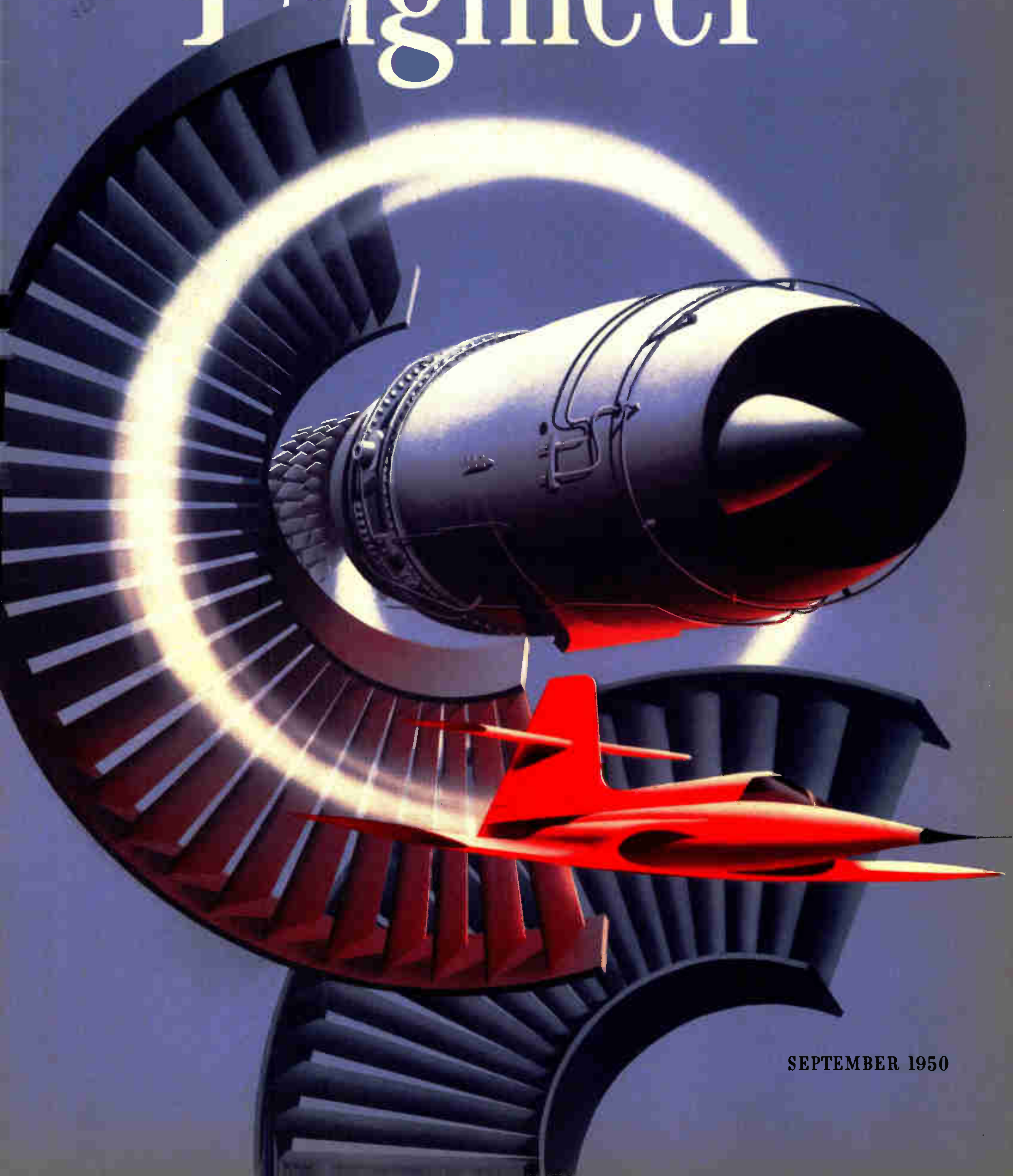
# WESTINGHOUSE Engineer



SEPTEMBER 1950

# What Is the *Electrical Manufacturing Industry?*

In thinking of the business of providing apparatus for the electrical industry, we are reminded of the bit of doggerel:

"What are little boys made of, made of?
What are little boys made of?
Snips and snails and puppie-dog tails,
And such are little boys made of."*

Like little boys, the electrical manufacturing industry is not—as one might suppose—composed of any one element or branch of engineering. It is not mainly concerned with electrical circuits, principles of electrical machines, electrical phenomena, waves, volts, amperes, and such. These are but a part of the whole, and perhaps the smaller part. Without attempting to fix proportions, the industry is really a combination of many branches of engineering and science that are overshadowed by the electrical only in name or in concept.

