-kv operating lines tested. Hourly records of weather conditions in the vicinity of this installation were available.

Graphic recording was used extensively, but it was more convenient to use visual readings in many tests, such as those covering a wide range of frequencies, calibration tests, and where it was necessary to move the meter to many locations. When average, quasi-peak, and peak RI readings were obtained, the three readings were always taken within a few seconds of each other to avoid the effect of changing conditions. During and prior to many of the tests, a graphic meter was used to monitor the RI and to determine its constancy.

Radio-influence measurements are at times affected by high ambient interference such as atmospherics and ignition noise, where the source can be many times farther from the instrument than the transmission line. Also when testing in the broadcast band, broadcast stations may cause considerable interference unless the meter is very carefully tuned and monitored. Usually these sources of interference can be detected by listening to the noise with headphones or by noting the characteristics of the noise on chart records.

At the test site graphic instruments were in continuous service to record rainfall, humidity, temperature, and barometric pressure. A photographic weather recorder, operating at 20-minute intervals, indicated rain, snow, condensation on insulators or conductors, and visibility.

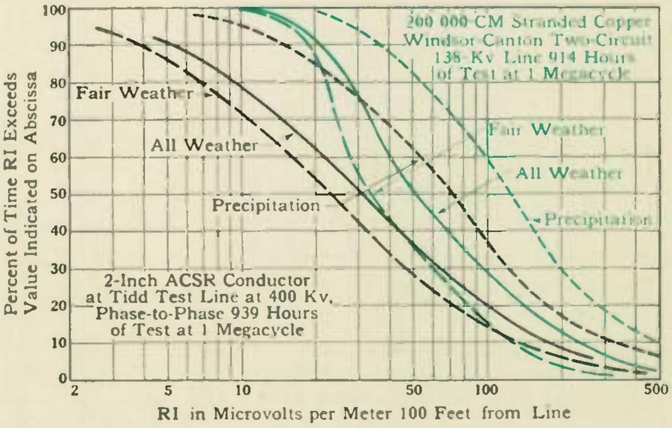


Fig. 3—As shown here, RI varies considerably even with similar atmospheric conditions. Data for these curves were obtained from test lines at Tidd and from a two-circuit 138-kv operating line.

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*The quasi-peak value is a fraction of the peak value of the IF amplifier output and the measurement obtained depends on the charge and discharge time of the weighted detector circuit. This measurement indicates the annoyance value, especially for pulses of low repetition rate, to many types of communication.

Conditions Affecting Radio Influence

Radio influence is affected by many variables. Tests made on the same day, with temperature, barometric pressure, and humidity constant, show variations as much as two to one. Therefore, it was necessary to make many similar tests in order to obtain representative results. Of the many factors that affect RI from a conductor, rain is the most important. Snow and fog, and atmospheric contamination such as airborne dirt, smoke, and dust, also cause an increase in RI but to a lesser degree than rain.

It was found that a conductor left unenergized for some time has higher RI when again energized, but this higher value decreases in a few minutes, possibly because the dirt particles on the conductor are burned off by corona. Because of this peculiar behavior, test conductors were energized at high voltage for several minutes preceding RI tests in order to obtain more stable conditions.

Effect of Weather

All test results obtained during weather other than rain, fog, sleet, and snow were considered fair-weather tests. Fair-weather tests did not exclude the presence of dirt particles in the air or on the conductors. There was considerable variation in the fair-weather RI from test to test. This variation is shown in Fig. 3. It is believed to be caused by the shifting of strong local sources of RI with respect to the antenna location rather than by variation in the atmospheric conditions encountered at the test site. Analysis of many tests does not indicate any correlation between these weather conditions and the measured RI, unless the conditions result in condensation of water on the conductor surface.

Radio influence during rain is several times greater than fair-weather RI for conductor sizes used on transmission lines. Visual tests show increases during rain from 4 to 25 times the fair-weather values for quasi-peak and peak RI, and from 3 to 6 times the average RI. Analysis of the graphic data shown in Fig. 3, and visual data, indicates that the average increase of quasi-peak RI in rain is 4 times the fair-weather average. This is true for both the test lines and the 138-kv operating lines. There is no change in RI until some time after a rain, and then the RI decreases gradually at a rate depending on the voltage. Radio influence increases during fog, if conditions are such that moisture condenses on the conductors.

The effect of snow on RI values, it is believed, depends on its wetness. During an intermittent light snowstorm in cold weather no appreciable increase in RI was noticed. However, wet snow did increase RI, but not so much as rain. In one test, melting snow caused RI to increase 3.5 times.

If the RI of a conductor during heavy rain is determined, this value can be considered the maximum that will exist. This does not include the condition that might exist with hoarfrost or ice on the conductor. No data were obtained under these conditions.

Conductor Aging

The atmosphere at the test site is typical of industrial areas. It is affected by smoke from coal-burning locomotives on two adjacent railroads, from coal-burning river boats that pass a few hundred feet from the test line, and from an adjacent power plant. As a result, the surface of the line conductors at the test site changed considerably with time. After a few months the conductors were coated with a rough deposit. This deposit did not contain any conductor material, but consisted of dirt collected from the contaminated atmos-

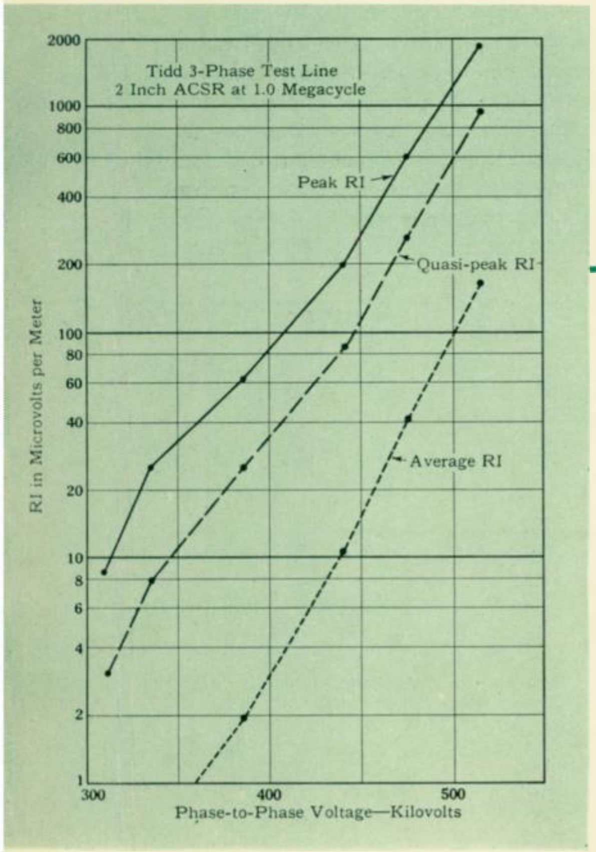


Fig. 4—As shown in this voltage run made at Tidd, peak, quasi-peak, and average RI values rise at about the same rate when voltage increases.

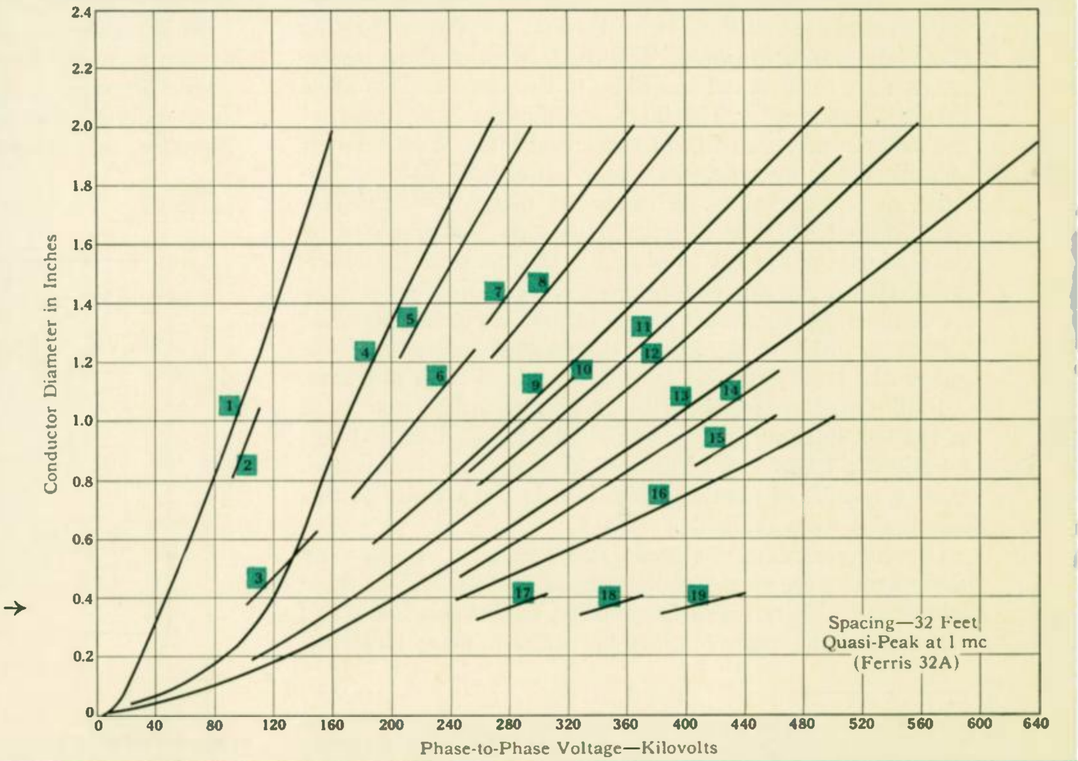


Fig. 5—Relations between conductor diameter and phase-to-phase voltage for given RI levels are shown here. Significant data pertaining to the curves is given in the table on the opposite page next to these curves. →

phere. There was no significant change observed in the RI of the conductors at the test site. During rain, conductor-surface conditions did not have any effect on RI, and stranded and smooth conductors of the same diameter, whether new or aged, had about the same RI.

