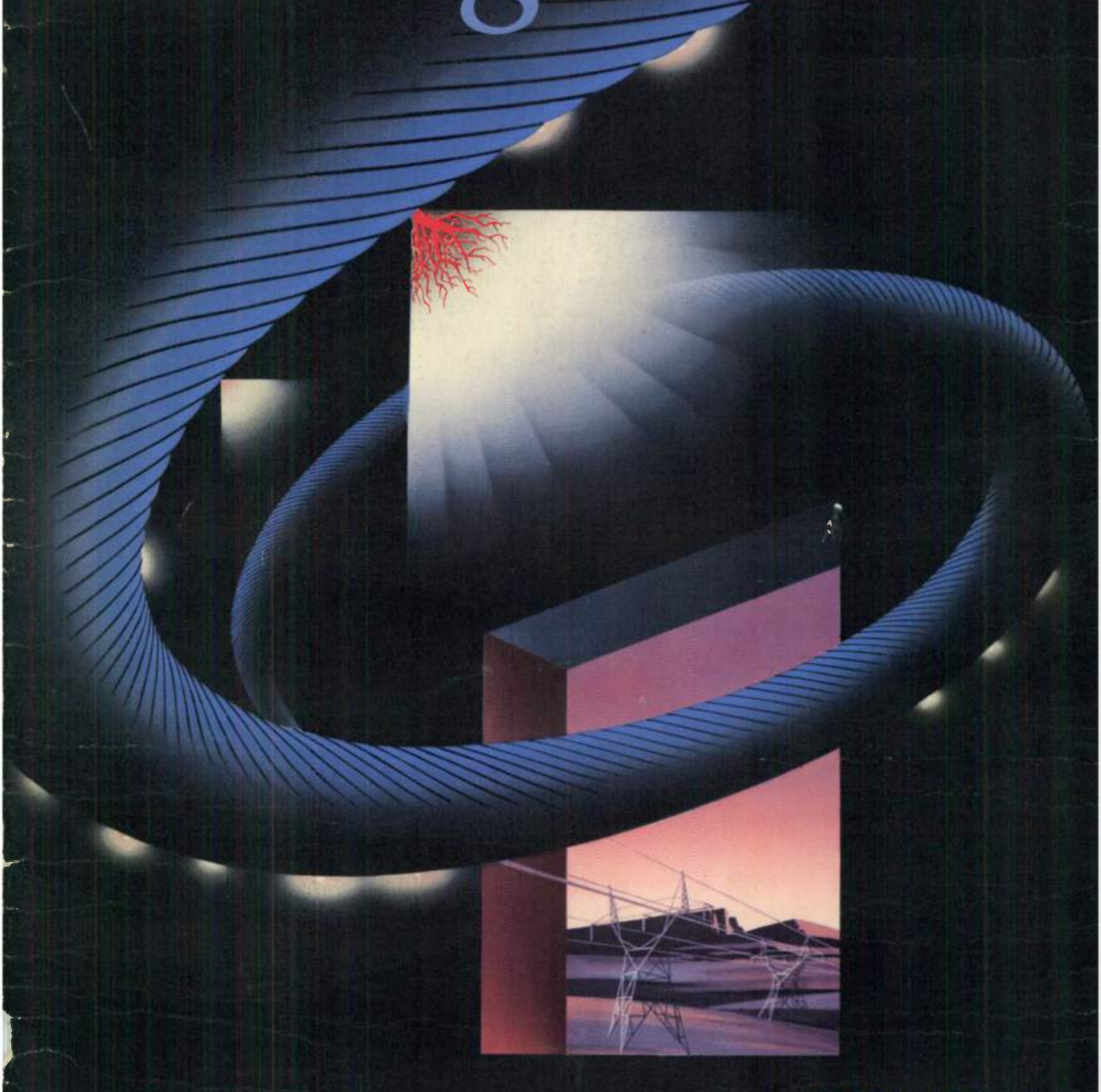
WESTINGHOUSE Engineer



SEPTEMBER 1951

Westinghouse *goes shopping*

To make millions of articles, from tiny lamps to giant turbines, requires a vast organization, a large fund of materials know-how, an amazing ingenuity in scouring the world to keep abreast of the designer's needs, and daily and intimate contact with thousands of suppliers. The result is of inestimable benefit not only to Westinghouse but also equally so to the raw-materials supplier, and to the purchaser of a single lamp bulb or the buyer of a 1000-kva transformer.

According to the prevalent concept of purchasing, the buyer sits in his office interviewing a stream of product salesmen—after each has cooled his heels an appropriate length of time in the reception room. Or, the buyers simply open bids from suppliers, take the lowest bid, and initiate the paper work to get the order in motion. In such a view, purchasing agents are presented as little more than order clerks. But, as a portrayal of materials purchasing in a large industrial organization, nothing could be further from the truth.

For an organization such as Westinghouse, that makes thousands of different products, purchasing becomes a highly complex business with countless ramifications little guessed as essential in producing electrical goods.

Just the statistics of such an operation are staggering—as one would know when he considers that for each billion dollars of sale (which was about the size of Westinghouse business in 1950) the purchasing organization must spend some $400 000 000 for materials, equipment, and services. This requires the full-time services of about 700 people and the part-time help of many more. Many of these men are technically trained specialists; some specialize in organic chemistry, some in petroleum, some in steel, or copper, or wood, and many other fields. In the course of a year, such as 1950, these 700 plus people buy goods from some 15 000 suppliers, and issue purchase orders at the rate of about 700 per working hour, or a total of over a million and a third separate orders per year.

While the great bulk of the materials are produced within the United States, literally scores are obtained from sources abroad: tungsten ore from Australia; mica from Madagascar and India; shellac from India; paper from Japan. A simple list of them all would more than fill this page.

Purchasing is seldom a matter of having the salesman and his product come to the buyer—even in the days of a "buyer's" market. Frequently, buyers must go to the source of the materials to facilitate selection or to aid in the negotiation. As an example, Westinghouse uses a quantity of hickory as strain members in line material and equipment. Not just any hickory will do. On occasions a wood expert from East Pittsburgh has been sent into the lowlands of the South, where the desirable rapid growing, second growth hickory is to be found, and personally selects trees considered potentially suitable.

The total number of kinds of raw materials that must be gathered in a year to make a billion dollars' worth of electrical and power apparatus is literally indeterminate. If one were to count all of the different sizes, shapes, and other mechanical and chemical variations the number would be astronomical. The purchasing code book, however, breaks these down into about 5500 categories. Westinghouse buys, for example, 11 different kinds of sand—for glass making, for porcelains, for sandblasting, for foundry casting, for the sand boxes of locomotives—and some for just ordinary concrete. A dozen varieties of shellac are required, 17 of solder. The different kinds of products for bonding mica flakes for electrical insulation totals about 75.

One essential element in today's close control of product quality is the purchased-material specification. Westinghouse has about 7000 of these, of which 4500 are designations for standard or nearly standard open-market products. The other 2500 are for materials required to meet Westinghouse's specific exacting needs.

Materials specifications are the handiwork of five groups working as a team: the design-engineering departments, the materials engineering department, the materials and standards group, the purchasing departments, and—equally important—the suppliers. A new material specification may originate with any of these five groups. Also the combination of these team members cooperating to produce a material specification differs from case to case. The important point is that the system is arranged for maximum flexibility, but with the assurance that the final, accepted specification embodies the views of all interested groups. The end objective is to describe a material clearly, as exactly as the application requires, with least possible restriction, and for least cost to both supplier and purchaser compatible with the qualities the material must have.

In a large organization such as Westinghouse, with about 75 manufacturing centers scattered from New England to the Pacific Coast, a purchasing organization could become very inflexible—particularly if it were completely centralized. To prevent this a combination of local and centralized purchasing is effected. Each manufacturing unit does its own buying, but with the knowledge and guidance of a headquarters group. This insures the economies of large-volume purchasing, permits the pooling of purchases for the items that are rare or more difficult to obtain. Also such a system results in the savings that come from allowing one plant that uses a large quantity of one material to purchase for a distant plant that uses the item in small amounts or infrequently.

Establishment of the channels for flow of the thousands of raw materials for the manufacture of a heterogenous mass of electrical products is not a passive thing. It is not just a simple matter of announcing to suppliers the desire for such and such material. In general Westinghouse considers that its business is manufacture of finished goods and prefers to purchase all its raw materials rather than make them. Firm adherence to this policy calls for real effort and ingenuity. Sometimes a new product to be made in quantity requires more of a material than has been produced before in the whole United States. Especially is this true in the chemical field. Not long ago Westinghouse needed a supply, in tank-car lots, of a liquid, of unpronounceable name, previously used only by the pharmaceutical industry in gallon-size quantities. To establish a reliable and large-volume source, a chemical company was given financial inducement to equip itself to produce the substance.

It frequently happens that, to help a raw-material supplier provide a given item in the quantity or to the quality needed, the purchasing department arranges for Westinghouse materials or factory engineers to spend time—perhaps several months—in the supplier's plant helping establish manufacturing methods and equipment, process control, or testing procedures. Such guidance sometimes extends to ways of packaging and shipping to effect mutual economies and to reduce losses.

In periods of short supply even more aggressive measures must be adopted. For example, after the last war, with steel hard to get, Westinghouse envisioned a delay in meeting customer commitments. It was able to lease a surplus open-hearth furnace controlled by the War Assets Board, and produced steel ingots that were turned over to steel-fabricators to be processed according to Westinghouse material specifications.

Then there comes the time when a material simply is not obtainable in the open market or no supplier can be induced to produce. Then there is no choice but to manufacture it. Westinghouse makes some 300 of these. They run the scale from special high-temperature alloys, tungsten wire, certain resins, enamels, to uranium. Dr. Rentschler of the Lamp Research Laboratories needed some metallic uranium in 1920. No firm then was remotely interested in producing the few pounds desired. So Westinghouse developed a way to make it. As a result Westinghouse was able to supply essentially all of the urgently needed uranium for the first atomic-energy pile at Chicago in 1941 and 1942 when it appeared that the western world might come out second in the atom-bomb race.

Another example is ultra-high-purity iron. Several years ago, the Research Laboratories desired, for spectrographic work, iron of extreme purity—99.99+ percent iron. There was none in the world. The requirement of a few pounds was of little interest to steel companies that deal in thousands of tons. A technique to make it was developed. About 1000 pounds of high-purity iron is now provided each year, largely as a service, to the various government standards bureaus and industrial research laboratories throughout the world.

Industrial purchasing is one little-seen but vital phase of our industrial society—the best in the world—at work.

WESTINGHOUSE Engineer

VOLUME ELEVEN

SEPTEMBER, 1951

NUMBER FIVE

On the Side

The cover—Most of our readers probably have never seen a corona discharge close up. Our cover artist hadn't either. And there weren't any pictures available that showed any of the details of corona. So we took Dick Marsh out to the high-voltage lab at Trafford, Pa., where many of the tests described in the article on corona were made. There, with the help of the engineers at the lab and a pair of binoculars, we showed Dick—and ourselves—how corona looks. The cover is Dick's conception of what he saw.

• • •

The Westinghouse Company has been selected to sponsor the television broadcasts of all college football games this fall. In the ten-week season, the games of 40 colleges will be telecast on a carefully planned basis to provide information on the effect of television on attendance at college football games.

A factor in the choice of Westinghouse among several companies competing for the sponsorship is the fact that it has been closely associated with colleges and universities through intensive training programs, scholarship awards and graduate placement activities. The firm also cooperates in advanced educational programs and provides a teaching aids service to high schools.

• • •

Going. Going. But not yet gone. We still have copies of the cumulative index, which covers everything printed in the *Westinghouse* ENGINEER from 1941 through 1950. If you want a copy, just let us know where and to whom to send it.

In This Issue

The following terms, which appear in this issue, are trademarks of the Westinghouse Electric Corporation and its subsidiaries:
AB De-ion, Full-View, Inerteen

The *Westinghouse* ENGINEER is issued by the Westinghouse Electric Corporation six times a year (January, March, May, July, September, and November). Annual subscription price in the United States and possessions is $2.00; in Canada, $2.50; and in other countries, $2.25. Single-copy price is 35c. Address all communications to *Westinghouse* ENGINEER, P.O. Box 1017, Pittsburgh (30), Pa. The contents of the *Westinghouse* ENGINEER are regularly indexed in Industrial Arts Index. Reproductions of the magazine by years are available on positive microfilm from University Microfilms, 313 N. First Street, Ann Arbor, Michigan.

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

The Series Capacitor and the High-Voltage Line

The series capacitor is no longer merely a voltage regulator. Last spring, for the first time in America, a series capacitor was installed on a high-voltage transmission line to improve power-transfer ability. As power loads continue to grow, this new application of the series capacitor promises to become equally as important to utilities as voltage regulation has been for many years.

R. E. MARBURY
Manager, Capacitor Engineering
Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania

SERIES capacitors have been used successfully to reduce light flicker on radial feeders for 10 or 15 years. The sudden voltage drop caused by rapid, repetitive load fluctuations is, for all practical purposes, instantly compensated by the series capacitor.

With the recent installation of a 15 000-kva bank on the Bonneville Power Administration system, series capacitors have assumed another and different function—that of increasing the amount of power that can be transmitted over a high-voltage line. These two services—to regulate voltage on fluctuating loads, and to raise the power-transfer ability—are quite different from the point of view of the series-capacitor protective system. Mostly this difference hinges not on the normal operation of the series capacitor but on the operation during fault conditions. Specifically it has to do with the length of time a series capacitor may be removed from the line during a short circuit. For a power-transfer capacitor this duration must be as brief as possible. On the other hand when the capacitor function is to regulate voltage, an appreciable delay is not critical. Thus, the development of series capacitors is taking two directions. One is to meet light-flicker problems on transmission, subtransmission, and distribution circuits. The other is to enhance the load-carrying ability of long, high-voltage lines, which is the subject of this article.

On transmission lines used to transfer power between two points on a system, the series capacitor increases the power transfer for a given phase-angle difference between the sending- and receiving-end voltages and greatly improves synchronizing and stability conditions. The series capacitor in such applications makes possible either an increase in transmitted power with the same transient-stability margin, or an improvement in transient-stability margin for a given power transfer.

The series capacitor also can be used to balance reactances on parallel circuits. Where two circuits are operated in parallel, it is desirable for the circuits to share the load in proportion to the current capacity of the circuits. Since the length of the circuits may differ, the reactance also may differ and the circuit with lower reactance then passes more current. Adding reactance to this branch is objectionable since the combined reactance of the feeder then increases. The reactance of parallel feeders can be equalized to better advantage by compensating with series capacitors. This also improves the voltage and stability performance of the feeder circuit.

Requirements in Light-Flicker Applications

When a series capacitor is used to reduce light flicker, several factors must be considered:

The maximum continuous line current is important because once the series capacitor is installed it is often quite costly to increase the continuous current rating of the capacitor. Therefore, possible future load increases should be given serious consideration when a capacitor rating is chosen.

Naturally, the capacitive reactance (X_C) necessary to achieve the desired result must be determined.

Protective equipment must be provided to protect a series capacitor against overvoltage resulting from fault currents. Since the voltage on the series capacitor varies directly with line current, faults on the line beyond the series capacitor subject the series capacitor to high overvoltage—perhaps 20 times normal—so arrangements are made to limit the voltage during faults. An air gap provides the only satisfactory means of doing this because the voltage must be limited during the first half cycle. No switch can operate fast enough. A gap can be placed in parallel with the capacitor and set to discharge at a value safe for the capacitors.

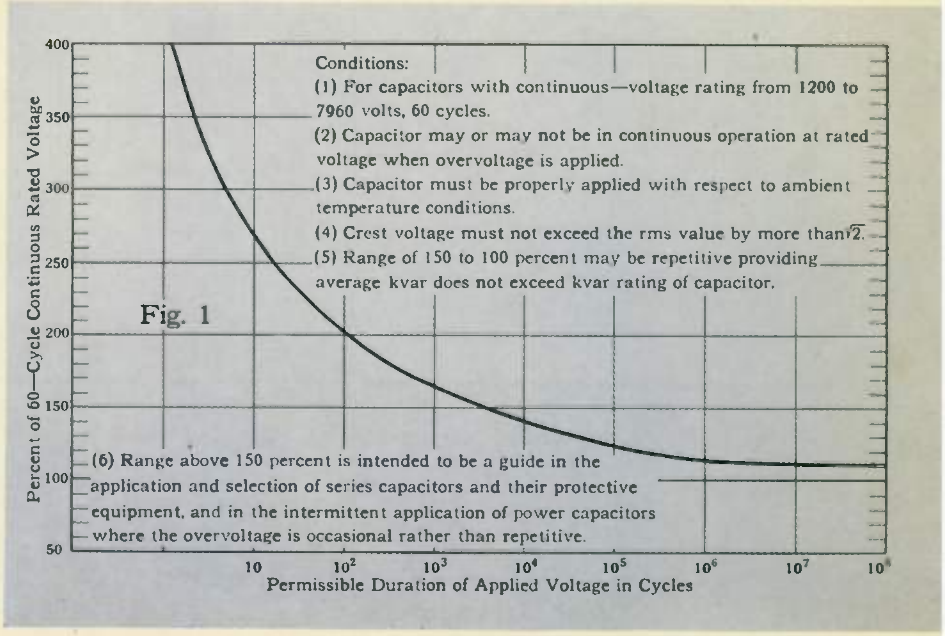


Fig. 1

Conditions:
(1) For capacitors with continuous—voltage rating from 1200 to 7960 volts, 60 cycles.
(2) Capacitor may or may not be in continuous operation at rated voltage when overvoltage is applied.
(3) Capacitor must be properly applied with respect to ambient temperature conditions.
(4) Crest voltage must not exceed the rms value by more than $\sqrt{2}$.
(5) Range of 150 to 100 percent may be repetitive providing average kvar does not exceed kvar rating of capacitor.
(6) Range above 150 percent is intended to be a guide in the application and selection of series capacitors and their protective equipment, and in the intermittent application of power capacitors where the overvoltage is occasional rather than repetitive.

On a voltage-regulation capacitor, when the gap breaks down, the gap current is used to close a by-pass switch or breaker, which permanently removes the capacitor from service. This is usually referred to as non-restoring protection.

The gap can also be arranged to clear automatically after the fault on the line is cleared; or, if a breaker is used, the breaker can be automatically reopened. In either case this method of protection is referred to as self-restoring.

Self-restoring protection requires no attention following a line fault. Since light flicker usually can be tolerated for short periods, the time required to restore the series capacitor automatically is not critical. This permits the use of reclosing breakers, thermally operated by-pass switches, or conventional timing devices.

The protective-gap breakdown usually is set at 250 percent of the continuous rated voltage of the capacitors. Experience shows that standard Inerteen capacitor units are quite capable of withstanding the voltage transients that such a gap setting permits. The permissible working voltage for standard capacitors is given in Fig. 1. This is the basis for gap settings.

The probable magnitude of fault current is important because it may determine the type and cost of the protective equipment. The protective equipment for a series capacitor must be able to handle the maximum attainable fault current for the entire duration of the fault.

In selecting appropriate ratings for the individual capacitor units, the phase voltage of the series capacitor is easily obtained by multiplying the continuous current times the capacitive reactance. If this gives a value greater than 7960 volts, two or more groups of lower voltage capacitor units should be used in series in each phase. Even if this voltage is equal or less than 7960 volts, it may be desirable to install two or more groups of capacitor units in series to permit economy of protective equipment.

Each phase of the series capacitor must be insulated from ground. This can be done in a variety of ways, depending on the size of the series capacitor and the type of installation desired. Sometimes the series capacitor can be located near the transformer, with one phase of the capacitor inserted between the transformer winding and the neutral grounding point. When this is done, one side of the series capacitor is at ground potential, and the insulation problem then is determined by the voltage drop across the series capacitor rather than the line-to-ground voltage.

Series capacitors of this type usually are installed to improve instantaneous voltage regulation during sudden, momentary peak loads; therefore the benefits of the series capacitor are lost entirely if, under these conditions, the protective equipment short-circuits or by-passes the capacitor. It is standard practice to use protective equipment that permits momentary peak loads of 150 percent of the continuous current rating of the series capacitor without interfering with the effectiveness of the capacitor. Therefore, to benefit from the series capacitor, momentary loads should never exceed 150 percent of the continuous current rating. This means that sometimes the momentary load rather than the continuous load determines the voltage rating of the capacitor.

Requirements of Power-Transmission Series Capacitors

Some factors to be considered when series capacitors are used to improve power transmission differ from those involved in light-flicker applications. The requirements for continuous current rating, reactance value, and momentary current are the same, but other factors that must be considered warrant further discussion.

In power-transmission applications the protective equipment must not only be self-restoring but also must provide for practically instantaneous reinsertion of the capacitor following a fault. If the capacitor were to remain out of service for even a few cycles after the clearing of a fault, all of the advantages of improved system stability would be lost. In fact, this use of series capacitors was delayed for many years because protective equipment that would meet the fast reinsertion requirements was not available.

The protection system, recently developed, that is well suited to this application consists of an enclosed graphite gap arranged so that a strong blast of air passes through the arc, extinguishing it each half cycle. Each breakdown of the gap places a resistor in parallel with the series capacitor, and conversely, each time the arc in the gap goes out at current zero this resistor is disconnected. Thus, the air-blast gap becomes a synchronous switch that connects the resistor to hold down

TABLE I—POSSIBLE COMBINATIONS OF EACH BANK AT CHEHALIS

Connection	X_C	Continuous Working Current
Single	25.4	312 amperes 60 cycles
Series	50.8	312 amperes 60 cycles
Parallel	12.7	624 amperes 60 cycles

Fig. 1—The permissible periods of operation of standard capacitor units with overvoltage can be obtained from this curve. Voltage is given as a percentage of the continuous rating of the capacitor (continuous rating = 100 percent). The permissible duration of overvoltage is given in cycles along the abscissa.

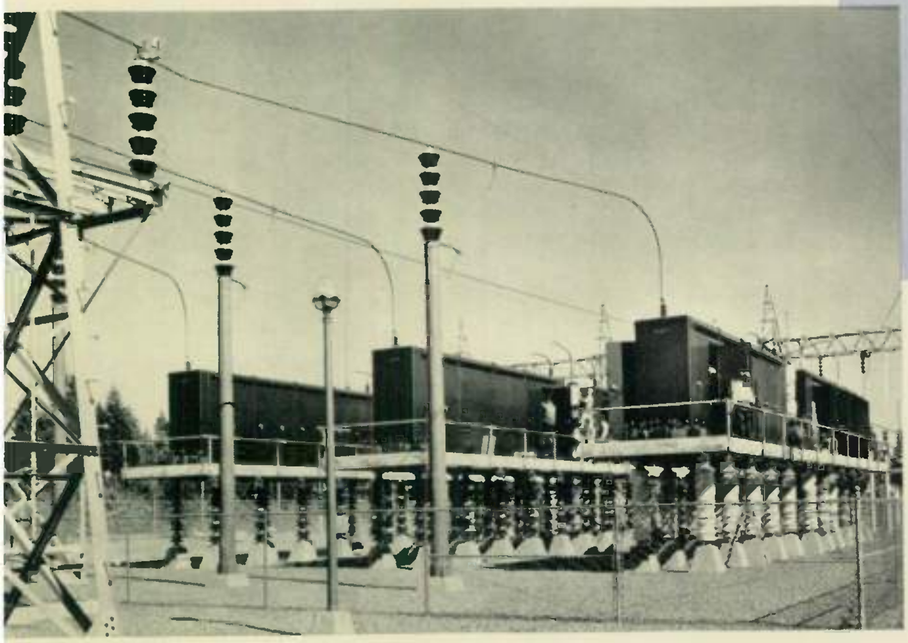


Fig. 2—This is the 230-kv, 15 000-kvar power-transfer series capacitor installed last spring at Chehalis substation of the Bonneville Power Administration.

the voltage and disconnects it at each current zero. In effect, the series capacitor is never removed from the circuit, but a by-pass is provided to handle the excess current during a fault. When the fault is cleared the voltage on the following half cycle is less than the breakdown voltage of the gap, so the resistor remains disconnected. The breakdown of the gap initiates the flow of air through the gap, and when repetitive gap current ends, the air supply is shut off.

Selection of capacitor-unit voltage ratings for power-transfer applications is similar to the procedure used where the problem is light flicker. If the product of continuous line current and X_C exceeds 7960 volts, two or more lower voltage groups of capacitor units should be connected in series in each phase. This is preferable because of the substantial increase in cost when each capacitor unit must be insulated for working voltages above 7960. In addition, it is desirable to place two or more groups in series so that no group exceeds 5000 kva. This is important. A 5000-kva step for a series capacitor is equivalent to a single-phase 5000-kvar shunt capacitor from the standpoint of energy released through a fuse and faulty capacitor unit. Since a unit may fail at or near 250 percent of rated voltage, the value permitted by the protective device, a release of energy amounting to 87 kilowatt seconds is possible. Concentrations of stored energy larger than that may result in damage to adjacent units if a capacitor fails. Limiting the maximum size of the groups also permits some standardization of capacitor protective equipment.

Since the voltage to ground may be quite high on transmission lines, the problem of corona must be considered also. The design of the supporting structure and the mounting of capacitor units, fuses, etc., must be such as to create no problem of corona or objectionable radio noise.

First Power-Transmission Series Capacitor

The first series capacitor installed in the United States on a high-voltage tie line for the purpose of improving power transmission is located in the state of Washington at the Bonneville Power Administration's Chehalis substation.

It consists of six 2500-kvar single-phase banks of 7960-volt, 15-kvar capacitor units. Each 2500-kvar bank, assembled in a metalclad housing, has a rated current of 312 amperes, a reactance of 25.4 ohms. Two housings supported on a platform make up each phase of the capacitor. The two housed assemblies can be operated singly, in series, or in parallel, with the reactances and working currents shown in table I.

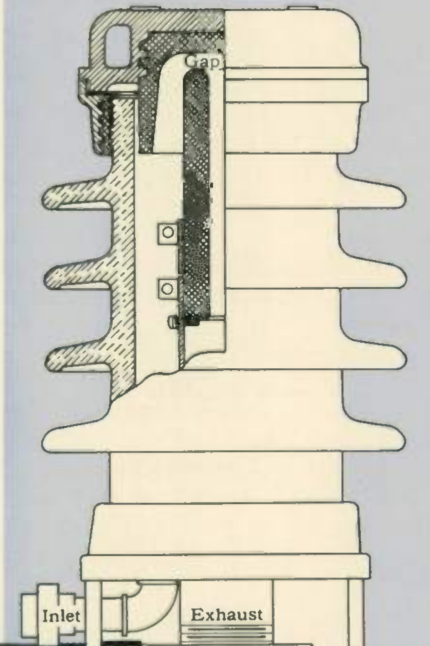


Fig. 4—Basic construction of the air gap. Air comes in through the side inlet, passes through the gap, then down the center hole. It exhausts through the opening in the bottom of the assembly.