The electrical manufacturing industry is chemistry. Chemistry underlies most of its insulation: oils, impregnants, bonds, plastics, even electrical insulating atmospheres. Lubrication problems demand the services of the chemist. So, too, finishes, paints, varnishes. Electroplating is another. Even the problem of behavior of carbon brushes at high altitude was laid on the doorstep of the research chemist. And the development of nuclear-energy plants has problems that only the chemist can tackle.

The electrical manufacturing industry is metallurgy. Important are the developments of magnetic steels, of special steels for shafting and other heavily stressed members, the whole family of high-temperature metals for turbines, metals for lamp coils and electrodes, electron-tube cathodes, x-ray tube targets, and electric-range tops. The industry calls for expertness in the common metals—the steel, copper, mercury, sodium, aluminum, tungsten, magnesium—and the "rare" ones—as uranium, thorium, cesium.

The electrical manufacturing industry is optics. Specialists in the properties of materials relative to light develop improved searchlights for the military forces. More efficient floodlights and luminaires for industry and home, better means of piercing fog at airports, better lenses and reflectors for lamps, for better photoelectric controls.

The electrical manufacturing industry is, even more than these, mechanical engineering. It rivals, if not surpasses in quantity, electrical engineering itself. Every device made—even to vacuum tubes—is a mechanical device first, an electrical one next. Such things as strengths of materials are obvious and basic. Problems attendant to ventilation, vibration, appearance, economy of dimensions and weight, are exclusively or primarily mechanical ones. Hinges, levers, latches, seals, covers, foundations, supports, bolts, welds, clamps—on these mechanical elements depends much of the success of any electrical device.

The electrical manufacturing industry is all these things, plus many more. We could go on, to mention physics, with its many branches, or civil engineering, or a multitude of others. But this sampling seems sufficient to illustrate that the industry is built on, and of, many kinds of engineering and science. This fact is being increasingly recognized. This is indicated by the rising proportion of non-electrical graduate engineers that yearly enter companies like Westinghouse from college. Men trained in mechanics, chemistry, and metallurgy now comprise nearly half the total.

All this does not indicate any decline in the importance of electrical engineering, nor any scarcity of electrical problems, but merely that some of the non-electrical problems—of which there are a multitude—are now being done by men with more intimate knowledge of the field involved. Neither does this mean rigid specialization in one field for all engineers. Rather it indicates an awareness of the nature of engineering problems. Better products are the logical end result.

---

*"What All the World Is Made of," by Robert Southey.

# WESTINGHOUSE Engineer

VOLUME TEN

SEPTEMBER, 1950

NUMBER FIVE

## On the Side

Zooming out of the "wild blue yonder," on this month's cover by Dick Marsh, is the new, high-flying aircraft power plant, the turbojet engine. Few man-made devices have so captured the public's imagination—even in these days of atomic bombs and other scientific wonders.

• • •

While on the subject of jet engines—the Westinghouse jet that powers some of the Navy's and Air Force's fastest experimental and operational combat planes has now been certified by the Civil Aeronautics Administration for commercial planes.

This newly certified engine, the J-34, currently powers the supersonic Douglas "Skyrocket" and the McDonnell "Banshee" fighter, among others.

• • •

Damaged turbine spindles customarily tie up a ship for days while repairs are being made. Not so with the *SS Olympic Star*. When she arrived at New York recently and started to unload, it was found that one of the tanker's two ships-service, 400-kw turbine generators was behaving strangely. Examination showed that the turbine shaft had developed a 0.004-inch deflection and would have to be pulled, straightened, machined, and balanced before the ship could put out to sea again.