Effect of Line Voltage

To determine the effect of line voltage on RI, the test lines were energized, in approximately 20-kv steps, from 265 kv to 530 kv, phase to phase. Meters were usually located directly under a conductor or 40 feet from the outside conductor. These tests were made at several points along the line, in order to obtain a representative value that included the effect of slight irregularities of the conductor surface. In most voltage runs, tests were made at two frequencies, one in the power-line carrier band, one in the AM broadcast band.

The conductor voltage at which RI starts is the same as the voltage at which visible corona is first detected. This starting voltage has been determined in the laboratory for new, dry conductors by means of headphones connected to the output of a radio noise meter. However, the RI starting voltage for dry weathered conductors and for all conductors in rain is not so clearly defined by listening as it is for dry smooth conductors.

The RI starting voltage can be calculated using the following relation:

$$V_o = 21.1\left(1+\frac{0.3}{\sqrt{d\,r}}\right) m\, d\, r \log_e \frac{S}{r} \tag{1}$$

where

V_o = voltage, conductor to ground, at which RI starts, in kilovolts
21.1 = critical gradient for air in rms kilovolts per centimeter
d = air density factor
r = radius of conductor in centimeters
S = spacing in centimeters (in this case $S = 2\,h$ where h is height of conductor above ground plane used for laboratory tests)
m = surface factor

Using a surface factor, m, of 0.846 for new stranded conductors, the calculated RI starting voltage agrees closely with laboratory test data. For the smooth conductors used in laboratory tests a surface factor of 1.0 should be used in calculating the RI starting voltages. For wet conductors a surface factor of 0.24 gives calculated values that agree with test data obtained in the laboratory.

RI from a conductor increases rapidly when the applied voltage is raised. This is shown in Fig. 4 where RI is plotted against voltage for a typical voltage test made at the test site. As the voltage is raised (Fig. 4), the average, quasi-peak, and peak RI increase at approximately the same rate.

In the laboratory the increase in conductor RI with voltage was measured simultaneously with the increase in sound from a radio loudspeaker. The increase in sound, measured in decibels, was directly proportional to the increase in RI.

Effect of Conductor Diameter

In eq 1 the relation of conductor diameter to RI starting voltage is given. The relation between conductor diameter and phase-to-phase line voltage for a given value of RI is shown in Fig. 5. The data in Fig. 5 includes new and weathered conductors, both stranded and smooth, and tests made in the laboratory, on operating lines, and at the test site during fair weather and rain. The curves represent the analysis of the data obtained and can be used to predict the RI characteristics of line conductors in the range of diameters and types shown.

Effect of Bundle Conductors

Bundle conductors were tested in the laboratory and at the test site. The results of these tests are also shown in Fig. 5. At the test site a bundle of two 0.92-inch stranded conductors with a 20-inch separation was tested. This bundle, when dry, was equivalent to a single 1.53-inch stranded conductor. In laboratory rain tests the same bundle was equivalent to a single 2.0-inch stranded conductor.

Curve No.	RI[*]	Weather	Type of Line[†]	Distance from Line[‡]	Type of Conductor
1	Threshold	Rain	Laboratory		Smooth or stranded copper
2	Threshold	Rain	Laboratory		2 x 0.92/18 inch bundle
3	15 μv/m	Fair	138-kv line	100′	Stranded copper
4	2000 μv/m	Rain	Laboratory		Smooth or stranded copper
5	15 μv/m	Rain	Tidd	100′	ACSR and copper H-H
6	15 μv/m	Fair	138- and 230-kv lines	100′	ACSR
7	15 μv/m	Fair	Tidd	100′	ACSR
8	15 μv/m	Fair	Tidd	100′	Copper H-H
9	150 μv/m	Fair	Tidd	100′	ACSR
10	2000 μv/m	Rain	Laboratory		2 x 0.92/18-inch bundle
11	15 μv/m	Fair	Tidd	100′	2 x 0.92/20 inch bundle
12	Threshold	Dry conductor	Laboratory		Stranded copper
13	Threshold	Dry conductor	Laboratory		Smooth copper
14	2000 μv/m	Dry conductor	Laboratory		New stranded copper
15	Threshold	Dry conductor	138- and 230 kv lines	40′	2 x 0.92/18 inch bundle
16	2000 μv/m	Dry conductor	Laboratory		Weathered stranded copper
17	Threshold	Dry conductor	Laboratory		2 x 0.375/4-inch bundle
18	Threshold	Dry conductor	Laboratory		3 x 0.375/4 inch bundle
19	Threshold	Dry conductor	Laboratory		4 x 0.375/4-inch bundle

[*] All values of RI are quasi-peak values measured at one megacycle with a Ferris 32a radio noise meter. μv/m = microvolts per meter.

[†] Conductor spacing = 32 feet.

[‡] In the laboratory, meters were connected to the test conductors through coupling capacitors.

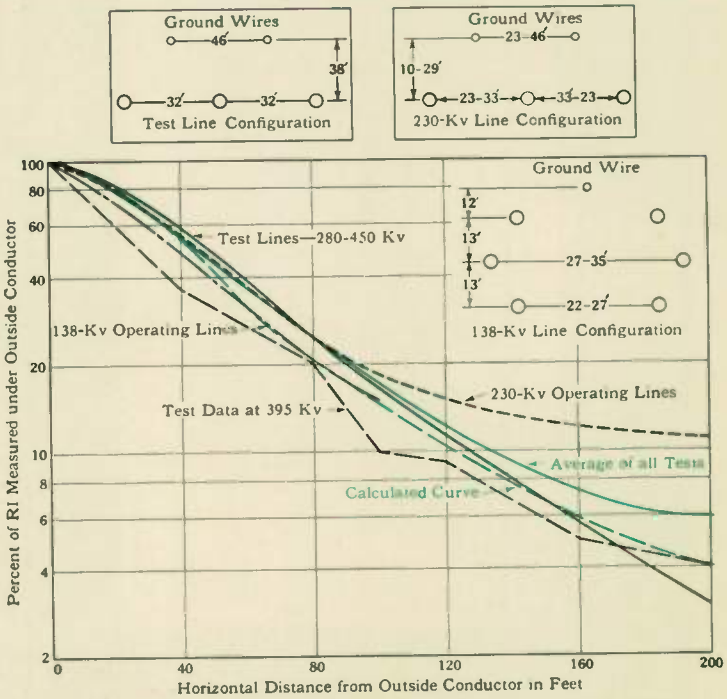


Fig. 6—Attenuation curves for several lines tested. Readings were quasi-peak RI in the frequency range, 0.2 to 1.5 megacycles.

Effect of Lateral Distance from Line

Lateral profiles were made on both the test lines and the operating lines to determine the attenuation of RI as distance from the source increases. All tests on operating lines were made at the normal operating voltage of the line. The voltage on the test lines was held constant for each test, but profiles were made at voltages up to 450 kv.

Radio influence decreased rapidly as the noise meter antenna was moved away from the line. This is shown in Fig. 6, where average RI values on operating lines and on the test lines are plotted against distance. The dashed curve in Fig. 6 indicates the attenuation of RI calculated from the relation:

$$P = \frac{100}{1 + \left(\frac{D}{H}\right)^2} \qquad (2)$$

where

D = lateral distance from the line

P = percentage, at the distance D, of the RI at a point directly under an outside phase conductor

H = height of conductor above ground

The values obtained for the operating lines at 160 and 200 feet include ambient RI and are probably slightly higher than the actual value of RI from the line.

Effect of Line Length

Tests were also made longitudinally on the operating lines and the test lines. On operating lines these tests indicated the effect of conductor surface irregularities, conductor height, and the shielding effect of the line towers. At the test site, with the lines unterminated, the effects of standing waves were observed. To determine the effect of line length, tests were made adjacent to a 1900-foot section of the 7160-foot test line, and then they were repeated with the entire test line connected.

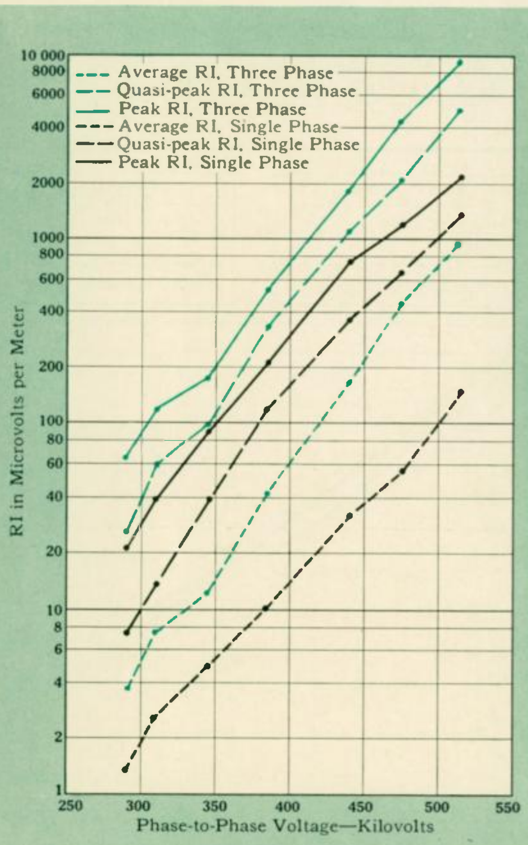


Fig. 7—Correlation between single-phase and three-phase RI. Three-phase curves are shown in color.