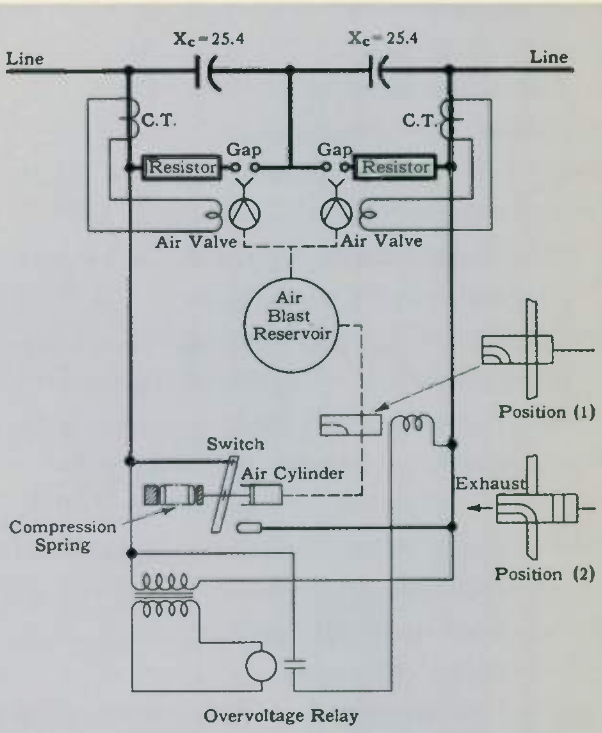
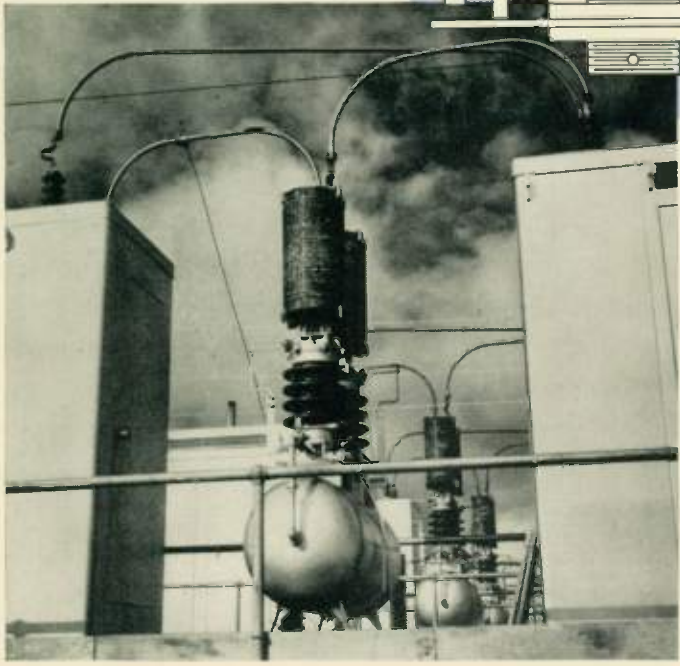


Fig. 3—The air reservoir, gaps, and resistors are mounted between housings as shown below.



The complete installation at Chehalis is shown in Fig. 2. The housings have sufficient space available for adding 15-kvar capacitor units to bring the total 3-phase kvar up to 23 000 for a phase working current of 500 amperes. The two housings forming one phase of the series capacitor are mounted on a structural-steel platform supported and insulated from ground by standard post-type insulators. The three platforms forming the complete installation are placed side by side. The walkway surrounding the housings provides accessibility to all equipment. The railing, in addition to being a safety feature, controls the field-stress distribution.

The steel structure at the left in Fig. 2 supports the switches used to by-pass the installation for maintenance purposes. Disconnect switches at each end of the yard isolate the complete installation after it is by-passed. A three-pole gang-operated grounding switch at the far end of the platforms permits grounding the platforms for safety.

The Gap

The gap and resistor assembly shown in detail in Fig. 3 is mounted between the two housings in each phase. It can protect two groups of capacitors, which can be supported on one platform. In the Chehalis installation each gap and resistor protects one 2500-kvar assembly.

The gap itself, shown in Fig. 4, consists of two graphite-type electrodes; one is an inverted cup, the other is a central post with a vent hole through its center. The arc takes place at the gap at the tip of the center electrode. During arcing, air is fed into the porcelain tubular body, then passes through the arc, down through the vent hole in the center electrode, and exhausts to the atmosphere.

The circuit arrangement of gaps and resistors is shown in Fig. 5. The resistors limit the oscillatory discharge current so that the gap can break down and restrike repetitively without damaging the capacitor.

An air reservoir and two electrically operated air valves, shown in Fig. 3, release compressed air through the gaps. The air is initiated by gap current, and continues to flow for 7 to 10 cycles after the gap stops arcing. This delayed shut-off is desirable to cool and remove arc gases after the arc goes out. The general arrangement is shown in Fig. 5, while the drawing in Fig. 6 shows the construction of the blast valve. The opening time is 1¾ to 2¼ cycles.

Operation of the gap protection is best illustrated by the oscillograms of a laboratory test, shown in Fig. 7.

Automatic By-Pass Switch

The automatic by-pass switch (see Fig. 5) is spring closed and is held open by compressed air. Normally it remains open since all fault currents are cleared by the operation of the gap and the action of the air. However, this switch is used for back-up protection in case something else fails or in case certain abnormal conditions exist.

The switch is closed by cutting off the air supply to the switch cylinder and then dumping the air in the cylinder. This is accomplished with electric or air relays when any of the following conditions exist:

a—Arc hangs on too long in the gap because of insufficient air pressure. Closing switch protects the gap resistor.

b—Low air pressure in gap reservoir.

c—Overvoltage on capacitor caused by excessive load current, or change in X_C due to fuse operations.

The by-pass switches and controls are located in one of the metal-clad housings. Voltmeters provided on the ends of these housings indicate the voltage across the capacitor.

←

Fig. 5—This schematic diagram of the protective equipment for the series capacitor illustrates the electrical arrangement. The air gaps and shunt resistors are shown at the top of the diagram. Just below the gaps is the air system, shown dotted. The automatic by-pass switch at the lower left operates under abnormal conditions. The solenoid-operated valve at the right controls the operation. Position 1 is normal—compressed air from the reservoir keeps the switch open. In position 2, the valve is open and the air from the cylinder can escape. The by-pass switch is closed by the compression spring.

Fig. 6—When a fault occurs on the line, the solenoid, (a), is energized and forces the heavy metal sleeve, (b), upwards. This sleeve strikes the shoulder at the top of the valve, (c), and forces the valve open. The compressed air coming from the passage through the right side of the housing then enters the chamber, (d). The pressure of 150 psi distributed over the Neoprene diaphragm transmits enough force through the enclosed area below the diaphragm to open the valve, (e), against a pressure of 150 psi. The compressed air from the reservoir is then free to pass through this valve to the gap.

→

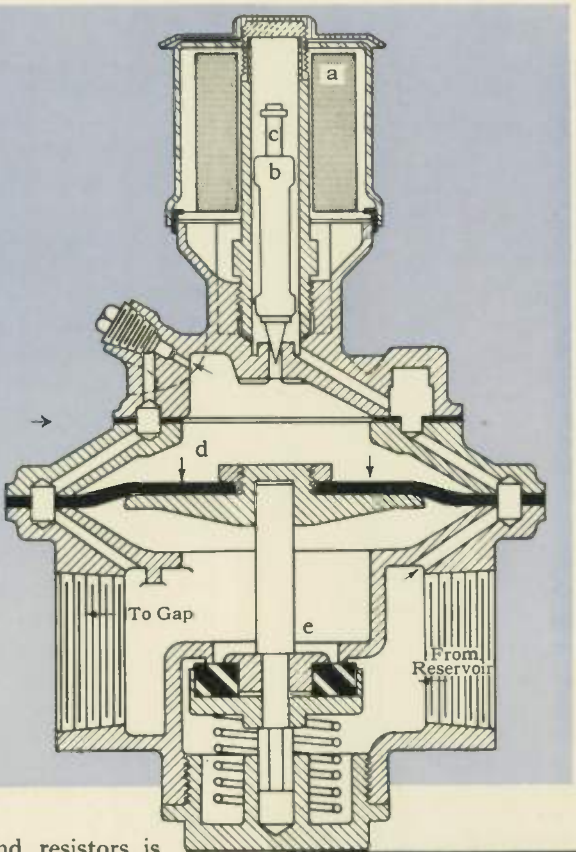


Fig. 7—Operation of the protective equipment (below). The capacitor was energized with an excessive line current shown by the bottom trace. Since this produced excessive voltage across the series capacitor, the gap broke down immediately, as indicated in the two top traces. The gap solenoid coil was energized when the gap broke down (second trace from the bottom). Exhaust air began to appear at the gap exhaust 2½ cycles later, and at about the same time the arc started to restrike. Shortly after that the line current was reduced to the normal value—in this case, 1150 amperes—and the arc stopped carrying current on the following half cycle. At this point the series capacitor was automatically reinserted and became fully effective again. The blast-valve solenoid was then de-energized due to the absence of gap current. Several cycles after this the air flow stopped. This is indicated below by the third trace from the top.

↓

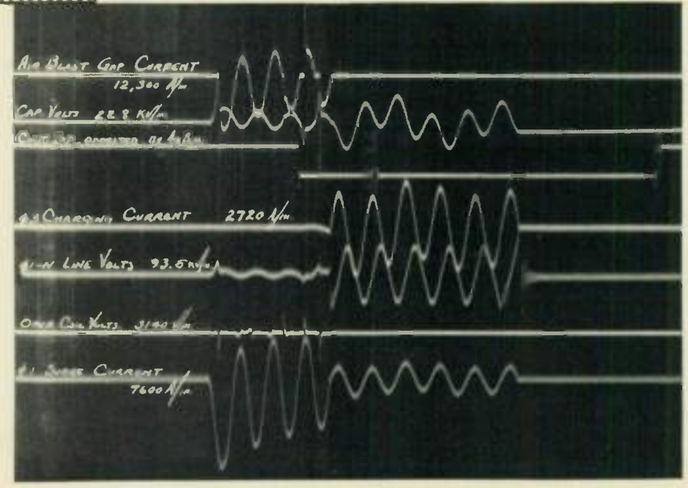
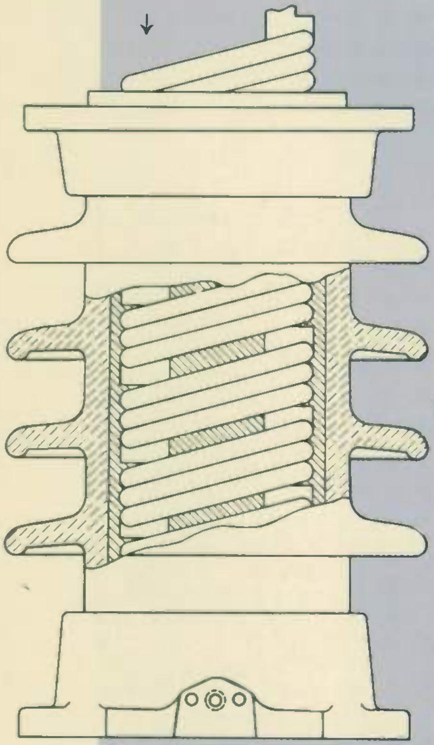


Fig. 8—The insulated air columns are made up of stacked units like the one shown below. The three air hoses in each column spiral around the inside; they are held firm and protected with compound.



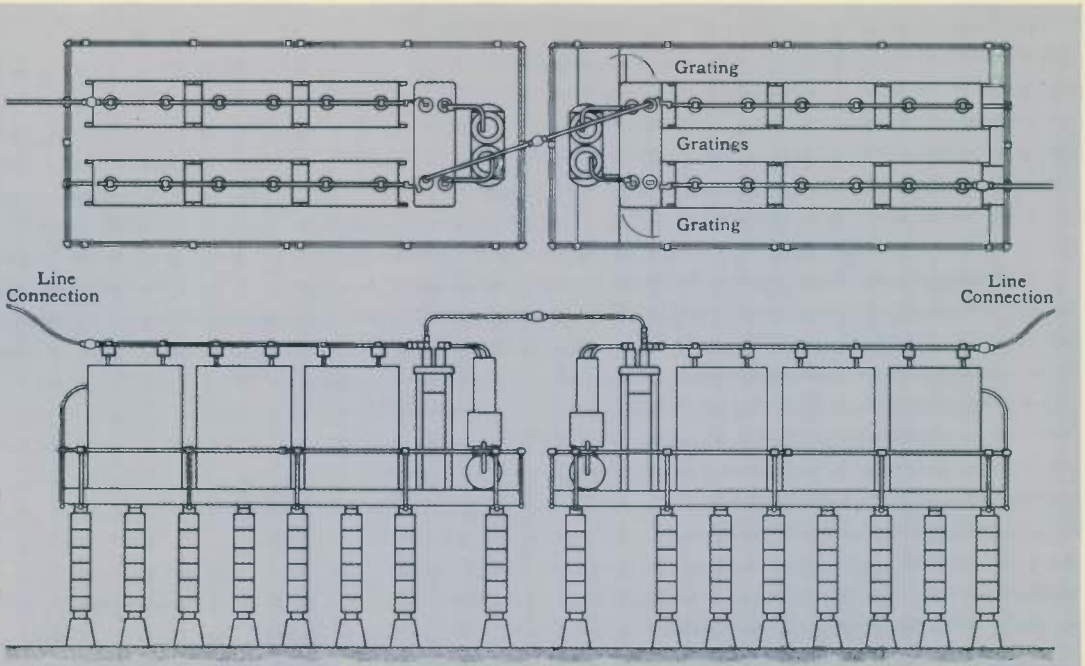


Fig. 9—Shown above are the plan view (top) and elevation view (bottom) of one phase of a typical series capacitor. Each phase contains two separately insulated platforms, provided with individual gap protection and a compressed air supply, which are located on the platforms.

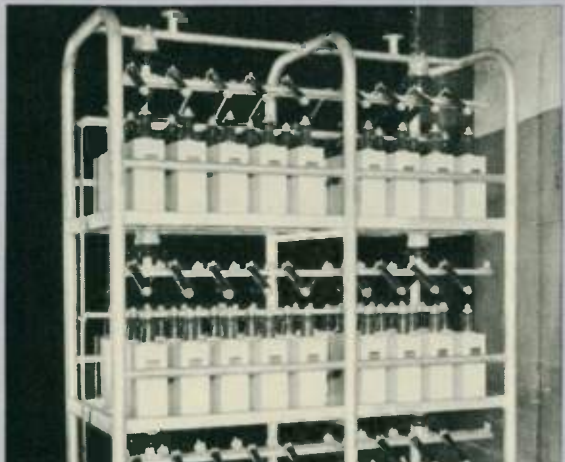


Fig. 10—This is a standardized open-type assembly of outdoor units. The pipe frame shields against corona.

TABLE II—TYPICAL RATINGS OF SERIES CAPACITORS FOR 230 KV, 970 AMPERES, USING 4160-VOLT CAPACITOR UNITS

No. Platforms per Phase	Reactance per Phase	Voltage per Phase	Groups per Phase	Total 3-Phase Kvar
One	8.6 ohms	8 320 v	2	24 210
Two	17.2 ohms	16 640 v	4	48 420

Air Supply

The compressed air is supplied to each of the three reservoirs through three insulated air columns (Fig. 8). Each of these contain three 57-foot hose lines. One hose line is connected to the underground air line running from the compressor house. Another relays a signal to the compressor house when the automatic by-pass switches are closed. The third furnishes compressed air for resetting the by-pass switches to the open position. This operation, however, cannot be performed without first removing voltage from the capacitor by closing the main high-voltage by-pass switch; the isolating switches need not be opened.

The compressor house contains a large air reservoir where air pressure is raised to 200 pounds. From here it passes through a reducer and then flows through an activated alumina dryer that prevents moisture condensation in the air columns or valves.

In many locations an auxiliary source of power is not available for operating a compressor. In such cases the compressor can be operated from the voltage drop across the series capacitor. If each phase of the series capacitor contains more than one platform assembly, each assembly includes a compressor that derives its power from the voltage drop across the capacitor units on a single insulated platform.

A typical arrangement of a series capacitor having two separately insulated platforms per phase is shown in Fig. 9. Typical ratings for such an installation are given in table II. Each platform in Fig. 9 contains two groups of capacitors operated in series, with the midpoint connected to the supporting platform. Such an arrangement makes it possible to divide each phase into four separate capacitors that can be operated in series. This is desirable in very large series capacitors so that the electrical size of any single group of capacitors can be limited to about 5000 kvar. Then, if a unit fails, the energy released through an individual fuse is limited and the compressed-air protective gap can be standardized in the most favorable working range.

Each of the groups of capacitors on a platform can be enclosed in a metal-clad housing, or it may consist of one or more open-type racks containing outdoor-type capacitor units. This type of construction is shown in Fig. 10. Where these open-type racks are used on high-voltage lines it is necessary to provide an electrostatic shield to prevent sharp points such as fuses and terminal studs from causing corona. The racks in Fig. 10 are made of large-diameter pipe so that the rack itself shields against corona.

Since each platform in Fig. 9 provides a connection common to the two groups of capacitors it supports, one air reservoir and two gaps and resistors are used to protect these two groups. These are mounted at the end of each platform.

The voltage drop across both groups of capacitors on a single platform can be stepped down and used to operate the air compressor. The transformer for this purpose and the compressor equipment are located in the lower portion of a metal-clad cubicle as shown in Fig. 11. This cubicle is placed between the gaps and the capacitor unit assemblies in Fig. 9.

When the compressed air supply is located in the cubicle, the pneumatically operated by-pass switch previously described is not necessary. Therefore, another type of switch has been developed. This switch is mounted in the same cubicle as the compressor, and consists of a spring-closed disconnect-type switch with a latch that holds it normally in the open position. The switch is manually opened to this latched position by means of a lever that projects from the side of the cubicle. This lever is moved with a hook stick used from the ground when the equipment is de-energized. Visible indicators show whether the switch is open or closed.

Two of these switches are used to by-pass each group of capacitors on a platform. As shown in Fig. 12, they are equipped with two mechanisms, one operating on voltage and one on current. The voltage mechanism trips the latch and allows the switch to close when (a) a voltage relay in the cubicle detects prolonged operation at voltages in excess of the continuous-voltage rating of the series capacitor, or (b) the same relay detects overvoltage across the capacitor due to a change in the reactance of the capacitor, as would happen if a number of fuses operated to disconnect capacitor units.

The current mechanism trips the latch and allows the switch to close when current through the gap is prolonged. This would happen if for any reason the air supply should fail and prevent the extinction of the arc in the gap.

The voltage ratings of the capacitor units are governed largely by the number of platforms used. For capacitors rated at 10 000 kvar or less, one platform per phase would normally be used, with an additional platform for each additional 10 000 kvar, or fraction thereof, per phase.

Conclusions

Availability of the newly developed compressed-air by-pass gaps should now remove the long-standing obstacle that has hindered the use of series capacitors to improve the transfer of electric power. Simplifications and improvements incorporated in the most recent designs described should result in a more general application to other systems.

Some of these protective-device developments now available will make it possible to build large series capacitors for elimination of light flicker in sizes and voltage ranges not adequately covered by earlier protective equipment.

The effective principle of the air-blast gap is its self-clearing characteristic when air flows through it. This makes it possible to use it as a synchronous switch to cut in the resistor and thus provide lower overall impedance sufficient to handle the fault current. This action as a synchronous switch is affected by many factors such as capacitance, air velocity, gap breakdown, fault current, electrode material, and air distribution over the center electrode. Each application requires careful analysis, particularly of fault current values and the relationship of fault current to reinsertion currents.

One undesirable phenomenon associated with series capacitors is sub-synchronous resonance of a motor during starting, which occurs when a series capacitor causes a motor to generate large undamped currents of low frequency. This happens when the motor-stator and circuit resistance is low compared to the reactance of the capacitor, and can generally be eliminated by permanently connecting a suitable resistance in parallel with each phase of the capacitor. Although a problem in light-flicker applications, sub-synchronous resonance is normally not encountered in power-transfer applications.

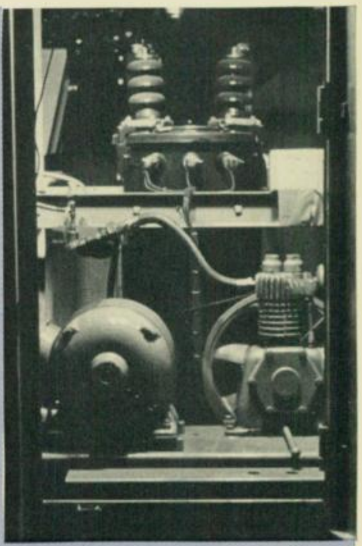


Fig. 11—Where a compressed air supply is not available, the compressor equipment can be mounted in the switch cubicle as shown here. Power to run the motor comes from the voltage drop across the capacitor.

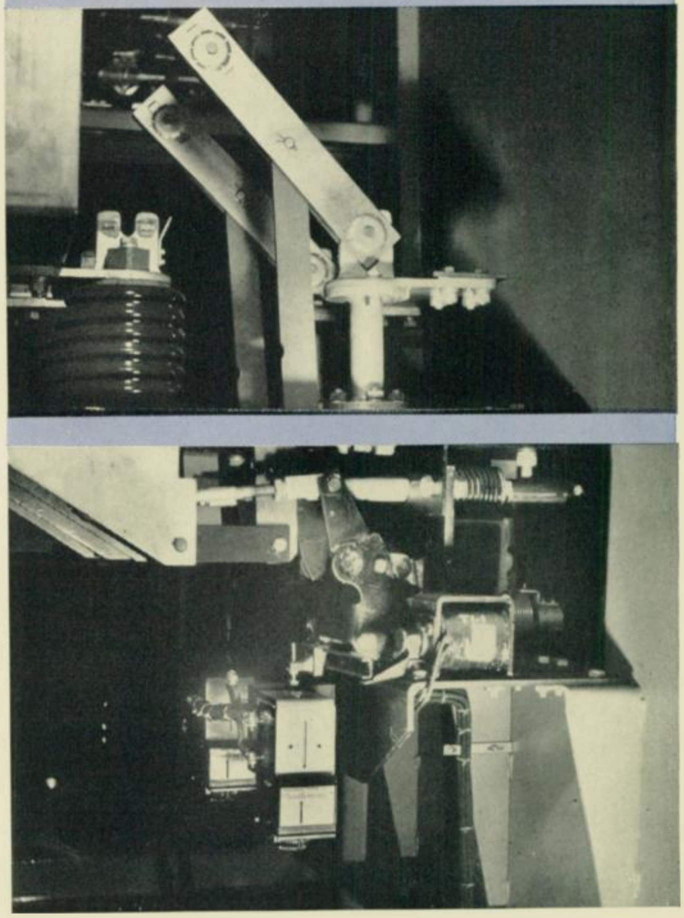


Fig. 12—This automatic by-pass switch shunts the series capacitor under abnormal conditions. The two trip units can be seen in the lower picture. The springs at the upper right of the lower picture control the position indicators on the outside.

Corona Loss at Extra-High Voltages

Corona presents a serious problem on transmission lines at voltages above 230 kv. As more lines at these extra-high voltages are built a better understanding of corona becomes increasingly important. Although there still is much to be learned, high-voltage investigations are giving us a more complete knowledge of the phenomena.

R. L. TREMAINE AND A. R. JONES
Central Station Engineering
Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania

OTTO NAEF
Electrical Engineering Department
American Gas and Electric Service Corporation
New York, New York

As TRANSMISSION voltages are raised, corona becomes increasingly important in the design of transmission lines. The highest voltage line in use today is the 287.5-kv Hoover Dam–City of Los Angeles line, which has been in service for 15 years. Now, voltages are going still higher. The Swedes are building a 380-kv line, scheduled for completion in 1951. The French are planning to convert an existing double-circuit 220-kv line to single-circuit, 380 kv. The Swiss have two lines crossing the Alps, which they plan to convert later from 220-kv to 380-kv operation. The towers on these lines are designed for 380 kv. In the United States, the American Gas and Electric Company is building a 300/315-kv line.[13]

In the design of extra-high-voltage lines, the manifestations of corona, both radio influence and corona loss, are very important. Corona is a partial breakdown of air, defined by AIEE as a "luminous discharge due to ionization of the air surrounding a conductor around which exists a voltage gradient exceeding a certain critical value." Air in the vicinity of the conductor becomes conducting while the remainder acts as an insulator. Radio-influence fields are produced by the steep-front pulses of corona current. Radio influence will be discussed in greater detail in a subsequent issue.

Theory of Corona

A voltage applied to a smooth, round conductor produces a charge on that conductor, and establishes a uniform voltage gradient in the surrounding air. The magnitude of this gradient varies inversely as the distance from the center of the conductor. When the air adjacent to a conductor is electrically stressed above a certain critical gradient, a corona discharge occurs. Since voltage gradient is proportional to applied voltage, there is a definite maximum voltage that can be applied to a conductor without the formation of corona. This voltage is given by eq 1.

For transmission-line corona-loss calculations, both Peterson[1] and Peek[2] give the critical gradient, g_0, in eq 1 a value of 21.1 kv per centimeter, rms. However, recent work[3] indicates that the critical gradient is more accurately determined by eq 2. This is the equation Peek gives for visual gradient.

Effect of Conductor Surface on Corona Characteristics

The maximum critical voltage, assuming constant outside diameter, is obtained with a smooth conductor. The degree by which the actual surface of the conductor deviates from a smooth cylinder, and thus reduces the critical voltage, is indicated by the surface factor, m. Based on recent data on weathered conductors, the surface factor for segmental conductors is about 0.92. For stranded conductors it is about 0.82 to 0.85. Thus, so far as corona is concerned, a segmental conductor in fair weather is good for about 112 percent of the voltage of a stranded conductor. But, as pointed out later, segmental conductors cannot necessarily be operated at 112 percent of the voltage of stranded conductors.

Conductors are subject to both short-time and long-time aging. Short-time aging is of little importance except in corona testing.[4] If an operating line is de-energized a day or more, the corona performance is worse when the line is energized again; but it returns to normal in a matter of hours. The reason for this is not clearly known, but it is presumed to be a characteristic of the surface contamination of the conductor. When a conductor is de-energized, small dirt particles collect on it and project from its surface. Then, when voltage is applied, the gradient at the surface of these particles is higher than it is at the surface of the conductor and excessive corona results. The action of corona, or the electric field itself, apparently reduces these projections.