However, the spindle was shipped to Westinghouse at South Philadelphia, where it arrived early one Friday morning. Working against time—the ship was due to sail early the next morning—the Steam Division ground, machined, trued, and dynamically balanced the spindle. Eleven hours later the spindle was on its way, and was installed in time for the sailing.

## In This Issue

Distribution transformer—Photographing oscillograph traces—Instrument transformer—Impedance matching reactors—New colors for fluorescent lamps—New CSP transformer—New slimline lamp—Continuous viscosity control—Grand Coulee switchboard—New impulse generator.

The following terms, which appear in this issue, are trade-marks of the Westinghouse Electric Corporation and its subsidiaries:
CSP, Cupaloy (not registered), De-ion, Discaloy, Hipernik, Hipersil, K42B, Precipitron, Rectomatic, Rectox, Refractaloy, Thermalastic, Visicode.

*Editor* . . . . . . . . . . CHARLES A. SCARLOTT
*Managing Editor*. . . RICHARD W. DODGE
*Layout and Production* . . EMMA WEAVER
*Editorial Advisers* . . . . . R. C. BERGVALL
W. W. SPROUL

The *Westinghouse* ENGINEER is issued six times a year by the Westinghouse Electric Corporation. Dates of publication are January, March, May, July, September, and November. The annual subscription price in the United States and its possessions is $2.00; in Canada, $2.50; and in other countries, $2.25. Price of a single copy is 35c. Address all communications to the *Westinghouse* ENGINEER, 306 Fourth Ave., P.O. Box 1017, Pittsburgh (30), Pa. The contents of the *Westinghouse* ENGINEER are analyzed and indexed in the INDUSTRIAL ARTS INDEX.

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

# The *Jet Engine* Comes of Age

**First years are the most difficult, but the aviation gas turbine has progressed amazingly in the decade of its existence. Cumulative improvement in the different measures of performance is not just a few percent, but 20 or 40 percent. This development, spurring exploration in such fields as compressor design and high-temperature metallurgy, has broadened the horizon of aircraft designers.**

R. P. Kroon, *Engineering Manager, Aviation Gas Turbine Division, Westinghouse Electric Corporation, South Philadelphia, Pennsylvania*

From the Wright brothers' first flight in 1903 until 1945, the power plant limited aircraft performance. Although steady advances increased available power and reduced engine weight, the huge bulk and limited maximum power of the piston engine blocked hopes of attaining the truly high flight speeds that the aerodynamics of the airframe would permit. But in less than a decade, the turbojet engine has broken through these limitations and made possible great advances in aircraft performance.

Early evaluation of the turbojet aviation gas turbine showed that it would be a light power plant particularly adaptable for operation at high speeds and high altitudes. It promised almost limitless power. The turbojet is fulfilling these early promises.

Jet-propelled aircraft of many types have flown at altitudes above 50 000 feet in routine flights. Turbojet engines have propelled the Douglas "Skyrocket" at supersonic speeds. At these high speeds the power of the larger jet engines is already more than five times that of the largest piston-engine propeller drives. The installed weight of the jet engine, on the average, is less than one quarter that of a piston engine of comparable power at high speed. The procession of new military aircraft testifies to the enthusiasm of the plane designer in being freed of previous power-plant limitations.

However, much remains to be done in developing and perfecting the several forms of aviation gas turbines, in both the military and commercial fields. Engine requirements are increasing to permit flight at ever higher altitudes and operation through wider variations in air temperature. Providing additional services to the aircraft, such as compressor airbleed for cabin supercharging or de-icing, and increased power for electrical or hydraulic accessories, makes ever greater demands on the engine. The present evolution and the foreseeable future promise extremely active development with continuing demands for power plants of increased output, better performance, improved reliability, and greater durability.

## Trends in Turbojet Engines

In evaluating engine performance, note what is happening to the most important engine characteristics—efficiency, weight, and thrust per unit frontal area. The trends in these characteristics are shown in Figs. 1, 2, and 3, based on unrestricted data of British and American engines. The performance of more recent engines is even better, but this data has not yet been made public.

### Fuel Consumption

Improved engine efficiency means that, with a given amount of fuel, the range of the aircraft can be increased. Conversely, with less fuel the aircraft's payload can be raised without sacrificing range. In 500 hours of operation a jet engine consumes an amount of gasoline that costs half as much as the engine itself. Fuel economy, therefore, is an important economic factor, even independent of the longer range or higher payload it makes possible.