In the laboratory, where tests were made using from 1 to 15 identical corona generators, RI varied as the square root of the number of generators. From this, one would think that RI on a transmission line varies in proportion to the length of line; however, at the test lines this was not true. There, RI increased only slightly when the length of the line was increased from 1900 to 7160 feet.

Single-Phase and Three-Phase RI

Bundle conductors as well as several types of single conductors were tested single phase only. So that these single-phase test readings could be converted to equivalent three-phase readings, comparison tests were made on one of the long test lines between single-phase and three-phase RI. Results of these tests are shown in Fig. 7. These data were obtained on the same day during comparable weather conditions. At a typical voltage for the test conductor, the ratio of three-phase to single-phase RI is 3.5 for average, 2.4 for quasi-peak, and 2.3 for peak values.

Correlation of Field and Laboratory Data

To correlate the data obtained on operating lines and in the laboratory, samples of conductors tested in the field or at the test lines were also tested in the laboratory. The conductors on the operating lines had been in service at least five years. Test samples of the 138-kv lines were taken from operating lines so that the laboratory specimens were, in all respects, identical to the line conductors. New conductors, identical to the operating-line conductors except for age, were also tested in the laboratory.

The RI starting voltage for a dry conductor in the laboratory was higher than the line voltage that produced considerable RI on the operating line. From the laboratory data on dry, weathered, stranded conductors alone, a line conductor might be selected that would be one-third the diameter required for satisfactory RI characteristics. It may be that the 20-foot laboratory samples of weathered stranded conductors did not have all the surface irregularities that can exist on a long transmission line.

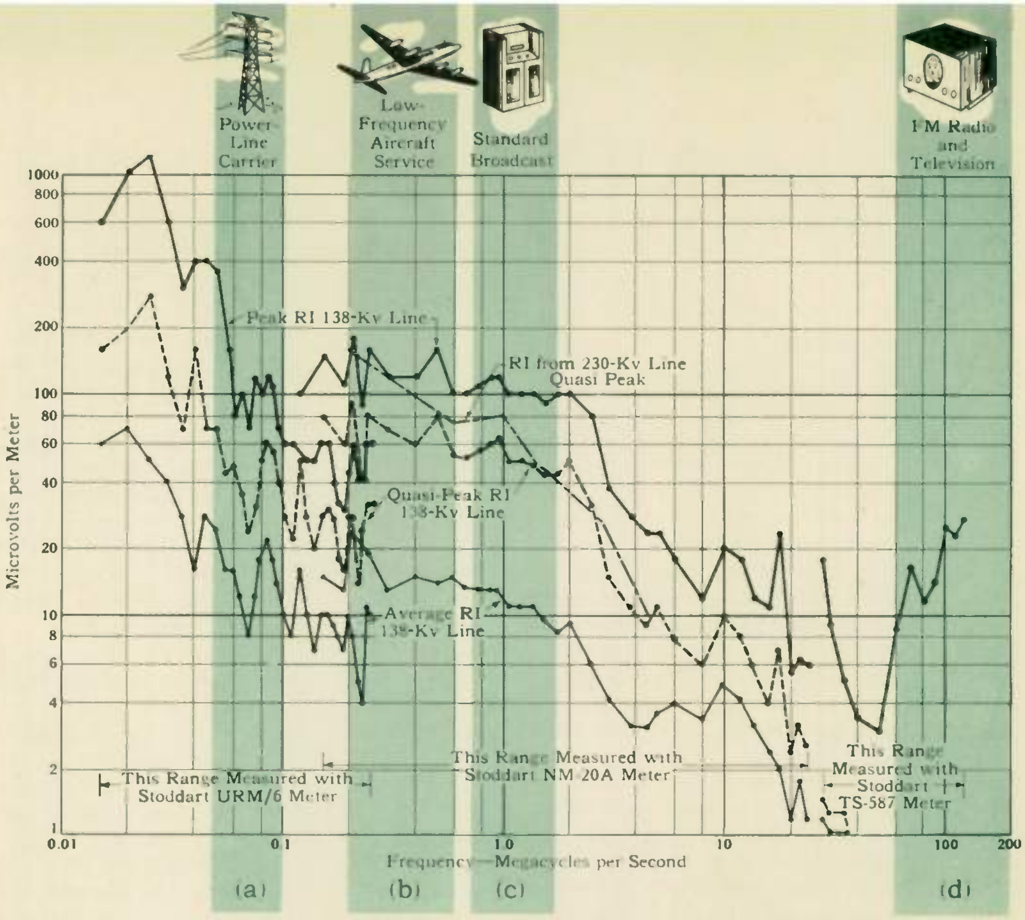
Tests on smooth, dry conductors in the laboratory give results that agree well with eq 1, while rain tests in the laboratory on stranded weathered conductors give results that agree with rain tests on the test lines.

Effect of RI on Radio Reception

To determine the effect of various RI levels on radio reception, listening tests were made both in the field and in the laboratory. The receiver was tuned to different stations throughout the broadcast band, and reception quality was judged by several listeners. The broadcast signal and the RI levels were measured with a radio noise meter. From these tests, the signal-to-noise ratios for different qualities of reception were obtained.

The variation of RI with frequencies from 0.015 to 380 megacycles was determined on operating lines as well as on the test lines. These tests were made with the line voltage constant and the meter placed 40 feet from midspan of an outside conductor. Data from a typical frequency run made near an operating line are shown in Fig. 8. This and similar data obtained adjacent to test lines indicate that RI decreases rapidly as the frequency increases.

Fig. 8—Variation of RI with frequency on several lines tested is shown at the right.



Since radio influence from corona is highest at the lower frequencies, power-line carrier, low-frequency aircraft services near transmission lines, and AM broadcast frequencies require the most consideration in line design.

It is believed that if line design is satisfactory in the AM broadcast band, no interference to television reception will result. Because of the very rapid increase in the use of television receivers, many tests were made at Tidd to determine the effect of an extra-high-voltage line on television reception. With an antenna 50 feet high located 100 feet from the line, no change in picture or sound quality was noted for the conductor tested, at line voltages considerably above a practical operating voltage chosen on the basis of other considerations. Tests were also made with an FM radio receiver. As with television reception, no effect on sound quality was noted due to the presence of extra-high-voltage lines. The effect on other types of communication can be estimated from the test data obtained in these studies.

Radio Influence on Existing Transmission Systems

Results of tests made on several 138- and 230-kv lines are consistent with the data shown in Fig. 5 for test lines. An analysis of a graphic test of long duration on the operating line having the highest RI is shown in Fig. 3. This record is similar to the data obtained at the test lines, also shown in Fig. 3. Tests made near single-circuit and double-circuit lines gave results that were practically identical, and there was no significant difference between vertical and horizontal configuration of the line conductors. The operation of the transmission system of the American Gas and Electric Company, including voltage from 69 kv to 138 kv, has caused very few complaints of poor radio or television reception during all weather conditions. The complaints of interference that were definitely traced to the transmission system were due to defective insulators or line hardware, and replacement cleared up the trouble. With the great increase in the number of television sets in use, complaints from television owners are increasing. These complaints are all investigated and almost without exception the interference is from sources other than transmission-line RI.

Many years of experience with transmission lines operated at voltages from 69 to 230 kv indicate that existing RI levels usually can be considered as conservatively low for the design of transmission lines. If line conductors for an extra-high-voltage line are selected, using curve 7 as a guide, the expected RI should not exceed a value that long experience has shown to be highly conservative.

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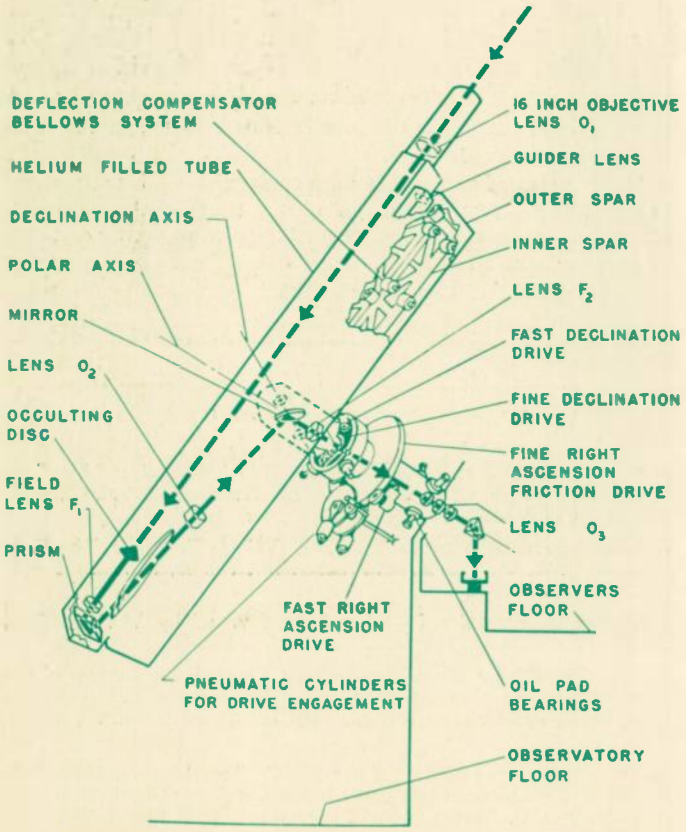
What's NEW! . . . . in Engineering

It's Astronomical!

In primitive native tribes anyone who can conjure up an occasional thunderstorm when crops need water becomes a high priest—or at least a medicine man. You would probably be a pretty important god if you could turn the sun on and off or make an artificial sun when evil spirits interfere with turning on the real one. Yet, so far as we know, there is not one Westinghouse distributor in the medicine-man section of Central Africa. And there, it would seem, someone is missing a good bet, because making artificial suns is a commonplace occurrence at Westinghouse. These artificial suns include sun lamps, high-intensity krypton lamps, and color-corrected mercury-vapor lamps.