Of somewhat more importance is the long-time aging characteristic, which also is not completely understood. New conductors require 6 to 12 months to become stabilized, and the fair-weather corona performance of new conductors is likely to be worse than that of aged conductors. A large part of the high corona losses on a new conductor can be attributed to die grease, die burrs, scratches, and dirt deposited on the surface by handling. If the surface is cleaned and visible defects are corrected, corona loss is reduced—but not so much as it would be reduced by aging. This is true even though the strong electric field surrounding an energized conductor precipitates dirt on the surface of the wire, making it appear rougher than a new conductor. This is shown in Fig. 1. It is hard to explain how this surface deposit reduces corona loss.

An analysis of the surface contamination on an aluminum conductor, which had been in service for about 18 months on the Tidd 500-kv test lines, showed no compounds of aluminum.[3] Corona produces ozone and oxides of nitrogen, and, in the presence of moisture, nitric acid. These have a negligible effect on aluminum.

Effect of Weather

Weather affects corona performance more than anything else. Corona is so extremely sensitive to weather variations that successive fair-weather tests made under ostensibly the same weather conditions do not yield consistent results. Corona-loss data, obtained at Tidd[5] for the same test voltage at intervals of one to two weeks, give fair-weather losses of 10.5, 3.5, 11.0, 4.0, 1.5, 6.0, 10.0; and, in another series of tests, 1.2, 1.4, 1.0, 21.0, 2.2, 3.4 kw per mile. These data have been corrected by accepted methods to standard atmospheric conditions. They were taken at voltages where the rate of change in corona loss with change in voltage is high, thus magnifying this effect to some extent. Large conductors are more sensitive to weather than small conductors—probably because, once started, corona increases more rapidly on large conductors than on small conductors.

One of the most important single weather conditions causing corona is rain. The Tidd tests show that on a 2.00-inch ACSR conductor in a given configuration, under the best fair-weather conditions, 520 kv produces a corona loss in the order of 21 kw per mile. Under the most severe rain condition experienced, this same loss was produced at 270 kv—just over half of the fair-weather voltage. On the 1.65-inch HH conductor in best fair weather 515 kv causes a corona loss of 25 kw per mile. The same loss in worst bad weather occurred at 270 kv. These observations show that it is not practical to design a line such that it would never be in corona under any weather condition, because the conductors and towers necessary would be too large to be economical.

During the most favorable fair weather at Tidd the corona performance of the 1.65-inch HH conductor is slightly better than that of the 2.00-inch ACSR conductor. However, the average loss on the 1.65-inch HH under all weather conditions is some 50 percent greater than the 2.00-inch ACSR, except at very low voltages. Graphic measurements indicate that the 1.65-inch HH has the same average corona loss at 365 kv as the 2.00-inch ACSR at 380 kv. This shows that fair-weather observations can give misleading results; the all-weather performance of a conductor is more important.

Other adverse weather conditions also affect corona loss. On experimental lines, condensed moisture and hoarfrost cause extremely high losses; but these conditions are believed to be particularly pronounced on experimental lines. On an operating line, I^2R loss normally keeps the conductors above ambient temperature, and condensation or hoarfrost is less likely to occur.

Equation 1. $E_0 = g_0 \delta^{2/3} r m \log_e D/r$

where,

E_0 = critical disruptive phase-to-neutral voltage in kv

g_0 = critical gradient in kv per centimeter

r = radius of conductor in centimeters

D = distance in centimeters between conductors for single-phase, or the equivalent phase spacing for three-phase voltages.

m = surface factor

δ = air density factor

Equation 2. $g_0 = 21.1\ (1 + \frac{0.301}{\sqrt{\delta r}})$ in kv per cm, rms

Equation 3.

$$\delta = \frac{17.9 \times (\text{barometric pressure in inches of mercury})}{459 + (\text{temperature in degrees F})}$$

Equation 4. $g = \frac{e\,(1+2r/S)}{2r\, ln\, D/\sqrt{rS}}$

where,

g = maximum voltage gradient in kv per cm

r = radius of one subconductor in cm

D = center-line distance in cm between bundles for single-phase, or equivalent phase spacing for three-phase voltages

e = voltage to neutral in kv

S = separation between subconductors in cm

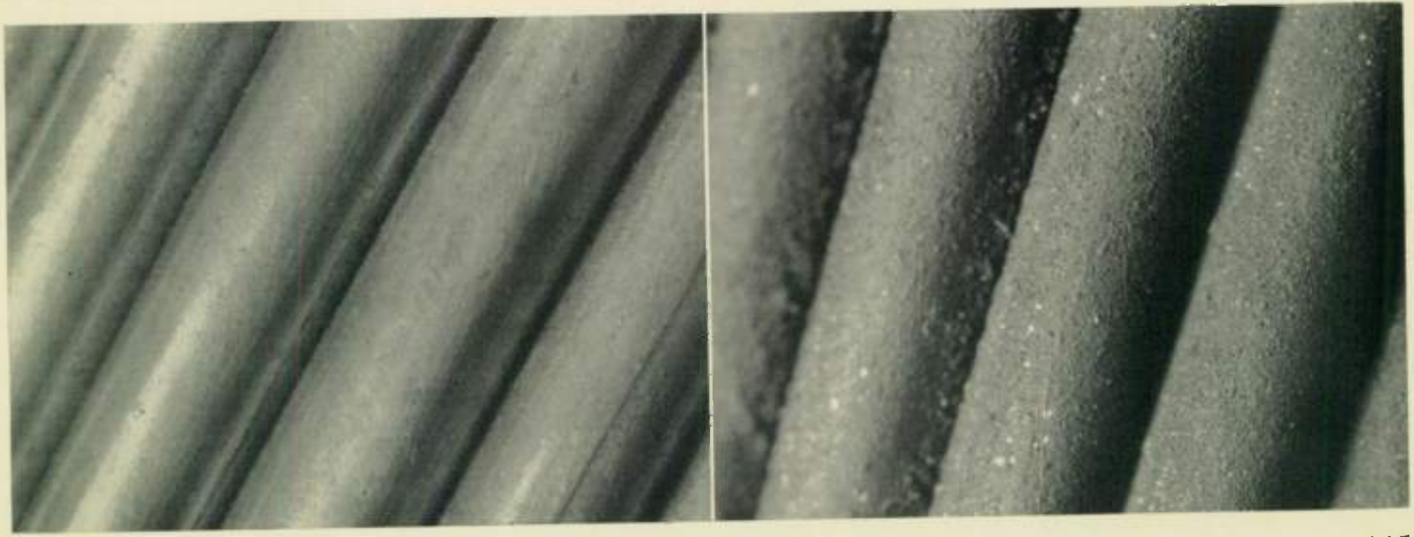
Equation 5. $E_0 = \frac{g_0\, m\, \delta^{2/3}\, 2r \log_e D/\sqrt{rS}}{1+2r/S}$

Equation 6. $g = \frac{e\,(1+r/S)}{2r\, ln\, D/\sqrt{rS}}$

Snow causes only a comparatively small increase in corona loss. During the storm last winter when 30 inches of snow fell on Pittsburgh, test conductors at Tidd (50 miles from Pittsburgh) were energized at 330 kv. The average corona loss was only 7 kw per mile on the 2.00-inch ACSR conductor. During heavy rain the average loss at that voltage is 50 kw per mile.

High humidity causes only a slight increase in corona loss. No effect from atmospheric gradient has been determined.

Fig. 1—You can see from these microphotos how the appearance of a two-inch ACSR conductor changes with age. The picture at the left is a new conductor. The one at the right is the same conductor after 18 months of service at Tidd. It looks a lot rougher, and feels a lot rougher, but, with this black deposit on the conductor, corona performance is improved.[3]



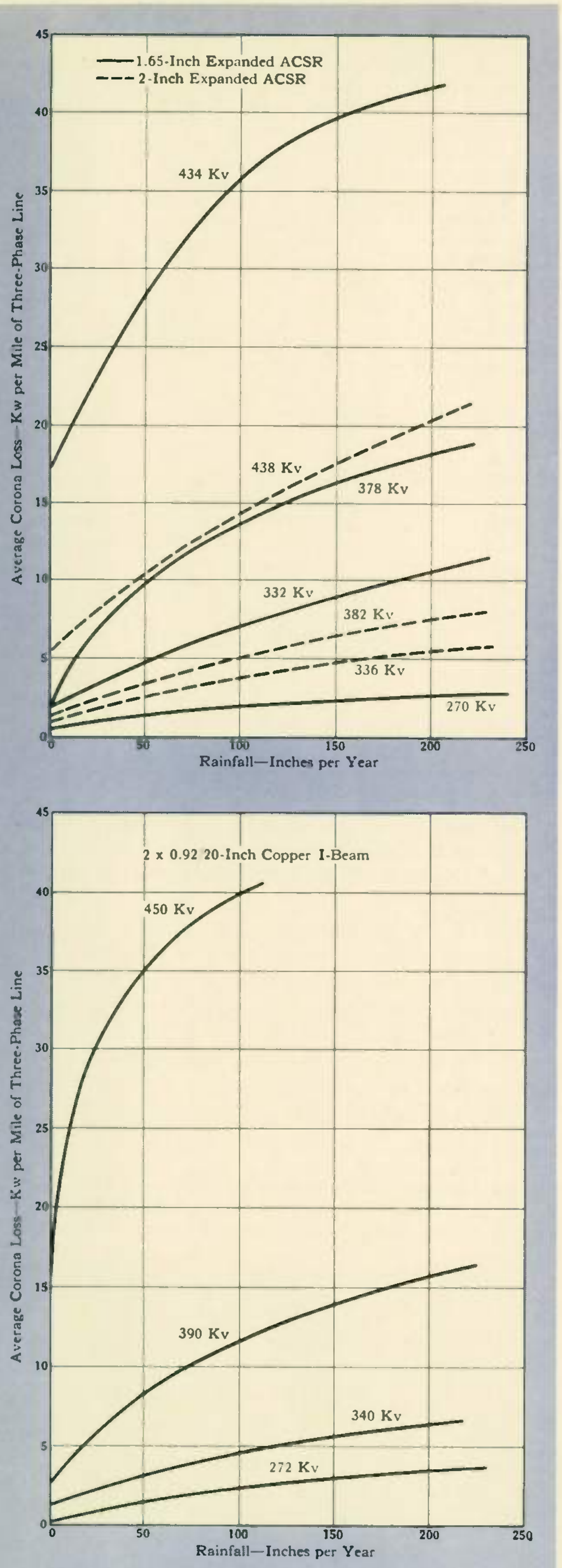


Fig. 2—These curves show the effect of rainfall on corona at the Tidd 500-kv test project. The top two sets of curves give a comparison between the performances of two ACSR conductors. The curves in the lower graph are for a two-conductor bundle. Loss and precipitation were averaged for several months during both fair- and foul-weather periods. All voltages are line-to-line for 32-foot flat spacing.[6]

Temperature and barometric pressure also affect corona performance. This is accounted for in the disruptive voltage equation by the air-density factor, δ, given by eq 3. One authority states that the temperature to be used in this equation may be considered conductor temperature. Practically, this is a rather indeterminate quantity; and since other factors affect corona more than temperature, air temperature is a satisfactory value to use. It is generally agreed that the effect of temperature and barometric pressure is most accurately evaluated by including $\delta^{2/3}$ in the equation for critical voltage. For normal weather conditions prevailing in the United States, the air-density factor does not deviate greatly from one, so in general it can be neglected. However, for lines at high altitudes or where extreme temperatures are encountered, it must be considered. But the corona information at high altitude and under extremes of temperature is very limited, and the accuracy of correcting for extreme conditions by multiplying by $\delta^{2/3}$ has not been verified. Losses higher than expected have been observed in the desert.[6]

The critical voltage of a conductor provides an index to fair-weather corona characteristics, but does not necessarily indicate performance during adverse weather conditions. With a normal line design, corona is negligible during fair weather. Thus, foul-weather operation would appear to be the best criterion of acceptable corona performance.

An evaluation of corona loss during foul weather can be made if the weather conditions along the transmission line and the effect of weather factors on the conductor are known. Such an analysis will not necessarily show the same relative performance as is indicated by the critical voltage obtained for fair-weather conditions.

For this reason, care must be exercised in comparing stranded and segmental conductors. Tests on equal diameter stranded and segmental conductors show that the segmental conductor has superior performance during fair weather as would be expected. During most bad-weather periods the segmental conductor gives better corona performance; but during extreme bad weather the difference becomes smaller. This result has been obtained by rain tests in the Westinghouse High-Voltage Laboratory under controlled conditions and by measurement at the Tidd Test Project in bad weather.

Effect of Conductor Spacing

In addition to surface and weather factors, line configuration also affects corona performance. A wealth of information in the literature shows that, as stated in reference 6, "the corona loss of a conductor can be completely determined in terms of the nominal gradient at the surface for given weather and surface conditions. Nominal gradient as defined here is that gradient that would exist at the surface if there were no corona present and the conductor were a perfect cylinder." Thus, line configuration affects corona through its effect on the voltage gradient at the surface of the individual phase conductors. Engineering accuracy in estimating the effect of configuration can be obtained by noting the change in E_0 of eq 1 for different configurations. The improvement in corona performance with increased spacing is only moderate. For example, increasing the phase spacing from 32 to 45 feet reduces the average gradient only about 5 percent. Thus, in general, instead of improving corona performance by increasing phase spacing, it is more efficient to increase conductor size or to use bundle conductors, i.e., two or more wires used to form one phase conductor. Phase spacing should be determined from insulation and operating requirements. Then a conductor is selected that has the desired corona characteristics.

A very small amount of ionization is always present in the earth's atmosphere. This ionization is produced at low altitudes by cosmic radiation. Although these ions occasionally collide with neutral particles, they do not cause cumulative ionization, the phenomenon of corona and sparkover.

However, if a voltage gradient is established in air, the free electrons are accelerated. When the gradient around a transmission-line conductor reaches approximately 30 kv per centimeter, the electrons move fast enough to produce cumulative ionization and conduction. If this electrical breakdown of the air occurs only in the vicinity of one or both conductors, it is called corona. A complete breakdown from one conductor to the other is called a sparkover. Whether the breakdown results in corona or in a sparkover depends on the geometry of the setup. On parallel wires, corona is formed when the ratio of the separation of the wires to the conductor radius exceeds 5.85.[14] Since this ratio is always very much greater on practical transmission lines, corona occurs.

Negative and Positive Corona

When a free electron near the surface of a negatively charged conductor is accelerated to sufficient velocity by the electric field, ionization by collision occurs. This produces positive ions, and more free electrons. The positive ions are then attracted toward the negative conductor, and bombard it with sufficient energy, received from the field, to free more electrons. Thus, the discharge becomes self-sustaining and remains so as long as the electric field is maintained. The electrons released in this process move away from the conductor, and most of them quickly form negative ions by attachment to neutral particles. Since negative ions have a relatively low mobility, they migrate slowly away from the conductor in the form of a negative space charge. If the voltage on a smooth conductor (cylinder) is barely enough to produce corona, corona discharges are very random, occurring first at one point, and then at another, depending on localized surface conditions.

With positive voltage, the formation of corona is similar in that ionization by collision occurs. However, the free electrons are attracted toward the wire, and collisions with neutral particles form electron avalanches that maintain the highly ionized state around the conductor. The positive ions produced by these avalanches are repelled from the conductor and form a positive space charge in the vicinity of the conductor.

A-C Corona

The formation of corona by a-c voltage is more complex, because corona on one half cycle is affected by the space charge left from the previous half cycle of corona. As shown in the illustration, right, if we assume an a-c voltage starting at zero without transients, the dielectric strength of the air is exceeded when the instantaneous voltage reaches the critical disruptive voltage, E_0* (taken as 70 percent of the applied voltage in the illustration). Ionization occurs at that point and positive corona current "flows" into the space around the conductor. A rapidly increasing positive space charge is formed as long as the applied voltage continues to rise. Considerable energy is required to form the space charge; so the current is large as long as the voltage is increasing. However, when the crest of the voltage wave is reached, the volume of air being ionized is no longer increasing rapidly, and only a comparatively small current is required to maintain ionization. For all practical purposes, corona current stops at the voltage crest. A space charge requires a long time to deionize compared to a half cycle of power frequency; so it remains in the air surrounding the conductor as the voltage decreases. The charge on the conductor is then determined by the applied voltage and the space charge. For simplicity, the effect of space charge can be considered to be a voltage which is the difference between the crest of the applied voltage and the critical corona voltage. When the polarity of the voltage reverses, the critical gradient is exceeded and ionization starts before the critical disruptive voltage is reached. The instantaneous starting voltage is given by $2E_0—e$. As shown in the illustration, the first action of ionization on the negative half cycle is to neutralize the positive space charge left from the previous half cycle. This action is completed when the voltage E_0 is reached. A negative space charge is then formed, as previously described, with negative corona current stopping at the crest of the negative half cycle. This process is not cumulative and ionization starts again at $2E_0-e$ on the positive half cycle.

As voltage is increased above the critical value for air, the instantaneous voltage at which corona starts $(2E_0-e)$ becomes smaller. This probably accounts for the rapid increase in corona loss as voltage is raised. If the applied voltage is more than twice the critical voltage, corona on one half cycle starts during the previous half cycle before zero voltage occurs.

Observable visual and aural characteristics are associated with corona. Corona at moderate voltages on small wires (No. 18 and below) is characterized by a bluish-white glow, and a quiet buzzing or humming sound. However, on large conductors (one half inch and up) the visual effects of corona are different. On the positive half cycle there is a streamer or plume discharge consisting of a bright filament radiating from the conductor for a distance of 1 to 4 inches. The filament terminates in a barely visible, luminous glow that is roughly hemispherical, extending between 6 and 15 inches from the conductor. Some streamers remain fixed while others dance merrily around, and along the conductor. As voltage is increased the streamers get larger and closer together. At the Tidd 500-kv test project this separation ranges from 6 to 200 feet.

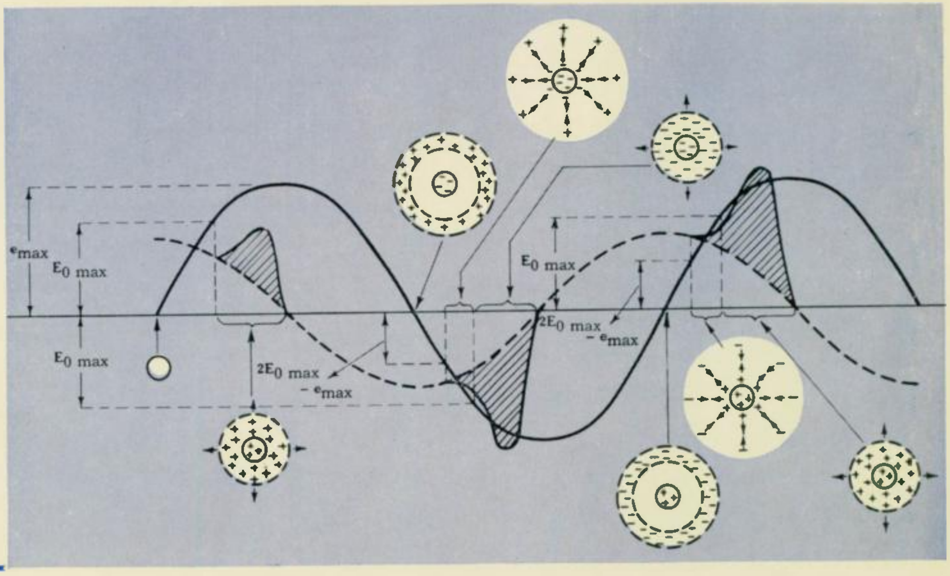
In contrast, negative corona appears as short (1 to 3 inches), straight filaments of light only a few inches apart, extending radially from the conductor. They are almost completely fixed and tend to cluster at points of highest stress. Raising the voltage increases the density and number of the filaments and to some extent their length. Negative corona usually cannot be seen from the ground with the unaided eye. Without a stroboscopic device, both polarities of corona are seen simultaneously.

Aurally, corona ranges from an occasional, barely audible spit at a voltage just above the critical, to an angry, crackling sound superimposed on a pronounced 120-cycle hum at very high voltages.

---

*All voltages referred to in this paragraph are maximum values, since strictly corona is a function of instantaneous voltage rather than rms voltages.

Corona current and the formation of space charge are illustrated in the sketch below. The shaded areas show how corona current distorts the normal current wave. Circular areas show the distribution and polarity of the space charge along the voltage wave (the solid curve). For purposes of illustration, the broken circles show definite boundaries around the space charge although these boundaries actually are diffused and indefinite.



Economics of Corona Loss

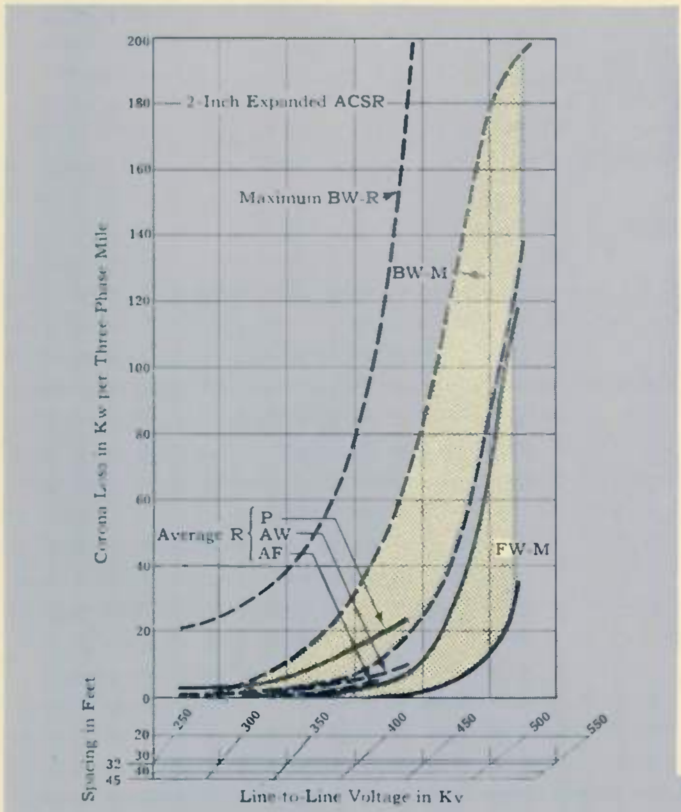
Experience shows that 230-kv lines designed for a fair-weather corona loss up to one kw per mile of three-phase line, according to Peterson's formula[1], have satisfactory corona performance. In the case of 138-kv lines considerable margin below a corona loss of one kw per three-phase mile usually is required during fair weather.

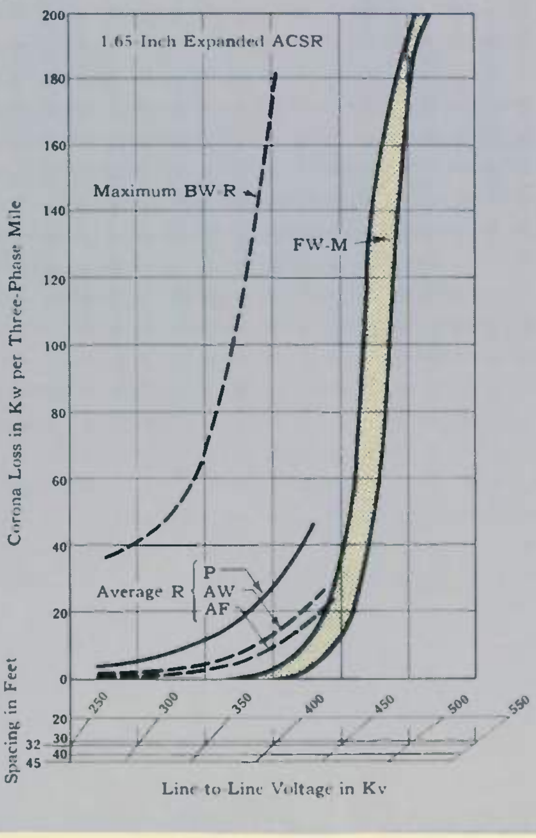
More important than fair-weather loss is the average corona loss for a year. This is the loss the utility must pay for. Since rain is the most important factor affecting corona loss, the Tidd investigators have attempted to correlate average corona loss and annual rainfall. The results are shown in Fig. 2. With a 2.00-inch ACSR conductor, operating at 380-kv line voltage, and 50 inches of rain per year, the average corona loss is of the order of 3 kw per three-phase mile. Even twice this much would not be economically important. The I^2R loss on such a line, operated at safe loading, is about 140 kw per three-phase mile, with the average loss perhaps half of this value. This value of loss is based on the assumptions of a 250-mile line, a permissible loading of 1.2 times surge-impedance loading, and a conductor resistance of 0.1084 ohm per mile. Thus, annual corona loss appears to be of little economic importance in the design of extra-high-voltage lines.

The determination of the peak value of corona loss to be expected on a transmission line is extremely difficult. An accurate prediction of this would require a knowledge of all the rates of rainfall that could exist simultaneously along an entire line. Such information is obviously impossible to obtain. However, since high rates of rainfall do not exist simultaneously over extremely large areas, it is probable that the maximum loss on a long transmission line is the loss corresponding to a light rain, say 0.1 inch per hour. This rate corresponds to the lower values of manually recorded foul-weather data given in Fig. 3. For shorter lines, higher rates of rainfall should be used.