High fuel consumption appeared as one of the weakest traits of the turbojet engine, but continuing progress is achieving better fuel economy. While specific fuel consump-

**Figure 1**

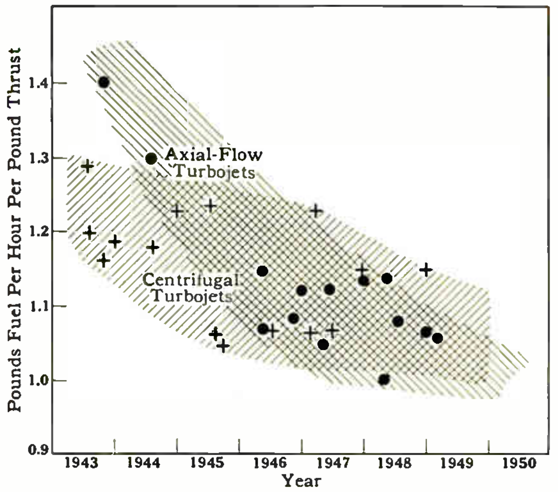
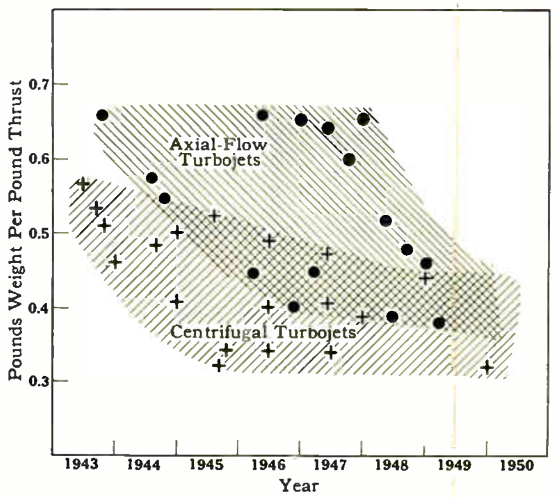


**Fig. 1—Specific fuel consumption of a number of turbojet engines at maximum (military) rating at sea-level conditions.**

**Fig. 2—Trends in specific engine weights for some British and American jet engines.**

**Figure 2**



tion for a typical 1944 engine was around 1.25 lb fuel per hr per lb thrust (static, sea level), the engines now in production average about 1.05, and further improvement is coming. These improvements are due to many component refinements, as well as to a general increase in compressor pressure ratio (ratio of compressor exhaust to inlet pressures). Thermodynamic calculations show that, with reasonable component efficiencies, increasing the pressure ratio from 4 to 6 cuts down fuel consumption by about 4 percent. Increasing the pressure ratio to 15 saves another 12 percent of fuel, accomplished, of course, at additional cost and weight of compressor. Hence, we can expect to see engines with higher pressure ratios where fuel consumption is important—in long-distance flying. Further development might well reduce turbojet fuel consumption to 0.7 lb fuel per hr per lb thrust (static, sea level) within the next decade.

The trend to lower fuel consumption has been more pronounced for axial-flow engines than for the centrifugal type, as indicated in Fig. 1. One reason is that the centrifugal compressor, when first applied to the aviation gas turbine, had reached a higher degree of perfection than the axial-flow type. The axial compressor, although successfully applied for land use with high efficiency but with a large number of stages, is still undergoing continuous improvements in performance—particularly increased pressure ratios with high efficiency.

Present engines operate at turbine inlet temperatures of about 1500 degrees F. A higher inlet temperature improves thermal efficiency and increases power output, but, in the turbojet, higher temperatures also mean poorer fuel economy. More fuel is used because higher operating temperatures give a higher jet velocity and, therefore, a lower propulsive efficiency. This, at all but extremely high speeds, more than offsets the improved thermal efficiency of the power plant. Hence, better turbojet fuel economy must come from other improvements in the gas-turbine cycle.

From the standpoint of non-aviation gas turbines, it is interesting to note that present "simple open-cycle" turbojet engines have thermal efficiencies in the neighborhood of 25 percent, i.e., comparable to those of a modern marine power plant. Increased turbojet efficiency has already led to the use of this engine for long-range planes, bombers as well as transports, that were not envisaged even a few years ago.