Now we are in the business of making equipment for turning the sun on and off. Nearing completion at the Sunnyvale, California M & R Plant are two mechanical mounts for large equatorial-table coronagraphs. Coronagraphs are special telescopes that make it possible to produce artificial eclipses of the sun. These two new ones will be used at two high-altitude observatories in the Rockies. One will be installed at Climax, Colorado, at the High-Altitude Observatory of Harvard University and the University of Colorado. The other will be installed at the Sacramento Peak Station of Harvard College Observatory at High Rolls, New Mexico.

The two coronagraphs were designed by astronomers at these observatories who hope to obtain information that will be of value in making long-range, world-wide weather forecasts, and in predicting favorable and unfavorable years or seasons for growing crops and raising livestock. They also hope to learn more about atomic reactions and the strange effect the sun has on communication services and radar.



The details of a coronagraph are shown in this sketch. The tube of the coronagraph, mounted on top of the outer spar, is filled with helium to help dissipate the heat created by the sun's rays. Light from the sun follows the path indicated by the broken line.

We already know the sun is a huge sphere of intensely hot gases—principally hydrogen. It has been estimated that these gases reach the unbelievable temperature of 30 million degrees F at the sun's core. This tremendous energy is produced by atomic reactions. Dr. Donald H. Menzel, Harvard astrophysicist, has calculated that in one second the energy produced within the surface of the sun exceeds the total work obtainable from over ten billion atomic bombs.

Although the sun is gaseous throughout, the edge or "limb" between the intensely bright center portion—the photosphere—and the much thinner atmosphere is extremely definite and clear cut. Around the photosphere, which is opaque, is a layer of thinner gases called the atmosphere. This is the most fertile field for solar research, partly because the atmosphere, unlike the photosphere, is for the most part transparent and we can see things happen there. By using special observing equipment it is possible to study different parts of the atmosphere independently.

At the base of the atmosphere, next to the photosphere, is a layer of very thin gases, called the chromosphere. This consists of hydrogen, helium, and vaporized calcium. It varies in temperature from about 11 000 degrees F at the limb to perhaps 50 000 degrees 9000 miles or so above the surface of the sun.

Directly above the chromosphere are the remarkable solar prominences. Instead of a quiescent uniform sphere of gas, these are very irregular, fast-moving clouds of luminescent gas. They are the flame-like protrusions in the photos on the opposite page. They move as fast as a million and a half miles per hour (500 miles per second) and sometimes erupt to heights of a million miles above the surface of the sun. The movement, one of the great mysteries of the sun, is believed to be caused by the complex pattern of magnetic fields in the atmosphere of the sun.

But the most striking feature of the sun is the great white halo extending far out from the surface. This is the corona, which presents perhaps the most intriguing and numerous of the unsolved problems of the sun's atmosphere. Temperatures there apparently rise to at least two or three million degrees—many times greater than the 11 000 degrees at the edge of the photosphere. Lines of the spectrum originate in the corona of the sun that have never been found here on earth.

The sun's corona cannot be studied unless the intensely bright photosphere—500 000 times brighter than the corona—is blocked off. This happens naturally only during eclipses of the sun. But, since 1930, when Dr. Bernard Lyot of France invented the first coronagraph, astronomers have been able to simulate eclipses of the sun. The coronagraph was first used in the Western Hemisphere in 1940 at Climax, Colorado, by the High Altitude Observatory. The coronagraph blocks out the bright face of the sun, and the atmosphere and corona can then be observed through the optical system of this instrument. This makes possible virtually continuous daytime study of the sun's corona.

The new coronagraphs differ from conventional telescopes. Instead of being enclosed in a metal tube, the optical system is mounted on the outside of a rectangular steel spar, as shown in the sketch to the left. Occulting disks mounted on this spar block out the sun's blinding photosphere.

The equatorial mounting for each of the two new coronagraphs consists of an inner spar, an outer spar, a polar-axis shaft, and a heavy base. The spars will be 26 feet long, and the outer spars will have a rectangular cross-sectional area 40 inches wide and 32 inches deep. Made of fabricated steel, the spar furnishes a rigid support for the optical equipment. As many as 11 complete optical systems and other devices may be mounted on the top and two side surfaces of this spar. To keep the spar in the extremely accurate optical alignment necessary, the inner spar supports the outer one through multiple hydraulic bellows and counterweights that compensate for gravity deflection. This inner truss spar keeps the outer beam straight within one thousandth of an inch regardless of the spar's position.

The spar is supported at its center by a heavy cast-iron base. A polar-axis shaft, supported by the base, points to the North Star at an angle equivalent to the latitude. The spar automatically moves around this axis from east to west, a movement known as right ascension, to counteract the west-to-east rotation of the earth. By means of bearing hubs on the stub of the polar axis, the spar moves from north to south through an arc of 25 degrees above and below the plane of the earth's equator. This is the declination axis and compensates for the seasonal variation of the sun's path relative to the earth, as well as errors imposed by changes in the index of refraction during each day.

The driving mechanism for coronagraphs also differs from those in typical astronomical telescopes. Instead of the usual timekeeping clocks and synchronous mechanisms, servomechanisms are used to drive the rotating elements. These servos are actuated by photoelectric cells that detect a deviation of as little as one millionth of a radian from accurate alignment on the sun. When the coronagraph gets out of alignment, its position is automatically corrected. If right ascension is leading or lagging the sun, the photoelectric cells act to change the speed of the motor that drives the equipment in right ascension. When declination is in error, the declination-correction motor is automatically started in the proper direction and continues until the necessary correction is made. When the instruments are once again aligned on the sun correctly, the right ascension motor has returned to normal speed and the declination motor stops. When the sun is obscured by clouds so that the photoelectric guider cannot operate, approximate alignment is maintained without correction until the sun is again exposed, at which time correction takes place immediately.

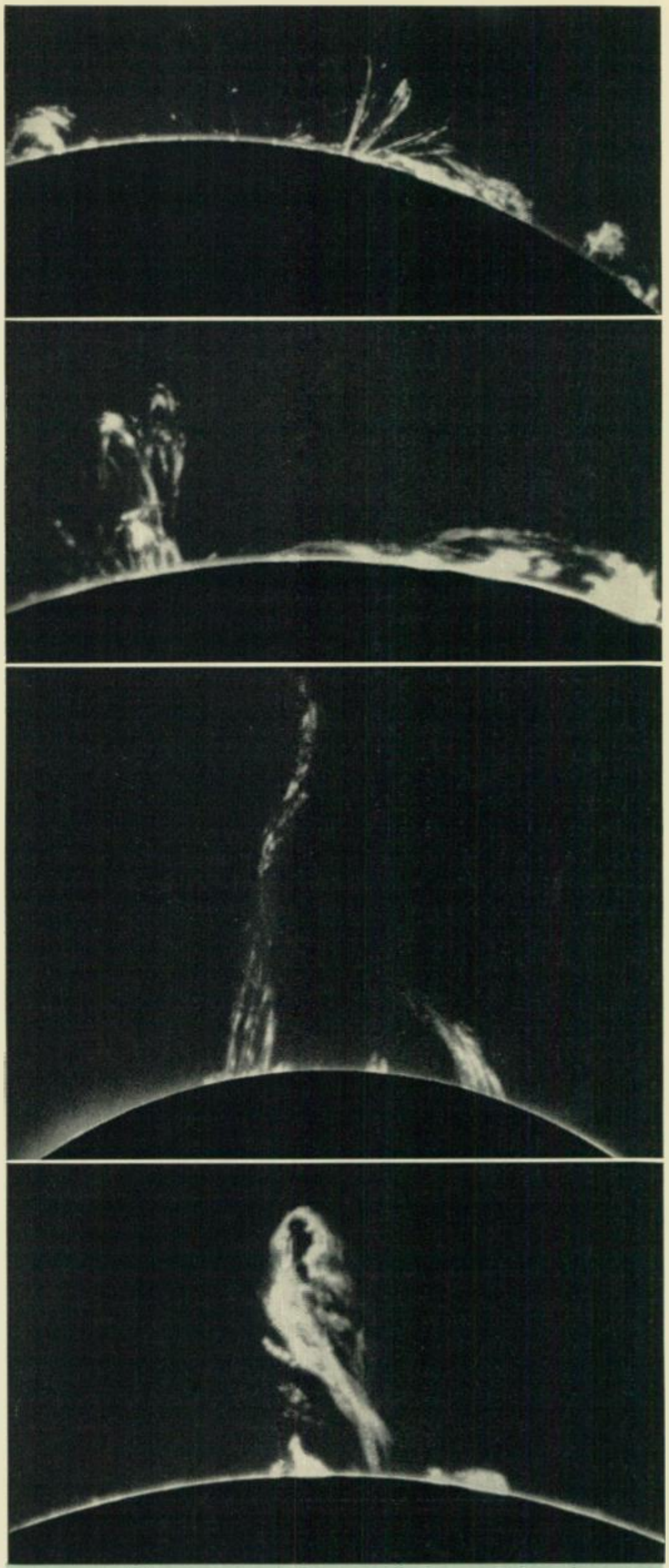
The main requirement of these drives is that they be extremely smooth and free from sudden changes of rate. The polar axis is mounted on two sets of oil-pad bearings with another single-pad thrust bearing at the upper end. Smooth positioning in right ascension is accomplished through friction wheels instead of the usual precision gears. Large changes of positioning in declination are through a worm and segment gear, while changes by correction are accomplished through combinations of extremely accurate gears that operate a smooth cam and roller.