Bundle Conductors

Bundle conductors are phase conductors made up of two or more wires. This idea is not new, having been proposed as far back as 1909 by P. H. Thomas. They are the subject of two patents issued in 1910. However, their use had to await actual





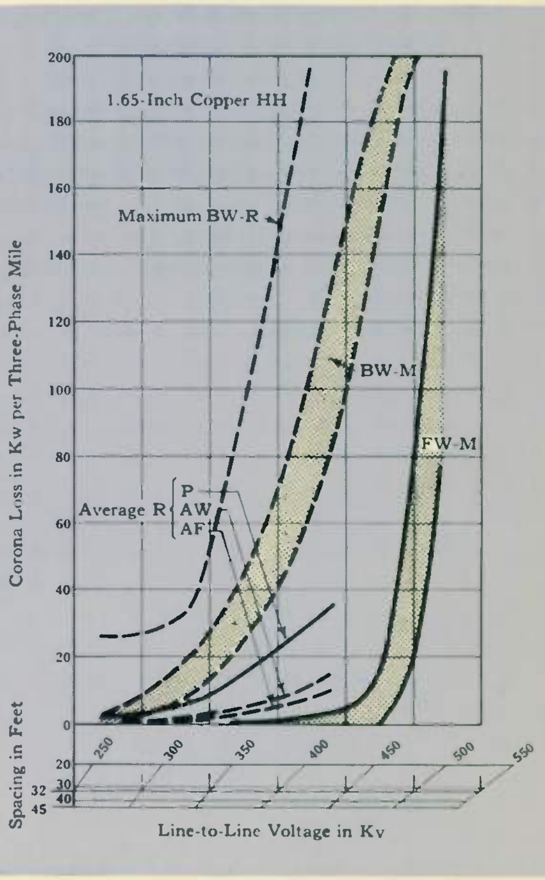


Fig. 3—The shaded areas indicate the corona loss variations of different conductors for fair- and foul-weather performance as obtained from the Tidd 500-kv corona tests.[4] The abscissa changes for different conductor spacing, as indicated under each graph. The voltage lines along the abscissas are plotted for direct reading at a phase-to-phase conductor spacing of 32 feet.[6]

Abbreviations used:

Avg R	**—obtained by averaging the graphically recorded data.**
M	**—manually recorded data.**
R	**—graphically recorded data.**
P	**—sufficient precipitation to give an indication on a standard rain gauge.**
BW	**—foul weather.**
FW	**—observed fair weather conditions.**
AF	**—apparent fair weather—no indication of precipitation on a standard rain gauge.**
AW	**—all weather.**

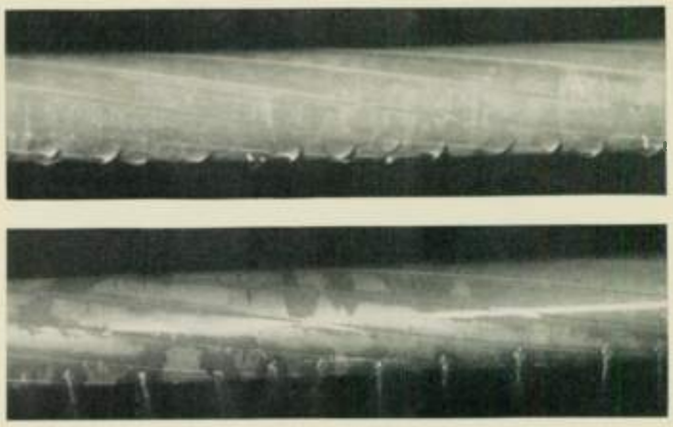
construction of extra-high-voltage lines. Double conductors were first used by the Swedes on their 220-kv system and are being used on their new 380-kv line.

Bundle conductors offer several advantages: low corona loss without excessively large conductors, improved corona characteristics during foul weather[10, 15], reduced surge impedance with consequent higher power capabilities, and increased reactive kva where this can be used to advantage. Weighing against these advantages is higher cost.

Comparisons between bundle- and single-conductor construction costs are limited except for information supplied by the Swedes.[7] They have been able to justify two-conductor bundles for 220-kv transmission on the basis that while the cost is increased 21 percent, the power capability is increased 30 percent, thus resulting in a net decrease in the cost of power transmission in their case.

Bundle-conductor corona performance differs considerably from that of single conductors. Because of the presence of a second conductor in a two-conductor bundle, the voltage gradient around the surface of a subconductor is not uniform. It varies in a cosinusoidial manner from a maximum at a point on the outside of the subconductor on the line of centers to a minimum at the corresponding point on the inside. This is shown in Fig. 4. The maximum value of the gradient on a two-conductor bundle conductor is given by eq 4.[8] Equation 5 gives the critical voltage. Wagner[8] also gives the equations for surface voltage gradients on bundles made up of more than two sub-conductors.

The French[9] state that the corona performance of a bundle is more accurately indicated by the mean between the average and maximum gradient, given by eq 6, because of the non-uniform gradient. The French work indicates that this value should be used when estimating corona performance.

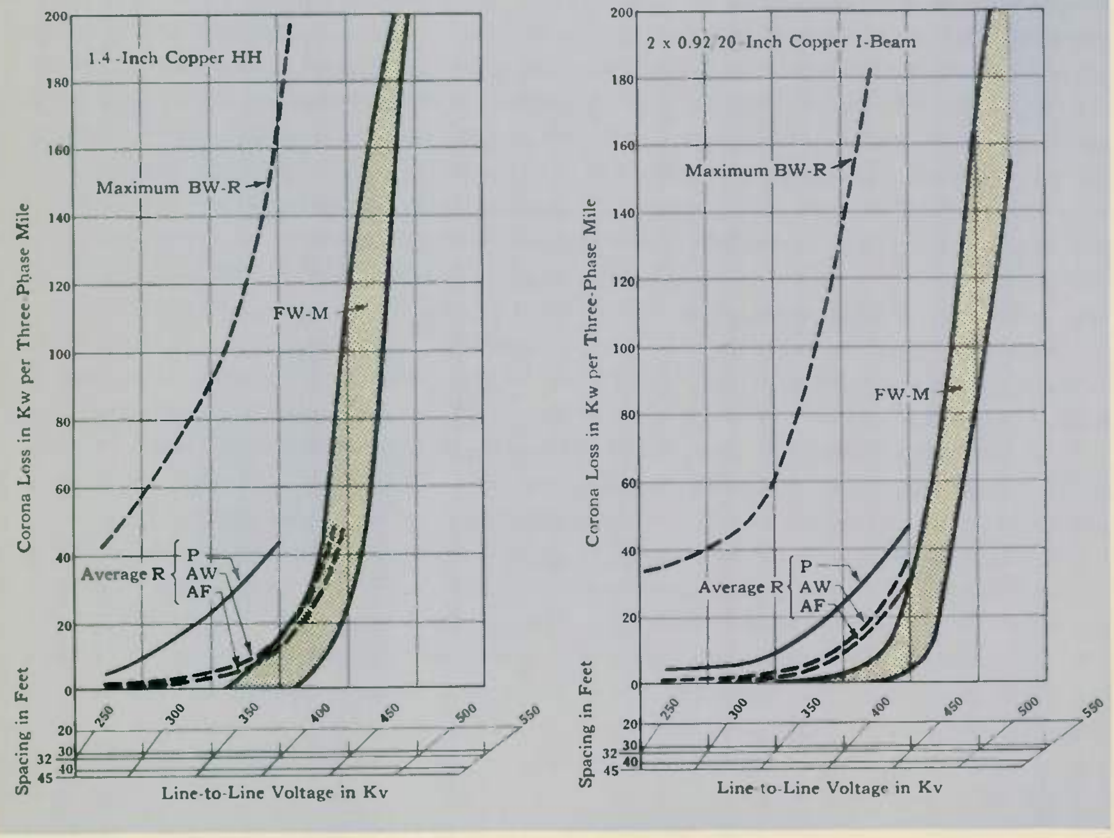


These photographs show a 1.4-inch HH conductor subjected to artificial rain in the high-voltage laboratory. The top picture was taken with no voltage applied. The bottom one, taken with voltage applied, shows the effect of corona—note the regular spacing and changed shape of the water drops caused by the corona discharge.

Until more information is available it is probably safest to determine gradient using eq 4. This does not have much effect on conductors at large separations, but does penalize conductors at small separations.

Because the relation between foul-weather and fair-weather corona loss is not necessarily the same for bundle conductors and single conductors, an accurate comparison of the two types of conductors is very difficult. It should be based on actually measured foul-weather performance rather than on fair-weather operation. However, a very approximate idea of the relative merits of the two types of conductors may be obtained by computing the critical voltage at which corona starts in fair weather.

Using eqs 1 and 5 it can be shown that a two-conductor bundle can be operated at about 150 percent of the voltage of a single conductor of the same diameter. Therefore, bundle conductors offer a relatively inexpensive way to increase the operating voltage of existing lines where the present towers have sufficient size and mechanical strength. This idea is particularly attractive where there is enough margin in the existing conductors and towers to permit use of the next standard operating voltage.



Extra-High-Voltage Projects

The Europeans have shown more interest in extra-high-voltage transmission than we in the United States. This is primarily because they have more need for the transmission of large blocks of power over great distances. In Sweden, the water power is in the central and north-

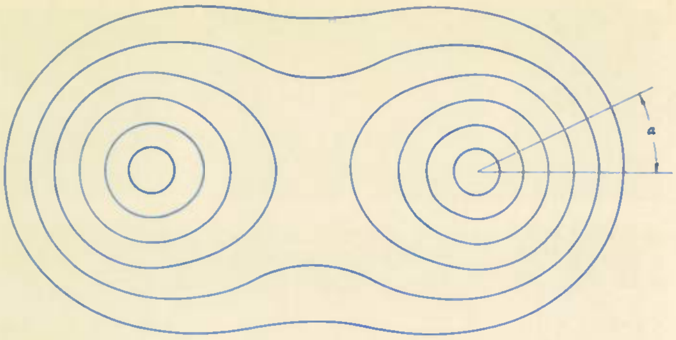


Fig. 4—This sketch shows the voltage pattern around a two-conductor bundle. The voltage gradient at the surface of each conductor is a minimum on the inside at the center line between the conductors, and a maximum on the outside at the center line.

ern parts of the country, with the bulk of the load in the South. In France most of the water power is in the central and southern parts of the country with the bulk of the load in Paris and along the coast. In Germany, the water power is in the South and most of the load is in Berlin and Western Germany. Therefore, long transmission lines are required.

During the war, the Germans did considerable work on bundle conductors.[10] They planned a tremendous extra-high-voltage transmission system to bring power from the Scandinavian Peninsula and from Southern Germany to the industrial areas of Europe. At present, they are considering a four-conductor bundle in Southern Germany so that they can operate a line at a much higher voltage than it was originally designed for. With phase spacing limited, the four-conductor bundle offers a means of obtaining satisfactory corona performance. For voltages contemplated today, however, bundles of more than two conductors probably will not be used except in similar circumstances.

France has a 251-mile, double-circuit, 220-kv line that runs from Breuil in central France to the outskirts of Paris. This line was designed to operate eventually at 400 kv maximum. The towers have single crossarms with all six line conductors in one plane. Stranded 1.04-inch aluminum conductors are used. The French plan to use these same conductors in a two-conductor bundle when the voltage is changed. Eventually they will need a number of extra-high-voltage lines roughly paralleling their present line.

The Swedes[11] have almost completed their first 380-kv line from Harspranget to Midskog to Hallsberg. This line has a two-conductor bundle of 1.25-inch stranded aluminum conductors separated 17¾ inches. The Midskog terminal of this line eventually will be the central point of a major 380-kv system. As it becomes economical to develop more water power in the north, these plants will be tied in, and their 380-kv system will be extended south to Goteberg, making the total length from end to end 600 miles.

The Swiss[12] have constructed two circuits from Riazzino to Mettlen across the Alps. They plan to operate them ultimately at 380 kv—they are now in service at 225 kv. From Lavargo to Amsteg they follow separate routes. The remainder is double circuit. The towers will be adequate, but the conductor will have to be restrung when the change to higher voltage is made. These lines will reach an altitude in one place of over 8000 feet. If single conductors are used, smooth copper conductors of 1.97 to 2.36 inches diameter are planned on the high-altitude section, and conductors of 1.81 inches diameter on the lower (below 3300 feet) altitude section. Bundle conductors are under consideration for the entire line.

In the United States, the American Gas and Electric Company is building a 63-mile, 300/315-kv line from the Philip Sporn Station to the Kanawha Station. Single-conductor construction, using 1.60-inch diameter expanded ACSR, has been chosen. This line will be the first section of an extra-high-voltage "backbone" for their system, which ultimately will extend from Roanoke, Virginia to New Carlisle, Indiana.

The Future

There are a number of possible locations for extra-high voltage lines, particularly in connection with remote hydro-electric power developments that might be built. Many of these developments hinge on the economics of transmission of power over long distances.

Much work is still to be done before the corona characteristics of conductors for use on extra-high-voltage lines can be predicted with a high degree of accuracy. With presently available information, lines can be built with reasonable assurance of satisfactory corona performance, but perhaps future work will allow the use of smaller conductors for a given voltage. As operating experience is gained and further experimental work is completed, more accurate prediction of a line's corona performance will be possible.

REFERENCES

1. "Development of Corona Loss Formula" (discussion), by W. S. Peterson, *AIEE Transactions*, Vol. 53, pp. 62–3.
2. "Dielectric Phenomena in High Voltage Engineering" (a book), by F. W. Peek, Jr., McGraw-Hill Book Company, 1929.
3. "Radio Influence Test in Field and Laboratory—500-Kv Test Project," by G. D. Lippert, W. E. Pakala, C. D. Fahrnkopf, and S. C. Bartlett, presented at Winter General Meeting of AIEE, New York, Jan. 1951.
4. "Techniques of Corona Loss Measurement and Analysis—500-Kv Test Project of the American Gas and Electric Company," by O. Naef, R. L. Tremaine, and A. R. Jones, presented at Winter General Meeting of AIEE, New York, Jan. 1951.
5. "Corona Investigation on Extra-High-Voltage Lines—500-Kv Test Project of the American Gas and Electric Company," by I. W. Gross, C. F. Wagner, O. Naef, and R. L. Tremaine, presented at Winter General Meeting of AIEE, New York, Jan. 1951.
6. "Desert Measurements of Corona Loss on Conductors for Operation above 230 Kv," by W. S. Peterson, B. Cozzens, and J. S. Carroll, presented at AIEE Convention, Pasadena California, June 12–16, 1950.
7. "Series Capacitor and Double Conductors in the Swedish Transmission System," by A. Rusck and B. G. Rathsman, *Electrical Engineering*, Vol. 69, Jan. 1950, pp. 53–7.
8. Discussion by C. F. Wagner of "Relative Surface Voltage Gradients of Grouped Conductors," by M. Temoshok, *AIEE Transactions*, Vol. 67, 1948, Part II, p. 1590.
9. "Results of Tests Carried Out at the 500-Kv Experimental Station of Chevilly (France), Especially on Corona Behavior of Bundle Conductors," by F. Cahen, *AIEE Transactions*, Vol. 67, 1948, Part II, pp. 1118–25.
10. "Bundelleitungen" (Bundle Conductors), by W. V. Mangoldt, F. Busemann, A. Buerklin, G. Markt, and F. I. Kromer, Siemens-Schuckertwerke, A. G. Pamphlet, Berlin-Siemensstadt, 1942.
11. "The Swedish 380-Kv System," by A. Rusck and B. G. Rathsman, *Electrical Engineering*, Vol. 68, Dec. 1949, pp. 1025–9.
12. "La Nouvelle Ligne Trans Alpine de l'Atel," by R. Vögeli and R. Leresche, *Bulletin de l'Association Suisse des Electriciens*, 42e, Année #3, 1951.
13. "The 300/315-Kv Extra-High-Voltage System of the American Gas and Electric Company," by P. Sporn, E. L. Peterson, I. W. Gross, and H. P. St. Clair, presented at Winter General Meeting of AIEE, New York, Jan. 1951.
14. "Gaseous Conductors" (a book), by J. D. Cobine, McGraw-Hill Book Co., Inc., 1941.
15. "400-Kv Transmission Lines with Special Reference to Multiple Conductor Lines (Bundelleitungen)," British Intelligence Objectives Subcommittee, Final Report No. 1833, Item No. 33, S. O. Code No. 51-8275-33, Technical Information and Documents, Cadogan Square, London, England.

TIN ...TUNGSTEN

Tin and tungsten differ greatly. Tin has a low melting point whereas tungsten is the least fusible metal. Tin and its alloys are soft whereas tungsten and its alloys are among the hardest of industrial metals. Unlike nickel and cobalt, discussed in the July issue, tin and tungsten are little related as to preparation, properties, or use. But a vital importance of both to the electric-power industry warrants a better acquaintance with them.

CERTAIN METALS, like some people, are continual storm centers. Tin is one. Tin has had a turbulent past, one marked with violent price fluctuations, periods of oversupply and undersupply, controlled buffer stocks, various plans of artificial price and production controls interlarded with periods of free trade.

The immediate future promises to be no more quiet than the past. Recent months have seen tin the subject of rapid price gyrations, voluminous and heated debate in committee rooms, with many caustic allegations and counter allegations.

The reason for all this is not apparent. Everything that has happened to tin has happened to other metals and some non-metallic raw materials—in some cases more so—without so much fuss resulting. Furthermore, the tonnage of tin produced is not great by comparison with other metals less frequently in the news and as essential to our economy. Compared to tin, the world produces 14 times as much copper, 10 times more zinc, 9 times more lead, and 8 times more aluminum. However, facts surrounding tin can be set forth to act as a backdrop for judgment.

At the outset, it is important to realize that the world's tin is produced in countries that don't use much of it, and, contrariwise, the countries that do use it produce essentially none. Furthermore, to tin-producing countries, it is the principal source of government income and employment of their people.

Where Tin Comes From—The United States is definitely on the receiving end. It is the world's largest user of tin—from a third to a half—and produces none. Almost none, we should say. Since 1910 United States' mines have turned out a total of less than 1700 long tons,* mostly from Alaska. This production at 1950 rate of use would, however, last less than one week. Literally dozens of tin-bearing ores in the United States have been examined critically by the Bureau of Mines and the Geological Survey, but the answer always comes out the same—too low grade, production costs too high to be remotely competitive.

The capital of the tin-producing world is Malaya, which, furthermore, has been a consistent producer since 1891. Malaya contributes an even one third of the world's total tin. In 1950 this was 57 500 tons out of a total of 167 400. It has produced as much as 83 000 tons in 1940 and as little as 24 000 tons in 1933 (although in World War II production essentially stopped). The tin-bearing particles are recovered from sand by large dredges, by hydrosluicing, and, in a few cases, by conventional open-pit mining (see pages 152 and 153).

World War II crippled the Malayan tin industry. Production had fallen from about 84 000 tons in 1940 to a low of 3100 tons in 1945. The Japanese occupation left the dredges ruined or in disrepair. But by a courageous and expensive rehabilitation program many dredges have been rebuilt and new and much larger ones have been added so that production is currently running close to the prewar average.

But everything is not lovely in Malaya. The new problem there is, figuratively, to mine with one hand and hold a gun in the other. Banditry, Communist encouraged if not inspired, is making serious raids on mining activities. The words of James Griffiths, Secretary of State for the Colonies, speaking in the British Parliament a year ago, dramatically outlines the situation: "Between January, 1948 and May, 1950 . . . 1138 bandits had been killed, 646 captured, 359 surrendered. In the process, 323 police, 154 members of the Fighting Services, and 803 civilians had been killed." He added that 3000 armed bandits were still operating and that attacks were running about 60 a week, a situation still con-

---

Prepared by Charles A. Scarlott from information supplied by the U. S. Bureau of Mines, Tin Research Institute, Molybdenum Corporation of America, U. S. Vanadium Corporation, Tungsten Mining Company, Wah Chang Corporation, and Westinghouse.

*Tin figures are always quoted in long tons of 2240 pounds, which practice is followed in this article.

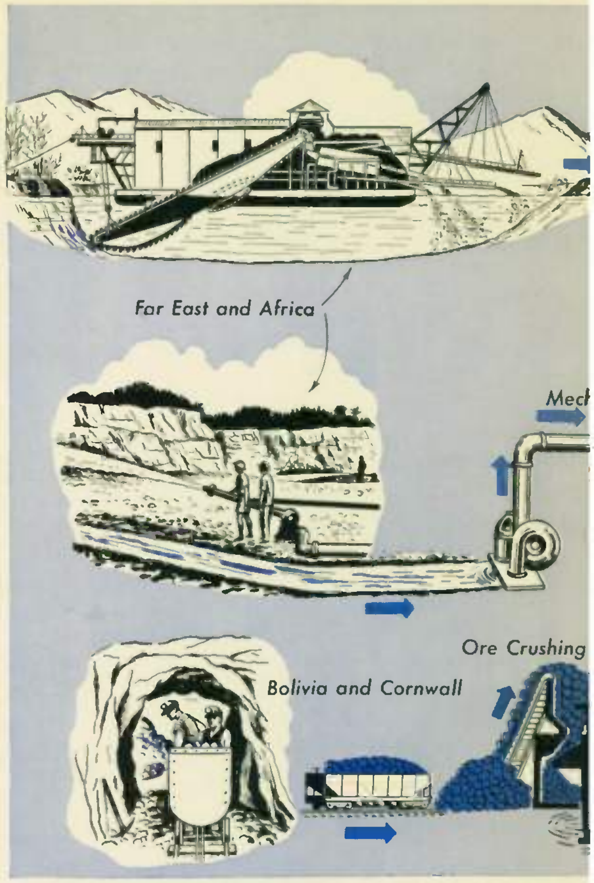
tinuing. This not only discourages production in outlying districts, but has brought exploration to a virtual halt.

In addition to Malaya, other countries of southeast Asia are major tin producers. Second after Malaya is Indonesia, which in the five-year period from 1937 through 1941 accounted for almost one fifth of the world total. Others of the Asian group were Siam, 7.8 percent; China, 5.3 percent; Burma, 2.6 percent; and Indo-China, 0.7 percent. Before the upset caused by war, Asia provided two thirds of the world's total tin.

Many of the tin mines of the Far East suffered in major degree from the war. However, except in Burma, China, and Indo-China, tin production has made a surprising comeback. By 1949 Asia was again contributing its prewar share of the world total. The political situation in several of these countries, notably China, however, makes the availability of their tin to the western world precarious.

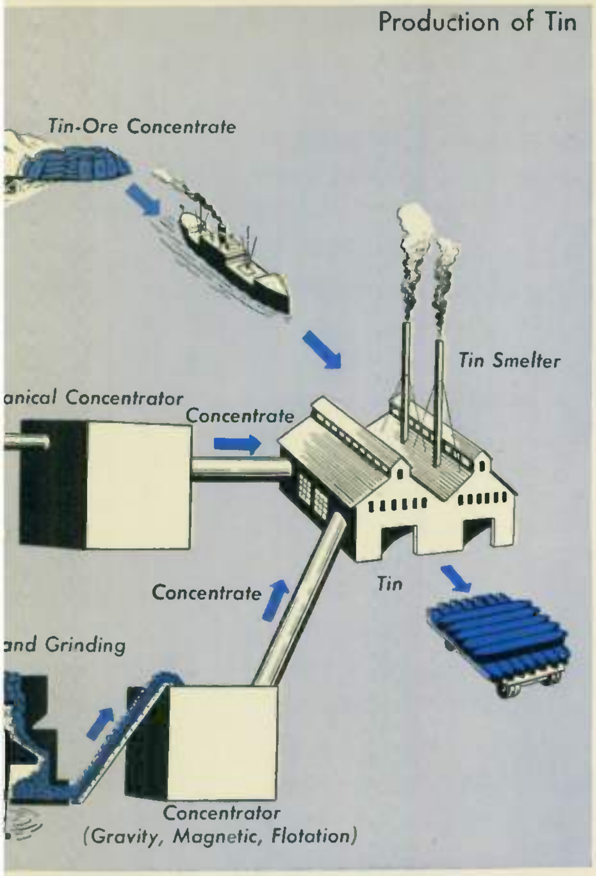
Number three in the tin-producing hit parade is Bolivia, which has been turning out tin on a notable scale since 1887. In the late 30's it ran a pretty consistent 26 000 tons yearly or 15 percent of the world output. Unlike placer mining in Malaya, Bolivian tin is mostly deep underground. It runs in almost vertical veins of high quality in high mountains at altitudes of 12 000 to 17 000 feet, which makes physical exertion difficult, even for native Bolivians. In the Andes the ore is reached by tunnels bored almost horizontally into the mountains. Also unlike placer tin ore, in which the problem is the relatively simple one of separating tin particles from sand, the Bolivian cassiterite and other tin minerals are in hard rock. Also the tin particles are associated with other minerals difficult to separate.

As a result, recovery of tin from Bolivian ore is poor. The range is from 35 to 85 percent cassiterite with the average being barely half. Much of the loss comes in attempting to provide a high-grade concentrate by the several forms of gravity separation. There are some arguments that tin smelters in consuming countries should make it profitable for Bolivia to ship a lower grade concentrate to obtain more of the tin from the ore. Even as it is, the resulting concentrate shipped to the European and the one United States' smelter is both poorer in grade (15 to 65 percent by comparison with about 72 percent) and more difficult to smelt than placer tin. These factors, plus the difficulty of mining at such high altitudes, and the desire of the Bolivian Government to raise the standard



Unlike most metals, tin occurs in only one form of commercial importance. This is the oxide of tin, cassiterite, often called tinstone (SnO_3), which is 78.6 percent tin. Its original occurrence was as small particles (from 1/50 to ¼ inch) scattered through hard rock and amounting up to 3 or 4 percent of the total. In this form it is mined underground in Bolivia and Cornwall and, in small amounts, in a few other places. But most of the tin comes from alluvial deposits 50 to 100 feet thick where the tiny grains of tin have been washed from disintegrated mountains by the earth's waters over a period of many thousands of years. While the grade is low—frequently less than a pound per cubic yard—mining costs are also low. The principal methods of recovery are by floating dredges, sluicing it out of banks with powerful water jets, or, in flat country, lifting tin-bearing gravels from pits for washing. Preparation of concentrate from either type of surface operation is the relatively simple mechanical one of separating the cassiterite particles from the quartz and other waste material. Because cas-

Much of the tin ore in the Far East and Africa is scooped from alluvial deposits by floating barges (below). These are huge, electrically powered affairs, that can dig up to a depth of 135 feet. At right is a scene in a typical Cornwall tin mine.



siterite is heavy—about two and a half times as heavy as quartz or sand—various gravity-type methods such as washers, jigs, and vibrating tables are efficacious. No prior crushing is required for surface-mined tin ores.

With cassiterite obtained underground the problem of concentration is more difficult because the rock is hard and must be crushed to small particles to free the tin from worthless material. Also the tin particles are more likely to be associated in the rock with other minerals impossible to separate by gravity methods. This is particularly true of Bolivian ores.

The final mine concentrates go to the six major tin smelters of the world (Malaya, Europe, and one in the U.S.A.). Here, in the simplest case—which holds for most surface-type ores—it is necessary only to heat with coke to a high temperature for the tin and oxygen to separate, leaving metallic tin. Depending on the amount and variety of accompanying impurities and the efficiency desired, other complicating operations are required at the smelter to arrive at commercially pure tin.

of living for its workers, make Bolivian tin more costly on the average. Another complicating factor is that during the last war, with Malayan tin cut off, Bolivia cooperated to bridge the gap and accelerate production. In doing so, the best ores were used, with detriment to the remaining deposits and a consequent reduction in eventual total recovery. Patino, Bolivia's largest tin mine, suffered a drop in grade from 2.31 percent before World War II to 1.50 percent in 1949.