### Engine Weight

For a given aircraft, lighter engines permit longer range or higher payload. A typical specific weight (Fig. 2) for 1944 engines was 0.55 lb per lb thrust, but present production engines average nearer 0.40 lb per lb thrust. Although many active developments favor weight reduction, there are several tendencies towards heavier engines.

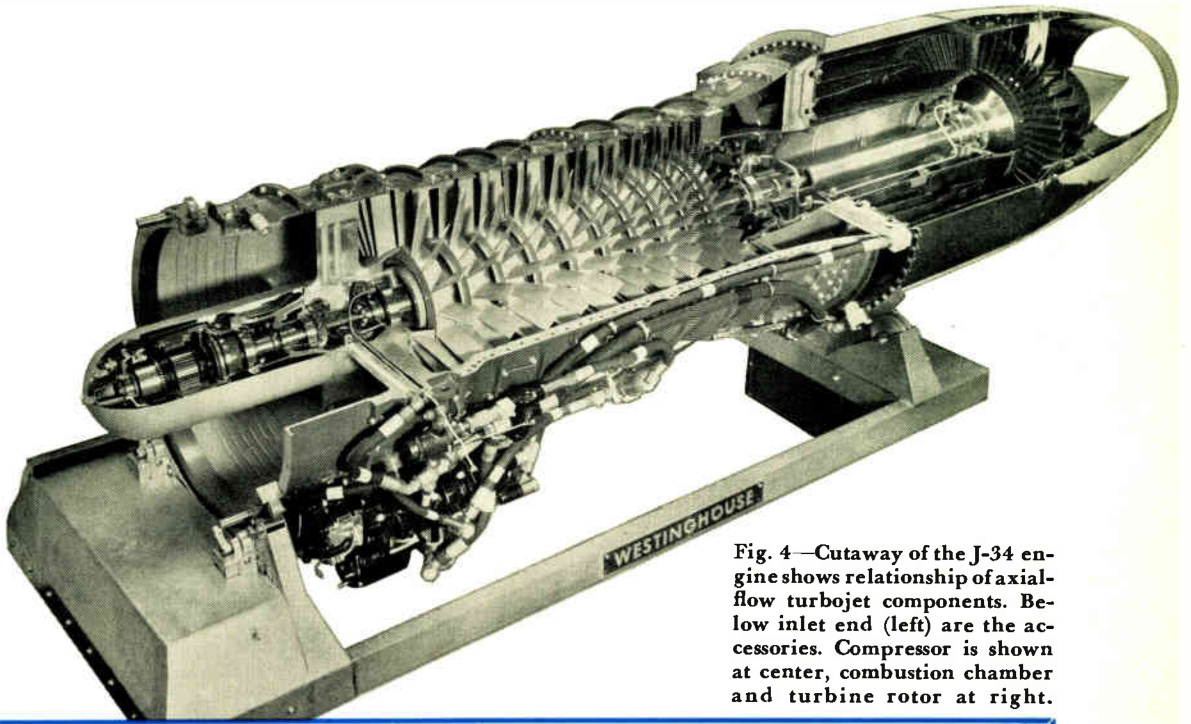


**Fig. 4—Cutaway of the J-34 engine shows relationship of axial-flow turbojet components. Below inlet end (left) are the accessories. Compressor is shown at center, combustion chamber and turbine rotor at right.**

**Figure 3**

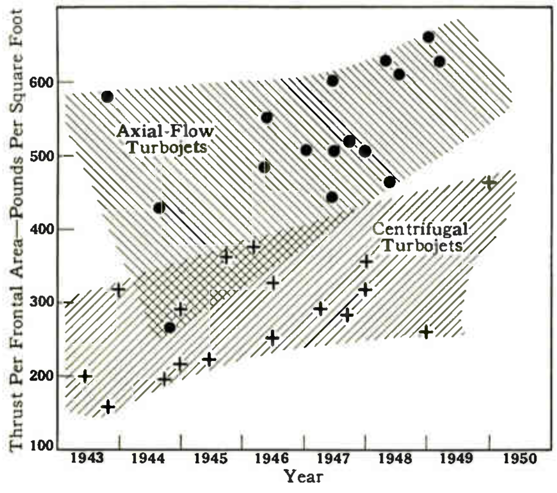


**Fig. 3—Values of thrust per frontal area for a group of typical turbojet engines show the definite disparity between the two basic types.**

*Note:* To eliminate freak experimental values, only those engines are compared that attained some degree of production. The year for which each engine is plotted corresponds to the date it reached production status with the performance given.