The 14 tons of equipment that make up one of these coronagraphs will be so delicately balanced that a tiny electric motor—only one four-thousandth horsepower—will drive the mechanism as it follows the sun. To achieve such precise balance, some parts must be kept within tolerances of one thousandth of an inch or less. Accuracy like this requires some of the most precise of high-precision machine tools.

Although the coronagraphs are new, working to close tolerances and building astronomical instruments is an old story to the men at Sunnyvale. Many of them, including George F. Gayer, Assistant Plant Manager, helped build the mount and tube for the giant 200-inch reflecting telescope atop Palomar Mountain in Southern California. Work on that huge project was done at the Westinghouse plant in South Philadelphia, Pennsylvania, in the early 30's.

Experience obtained since 1938 with the first coronagraph in the Western Hemisphere guided the scientists and engineers of the two observatory groups in designing and building the new instruments. Internationally known astronomers and astrophysicists are directing the research program—such men as astrophysicists Dr. Donald H. Menzel and Dr. Walter O. Roberts, optical physicist Dr. John W. Evans, optical designer Dr. James G. Baker, and others.

Studies at the High Altitude Observatory will be under Dr. Roberts' direction. The coronagraph there has been financed by the Office of Naval Research and Research Corporation. Dr. Menzel will head the Harvard University activities at Sacramento Peak, where the Air Forces Cambridge Research Laboratories



The spectacular solar prominences that rise out of the sun are shown in the photographs above. The fireworks-like display in the top photo and the cloud on the left of the second photograph are prominences controlled by the magnetic fields above sunspots. The long, low cloud in the second picture is more stable and moved slower than the others. The stream of incandescent hydrogen in the third picture erupted to nearly a third of a million miles above the sun's surface. Portions of it moved faster than 100 miles per second. An outstandingly active prominence is shown in the bottom picture.

are building a large solar and upper-air research station. The Harvard scientists will work closely with Air Force scientists under the guidance of Dr. Marcus O'Day, and with scientists from Cornell and other universities.

More Pep for Rectifier Arc Welders

An automatic booster circuit, appropriately termed an Arc Drive control, further improves the outstanding performance of the rectifier type d-c arc welder. During welding operations, globules of metal passing from the electrode to the work bridge the arc gap and cause instantaneous short circuits. In some applications, such as deep-groove welding, and vertical and overhead pipe welding, where an extremely short arc is maintained, these globules may freeze between the electrode and the work, thereby shorting out the arc.

What is needed to prevent this undesirable arc short-out condition is a sudden rise in current that literally blows the globules off the end of the electrode, thus breaking the short circuit and reestablishing the arc. The arc current must return to normal quickly to avoid overheating of the electrode and work, and to prevent magnetic blow disturbance. This control of the overcurrent bursts must obviously be instantaneous and automatic because the phenomenon is a random one, rapidly recurring and of short duration. On a representative test this short-circuiting condition was found to occur an average of 13 times per second and—with the Arc Drive on the job—to last only about 1/400 second each. No relay control can take care of such a situation.

The Arc Drive scheme accomplishes this as indicated in Fig. 1. It is essentially a small scale version of the main welding circuit itself and in parallel with it. A small tertiary winding is superimposed on the welding transformer which, in conjunction with a rectifier, supplies direct current "on-call" to the arc. The on-call is the neat part of the trick and comes about this way. The open-circuit voltage of the Arc Drive circuit is small—only 16 volts. Thus, under normal welding conditions, when the arc voltage is 20 volts or more, the Arc Drive circuit is overpowered and supplies no current to the weld. But when the arc voltage falls below that of the Arc Drive—for instance, when a globule of metal transfers from the electrode to the work—the Arc Drive delivers a surge of additional current into the arc, giving the extra pulse of power needed to clear the arc of the short-circuiting globules. This is shown in the curve in Fig. 2, where the effect of Arc Drive on a type RA d-c welder is reproduced in color. The normal volt-ampere characteristic is shown in black. The current surge produced by the Arc Drive when the load voltage is below 16 volts also produces a "hot start" when the welding arc is struck.

The amount of current surge which the Arc Drive delivers can be adjusted to give optimum welding conditions. By means of a control rheostat, the operator can adjust the current surge to suit his particular problem.

Singing Transformer Bases

The bases of some transformers can be very *bass*. Seems that the noise that a transformer inevitably makes sometimes includes a 120-cycle hum caused by resonance of the air space between the bottom of the transformer tank and the concrete foundation on which it rests. However, unlike some transformer noise, this one was easily eliminated once the cause of it was found.

Westinghouse, like all manufacturers and users of power transformers, has been reluctantly living with the problem of transformer noise, because eliminating the noise completely just isn't practical. Nevertheless, efforts to reduce the noise from present designs are constant and intensive. It was during noise tests conducted regularly at Sharon that the "singing" transformer bases were discovered. In checking the noise level of a 500-kva power transformer, engineers in the sound room noticed a higher noise level near the base of the transformer. This was particularly pronounced right near the holes in the channel base. Holes are placed in the channel-iron bases of transformers to provide access to the bottom of the transformer tank for painting with a spray gun and for ventilation.

Since the noise was loudest near the holes, they tried plugging the holes. That caused a five-db drop in the noise level. But eliminating the holes wasn't a good solution to the problem, because the holes are needed. So T. R. Specht, Development Engineer at Sharon, figured out what was causing the noise, in the hope of finding a better solution.

This is what was happening—the air space under the transformer, in combination with the holes, formed a resonant cavity. As Specht puts it, "The combination of holes and the elasticity of the air formed a resonant combination that was driven by the 120-cycle vibration of the bottom of the transformer tank. It was acting very much like a glass bottle which will resonate and make a noise when you blow across the opening in the top."

All that was needed to eliminate the noise was to detune this resonant cavity. Specht calculated that a volume of 3550 cubic inches of air in a transformer base will resonate at 120 cycles, the basic transformer noise frequency, if the base channels contain eight holes, one and one-half inches in diameter. Transformers of about 500-kva capacity have dimensions of this order. The result—"singing" transformer bases. Transformers much larger or

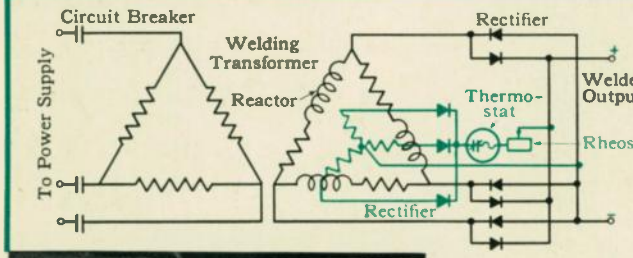


Fig. 1—This is a schematic diagram of the automatic Arc Drive control.

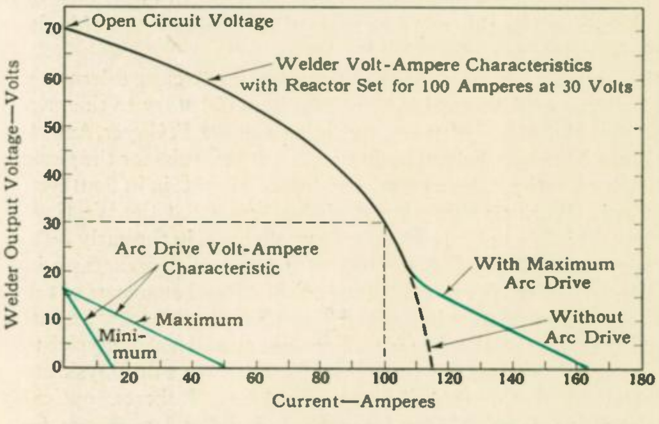


Fig. 2—Volt-ampere characteristic of a type RA d-c welder with the new Arc Drive control, an automatic booster circuit.

The picture at the left is a close-up of a welder with Arc Drive. The rheostat, shown being adjusted in the picture, controls the amount of the current surge delivered by the welder.

T. R. Specht is shown 'listening' to a singing transformer base.

much smaller than 500 kva are not likely to cause this trouble because the air spaces and the holes in the bases of transformers of other ratings will not form resonant combinations at a frequency of 120 cycles per second.

To eliminate the base noise from the transformer under test, the number of holes was changed. The number was arbitrary anyway and did not directly affect the operation of the equipment. When more holes were drilled, the noise level was reduced about five db. But this still wasn't a complete solution. In characteristic fashion, Specht and his cohorts left no opening uncalculated in finding the correct noiseless combination. Specht says, "We knew that the cracks between the transformer base and the foundation would also affect the resonance of the air space. To eliminate any noise that might be caused by this factor, the number of holes was chosen so that with an average space between base and concrete of $\frac{3}{16}$ of an inch or less the cavity under the transformer will not be resonant at 120 cycles."

This is the kind of meticulous attention to seemingly insignificant details that has paid off in quieter transformers. The great improvements made in transformer noise levels through the years have been made possible by constant diligence and thorough testing. Although improvements often amount to much less than the five decibels eliminated in this instance, each barely audible decibel adds to the total to give a substantial overall reduction in transformer noise levels.

. . . in Products

Packaged Monogas Generator

MONOGAS controlled-atmosphere generators are used in a wide variety of heat-treating processes where an oxygen-free neutral atmosphere is required. They are used in applications such as drawing, annealing, or hardening carbon and alloy steels, brazing high carbon and alloy steels, and food processing that requires an atmosphere with a high nitrogen content.

Monogas is made from Exogas, a neutral atmosphere obtained by burning fuel gas. Carbon dioxide and water vapor are then removed from the Exogas to produce Monogas. Until recently the Exogas generator and carbon dioxide removal system were separate units that had to be assembled in the field. Now these units are packaged as a complete Monogas generator. The new units require less floor space than the older type, and efficiency is increased. Greater efficiency is obtained by utilizing the waste heat from the Exogas generator in reactivating the chemical used to remove carbon dioxide from the Exogas.