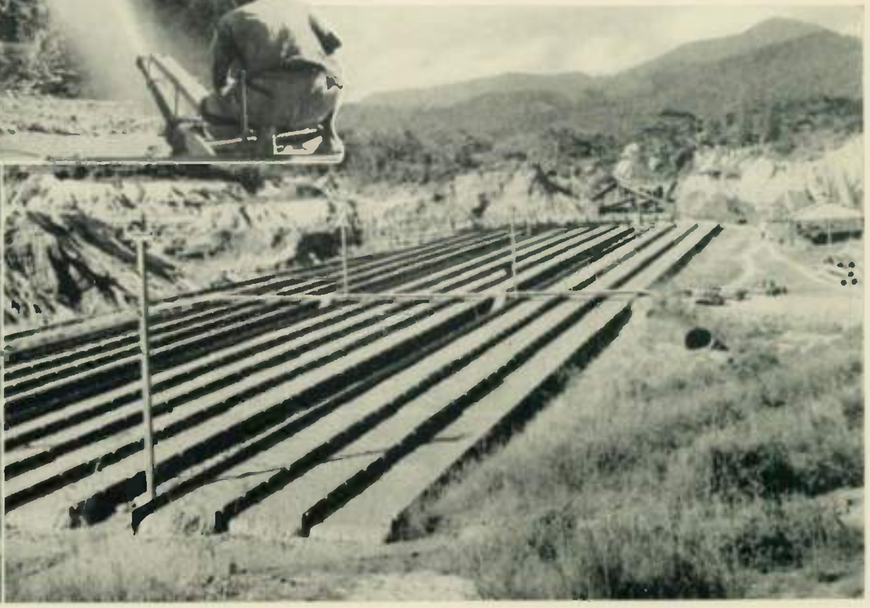
Bolivia has one small smelter. The remaining concentrate is exported, about 45 percent to England and 55 percent to the U. S. Government smelter at Texas City, Texas. Here the combined low-grade Bolivian concentrates difficult to smelt are mixed with high-quality concentrates from Indonesia, Thailand, and Belgian Congo and reduced to metal. The Texas smelter was built with Government funds in 1942, to provide a source of tin not in jeopardy of Nazi bombs.

Aside from the Far East and Bolivia the only sizable producers of tin are the Belgian Congo and Nigeria. In the five prewar years, together they turned out about one tenth of the world total. Production in these two African countries rose during the war but has returned since to approximately the prewar levels. Nigeria output is believed, however, to have passed its peak, which one year during the war reached 13 000 tons. Congo production touched a peak of 17 000 tons in 1945. The African mines resemble the surface operations of Asia. The U.S.S.R. claims now to be self-sufficient as to tin although production in the Soviet Union prior to World War II amounted to a few thousand tons yearly.

When the Roman legions invaded England in the first century BC, they found tin mining in Cornwall an established business. Until 1860 Cornwall was the largest provider of the world's tin. Cornish mines reached their peak of 10 000 tons per year between 1863 and 1875 but gave way after that to the lower cost producers in Malaya and elsewhere. Output has not varied much in recent times, running to about 1200 to 2000 tons of tin yearly, or roughly one percent of the world total.

The Cornwall mines are deep—some are 1800 feet. Some mines extend appreciable distances under the sea. They are now so deep and the dewatering problems so severe that mining costs are high. It was, incidentally, at the Cornish mines that the first steam engines were used. These were the pre-Watt variety, in which chilled water was sprayed in the cylinder at the end of the stroke to cause condensation.

The United States has one major tin smelter (center) at Texas City, Texas. In the Far East some cassiterite is washed from banks by powerful water jets (left). Below is a scene from a hydrosluicing tin-mining operation in Malaya.



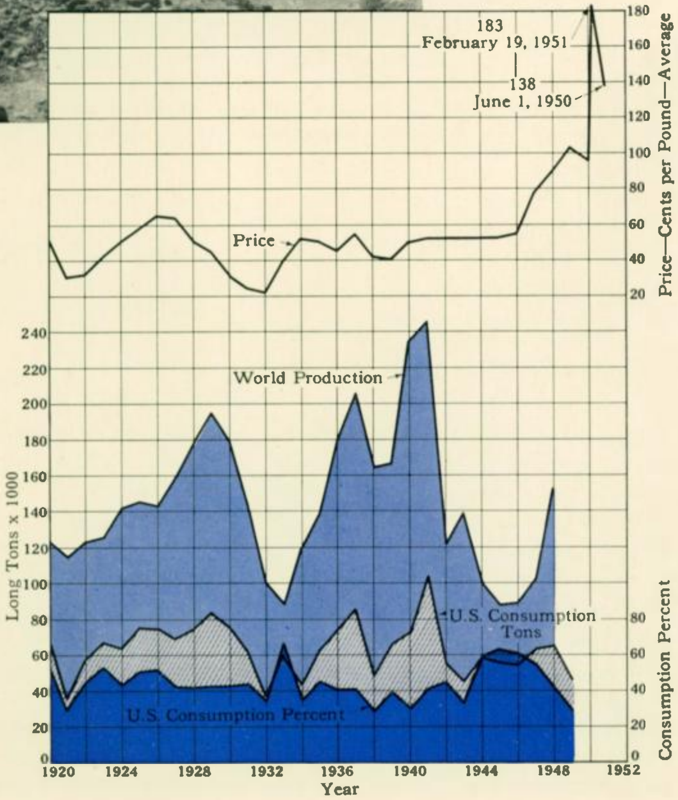
Small amounts of tin are produced in many other parts of the world. In 1950 thirteen nations mined between 100 and 1000 tons of tin each. Mexico sends a few hundred tons to the United States yearly. Canada produces about 200 tons. Australia and Argentina produce minor amounts, all used locally. These minor sums have amounted in recent years to about four percent of the world total.

In none of the alluvial tin deposits of the world is the percentage of tin high. Few of the large operations exceed about three pounds of cassiterite, which is 0.11 percent metallic tin per cubic yard. Many Malayan mines work sands of less than one pound and some as low as one-half pound (about 0.02 percent metallic tin).

How Much Is Left—Substantial figures as to world reserves of tin ore do not exist. In the April 15, 1950 issue of "Mining World" Robert J. Nekervis, of the Tin Research Institute, gave a figure of world reserves of recoverable tin as six million long tons or 38 years of 1949 rate of consumption. These are known deposits that can profitably be worked. Existing tin fields in Malaya have an expected life of about 20 years. The world will not run out of tin for many decades.

←
In the Far East powerful jets of water wash down banks of gravel containing tin-bearing particles.

Three decades of tin price, production, and United States' consumption. The price as of July, 25, was $1.06 per pound.
↓



The prospect for long life of Bolivian tin mines is, however, not good. The following statement was made by James Boyd, Director of the U. S. Bureau of Mines, before the Public Lands Committee of the House of Representatives on August 8, 1950: "Proved ore reserves in Bolivia in 1945 were estimated at 340 000 tons, from which 200 000 to 210 000 tons of tin may be expected. These reserves represent a 5- to 6½-year supply (i.e., at United States' rate of use). Apparently the development of reserves is not keeping pace with exploitation either in grade of ore or in total tin content, indicating a future trend toward decreased output. Estimates giving inferred and possible reserves are not available." While production in Bolivia can be expected to continue for many years, high outputs cannot be expected indefinitely.

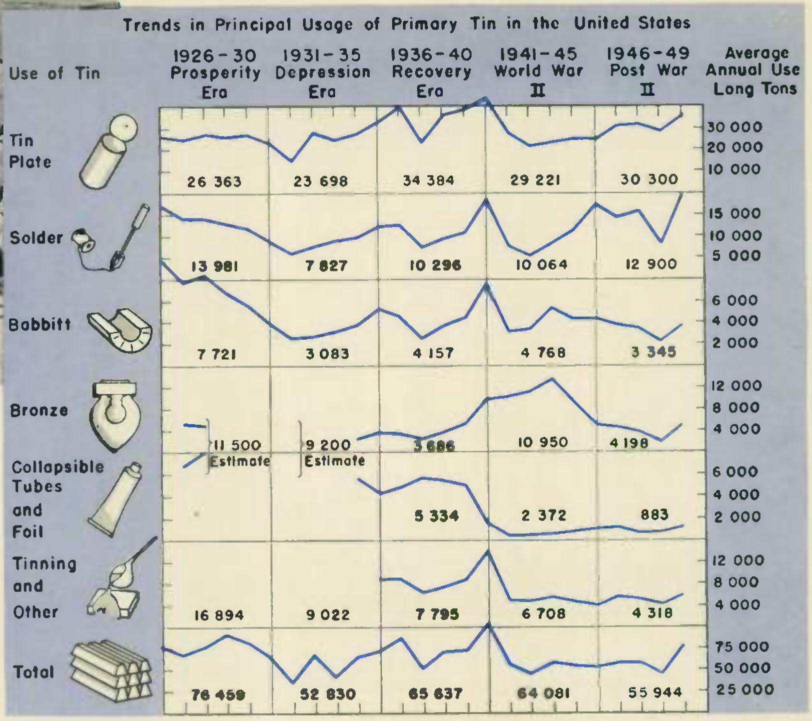
Price of Tin—Tin production and price have long fluctuated widely. Frequently production and consumption have been badly out of joint, resulting in booms and severe depressions in tin-producing areas, oftentimes causing great hardship on employers and workers. Attempts have been made to stabilize the industry by various types of artificial controls, such as cartels, establishment of buffer stocks, and intergovernment production-limitation agreements. Stability of the tin market was achieved by these methods in the period, 1934–1940. Since the beginning of World War II production has been unrestricted but price control was exercised in the principal consumer markets into late 1949. The United States Government imposed price controls during this period.

The price of tin has reflected the frequent dislocation of production and consumption, as the curve at left shows. In the years ahead of World War I the price per pound varied modestly between 25 and 40 cents. In World War I it rose to a peak of $1.10 per pound, dropping in the early 20's to 30 cents and rising during the prosperity years to 72 cents. It took a tumble in the early 30's to 22 cents but recovered to 40 cents in 1933 through the international tin agreement, and remained between 42 and 54 cents until 1947. In the months just ahead of hostilities in Korea the price of tin stood at about 75 cents, but then the climb began, touching $1.83 last February.

This fantastic rise created a Congressional storm, with acrimonious charges of profiteering. A great deal of dust has been raised over the issue. While we do not pretend to offer a critical analysis of the matter, three facts seem pertinent: (a) Tin has been in free competition, a principle of trade espoused by this country. (b) The onset of heavy defense programs, not only in the United States, but elsewhere, sent the demand for tin skyrocketing. (c) Superimposed on this normal plus defense demand were the very heavy purchases by the United States Government for stockpile. It hardly seems surprising that all this had a large effect on price of a metal always sensitive to supply and demand ratios. While the rise in price of tin since July, 1950 has been high—possibly to some degree unreasonable—tin has not been alone in such increases. But the fury has centered around tin.

As a result, last March the United States announced it had stopped purchasing for stockpile, and made the Reconstruction Finance Corporation the sole purchasing agent of tin and seller to industrial users in the United States. As a result, the price dropped to $1.42 per pound by May and, at press

Mud washed from banks containing cassiterite flows to a sump and thence to a mechanical-separation plant.



Trends in Principal Usage of Primary Tin in the United States

time, seemed to be leveling off around $1.00.

What Tin Is Used For—About one half the virgin tin used in the United States is for tin plate, this country being by all odds the largest user of "tin" cans in the world. In the four prewar years (1937–1940) the average annual consumption for this purpose was 35 700 tons or 55 percent of the total. Next in order of use in that prewar period came: solder, 15 percent; collapsible tubes and foil, 8 percent; babbitt and bronze, about 6 percent each; and tinning, about 3½ percent. Miscellaneous uses made up the remaining 7.

Such was the tin picture until bombs fell on Pearl Harbor. War needs then rose sharply. Meanwhile the flow of tin from Malaya and its neighbors was threatened and indeed did dwindle to a low figure. Strenuous efforts were made to reduce tin requirements. An intensive search was made for substitutes. Where none were found, the amount used for each purpose was decreased. These efforts were crowned with surprising success—especially in tin plate—to such extent that they have left a permanent mark on the pattern of tin use, as the chart above shows.

The biggest economy came in the way tin plate is made. Instead of dipping steel sheet in molten tin, the protective surface is applied electrolytically. As a consequence the thickness of adhering tin is as much as desired. For many purposes the saving is two thirds. Now 62.3 percent of all tin plate in the United States is made this way. Although tin-plate production has now doubled, the amount of tin required is the same. In the four postwar years (1946–1949), out of an average total new tin consumption of 55 800 tons, 30 300 tons went to tin plate. The tin-plate proportion of the total new tin consumed remains about the same as before the war.

The war brought about other tin-conserving measures. Many are here to stay. These include the reduction of tin in solder and babbitts. Foil and tubes of aluminum have grown widely in use, capturing much of their market from tin. As a result the total United States' tin consumption in the first four postwar years stood about 10 000 tons less on the average than in the four prewar years (55 800 tons as compared to 65 000, annual average). Only the amount used for solder has risen (from 9850 to 12 900 tons annually). The tonnage requirements for babbitt, bronze, and tinning have remained substantially the same, but the amount used for foil and collapsible tubes has dropped from 5380 tons to only 880 tons yearly. The amount of tin used for miscellaneous uses has been cut in half.

Further tin-saving measures are in prospect. One proposal is to apply a thinner coat of tin on the side of the sheet to be used on the outside of the can than on the inside. At present the two sides of the sheet are electrolytically coated equally with tin, amounting to 1.25 pounds per base box of tin plate. One proposal is to apply 1.00 pound of tin to one side and 0.25 pound to the other. Such differential coating would save one half the tin but it poses some difficult problems for the tin-plate industry. Besides which, only three tin mills are equipped or could be easily modified to accomplish it.

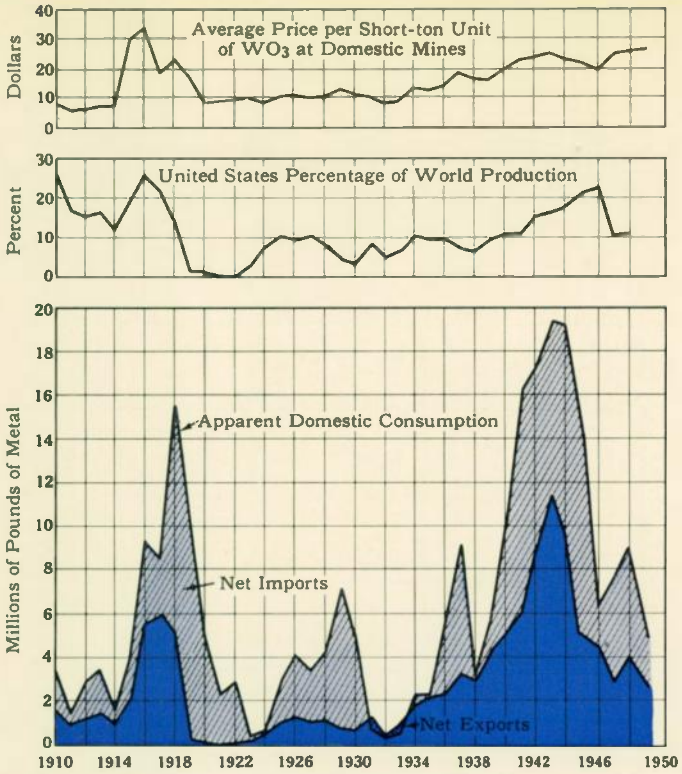
There is always the possibility that someone may devise some other protective coating for steel—such as a synthetic—that would replace tin entirely for all or some cans. Several aggressive research programs with this as the objective are in progress. However, the problem is not easy.

But, for all the tin-conservation measures, the day is not likely to come when we can do without it. Tin is basically too useful a metal. Given tin at reasonable price and in a world where supply does not always hang in the political balance, uses for it will grow—probably faster than conservation measures reduce its demand. Tin usage is older than history. It has weathered many an economic and political storm. It will outlast many more.

Tungsten

The present tightness of tungsten supplies has a simple cause. Tungsten from China—the world's leading producer—and from Korea is no longer available, while that from Burma, the third major Asiatic source, is unsure. Slightly more than one half of the world's tungsten has come from Asia. This decline in availability of tungsten and the sudden rise since mid-1950 in demand for cutting tools—the principal use of tungsten—have had the inevitable result. Government orders restricting the use of tungsten are now in effect.

Consumption of tungsten in the United States over the years has been extremely erratic. High peaks of consumption have been followed by sharp declines—a situation that has been exceedingly difficult for producers to cope with and one that does not encourage heavy mining investment. Use of tungsten in the five years ahead of World War II averaged



The recent history of tungsten.

about 6 million pounds of metal annually. Consumption skyrocketed in the war to a peak of nearly 20 million pounds in 1943, with an average of 17 million. The war over, use dropped immediately by two thirds, reaching a low of about 5 million pounds in 1949. More recent figures are not available, but obviously tungsten use is again increasing.

Where Tungsten Is Mined—While tungsten is in very short supply, the position of the United States is not so potentially precarious as it is with tin. In contrast to tin, the tonnages of tungsten used in the United States are small (only one fortieth as much), of which two fifths are supplied from mines within our own borders. In fact, since 1905, when tungsten records were begun, United States' mines have been a 13-percent factor in the world total (1945–1948 average: 16 percent). The United States is also the world's largest consumer of tungsten. In 1946, '47, and '48, which are fairly representative of peace-time years, this country absorbed just short of 30 percent of the world output.

The rank of the major tungsten-producing countries in 1948 (the last reasonably normal tungsten-producing year) stood as follows: China, 28 percent; United States, 11 percent; Portugal, 9 percent; Bolivia, 8 percent; Korea, 7 percent; Burma, 5 percent; Australia, 4 percent; Brazil, 3 percent. Russia is supposed to be producing about 5 percent of the world's tungsten. Canada, Mexico, Peru, France, Spain, Sweden, the Congo, and Thailand have produced minor quantities, while trace amounts come from many other nations.

Most tungsten mines in the United States are in the western states. California has been the principal producer the last two decades, and is currently providing about one third of the total. Until lately, Nevada has been next with about one fourth. Thirty years ago Colorado was the major producer, but in the last decade it has provided only four percent of the national total. Idaho during World War II was a significant producer of tungsten. In fact it set the all-time United States' record in 1943, even surpassing California in that year. However, since 1945 its production has declined to a low rate, as its principal mine was essentially exhausted during the war.

The newcomer, surprisingly, is not one of the western group. It is North Carolina. In 1941 the Tungsten Mining Company began operations at a mine near the northern edge of North Carolina. Here is a large quantity of ore running about 25 pounds of 60 percent tungstic-oxide concentrate.* Output has risen steadily until in 1949 with 28 percent of the United States' total, it just shaded Nevada and in 1949 was the largest single tungsten-producing mine in the United States. Thus California, North Carolina, and Nevada account for nine tenths of the United States' tungsten output.

Tungsten ore in the United States occurs underground in low concentrations, 0.5 to 3 percent. The grade is generally less than one percent. Ore running 3 percent is considered high grade and is rare.

Generally a tungsten mine produces only tungsten. Seldom are there any by-product minerals to help carry the high mining costs, although the big Pine Creek operation of the United States Vanadium Company in California produces molybdenum and copper in worthwhile amounts. For these reasons and because of much higher labor costs, tungsten costs more to produce in the United States than elsewhere. Thus, normally —when no political influences are at work—only those United States' mines with the most favorable cost factors can compete with foreign tungsten.

The United States, however, is not poor in tungsten reserves. The tungsten-ore deposits are large. How large is not known. Reserve figures are almost meaningless. Because mining of tungsten has not been a highly profitable operation and with almost no assurance of a succession of profitable years, the incentive for long-range exploration has been lacking. For example, the North Carolina mine of the Tungsten Mining Company is presently working at the 500-foot level. The vein is known to run undiminished down to 1500 feet. How much below that it goes no one knows. Whether tungsten ore at the lower depths can be counted on as reserve depends on the need and price for tungsten and on mining costs when those levels are reached—a number of years from now. The United States could in a pinch become self-sufficient as to tungsten for many years to come. The price would become higher than industry is accustomed to paying, but probably not intolerably so.

Natural Forms of Tungsten—Tungsten is never found uncombined. There are at least a dozen different chemical combinations, some extremely complex. Only four tungsten minerals are commercially important. One is scheelite or calcium tungstate ($CaWO_4$). The other three are combinations with iron and manganese, which run the complete scale of proportions. If the iron-to-manganese ratio exceeds four to one, the mineral is termed ferberite or iron tungstate ($FeWO_4$). On the other hand, if manganese predominates in about this ratio, or more, it is called Hubnerite or manganese tungstate ($MnWO_4$). All the intermediate proportions of iron and manganese—the greater part of the total—are wolframite.

Because all four tungsten-bearing ores contain, at best, but two or three percent tungsten, the first problem is to provide a concentrate. This is done by crushing the ore to a fine powder and effecting a concentration of the tungsten-bearing particles by various gravity separations and/or by flotation. The object is to obtain a concentration of 55 to 70 percent (60 percent is the industry standard) WO_3 concentrate. The char-

---

*Tungsten statistics are commonly not given in terms of tungsten metal, but as a concentrate containing 60 percent tungstic oxide (WO_3). This is because a very large part of the tungsten, particularly in steel making, is used in this form and is not converted to metallic tungsten. For purposes of mathematics, however, one ton of 60 percent WO_3 concentrate contains 952 pounds of tungsten. Thus an ore running 25 pounds of 60 percent WO_3 contains about 12 pounds of tungsten per ton or a grade of 0.6 percent. Tungsten is marketed on a per-unit basis, a unit being one hundredth of a short ton or 20 pounds of WO_3, which is 15.86 pounds of tungsten.

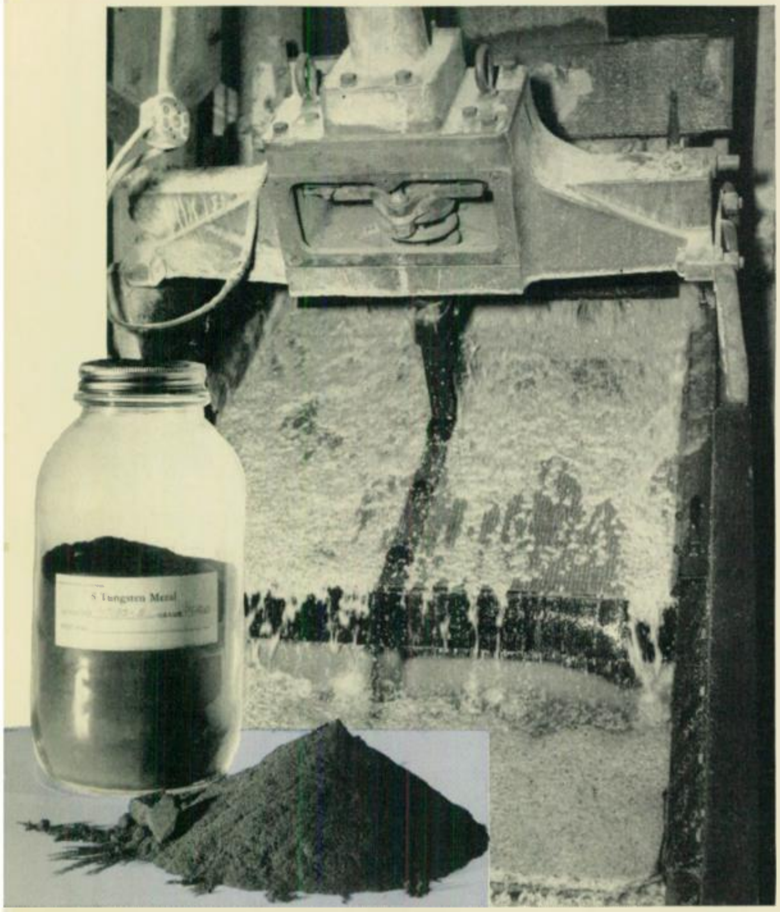
acter of further processing, if any, depends upon the end use.

Most metals are isolated from their natural chemical partners before they are used. This is not true of tungsten. High-purity tungsten concentrates are used without further change as an alloying charge in steelmaking. In 1949 one sixth of the tungsten consumed in the United States was used as metal. The form in which tungsten is most used—almost half in 1949—is ferro-tungsten, which is generally produced by charging tungsten ore together with coal, scrap, and flux-forming materials in an electric knock-down furnace. Only a little over one third of the tungsten used in this country ever passes through the metallic tungsten state, which is accomplished by a set of complex chemical processes.

Where Tungsten Goes—Tungsten is definitely a metal of the 20th century. Prior to 1900 it had almost no commercial use. True, it was an important but unsuspected ingredient of the legendary Damascus steel. Tungsten—from *tenn-spat* (later Swedish *tung-sten*) heavy stone—was identified in 1747 by Wallerius in a Bohemian mineral. Metallic tungsten was first isolated by the d'Elhuyar brothers of Spain in 1783. Probably the first planned commercial use of tungsten as alloying agent in steel was Mushet's self-hardening tool steel (six percent tungsten; two percent manganese) patented in 1868. Just before the turn of the century F. W. Taylor, of the Bethlehem Steel Company, and Maunsel White discovered that tungsten steel is vastly superior for cutting metal at high speed. Their alloy created a sensation at the Paris Exposition in 1900. Tools made of it could be used above temperatures that would ruin any carbon steel.

In addition to cutting at higher speeds, tungsten-steel tools were found to be capable of taking heavier cuts. The resulting economies effected all over the world have been enormous. The new tungsten-steel tools have been a dominant factor in the era of mass production of machine-tool products. Prominent among these tungsten-steel tools is the so-called 18-4-1 high-speed steel whose composition is: tungsten, 18 percent; chromium, 4 percent; and vanadium, 1 percent. The percentage of vanadium may vary up to 3 percent with or without the addition of cobalt.

A closeup of one of the tungsten-ore concentrating processes of the Tungsten Mining Company. In the foreground is the final tungsten powder as produced by Westinghouse for lamp filaments.



Nearly all steels containing tungsten are now made in the electric furnace. (The melting point of tungsten is far too high for a melt to be achieved in blast or open-hearth steelmaking furnaces.) Tungsten steels were once produced mostly by the crucible process, which required tungsten powder of 95 to 98 percent purity. The electric furnace, on the other hand, takes in its tungsten as ferro-tungsten. Ferro-tungsten melts between 3500 and 3700 degrees F, while tungsten powder melts between 6000 and 6200 degrees F. Neither, of course, will actually melt in a steelmaking furnace, but the ferro-alloy can be more easily dissolved because of its lower fusion temperature. The lower specific gravity of ferro-tungsten and its more favorable size, also, as compared with tungsten powder, results in a slower rate of settling through the bath.

High-speed cutting steels take more of the tungsten stocks than any other use. Other important uses of tungsten-alloyed steels are for hot-work dies, low-alloy tool steels, permanent magnets, and heat-resisting steels.

Of the tungsten reduced to metallic form, some is used for cemented carbides. High-purity tungsten powder is combined with carbon at high temperature in an inert atmosphere. The resulting carbide is crushed to a powder, mixed with cobalt powder that acts as the cementing agent when the product is sintered. The result is a cemented tungsten carbide, the hardest artificial substance. It even approaches the diamond for hardness. Cemented carbides are used for rock drills, dies, and many types of cutting tools such as single-point tools, form tools, milling cutters, etc.

While the tonnage use of tungsten as filament wire in incandescent lamps is small—one or two percent of the annual total—it is indispensable. There is no known substitute —not even close—for drawn tungsten wire in electric lamps. Nor is there likely to be. The energy-to-light conversion efficiency of an incandescent solid increases rapidly with temperature. And tungsten can be operated hotter without softening than any other substance except carbon, because its melting point—about 3410 degrees C—is the highest of all metals. But a small amount of tungsten makes a lot of lamp filaments. A pound of tungsten drawn into a wire 6.2 miles long, and 0.0022 inch in diameter provides filaments for 14 400 lamps of 60-watt size.

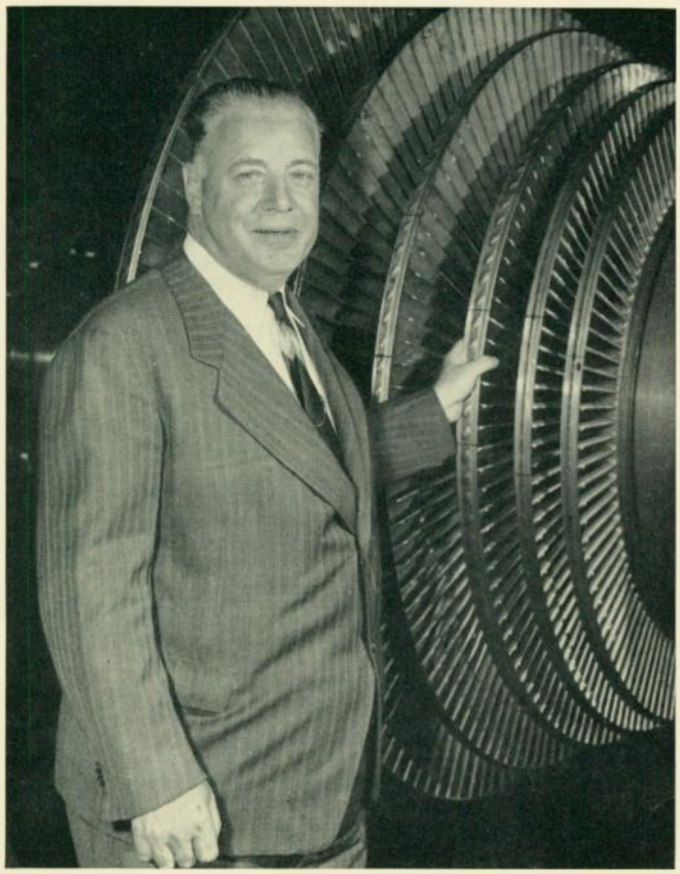
Tungsten, for all its high-temperature qualities, cannot be used for turbine blading, for example. At steam- and gas-turbine temperatures it forms a nonprotective oxide that soon leads to failure. Also its high density makes it undesirable for high rotating speeds.

Other important uses of metallic tungsten in the electric industry are as lead-in wires for electric lamps (tungsten and soft glass have nearly the same coefficient of thermal expansion) and for certain elements in electronic tubes. Electrical contacts and electrodes are made of sintered tungsten or tungsten carbide powder and copper or silver. But, in bulk, these uses of tungsten metal are far overshadowed by the use of tungsten for alloying with steel. It does not appear that this aspect of our industrial economy will in the long run have to be curtailed for lack of tungsten.

Personalities IN ENGINEERING — ROBERT L. REYNOLDS

'Tis said that people take on the characteristics of what they are long associated with. This would appear to be the case with Robert Reynolds, who has had a long career as designer of large steam turbines. The characteristics in common are several, such as high order of reliability, quietness, unspectacular performance, high efficiency, and a strength that justifiably invites confidence and respect. But, we suspect, it is the steam turbines that have in real measure acquired these characteristics from Bob Reynolds, not the other way around. For three decades Reynolds has played an important role in the design of a substantial number of the nation's large central-station turbines. Few powerhouses are without his influence.

But Bob didn't plan it that way. He was raised in Massachusetts, in an atmosphere of fine mechanics. His father was in charge of a blacksmith shop that, from the beginning of the automobile age until his death in 1934, fashioned swanky, expensive custom bodies for the automobiles of the rich, movie stars, potentates, and other celebrities. But his father was unable to provide college education for all five young Reynolds—so Bob arranged to get one without funds. He entered the fiercely competitive examination for entrance to the famous Webb Institute of Naval Architecture, which is uniquely endowed so that the select few who enter receive their engineering training at no cost. Reynolds was one of those successful few in 1916. Graduation was followed by a trip to London on the *S. S. Minnesota* as junior engineer. Following this he decided to apply his engineering talents to the building of marine equipment. He entered the Westinghouse apprentice course at the Steam Division—expecting to become associated with design and application of marine turbines. By a curious quirk of fate, Bob has not in his 30 years with turbines ever worked on marine turbines. His field consistently has been the big power-station units.



Before Reynolds was well begun on a turbine career, however, there came an interruption. The depression of 1922 had arrived. Business was near the vanishing point. Reynolds had just completed the Westinghouse student course and had not yet taken a design assignment. He decided to ride out the economic storm at sea. He became an oiler on the *Southern Cross*—one of the early Westinghouse turbine-equipped merchant vessels—plying between the Americas. The "storm" passed as quickly as it came and in the fall of 1922, Westinghouse urged Reynolds to return to the Land Turbine Engineering Department where he soon acquired such firm roots that he and it have never been separated.

The little "black book" in which Reynolds logs his design activities contains the names of many of the well-known pioneers among steam turbines. In fact that roster alone would form a pretty fair history of three decades of progress in turbine design. The record began with the 20 000- and 30 000-kw, 1800-rpm, single-cylinder machines for Connecticut Light and Power Co., and West Penn Power Company. These were big ones for their day. Among other outstanding pace-setting machines came, in 1926 and 1928, two big reheat machines for Crawford Station, Chicago—a type of turbine that has returned to favor in the last three years. In the late 20's the idea of economical station modernization by use of superposed turbines became quickly popular. Reynolds designed the 1200-pound superposed machine for Kansas City Power & Light Company, which was one of the first, if not the first, to go into service (1929). A real milestone came with "Big Ben," the 165 000-kw, 1800-rpm single-shaft turbine of the Philadelphia Electric Company. This machine established a long-time high-water mark for single-shaft, slow-speed machines—and is, in fact, still the largest single-shaft machine in the world, although it is to be surpassed by a machine for 185 000 kw now on the books.

Reynolds' technical career illustrates well one type of performance basic to engineering progress. It is not marked by mathematical brilliance or random flashes of inventive genius. Such, while more eye-catching, are no more essential than the steady, day by day hacking away at improvement here, a detail gain there, across the whole front of—in this case—turbine design. It is the painstaking, persistent application of theoretical and mechanical skill that has raised the steam turbine to its present high place of excellence.

Reynolds works with great modesty and quietness, as is illustrated by the fact that, although he has written many technical papers of basic engineering reference stature, frequently his associates only two desks away first learn of them when they appear in print.

Reynolds manifests the same consistency and solidity in his personal life. Although a member of several professional societies, he is not a "joiner." He is a firm believer that there is a relationship between a man's golf score and the pleasure obtained. In his words "the higher the score, the more fun." He has a serious interest in civic and world affairs. Like the turbines he builds, Reynolds is a solid, substantial citizen.

Controlled Starting of Steam Turbines

Few machines work best when operated fully loaded or continuously. The steam turbine, however, is one. When a turbine must be shut down and restarted frequently, the differential cooling of its massive parts introduces problems that must be given attention.

ROBERT L. REYNOLDS, *Manager, Central Station Turbine Section, Steam Division, Westinghouse Electric Corp., South Philadelphia, Pa.*

As turbine-generator units become older and relatively less efficient than newer generating units, shutdowns become more frequent, in some cases nightly. This type of service involves special problems in the design and operation of power-plant equipment.

Factors Affecting Starting Time

The time required to start a turbine after a shutdown (assuming it has not been dismantled) depends on several factors. The more important of these are:

a—Length of shutdown.

b—Temperature of the turbine metal prior to starting.

c—Temperature of steam used for starting and provision for its control.

d—Operation of rotor-turning device during shutdown period.

e—Turbine design, particularly such features as blade clearances and proportions of casing flanges.

The amount of cooling of high-temperature parts, such as throttle valves, steam chests, and turbine casings, is determined principally by the duration of the shutdown. It is also influenced by the adequacy of insulation on the high-temperature parts.

Measurements taken on several units indicate that the rate of cooling is about 27 degrees F for the first hour, decreasing to about 19 degrees F per hour after 6 hours, and to about 6 degrees F per hour in 36 hours. Thus, after an overnight shutdown of about six hours the high-temperature parts will have cooled off about 130 degrees F, whereas after a week-end shutdown of about 36 hours the metal will have cooled off about 450 degrees F. These values are illustrated by the curves in Fig. 1.

If the turbine casing cooled uniformly, the starting problem would be simple. But it doesn't. The lower part cools at a slightly faster rate than the upper half. As a result, the casing tends to "hump." This reduces the radial clearances between the stationary and rotating parts at the bottom and increases them at the top. This differential in the rate of cooling can be reduced, but not eliminated, by rotating the shaft by the turning device at a speed above that usually provided. This is particularly important for units operating with steam temperatures of 1000 degrees F and above. It is desirable to roll such units at about 30 rpm, or even higher, rather than the more common speed of 3 rpm.

Effect of Boiler Arrangement

The temperature of steam used for starting depends on the design and arrangement of boilers. In a unit arrangement, with a single boiler and turbine, steam temperature is generally too low unless the turbine has become quite cool after

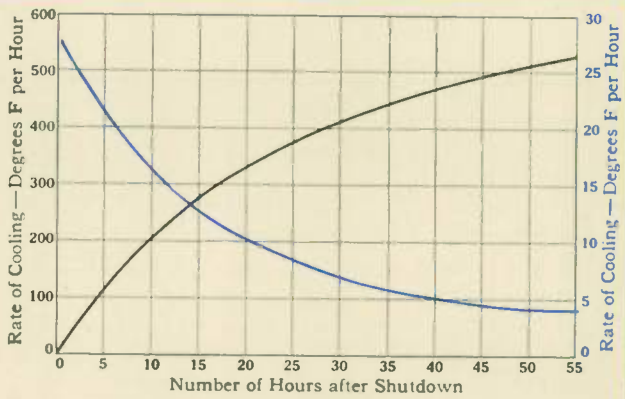
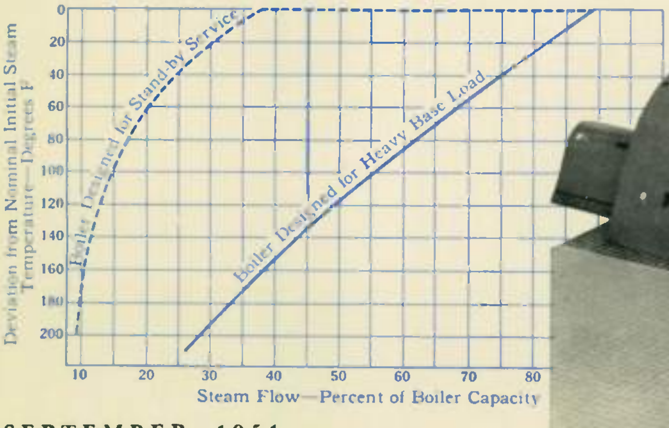
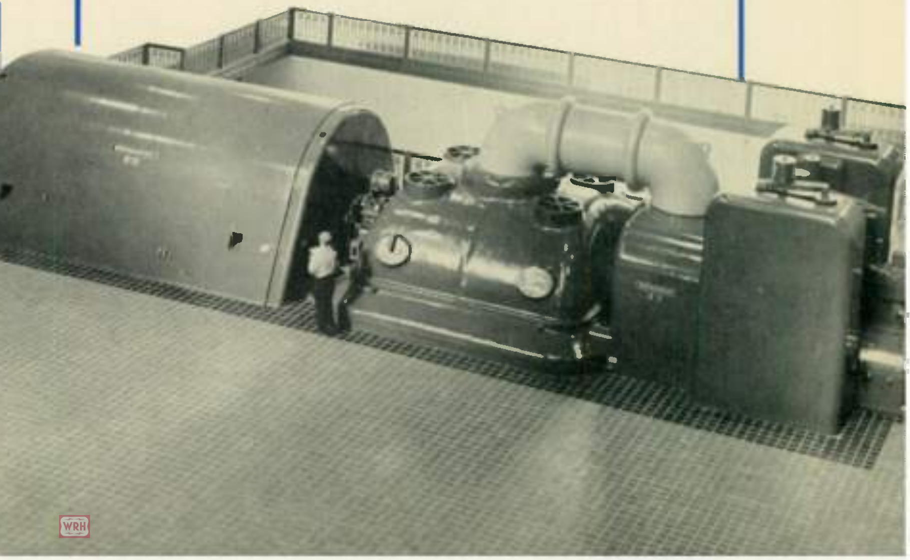


Fig. 1—Rate and cumulative total cooling of steam-turbine parts during shutdown.

Fig. 2—Effect of boiler design on initial steam temperature.



A 60 000-kw standard steam turbine generator.



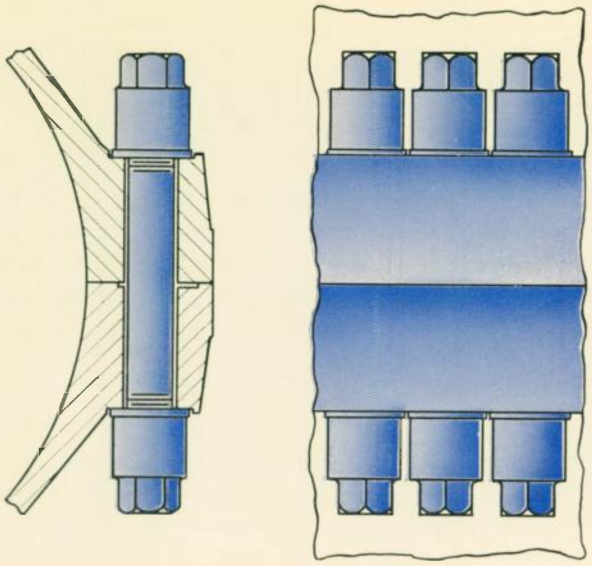


Fig. 3—Section and side view of bolted turbine flange.

a long shutdown. In a steam-header system, where the boilers have been kept in service supplying other turbines in the station, the steam temperature usually is too high except after a short shutdown.

Thus, the ability of boilers to supply steam at a temperature about the same as or slightly higher than the metal temperature, which is an important requirement for a quick start, may be quite difficult to attain. This is particularly true on an installation where quick starting of the turbine was not considered in the original design.

Effect of Boiler Design

The type of service for which the boiler was designed influences this situation, as shown in Fig. 2. The average boiler produces steam temperatures between these two extremes.

In the stand-by type of boiler, steam reaches rated temperature at comparatively small flows. In the example shown, full steam temperature is reached at about 37 percent of the boiler capacity and is maintained at this value at higher flows by desuperheating. On the other hand, steam temperature from the base-load boiler does not come to its rated level until the flow becomes much higher, this value being shown at about 90 percent of boiler capacity. Since the stand-by boiler generates steam at a higher temperature at low outputs it generally is better suited for quick starts after a short shutdown, provided it is equipped with controls for maintaining the steam temperature at the desired level.

Effect of Turbine-Cylinder Joint Design

The construction of the horizontal joint and bolt has an effect on quick starting on steam turbines. A typical joint and bolt are shown in Fig. 3.

This joint is held together by closely spaced through bolts that, under normal conditions, produce a pressure on the contact surfaces more than sufficient to keep the joint tight. The contact surface is often divided into an inner and outer surface with the center section at the bolts relieved. Washers under the nuts form a hardened surface for the nut and help distribute the loading on the spotfaced surface of the flange.

During the heating cycle, steam sweeping past the inner wall first heats the inner part of the flange. Heat is then conducted through the flange at a fairly fast rate. With the through type of bolt of Fig. 3, heat passes into the bolt at a much slower rate, this heat being transmitted principally by conduction through the washer, thence into the nut and fi-

Fig. 4

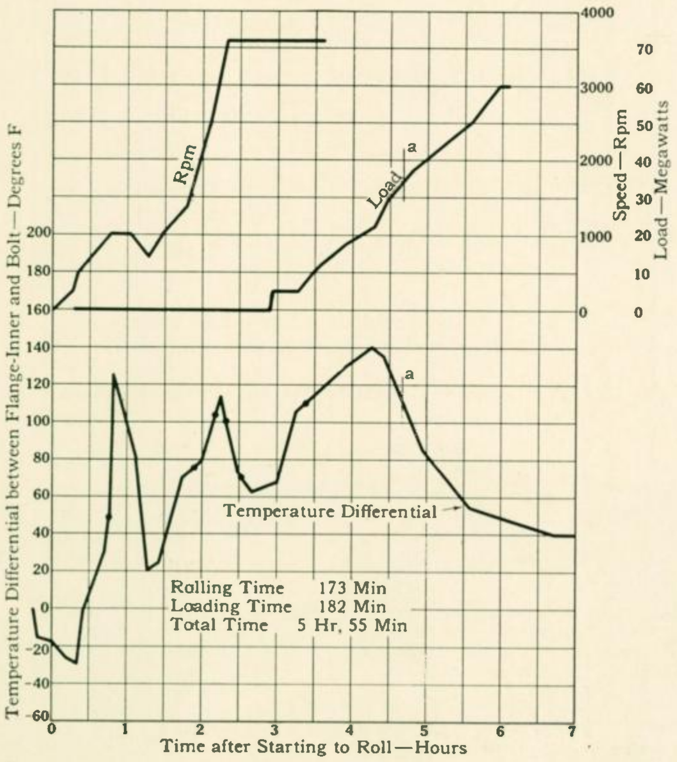
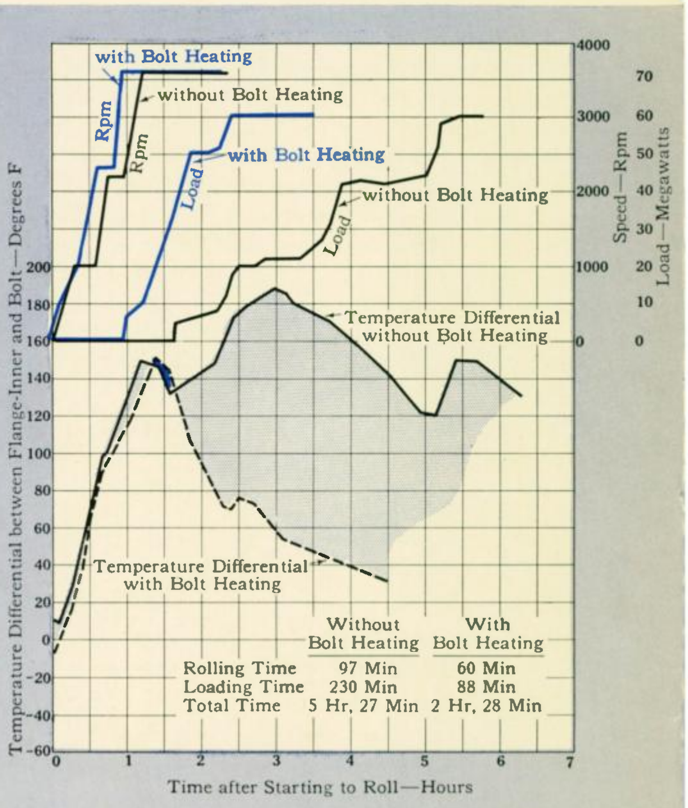


Fig. 5
(a)



nally into the bolt along the comparatively short thread engagement. Some heat is also transmitted slowly to the bolt by radiation across the narrow clearance space between flange and bolt.

Thus, as heating occurs the flange heats much faster than the bolt. This differential is dependent upon the rate of heating, which, in turn, is largely determined by the difference between the metal temperature and the temperature of the steam used for heating.

This differential heating causes the cylinder flange to expand more than the bolt, especially at the inner surface. This differential expansion increases the compressive stress at the contact surface of the cylinder flange and the tensile stress in the bolts. This differential may become large enough for the stresses in the flange and bolt to become excessive.

For example, if the differential temperature is 150 degrees F —which has been measured on some units during the starting cycle—bolt stress increases about 30 000 psi due to differential expansion of about one mil per inch of length. If, then, the bolts were initially tightened to a tensile stress of about 45 000 psi with a corresponding flange compressive stress of one half of that value, or 22 500 psi, the stresses become:

Bolt tensile stress = 45 000 + 30 000 = 75 000 psi

Flange compressive stress = 75 000 × 0.5 = 37 500 psi

With present bolt and cylinder materials these stresses are within the yield point limits of the bolting, but this is not the case with the flange. As a result, the flange material at the sealing surface flows plastically, or "crushes," whereas the bolts are not adversely affected.

During cooling, caused by shutting down or by reducing load, the opposite effect occurs. In other words, the compressive stress on the flange becomes less and, if the differential becomes great enough, the joint leaks. In the same manner the bolt tensile stress decreases and the bolts tend to loosen, particularly after they have relaxed following exposure to high temperature and stress over an extended period.

This means that potential damage to the flange and bolts occurs during the heating cycle, whereas the possibility of joint leakage results during the cooling cycle.

In some cases, with uncontrolled conditions during starting, the flange temperatures exceed those of the bolts by much more than 150 degrees F. It becomes quite apparent that under these conditions the joint sealing surface may become damaged and bolts broken.

During any starting cycle, whether fast or slow, the following conditions should be carefully observed and, where necessary, protective measures should be taken to insure against damage:

a—Radial and axial clearances between rotating and stationary parts.

b—Differential temperatures between flange and bolts.

Starting Tests on 60 000-Kw Unit

These conditions have been measured on several turbines and, to illustrate the conditions measured, tests on a 60 000-kw turbine were conducted under the following starting and loading conditions:

a—Cold start after an extended shutdown for inspection.

b—Starting cycle after shutdown periods of 48, 24, and 4 hours.

c—Rapid changes of load, both in the increasing and decreasing direction.

d—Rapid changes of initial steam temperature, both in the increasing and decreasing direction.

e—Concurrent rapid changes of load and initial steam temperature.

f—Load changes of 50 000 kw.

During these tests the following observations were made:

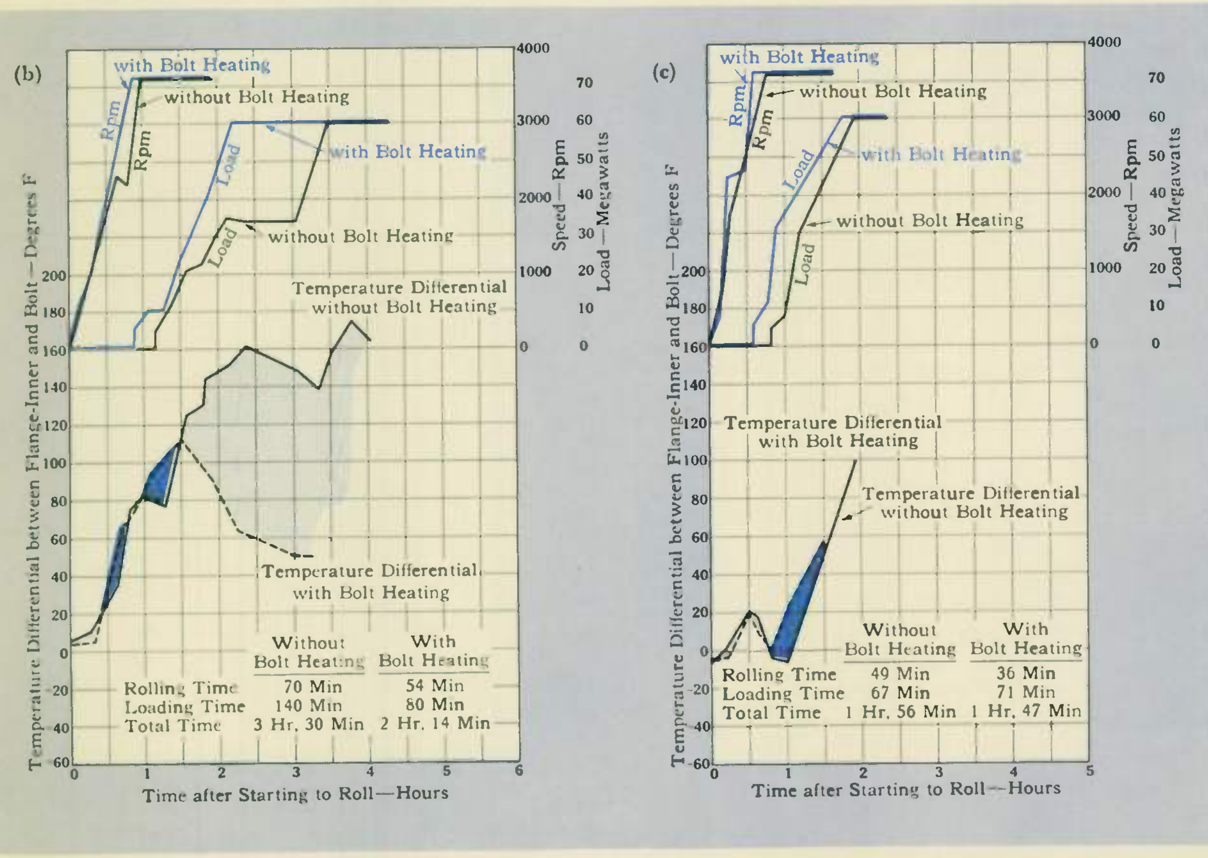


Fig. 4—Difference in flange and bolt temperatures when turbine is started cold after an extended shutdown.