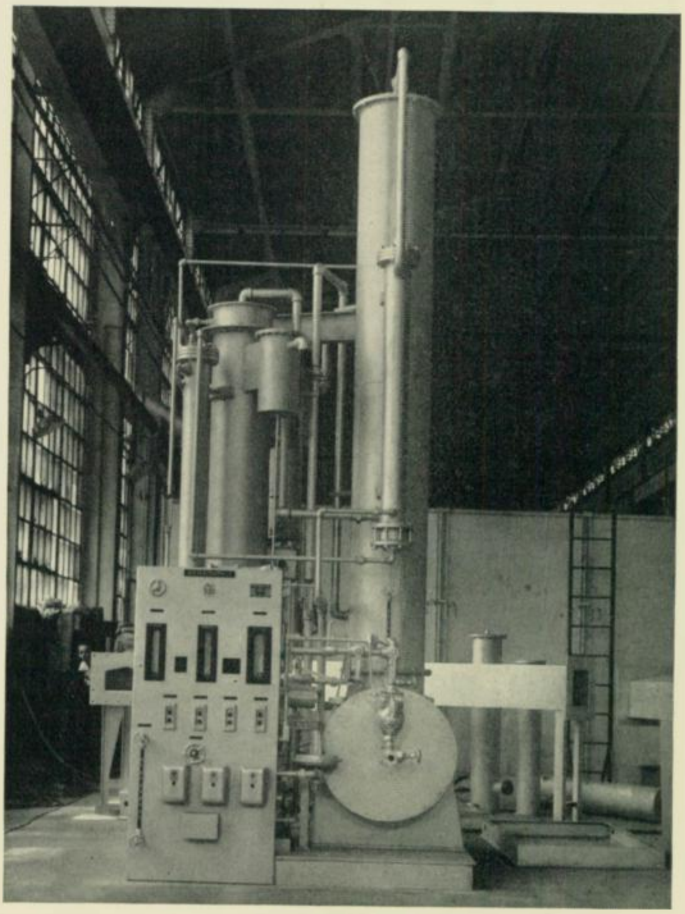
Any fuel gas—coke-oven, natural, propane, butane—can be used to produce Monogas. The generator can be converted from one gas to another by merely substituting the correct burner and flowmeters. The fuel gas is first mixed with air, then this mixture is burned in an Exogas generator. The output from the Exogas generator is passed through a condenser where some of the water vapor is removed. From there it goes to the carbon dioxide removal system. It enters at the bottom of an absorption column that contains packing rings wetted with monoethanolamine. This compound absorbs carbon dioxide from the gas to give undried Monogas, which then passes through a cooler and water vapor separator to additional drying equipment or to the point of use.

The monoethanolamine, which now contains carbon dioxide, is taken from the bottom of the absorption tower, where it collects, and is passed through a heat exchanger to a stripper column. Here the carbon dioxide is removed by passing steam up through the monoethanolamine. The steam is made by boiling the monoethanolamine solution with the waste heat from the Exogas generator. The pure monoethanolamine solution from the stripper column is then returned to the absorption tower to be used again in the carbon-dioxide removal system.

Three operating ranges are available from a Monogas generator. A lean Monogas atmosphere is inert and nonexplosive. The combustibles (H_2 and CO) in lean Monogas vary from 1 percent to a maximum of approximately 11 percent. This allows a range of reducing properties, at the same time giving a nonexplosive atmosphere. Medium-rich Monogas contains from about 11 percent to 23 percent of hydrogen and carbon monoxide. It is combustible. In rich Monogas, combustibles range from 23 percent to 35 percent of the total. The principal use of rich Monogas is for brazing and sintering operations where high reducing properties are desirable. This is an "active" atmosphere chemically, compared to lean Monogas, which is relatively inert.

Both lean and medium-rich Monogas can be obtained at rated

This is the compact, more efficient, packaged Monogas generator.



output with a lean Exogas generator ahead of the CO_2 scrubber. With a rich Exogas generator, rich and medium-rich Monogas can be obtained at full rated output, while lean Monogas can be obtained at about 60 percent of rated output. The same type of carbon-dioxide removal system is used for all three types.

The packaged Monogas generator requires about 35 percent less floor space than the previous model in which each unit was separate. Also, installation is simplified since much of the pipe fitting that was done on the job before is now completed at the factory. Units are available in sizes ranging from 500 cubic feet per hour through 20 000 cubic feet per hour.

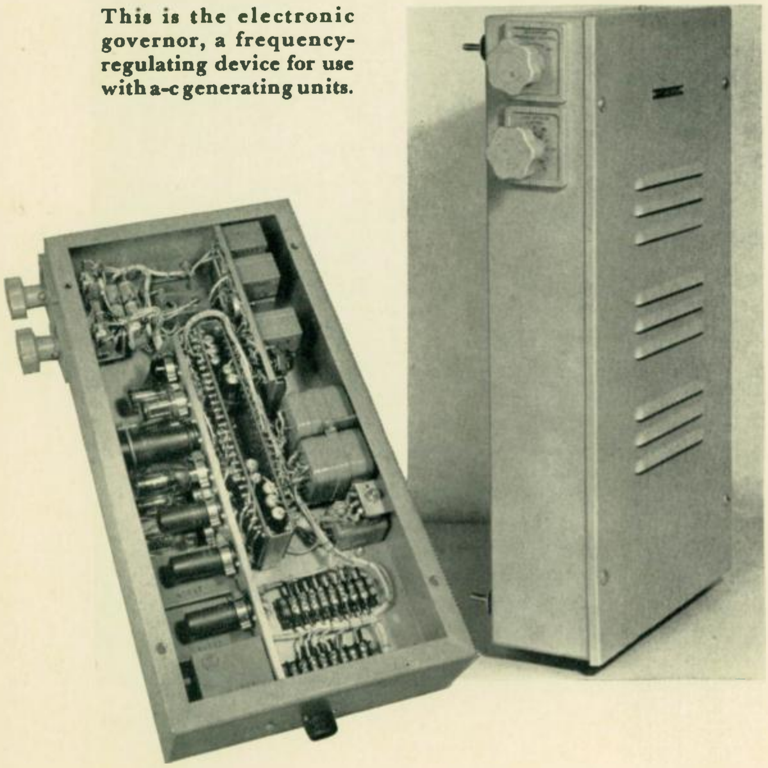
Electronic Governor

One problem that continually grows in importance is that of maintaining electric power frequency more nearly constant throughout system surges and load changes. Now an electronic governor, designed by the Westinghouse Special Products Development Division, has been designed to give a lower static regulation with faster response. This unit was designed specifically for a small turbine-generator set, but is equally applicable to diesel and carburetor-type engine-driven generators and to large central-station equipments as well.

The electronic governor can give a static regulation (change in frequency from no load to full load) of one half of one percent. The amount of overshoot when recovering from a transient condition is limited to two percent (about one cycle on 60-cycle equipment). And recovery time to a steady-state condition with sudden removal or addition of full load has been reduced considerably. This governor reacts to meet a load change on the system rather than to follow a change in load with a change in rotational speed to correct the unit to proper speed.

This governing system combines the high sensitivity of electronic circuits and the low-inertia, high-force characteristics of a hydraulic servomechanism to control the steam valves. The flexibility inherent in an electronic system is excellent. In the electronic unit it is possible, by varying the setting of standard potentiometers or changing the values of standard capacitors, to vary the stabilizing parameters of the governor over a range as wide as 100 to 1 within a matter of seconds.

The basic part of the electronic unit is a frequency network that detects the variation from the basic frequency and provides a signal voltage proportional to this deviation. This signal voltage is operated on by a stability network and amplified to control the solenoid cup valve—the important connecting link between the hydraulic system and the electronic system. The solenoid cup valve, in turn, controls the hydraulically operated steam-inlet valves. The stability network introduces quantities related to the error signal that, combined with the error signal, detect—almost instantaneously—changes in frequency and thereby correct for delays occurring elsewhere in the system.



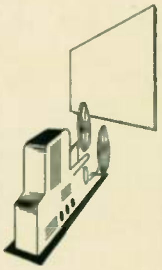
This is the electronic governor, a frequency-regulating device for use with a-c generating units.

In addition, other circuits and networks improve performance during the various modes of operation. When the turbine generator is operating singly, an electronic representation of the power output of the generator is combined with the error voltage from the basic frequency network and is amplified to operate the solenoid cup valve. This improves the regulation and response characteristics of the turbine generator. In operating an electronic-governor-controlled turbine generator in parallel with a conventionally governed turbine or another electronically governed turbine, it is possible to maintain proper load sharing without using the conventional "droop method" (three percent or more regulation) of parallel operation. Difference in load between the two is measured electrically and introduced into the electronic circuit to cause the desired proportioning of load regardless of the regulation of either turbine generator.

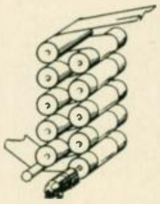
This governor has been designed to meet high shock specifications and is therefore rugged and durable. The circuits are designed with tubes having a guaranteed life of 10 000 hours (about 14 months of steady operation). All other electronic components are equally reliable. In case of failure, with attendant loss of output signal to the solenoid cup valve, a protective circuit returns the generator to the no-load, three-quarter speed condition, preventing a runaway.

What's NEW! . . . . in Literature

Westinghouse Electrified Oil Well Pumping is a practical booklet on the subject. It contains discussions of the motors and control necessary for different applications, the distribution systems, transformers and generators, with explanations of how to calculate ratings of each. Power factor correction is also discussed in detail. Booklet B-4039; 48 pp.