Fig. 5—Differential temperature between bolt and flange with and without bolt heating for starts after (a) 48-hour shutdown, (b) 24-hour shutdown, and (c) a 4-hour shutdown.

a—Differential movements between rotating and stationary parts, which determined the running clearances between these parts.

b—Truth of rotors, which determined the smoothness of operation during starting and loading cycles.

c—Temperatures at various points in the flange; near the inner surface; at the center of the flange at the top, near the joint and at the bottom; near the outer surface. Several sets of these readings were taken; near the high-pressure end, following the first stage, at about the center of the high-pressure casing, and in the exhaust.

d—Temperatures of the casing wall at the top and bottom.

e—Temperatures of the bolts at various points.

Analysis of these measurements suggests that if the differential temperature between the inner wall of the flange and the corresponding bolt is kept within a limit of 200 degrees F no excessive stresses occur in the flange or bolt. Also, the running clearances between the rotating and stationary parts will be sufficient to provide a safe margin against interference between these parts. Results of one set of these readings are given in Figs. 4, 5, and 6.

To keep the temperature differential between the inner surface of the flange and the bolt within the safe limit of 200 degrees F, the following controls were applied:

a—Initial steam temperature was controlled to a limited degree, but boiler operation did not permit wide control of this temperature.

b—When the temperature differential between flange and bolt started to increase too fast and to approach the 200 degrees F limit, speed or load was held for sufficient time to permit the flange conditions to become stabilized.

c—Provision was made to circulate steam around the bolts. Thus bolt and flange temperatures more nearly matched. Two sources of steam were available, one from ahead of the throttle valve, and the other being lower pressure steam from the impulse chamber.

Cold Start after Extended Shutdown—During the rolling period and the first part of the loading period, high-pressure steam was circulated around the bolts (Fig. 4). It was found somewhat difficult to control this steam with the result that the bolt would become hotter than the flange. During the latter part of the loading cycle, steam from the impulse chamber was circulated around the bolts, after which the temperature differential was kept well within the established limits. In fact, during the latter part of the loading cycle, load could have been applied at a faster rate without exceeding permissible temperature differentials.

Start after 48-Hour Shutdown—Two starts were made after 48-hour shutdown periods, one with and the other without steam circulation around the bolts.

The advantage of circulating steam around the bolts is readily apparent by a comparison of the two sets of curves (Fig. 5a). Steam circulation, using impulse-chamber steam, shortened the rolling period from about 1½ hours to 1 hour and the loading period from about 4 to 1½ hours. Thus the total time of rolling and loading was reduced from about 5½ to 2½ hours, or a saving in time of three hours. At the same time, the maximum temperature differential between the flange and bolt was reduced from 188 to 151 degrees F with the shorter steam-circulation start. Thus, steam circulation not only reduced the time about three hours but also resulted in lower stresses in the flange and bolt.

Start after 24-Hour Shutdown—Similar results were obtained for the rolling and loading cycles after a 24-hour shutdown. The total rolling and loading time was, as shown in Fig. 5b, reduced from about 3½ to 2¼ hours with an accompanying reduction in maximum temperature differential of from 175 to 113 degrees F. The steam-circulated start could obviously be shortened even more without exceeding permissible temperature differentials.

Start after 4-Hour Shutdown—After a short shutdown, the advantage of steam circulation becomes less significant, although it does result in a reduction in starting time and in the temperature differential between the flange and bolt. However, it is obvious that the starting cycle can be materially shortened without exceeding permissible temperature differentials, as shown in Fig. 5c.

Once the turbine has become thoroughly heated, load and initial steam temperatures can vary rapidly within rather wide ranges without serious consequence. This is illustrated by the curves in Fig. 6, all of which represent test results on a thoroughly heated turbine without any circulation of steam around the bolts. These curves make it clear that load and temperature can be changed quite widely, either separately or concurrently, without exceeding safe values in flange and bolt stresses.

A summary of these results, together with those obtained on several other units, indicates that with conditions controlled as described above, a turbine can be brought to speed in the time determined by the following formula:

$T_s = 0.06\Delta t\sqrt{T_{sD}}$ (without bolt heating)

$T_s = 0.03\Delta t\sqrt{T_{sD}}$ (with bolt heating)

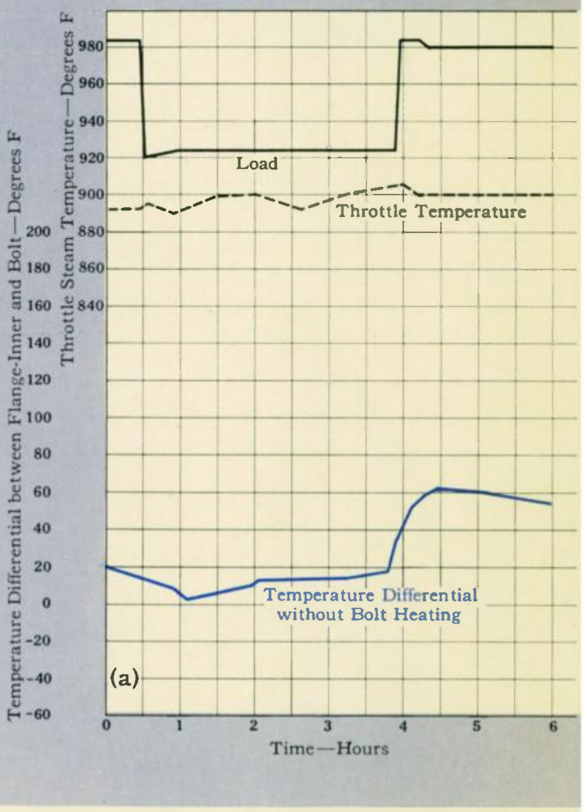
where T_s = time recommended for bringing unit to speed, in minutes

Δt = difference in temperature between throttle steam and the metal in high-pressure parts, such as throttle valves and steam chests, in degrees F

T_{sD} = length of shutdown period prior to start, in hours

For example, if a unit has been out of service over a week

Fig. 6—Effects on differential temperature of starting under different conditions: (a) rapid load changes; (b) rapid load and temperature changes; (c) large load changes; and (d) rapid variations in steam temperature.



end, say 36 hours, and if the steam temperature is 300 degrees F above the metal temperature, the times recommended for bringing the unit to speed are:

$T_s = 0.06 \times 300\sqrt{36}$, or 108 minutes without bolt heating

$T_s = 0.03 \times 300\sqrt{36}$, or 54 minutes with bolt heating

Further, after an overnight shutdown of six hours, with steam 100 degrees F above metal temperature, the time recommended for bringing the unit to speed is 15 minutes without bolt heating. Shorter times would probably not be advisable from the standpoint of steam-generation equipment.

This formula is shown graphically for the start without bolt heating by the nomogram in Fig. 7. When bolts are heated under controlled conditions, starting times can be reduced to 50 percent of the values obtained from the nomogram.

The recommended rate of increasing or decreasing load can be obtained by the nomogram in Fig. 8. As an example, 25 percent load can be applied instantaneously provided no steam-temperature change occurs during this application of load. Also if 65 percent load is added and an increase of 100 degrees F in initial steam temperature occurs during this load increase, the time recommended for this change is 20 minutes.

This curve also shows the recommended rate of load decrease. Of course, as pointed out above, more rapid load decreases can occur without damage to the flange or bolts although the joint may leak temporarily and again seal after conditions have become stabilized.

Analysis of Operating Conditions

After an operator has obtained information on his turbine similar to that described above, he is in a position to decide questions such as the following:

a—During light-load periods, is it more economical to shut down a unit or to operate it at partial loads?

b—When shutting down, should load be reduced slowly in order to cool the turbine as much as possible before it is taken out of service, or should load be removed fast in order to retain as much heat as possible?

Factors affecting these decisions are:

a—Comparative values of off-peak load to total installed turbine capacity.

b—Shape of efficiency curve of boiler, turbine, and associated auxiliary equipment.

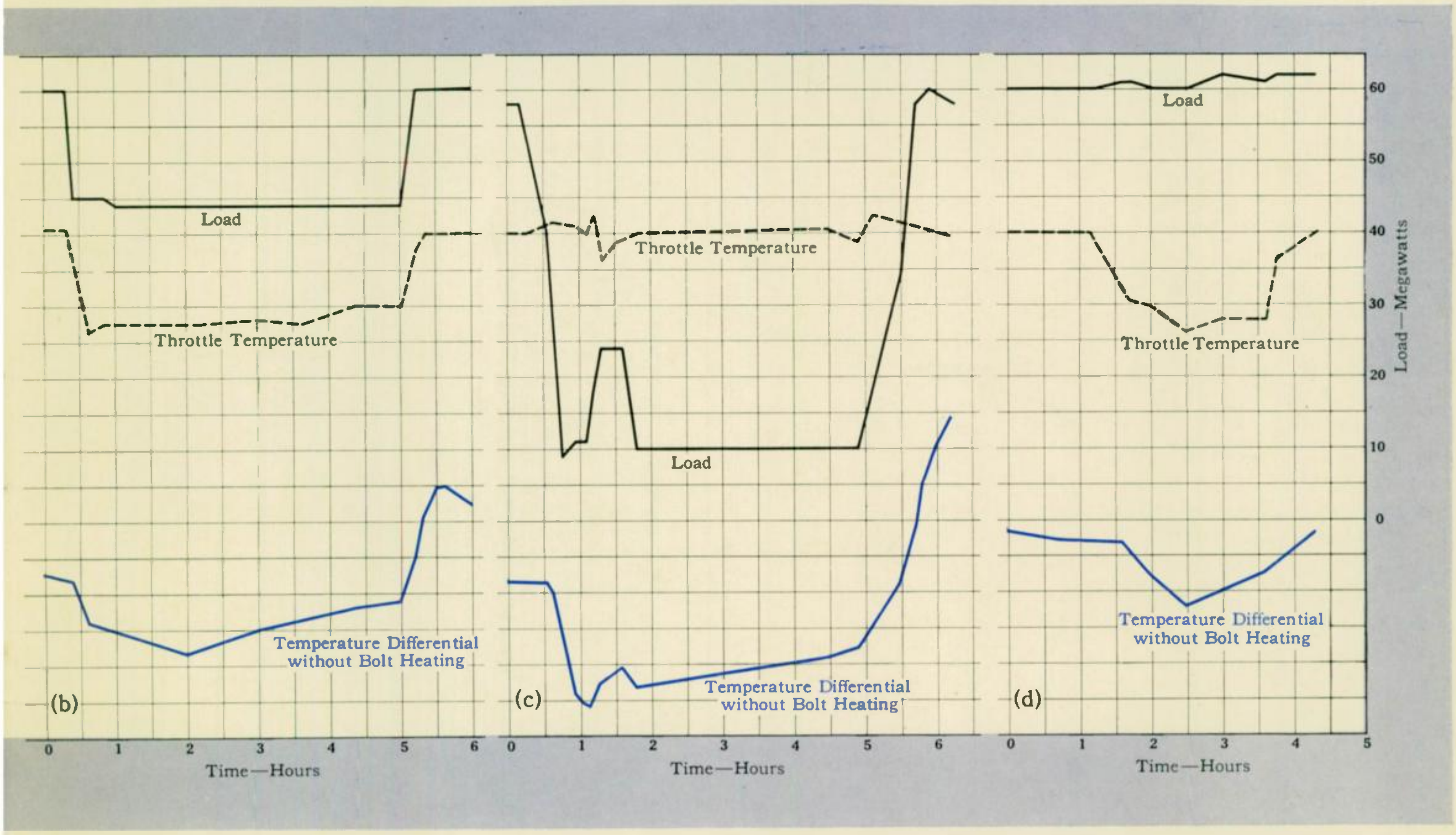
c—Ability of turbine to be started and loaded quickly without damage.

d—Need for short-time repairs or adjustments.

Efficiency of boilers and turbines is almost always poorer at light than at heavy loads. This is particularly true if the off-peak loads are less than half-rated load. As a rough rule, it is economical in most cases to keep the unit in operation provided it carries half load or more. If, however, it becomes necessary to transfer load from a more efficient unit to a less efficient one during the light-load periods, it might swing the balance in the other direction and justify shutting down the less-efficient unit.

Some turbines, particularly those of modern design, are better suited to quick starting and to rapid changes in load even though they may be operating with much higher steam pressures and temperatures. However, these units, being of modern design operating under higher steam conditions, would be the ones that should be kept in service during the light-load periods. Except on systems where the night or week-end load is only a small fraction of the peak load, this places the burden of shutting down and starting up chiefly on the older units that were not primarily designed for this type of operation.

The need for making minor repairs or adjustments during shutdown periods may dictate the desirability for taking a unit out of service. This is a normal operating factor that



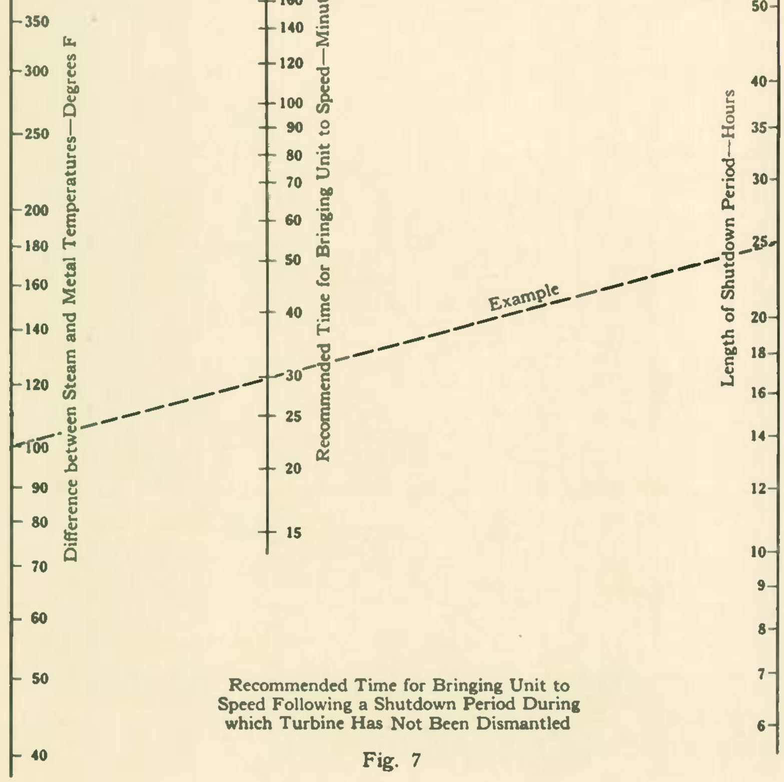
cannot always be anticipated or scheduled.

When a shutdown is scheduled to make necessary repairs or adjustments the operator usually knows about how long the unit will be out of service. He also knows what boiler or boilers will be available for starting and about what the steam temperature will be during the starting cycle.

When the unit is to be taken out of service for only a short time to make minor repairs, a fairly fast shutdown from heavy loads is dictated if the steam available for starting is at high temperature. On the other hand, it is advisable to remove load slowly and to cool the turbine as much as possible prior to being taken out of service if it is planned to start the boiler coincidentally with the turbine and thus use comparatively cool steam for starting. Starting a turbine is a combination of economics and safety to apparatus.

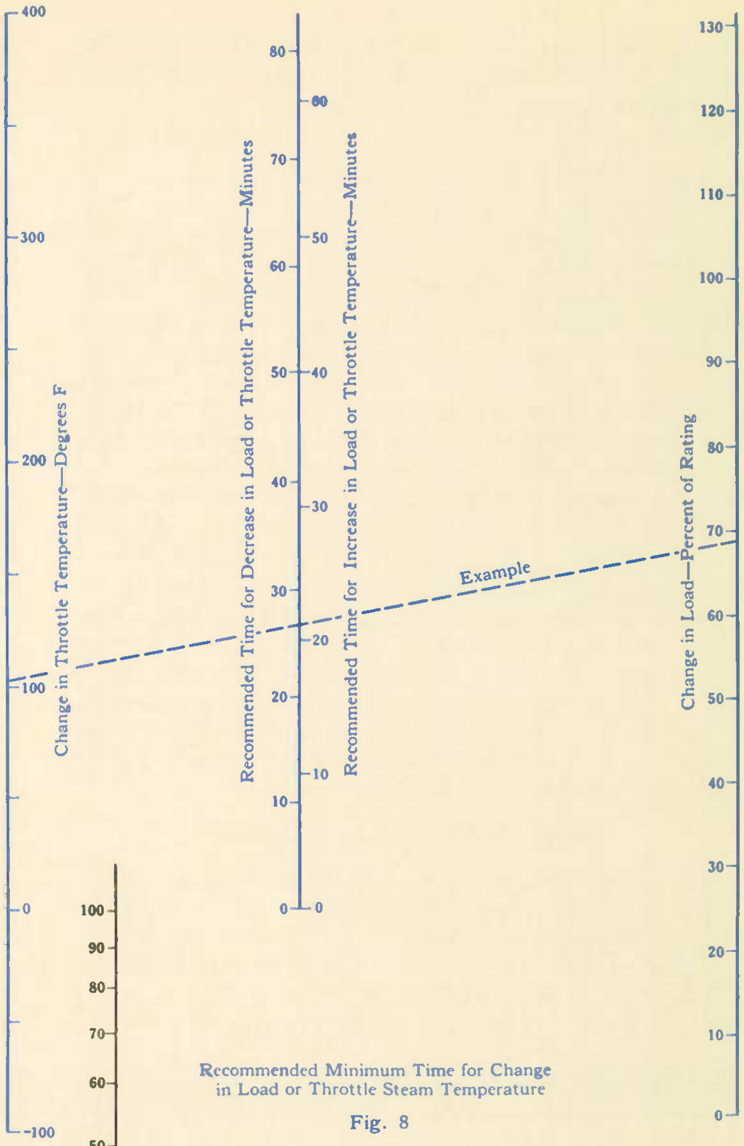
The loss in output and the consumption in fuel during the starting cycle can be quite large. It thus becomes extremely important that the starting time be reduced as much as practicable consistent with proper treatment of the steam apparatus.

An analysis of the behavior of the turbine, such as described in this article, enables an operating company to effect a substantial saving in starting time and, of equal importance, accomplish this saving with even greater safety to the equipment than when following the somewhat arbitrary rules established in the past for bringing a large steam-driven unit back on the line following a shutdown.



Recommended Time for Bringing Unit to Speed Following a Shutdown Period During which Turbine Has Not Been Dismantled

Fig. 7



Recommended Minimum Time for Change in Load or Throttle Steam Temperature

Fig. 8

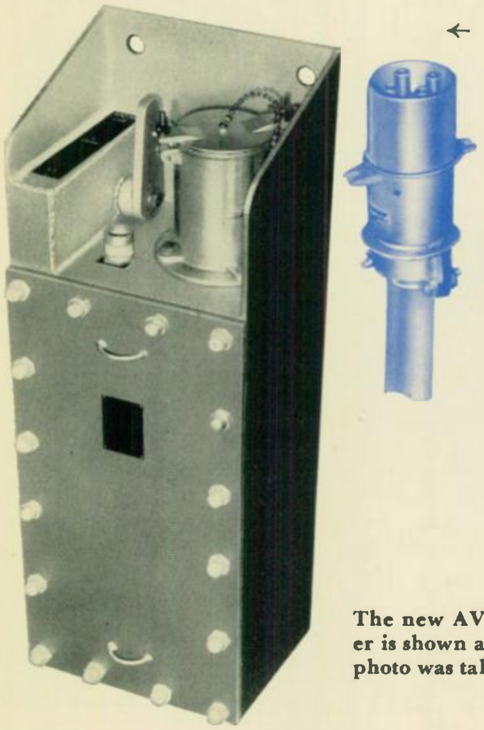
What's NEW! . . . . in Products

Just Plug Your Ship In

There is no standard method of supplying auxiliary power to ships tied up at piers. The system at every port is different, and often vessels have to obtain power from shipboard generating equipment while tied up. But a new Westinghouse development, the Pier Outlet Breaker, offers a simple, easy-to-get-at, safe supply of power to docked ships. It is the first of its kind, and was developed in cooperation with the Marine and Dock Engineers.

Ships now can be plugged in easily to the receptacle in the external housing of the Pier Outlet Breaker. Long tangles of power cable that clutter piers and hinder port activity are no longer necessary. Power is supplied from under the pier and is fed to the breaker through an opening in the bottom of the enclosure.

The drawout-type breaker is externally operated and has lifting handles that make it possible to remove the breaker from the enclosure quickly and easily. It cannot be removed while in service though. A mechanical interlock makes removal impossible unless the operating handle of the breaker is in the "off" position. The grade A, type AQB air circuit breaker (class HI) has overload, inverse time delay, and instantaneous short-circuit protection. The new breakers come for either 250-volt d-c or 440-volt a-c service, 2- or 3-pole. Interchangeable magnetic trip elements are used in ratings from 125 to 400 amperes. Where more power is required, these breakers can be installed in groups.



← **Top view of Pier Outlet Breaker and, below, receptacle plug.**

A watertight receptacle capable of interrupting its rated load provides the power takeoff from the breaker. These can be supplied for either three- or four-wire service.

The enclosure, compact and rugged, is watertight and corrosion resistant. Seam welded throughout, it is suitably protected from corrosion, then sprayed with aluminum paint to insure excellent performance and dependability in salty atmospheres. The top is extended and sloped so that hawsers cannot be fastened to the enclosure. This can be seen in the picture above.

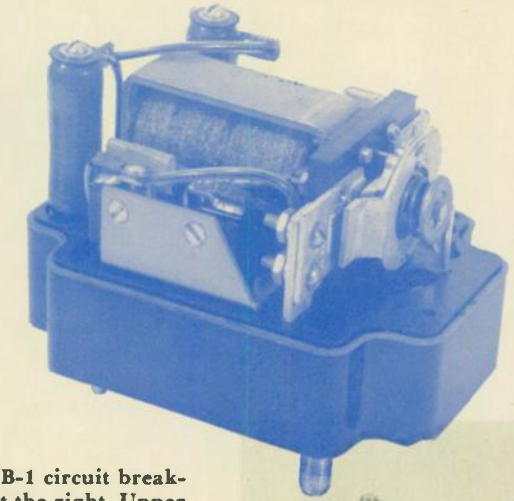
A heavy-duty Navy indicating light and heaters are connected when the breaker is not being used. The heaters, connected in series with the green indicating light, keep the inside of the enclosure warm and, hence, dry. Power for the heaters is supplied from a terminal board mounted inside the enclosure.

Tough Bimetal Serves a New Circuit Breaker

A unique breaker design, wherein the tripping element is located directly in the load line and not paralleled with a protecting shunt resistor, has been developed for 28-volt d-c aircraft electrical systems. This breaker, designated the AVB-1, is rated nominally at 300 amperes but was designed for use on aircraft circuits where excessively high currents with inverse time-current characteristics must be carried, for instance, on a conductor supplying power to a 10-million candlepower carbon-arc searchlight. This breaker will pass 300 amperes continuously, 600 amperes for 2½ minutes, or 800 amperes for 30 seconds without tripping and opening the circuit.

The unit is a modified bimetallic thermally operated breaker responding to load current to control a microswitch that in turn controls the current in a solenoid. The solenoid then opens the contacts in the load circuit. However, this bimetal operates as such only to currents of 2000 amperes. Above this value its thermal action is not fast enough. The bimetal acts as a one-turn coil to induce a field in an auxiliary armature. On short-circuit currents this armature opens the microswitch to de-energize the main solenoid. A holding coil prevents the microswitch from reclosing until a small thermal breaker reacts to currents drawn by resistors in the microswitch circuit to de-energize it.

The bimetallic element in this design is much more rugged than on conventional breakers; its calibration is thus less critical, facilitating maintenance. The unit is small and light, weighing only 3.9 pounds. Another feature of this breaker is the use of a double-



The new AVB-1 circuit breaker is shown at the right. Upper photo was taken with cover off. →

yoke contactor. The silver contacts of the primary yoke are protected from the eroding arc on opening and closing by having a secondary yoke that moves first on closing and last on opening to draw the arc away from the silver contact tips.

Adjustable-Trip Units for L-Frame Breaker

ADJUSTABILITY of the point at which a breaker will respond instantaneously to overload current is important. The magnetic trip should function, for maximum short-circuit protection, at a current just slightly greater than the momentary inrush current of motors or similarly connected loads. On AB De-ion circuit breakers, the magnetic trip consists of a fixed magnet with a moving armature that actuates the tripping mechanism. Varying the operating point—the current required for instantaneous tripping—is accomplished by changing the length of the air gap between the armature and the magnet.

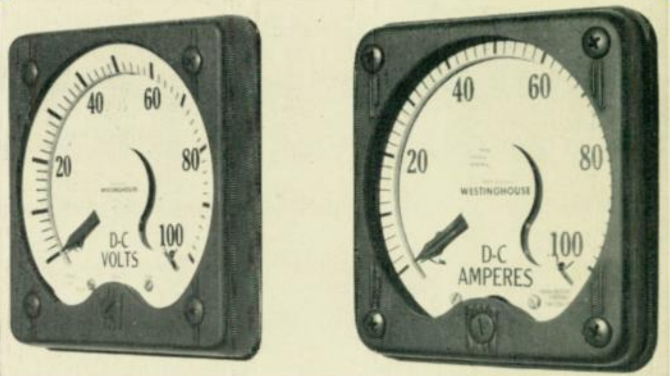
This adjustable feature has been standard for several years on the F-, G-, and K-frame breakers; now it has been added to the L-frame to complete the line. This new design uses an armature hinged at one end. The magnetic circuit is completed through an air gap at the opposite end. The armature is restrained in the open-gap position by springs that establish the calibration for normal current ratings. The air gap is adjusted to change the instantaneous trip point of any given rating by means of a cam that can be rotated against the armature. The shaft of this cam extends through the trip-unit cover, thus adjustments can be made after removing only the breaker cover. A further improvement is the use of laminations for the iron parts that form the magnetic circuit. This reduces losses and provides a uniform flux field, which in turn makes possible a uniform calibration.

The L-frame breaker with the new adjustable magnetic trip unit remains basically the same. The adjustable trip units are interchangeable with non-adjustable types.

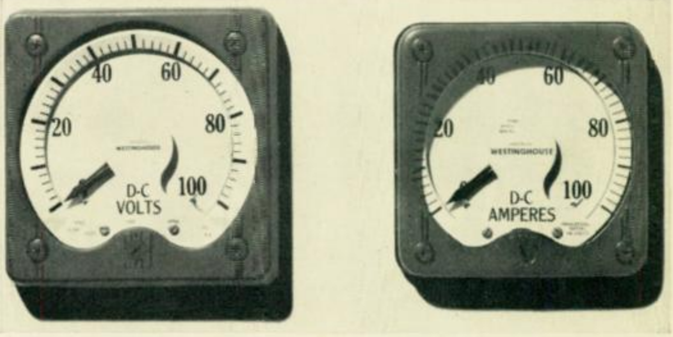
Instrument Dial Readability

With the new type of dial, termed Full-View, the scale markings can be read even under the most adverse lighting conditions. The new (left) and old (right) dials are here compared when lighted from lamps . . . .

sharply to one side . .



and directly overhead . . .



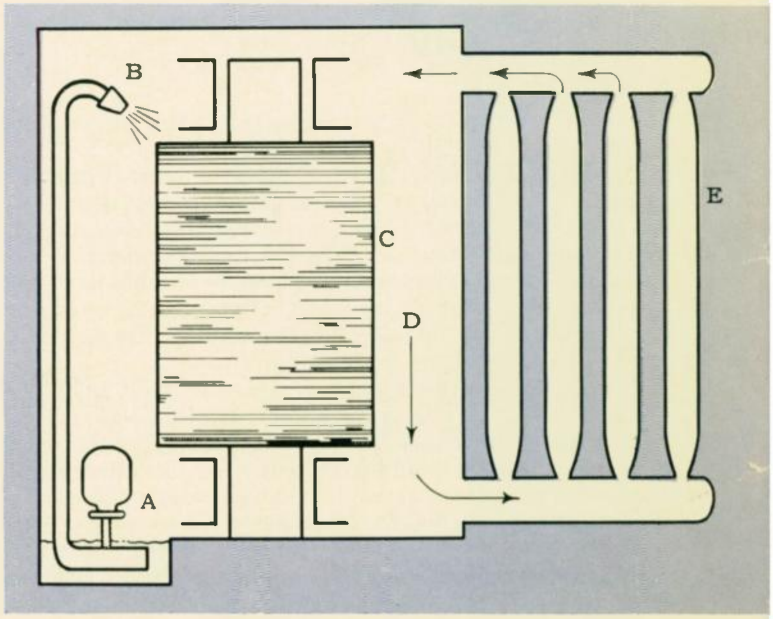
What's NEW! . . . . .in Engineering

Transformer Cooling—by Evaporation

WHEN you think of transformer cooling you automatically think first of oil, then of air. After 55 years of living with electric transformers engineers are still cooling them by these two very old methods. For some applications, engineers use non-inflammable insulating liquids; but mostly, oil and air are called on to cool transformers. In the not-too-distant future this situation may change. For several years the Westinghouse Transformer Division has been experimenting with a different kind of cooling, a technique that utilizes the heat of vaporization of liquid fluorocarbons for cooling and the dielectric strength of their vapors for insulating a transformer. The group of fluorocarbons being tested promises to bring a radical change to the science of cooling transformers.

There has been no basic change in transformer cooling techniques since 1887 when George Westinghouse was granted a U.S. patent for the use of oil in transformers. That innovation had a profound effect on the development of large power transformers. But it was not an unmixed blessing. Although oil is far superior to air in insulating and cooling properties, there is always the possibility of fire or explosion when liquid-immersed transformers are used. Consequently, dry-type transformers are commonly used for indoor applications. In dry-type transformers air is used as the cooling and insulating medium. Since air is a poor insulator and heat conductor, the capacities and voltage ratings of dry-type transformers are limited. For the same kva and voltage rating a dry-type transformer may be larger than an oil-immersed transformer. Sometimes, however, oil must be used in indoor applications. Then, extra safety precautions are necessary, and these are usually expensive.

For many years transformer engineers have been looking for a better way to cool power transformers. The most attractive idea has been vaporization cooling, but so far a practical vaporization-cooled transformer has not been developed. In this kind of cooling the latent heat of vaporization of an evaporating



liquid is used to cool the core and coils of a transformer. The trouble has been that no completely satisfactory liquid could be found. Such a substance must have a suitable boiling point and heat of vaporization, and its vapor must have good 60-cycle and impulse dielectric characteristics. It now appears that the power distribution and the transformer manufacturing industries have reached a turning point. Tests being conducted at the Transformer Division give promise that a practical vapor-cooled, vapor-insulated transformer is possible. Such a transformer will combine the advantages of both the liquid-immersed and the dry-type transformers.

This new method of cooling uses the latent heat of vaporization of high-molecular-weight fluorocarbons to cool the transformer. The process is illustrated in Fig. 1. The transformer tank and the coolers constitute a hermetically sealed system, suitable for either indoor, outdoor, or submersible application. Instead of completely filling the transformer tank with liquid, just a small amount is used—a fractional part of the quantity of oil now used in liquid-immersed equipment. This is stored in a sump at the bottom of the tank. An electrically driven pump forces the liquid fluorocarbon to a nozzle that sprays the liquid directly on the core and coils. The heat generated in the coils evaporates some of the liquid; but evaporation of the entire amount is not needed for cooling, so the remainder returns by gravity to the sump to be recirculated. The vapors formed in this process freely migrate toward the cooling surfaces of the transformer tank, where they condense and release the heat that was taken from the coils. The condensed liquid then flows back to the sump. The vapors fill the space inside the tank and insulate the transformer in the same way that oil insulates a liquid-immersed transformer.

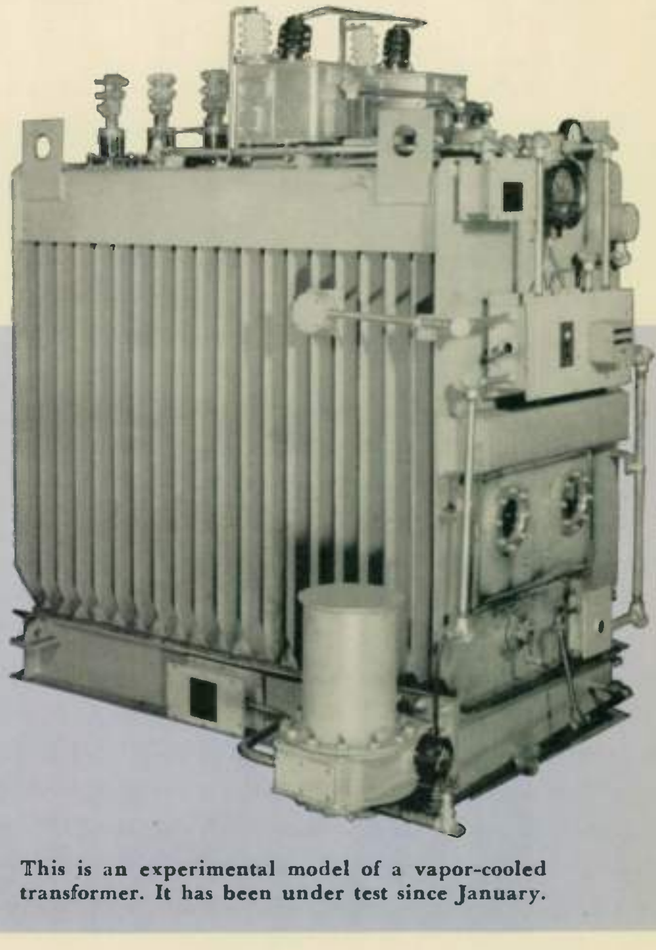
The key to the success of this system is the cooling liquid. Fluorocarbons, a large new family of synthetic compounds, are chemically inert and thermally stable. Another important property of these compounds is the high dielectric strength of their vapor at relatively low pressure. This combination of chemical stability and high dielectric strength makes fluorocarbons uniquely suitable for vaporization cooling and insulation of electrical apparatus. Under certain conditions of electrode configuration, the 60-cycle dielectric strength of fluorocarbons at atmospheric pressure is greater than that of transformer oil. In practical applications one has to be satisfied with less, but the value remains high enough to provide good electrical insulation.

It is still too early to know what disadvantages this kind of a transformer may have, but the advantages are pretty well established. Such a transformer will be free from danger of fire or explosion, because the liquid used is fireproof. In fact, it has fire-extinguishing properties. A transformer of this type will be as small as and lighter than an equivalent liquid-immersed transformer. There is no inherent limitation to the kva rating of vaporization-cooled transformers, because the heat transfer by vaporization is superior to that obtained with circulating oil. This makes possible a compact design of the coils, as well as a reduction in the amount of external cooling surface. The dielectric strength of fluorocarbon vapor is superior to ordinary gases, so it will be possible to extend the voltage rating of vapor-insulated transformers far beyond the 15-kv class, the present ceiling for dry-type transformers. Other advantages are in sight, stemming particularly from the excellent heat transfer in a vaporization-cooled transformer between the coils and the tank cooling surfaces. For instance, the coolers need not be right next to the transformers; they can be placed a reasonable distance away in applications where this is desirable.

The vaporization-cooled transformer is the result of a joint development program of the Westinghouse Research Laboratories and the Transformer Division. The idea to use high-molecular-weight fluorocarbons to cool a transformer, by spraying the liquid on the core and the coils, originated with Dr. C. F. Hill, Manager of the Insulation Department at the Research Labs. The task of developing a practical transformer using this cooling technique was placed in the capable hands of Dr. Paul Narbut, of the Transformer Division. Progress since 1947 includes the construction and operation of two vaporization-cooled transformers. The first experimental unit made use of a standard dry-type 50-kva transformer. Equipped with adequate cooler capacity and cooled by vaporization, this unit delivered in excess of 350 percent of its rated load, with the wet copper temperature much lower than is normal for dry-type operation. The heat dissipated was ten times greater than the dry-type transformer could handle. Unfortunately this spectacular performance is not of much practical use. At 350 percent of rated load, the losses and the impedance are much too high. However,

Fig. 1—This sketch shows how vaporization cooling works. At *A*, a small pump picks up the liquid fluorocarbon from a sump at the bottom of the transformer tank. The liquid flows through pipes to the nozzle shown at *B*. There it is sprayed on the core and coils of the transformer so that the entire transformer assembly is wetted uniformly. The liquid then evaporates, *C*, taking its latent heat of vaporization from the coils of the transformer. The liquid fluorocarbon is circulated at near the boiling temperature, and the heat necessary for vaporization is supplied by the coils. All of the wet parts of the transformer are at the same temperature, determined by the nature of the liquid and the vapor pressure inside the tank.

The fluorocarbon vapor fills the space in the tank, *D*. Since this vapor has a high dielectric strength (which depends on the cooling fluid used), it insulates the operating parts of the transformer. This vapor migrates freely toward the cooling surfaces of the tank, where it condenses into a liquid and returns by gravity to the sump. There it is recirculated by the pump. Condensation at the cooler is accompanied by only a small change in the temperature of the fluorocarbon. It remains near the boiling temperature throughout the system. The temperature of the cooling surfaces can become slightly lower than the temperature of the coils; however, in a self-cooled transformer using fluorocarbon, this difference is only a few degrees centigrade—much less than the usual temperature difference between copper and cooling surfaces in conventional liquid-immersed units. The copper temperature rise is utilized to better advantage.



This is an experimental model of a vapor-cooled transformer. It has been under test since January.

it does illustrate the possibilities of vaporization cooling.

Since the first of the year, a specially built, 500-kva, 2400/240-volt vaporization-cooled transformer has been in operation at the Transformer Division. This transformer, which is shown at the bottom of page 167, was built to verify the design. Of course, the experimental transformer in the picture contains a great deal of test equipment that is used to obtain design data. Such equipment will not be included on a finished commercial product, which, when a final design is arrived at, will look much different than this test model.

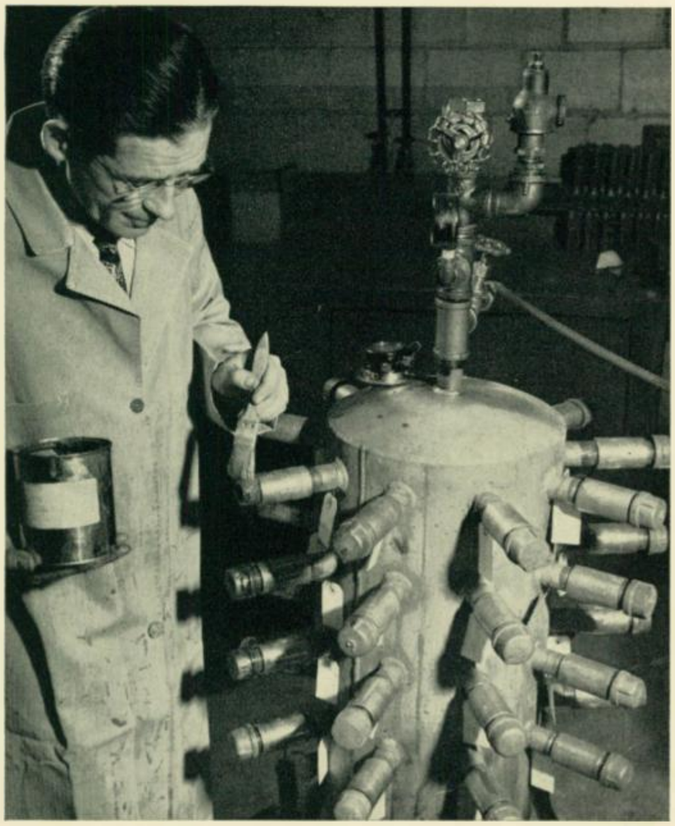
A trial vaporization-cooled network transformer, to be installed on the system of the Consolidated Edison Company of New York, is now being designed. This unit will provide valuable service experience with this new kind of cooling and insulating.

What applications vaporization-cooled transformers will find remain a question. Added to the usual complexities of guessing about the future is the fact that, in spite of the possibilities of smaller size and lighter weight, a vaporization-cooled unit may cost more than present types. This is primarily because fluorocarbons of the proper type are now very expensive. Aside from this, the particular advantages of vaporization-cooled transformers will determine their application. Where a degree of safety is required that is not obtainable from liquid-immersed transformers, where space and voltage requirements rule out dry-type transformers, and where extremely compact installations with forced external cooling or a remote cooler are required, a vaporization-cooled transformer may be expected to provide the most suitable and economical answer.

A Swell Thread Cement

NOTHING pleases an engineer more than to turn a product's weakness into an asset. This has been done to eliminate a long-standing nuisance of oil-filled transformers—oil leaks at threaded connections. Over the years many thread cements have been used, but none has been completely satisfactory. Most of them contain solvents that evaporate and cause the base material to shrink and make the cement porous. When a joint is subsequently tightened, the seal formed by the cement usually breaks. Since the cement cannot restore itself, oil then can work its way slowly past the threads.

As indicated here, the new thread cement can be easily applied.



It occurred to Jim Ford, head of Transformer Manufacturing Engineering, that a thread cement, which would swell in contact with oil, would solve the problem of leaky fittings, because such a cement could repair itself. Natural rubber and certain synthetics have that property. This has led to a thread cement containing small particles of synthetic rubber suspended in a resin that is simply a vehicle for the rubber and does not react with it. The rubber was specially selected to give the correct degree of swell when in contact with oil. The rubber particles retain their original size until the transformer oil acts on them. Then they expand and seal the potential leak.

In oil-filled transformers, the new cement is applied to the threads before oil is introduced to the tank. When the transformer is filled, the rubber in the cement of the first few threads expands and fills all the voids between the threads as soon as it comes in contact with the oil. If the joint is later tightened and the seal disturbed, further seepage of oil into the threads results in still more expansion and the joint once again is sealed. This process can be repeated a number of times before leakage develops. The connections can be removed with reasonable ease because the oil has a plasticizing effect on the cement.

This cement is now used for threaded connections on all oil-filled transformers, but is being made only in pilot-plant quantities. Later, production will be increased and the cement will be available for other applications.

More Starting Torque for Split-Phase Motor

WOULD you believe it, something new is being done with magnetic motor-slot wedges! A fractional-horsepower motor was required with somewhat greater starting torque than the standard split-phase motor possesses. Yet the designer was reluctant to use the capacitor motor, with its higher cost. He licked the problem by using steel wedges in the slots not occupied by the starting winding. This increases the leakage reactance of the running-winding circuit and has the effect of widening the phase angle between the currents in the starting and running winding, which is one of the determining factors in the amount of starting torque developed by a split-phase motor. Use of magnetic slot wedges would have the effect of reducing the maximum or pull-out torque, but this is compensated by altering the turns of the running winding. Some sacrifice in efficiency cannot be avoided, but this is very small.

More Kw Per Cubic Foot for Dry-Type Transformers

THE electric power used in hospitals, offices, and similar commercial buildings is steadily increasing. But sizes of their doorways, halls, and vaults through which power-supply transformers must pass aren't. Transformer engineers are being asked to pack more and more kilowatts capacity into the same space—and do it without use of oil cooling. A new triplex power center is one of their answers. It consists of three dry-type transformers stacked one above the other, flanked by a high-voltage switch and low-voltage panelboard and AB breakers in sizes from 45 to 300 kva in voltage classes through 5 kv. For network application a protector is provided in the assembly.

Also in the dry-type family are larger completely sealed transformers than ever before. A sizable number of 1250-kva, 15-kv units have been built for powerhouse service in several cities. Designers say bigger ones can be built. (Before last year 500 kva was the largest sealed dry-type unit.) These employ class-H insulating materials (glass, porcelain, mica, etc., some silicone varnishes—no organic materials) and are in smooth tanks with all seams welded. They are completely fire and explosion proof. Although primarily intended for indoor service, they are suitable for outdoor application when protected from surge voltages.

News in Books

Electrical Insulation—Many designers of rotating electrical machinery, operators, and maintenance men will be glad to know that at last there is a comprehensive yet simply written book on insulation. It has been written by Graham Lee Moses of Westinghouse, himself an old hand in the insulation business. But it does not embody just his experience or that of his company; it was prepared at the request of and under the guidance of the U.S. Navy, and includes information provided by 29 manufacturers of insulation and rotating machines. While the book concerns itself primarily with shipboard applications, most of the material is fundamental to all machinery use. In addition to eight chapters that extend from Insulation Theory and Basic Concepts to Preventive Maintenance, it includes two valuable appendixes. One lists the available Navy insulating materials and identifying information. A second covers properties and test information on electrical insulating materials. The book has 259 pages with many illustrations, and is available from McGraw-Hill Book Co., New York, for $5.50.

Plant Layout, Planning and Practice, a new book by Randolph W. Mallick and Armand T. Gaudreau, fills a long-standing need for a scientific approach to the proper planning and layout of industrial plants. The authors present complete engineering techniques for laying out entire plants and modernizing existing layouts. And they analyze the problems involved in determining plant capacities, balancing-machine operations, equipping work stations, designing production and assembly lines and material-handling systems. Capital outlays for plant and equipment, and provisions for future expansion are also considered in detail.

Mallick and Gaudreau write from an extensive background of experience gained through 20 years' service in American industry. Mr. Mallick is currently executive staff engineer for the Westinghouse Electric Corporation. Mr. Gaudreau, formerly associated with Westinghouse, is managing partner of Gaudreau, Rimbach and Associates, management consultants.

John Wiley and Sons, New York, is the publisher. The book contains 391 pages, and is priced at $7.50.

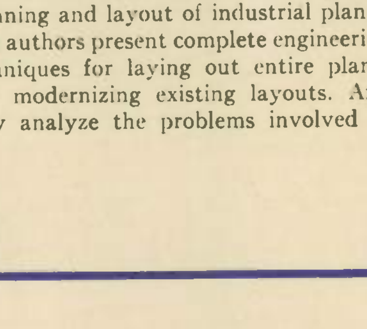
Personality Profiles

R. L. Tremaine and *A. R. Jones* are new names to this page. But this is not the first time they have worked together on an article; they have collaborated on several AIEE papers dealing with corona.

Tremaine came to Westinghouse in 1940 after graduating from the University of Maine. After completing the Westinghouse Student Course, he went directly to the Central Station Section of Industry Engineering, where he built the first model of the photographic lightning recorder, described in the article on lightning phenomena in the July issue. He didn't stay in Industry Engineering very long. A war started in 1941, and Tremaine became a part of it. Of his five years in the Army, he spent 37 months overseas, in Australia and New Guinea. Tremaine put his engineering training to good use in the Army. At various times he served as gunnery officer, radar officer, communications officer. He came out of the Army in 1946 a captain, and has retained a commission as second lieutenant in the Army Reserve Corps.

Back at Westinghouse in '46, he resumed his duties as a central station engineer. He has been in charge of the field testing and analytical work for Westinghouse at the 500-kv Corona Test Project at Tidd. As with every job Dick has tackled, this has resulted in several Tremaine innovations. His leisure time interest in photography led to his development of a photographic weather recorder. This is a modified movie camera that takes a picture every 20 minutes, providing a photographic record of extremely light rain, snow, sleet, condensation and fog conditions that do not register on standard rain gauges. He also devised a circuit to measure the loss of insulator strings. He is co-inventor of a color-television tube.

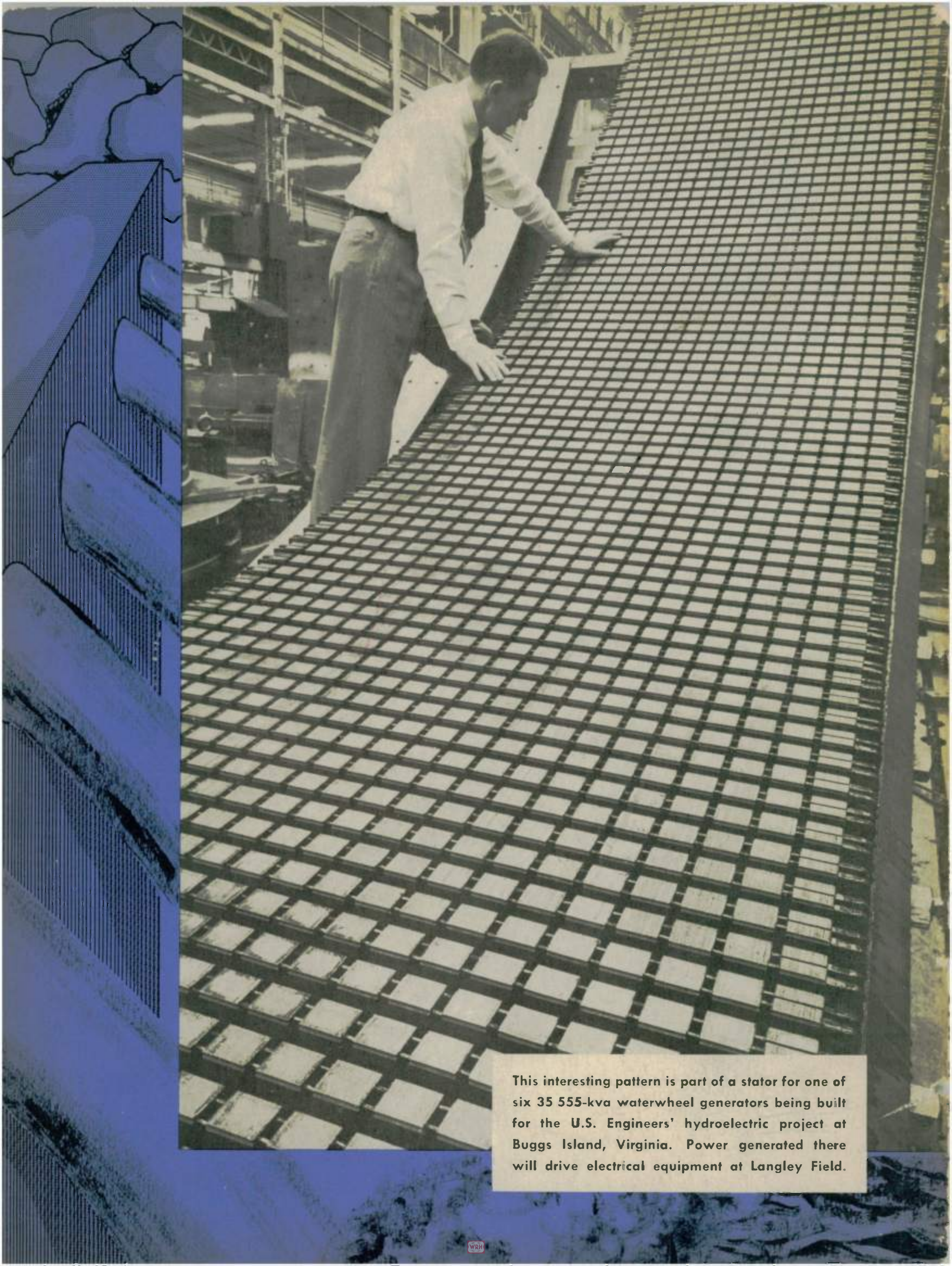
As a hobby, Tremaine makes home movies. Specializes in closeups using a telephoto lens to capture natural expressions and situations. He has built his own television set and at present is building a new home, on which he is his own architect and contractor.



Andy Jones took a slight detour from high school to the Central Station Section. He was born and raised on his father's 200-acre farm east of Quincy, Illinois. But farming was not for Andy. After high school he attended Western Illinois State Teachers College for three years and later taught school for a year. Then, in 1942, Uncle Sam beckoned and Jones hustled off to the Army, where he spent 40 months in the Air Force in personnel and transportation work. When he returned to civilian life in 1946, Jones decided to leave teaching. It was more satisfactory than farming, but high-school teaching didn't quite suit. He had been a physics and science teacher, so he turned next to engineering. The transition from teaching to electrical engineering would seem to be a difficult one, but apparently it was no great problem for Jones. Just one year after entering Clemson College, in South Carolina, he graduated with the degree of Bachelor of Electrical Engineering. From Clemson he came to Westinghouse. Since completing the Student Course, his engineering activity has centered around the Tidd 500-kv Test Project. His field work there has been an important factor in the success of the corona investigations and he has contributed a great deal to our present knowledge of the causes and effects of corona.

Regarding hobbies, Jones is one of that increasing legion of people who have decided there is nothing in photography quite like color. He has always been interested in photography—had his own darkroom while in high school. But now he spends his leisure time taking color transparencies rather than black and white. Jones doesn't confine his picture taking to any particular kind—his subject matter varies from linemen at work at Tidd to intimate shots of his family.

As you can surmise from this brief history, Andy Jones is constantly striving for change and improvement. At the present time, since corona investigations, photography, and his two children don't quite use up the 24 hours in a day, he is taking additional courses at the University of Pittsburgh working toward a master's degree in electrical engineering.



This interesting pattern is part of a stator for one of six 35 555-kva waterwheel generators being built for the U.S. Engineers' hydroelectric project at Buggs Island, Virginia. Power generated there will drive electrical equipment at Langley Field.