The *Westinghouse Sound Film Catalogue* lists 72 sound films available from Westinghouse. Subjects include general interest, product information, and training and instruction courses. Under each film title is a list of the people the film is likely to interest, an illustrated description of each film, and the film size, projection time, and type of film. Films are loaned free to church, social, professional, civic, or business groups, but the cost of transporting the film must be paid by the borrower. Catalogue B-4761.



Westinghouse Equipment for Textile Finishing contains information about the electrical drive equipment for continuous finishing and batch operations in textile mills. Basic considerations in choosing a drive, the features and advantages of each type of drive, and the best drive for typical applications are presented. Block diagrams show typical equipment arrangements. The booklet contains brief descriptions of the operation of adjustable-voltage d-c drives, AV packaged drives, and Mototrol drives as they are used in textile mills. Booklet B-4034; 30 pages.

To obtain literature, write to Westinghouse Electric Corporation, P.O. Box 2099, Pittsburgh 30, Pa.

Personality Profiles

H. L. Lindstrom began his academic career at Indiana University, but this was interrupted by lack of finances. After a two-year excursion with local power and electric railway companies, he entered Purdue to complete his undergraduate electrical training in 1928. He came to the Westinghouse Student Course that year, after which he worked with the engineers dealing with streetcar equipment and the gas-electric buses then being tried. He then moved over to the Dravo Corporation to work on cranes, hoists, and ore bridges, as well as towboats, dredges and other marine vessels. In 1933 Lindstrom received his E.E. degree from Purdue. He rejoined Westinghouse in 1941 to work first in Pittsburgh and later in Detroit on electrical applications for machine tools, resistance welding, and the fast-rising electronic controls. In early 1950 he transferred to the Control Engineering Section at Buffalo. One of his first assignments there was to help Walter Schaelchlin develop the adjustable-voltage cargo-winch system. He is also occupied with regulation jobs for mills, controls for steel mill auxiliaries and for machine tools.

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P. H. Brace, a native of Leavenworth, Kansas, attended college at Colorado University. He graduated in 1913 with a B.S. degree in E.E. and went directly to the Westinghouse Research Laboratories. He was a research engineer there until 1923, when he was made a section manager in the Metallurgical Department. In 1930 he was promoted to manager of the department, and six years later was made consulting metallurgist, a position he still holds.

Brace has played an important role in the development of new alloys and new techniques in electrolysis and induction heating. He did much of the basic development work on K-42-B and on Kovar. Cupaloy is also a Brace brainchild. Thirty patents have been issued to him in the fields of electro-technology, electronics, and metallurgy.

During the war he turned his talents to the problem of preventing gun erosion. His outstanding work in this field earned him the Presidential Certificate of Merit with citation in 1948.

More recently Brace collaborated with Dr. Ziegler of the Crane Company in developing Zerolling, a new method of rolling that produces a harder stainless steel.

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E. B. Fitzgerald came to Westinghouse on the Graduate Student Course in 1924 after graduating with a B.S. degree in E.E. from Norwich University. In 1926 he went with the J. G. Brill Company, where he worked in development and project engineering on mechanical, and gas- and diesel-electric railroad cars. His activities included the design and development of some of the first diesel-electric cars. In 1935 he left Brill to become Chief Electrical Engineer of the American Car and Foundry Company. There, he supervised the development of diesel-electric streamlined trains and subway cars, including the first diesel-electric streamlined train used in the South, one of the first trains to use power from the driving engine to supply lighting, air conditioning, etc.

Fitzgerald returned to Westinghouse in 1941 as section manager of the Transportation Engineering Department. In 1948 he assumed his present position as staff supervisor of manufacturing in the Transportation and Generator Division.

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C. D. Fahrnkopf went to college at the University of Illinois, receiving a B.S. in Engineering Physics in 1938. A year later he received his B.S. in E.E., then went with the Illinois-Iowa Power Company. In 1940 he came to Westinghouse.

His first assignment was in the Capacitor Laboratory where he checked the performance of new and redesigned capacitors. After 15 months in the capacitor lab he entered the Army, where he met his first radio interference problems in connection with VHF (very high frequency) communications equipment.

Since coming back to Westinghouse in 1946, radio influence from high-voltage corona has been his major field of study. He has worked on the instruments and testing techniques used in collecting data on RI from transmission lines.

To supplement his practical engineering work, Fahrnkopf has taken post graduate work at the University of Pittsburgh. Last June he received the degree of Master of Science in Electrical Engineering.

W. E. Pakala came to Westinghouse in 1927 after graduating from Montana State College. He started in the Graduate Student Training Course, and since then has worked on a wide variety of electronic equipment. His activities have included basic work in radio, power-line carrier equipment, high-frequency measurements, and the ignitron tube.

Pakala has received 25 patents. One of them, which he received jointly with Dr. Slepian, covers the design of the baffle and concentric arc shield used in the ignitron rectifier tube. Another is a method for measuring random arc-back in ignitron tubes. He also worked on the design of ignitron firing circuits.

At present, Pakala is in the Liaison Engineering group, where he helps the manufacturing divisions solve their radio noise problems. As a result of his wide experience with such problems, he has served on many committees investigating instrumentation and test methods for radio noise. In this capacity he has worked with the following organizations: NEMA, ASA, FCC, and the U. S. Navy.

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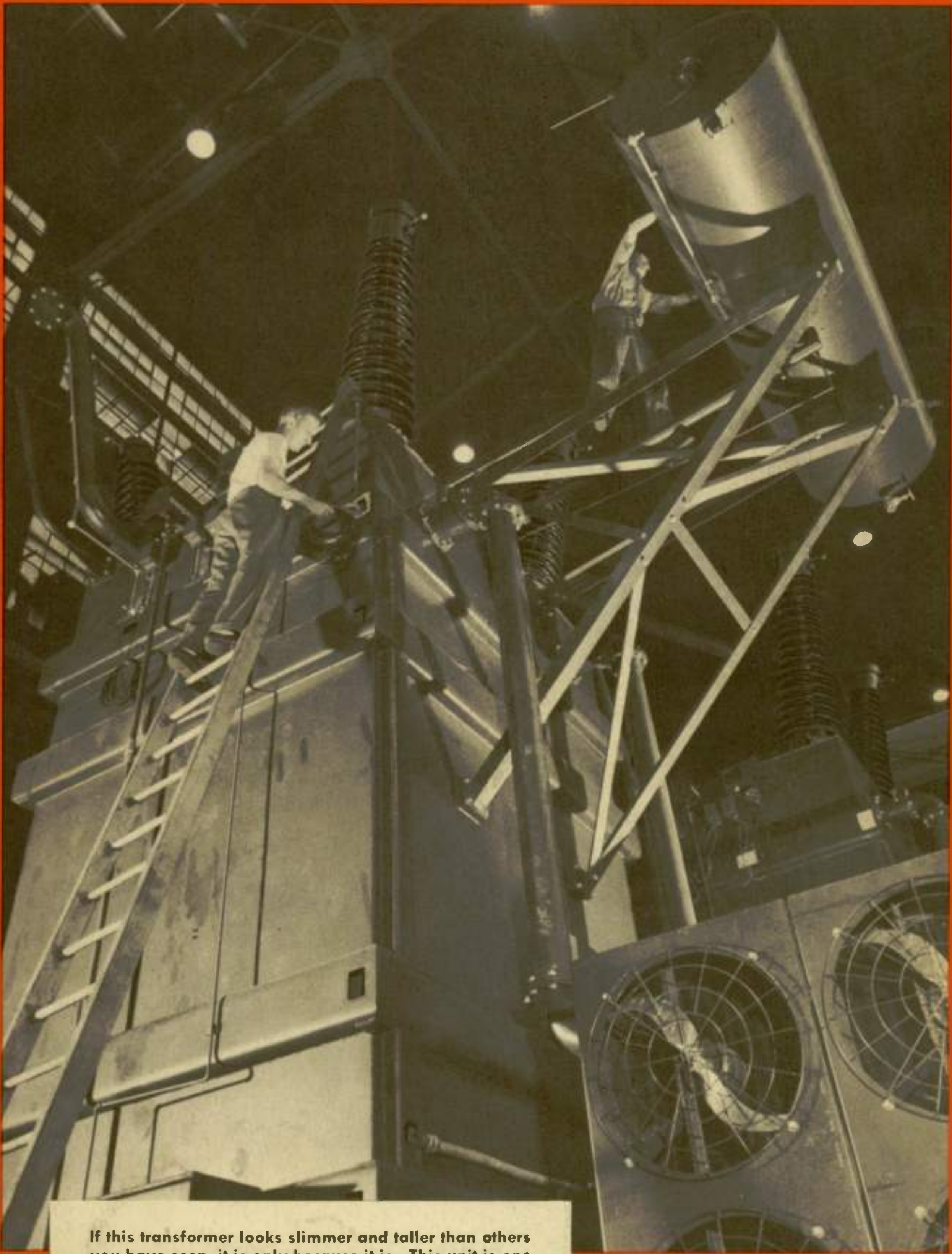
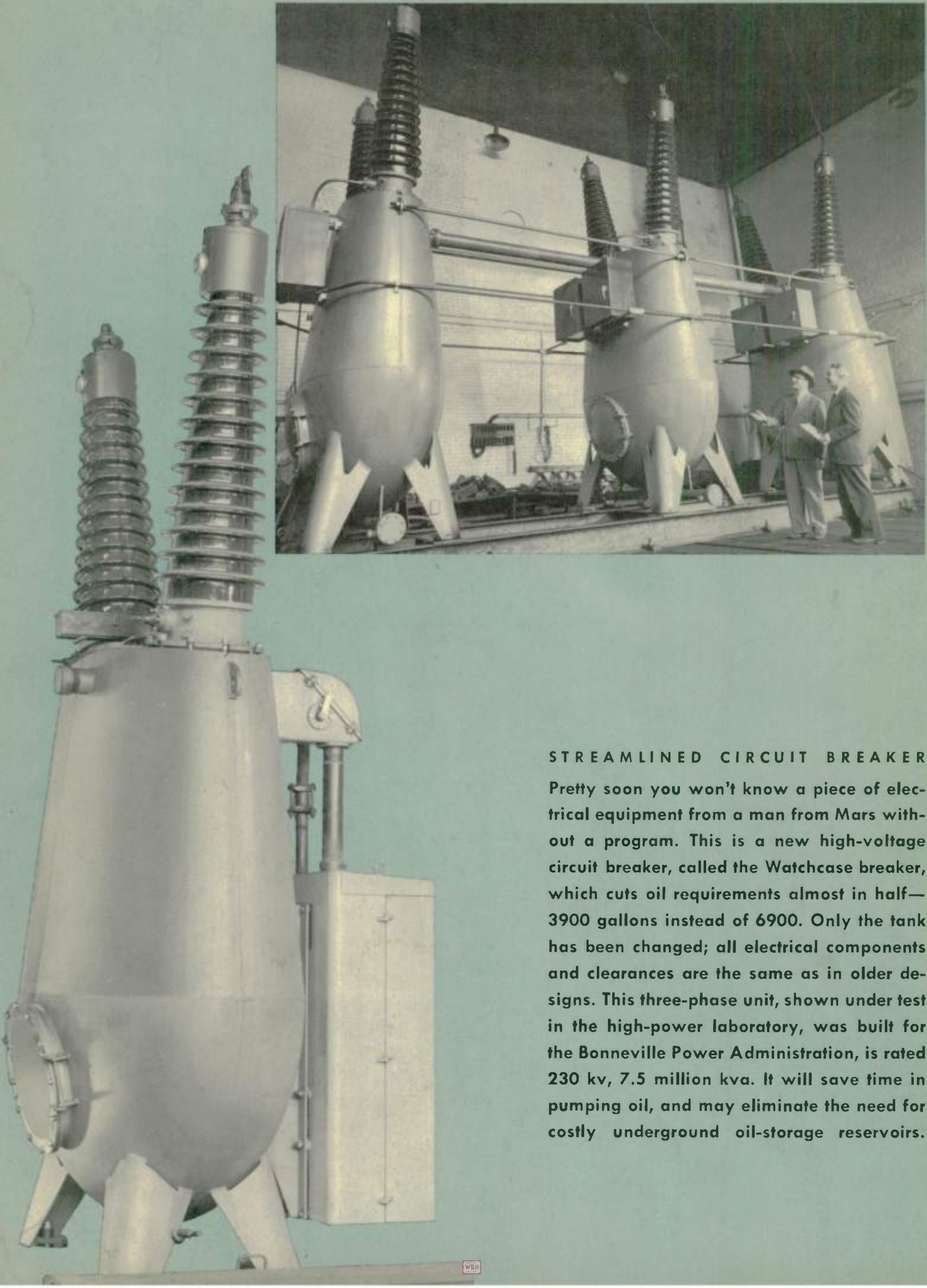
H. L. Prescott studied electrical engineering at Cornell University. He graduated in 1935, and in the fall of that year came with Westinghouse. After spending two months in East Pittsburgh, he moved to the Transformer Division.

Prescott has contributed to some of the major advances in control and regulation of transformers. He made significant contributions to the improvement of the early type CSP power transformers, and had an important part in the design of the present line of CSP power transformers. During the war Prescott worked on the electric torpedo that was developed and built by Westinghouse for the U. S. Navy. During 1948 and 1949 he was associated with the development of the type URS automatic step-voltage regulator. He also did much of the important development work on the new step-by-step switch control (see page 180). And the sequential control circuit that is used on most Westinghouse tap changers is another of Prescott's contributions.



If this transformer looks slimmer and taller than others you have seen, it is only because it is. This unit is one of seven specially designed 33 333-kva power transformers being built at the Westinghouse Transformer Division for shipment to France. Transformers of this size built for use in the United States won't fit in the narrower French railroad tunnels. Width is two feet less than that of similar 33 333-kva transformers installed in the United States; height is increased by five feet.



STREAMLINED CIRCUIT BREAKER

Pretty soon you won't know a piece of electrical equipment from a man from Mars without a program. This is a new high-voltage circuit breaker, called the Watchcase breaker, which cuts oil requirements almost in half—3900 gallons instead of 6900. Only the tank has been changed; all electrical components and clearances are the same as in older designs. This three-phase unit, shown under test in the high-power laboratory, was built for the Bonneville Power Administration, is rated 230 kv, 7.5 million kva. It will save time in pumping oil, and may eliminate the need for costly underground oil-storage reservoirs.

Personality Profiles

C. C. Sterrett and *C. A. Woods*, who collaborated on the article on bushing current transformers on page 98, are both named Charles, both proud Hoosiers, both graduates of Purdue. That's about where the parallel ends though. Sterrett is a mechanical engineer, Woods an electrical. Fate had a part in determining both careers, but in different ways.

Sterrett became a mechanical engineer largely because his father is one. Sterrett is one of those rare men who decided as a youngster what he wanted to be—and never changed his goal. Like a devoted Hoosier, he stayed in Indiana as long as he could; went only as far as Lafayette for his college training. He graduated from Purdue in 1936. That would seem like a bad year to come blushing out of college, but Charley says it wasn't. "As a matter of fact, it was a pretty good year. Jobs weren't plentiful, of course, but there were enough to go around." Sterrett accepted the offer made by Westinghouse, and—with a nostalgic sigh and several long looks west—headed east. Interest in hydrogen cooling of large generators was just beginning then and Sterrett moved into that field. Since then he has moved forward with that trend and has contributed much to the design of hydrogen-cooled machines. In retrospect, he would ask only one more favor from fate: a better climate for Pittsburgh. No, not like Florida—one like Indiana or Wisconsin!

And then we have Chuck Woods, who almost became a farmer. But in 1921 prospects in that field didn't look too bright. Engineering, particularly electrical engineering, was getting a lot of publicity about that time, enough to convince young Charles Woods that he should ride the "rising star of electricity." Forthwith to Purdue then, and four years later to Westinghouse. Since leaving the student course, he has been working with current transformers and circuit breakers. He had an important role in formulating the ASA and AIEE standards for current transformers. In 1940 he co-authored a paper on relaying performance of bushing current transformers, which formed a basis for that portion of subsequent ASA standards. Woods is satisfied in electrical engineering, but his attitude toward farming has changed some. Looking up from a crumpled grocery list he had been pondering, Chuck mumbled, "Looks like maybe I should have stuck to farming!"

• • •

M. L. Sloman is another engineer who got his start with an erector set. He has been interested in things mechanical ever since. The matches and toothpicks he transported on his electric train started him toward a career in transportation.

Although native Pittsburghers, Mac's family migrated to West Virginia while he was still in high school. His mechanical inclinations never wavered though, and from there he matriculated to Michigan to study mechanical engineering. He received his B.S. in M.E. in 1941. LST's in Pittsburgh and guns in Maryland occupied his thinking during the war. Then in 1945 he came to Westinghouse in the transportation section of Industry Engineering. After several years of design experience in the application of diesel-electric locomotives, he switched to city-transit equipment. For the past few years he has been particularly concerned with applications of the lightweight rapid-transit car, about which he writes on p. 94.

Mac's favorite topic of conversation: traffic congestion and what can be done about it. He too has to commute to work.

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Editor's Note: We were unable to follow our usual practice and interview Mr. I. S. Ritter personally. We asked him to supply the information in a letter. We found his reply too interesting for us to attempt any embellishment.

"I attended the University of Michigan for three years, class of 1916, in Marine Engineering. In the first World War, I spent my time in England as a ground officer in the Air Force.

"After the war, I started in the refrigeration and air-conditioning business with Frigidaire in Chicago where I had charge of the application engineering for the Northwest District, and later, commercial sales. In 1933 I went with Carrier in Cleveland.

"One year later my connection with Westinghouse materialized. I trained at Mansfield and then went to the Chicago Office on commercial refrigeration. In 1938 I was transferred to the Engineering Department at Springfield where I developed our line of milk coolers and beverage coolers. A little later I was shifted over to the Air Conditioning Department. In 1943 the air-conditioning activity moved to Jersey City (Elevator Division) and we started work on the experimental car for the Milwaukee Railroad. In 1945 the activity was again moved, this time to Hyde Park. I then became a Section Engineer.

"A perusal of the above will indicate that my hobby is moving. Seriously, for a long time, I have not had any hobby except the family.

"I do considerable reading with a definite aim of lessening my state of confusion so far as national and international affairs are concerned. To date I find the authorities on these matters nearly as confused as I am, but I still have hope."

• • •

Editors are made, not born. So *R. W. Ferguson* learned one morning to his consternation. Immediately after leaving the Westinghouse Graduate Student Course for the Central Station Engineering Department in 1949, he was put in charge of a major revision of the "Electrical Transmission and Distribution Reference Book." Ferguson acquitted himself well, but the experience, he says, left him with no desire to be a technical editor.

Ferguson, by his own admission, graduated from the finest school in the country—Texas A & M, in 1948, B.S. in E.E. But an engineering education even from Texas A & M was not enough, so he added a year at Cal Tech, arriving at Westinghouse in 1948 with an M.S. in E.E. Seems to have the studying habit. Is now taking additional work in mathematics at the University of Pittsburgh.

Ferguson is now engaged in a survey of powerhouse auxiliary practice in the United States, and with various specific central-station application problems.