Admittedly any such method of sampling engine statistics has its drawbacks. Guaranteed performance figures, which reflect the manufacturer's confidence in his product, and not test values, are used in this compilation. Although average or minimum performance values might be preferable, they are more difficult to obtain with equal reliability. Date of production depends on many requirements, some entirely outside the control of the engine manufacturer. Plotting performance against the date when the engine went into production (instead of when it first ran or first reached the performance quoted) has the advantage of having the overall design verified to some extent. Sea level, static values have been chosen here because they are more easily verified. The graphs are primarily an indication of overall trends.

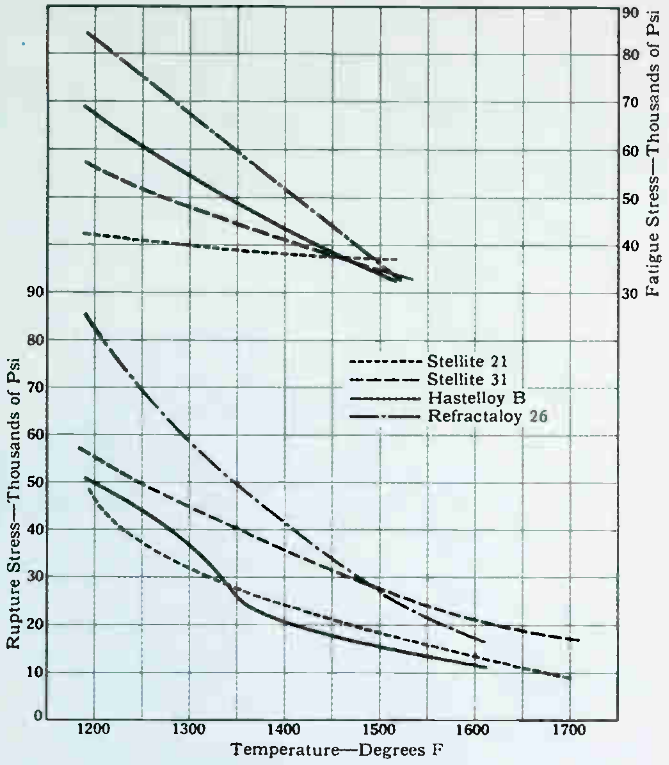


**Fig. 5—Fatigue strength and 100-hour rupture strength of several gas-turbine blading alloys at elevated temperatures.**

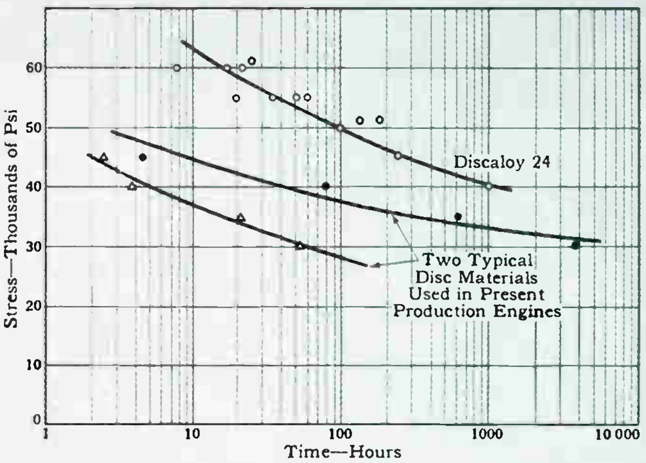


**Fig. 6—Comparison of disc materials for 1200 degrees F and creep of one percent for the interval indicated. Values given are for rotor forgings with a hardness range of 269–293 Brinell.**

**Fig. 7—Measuring temperatures of turbine blading undergoing "thermal shock" tests.**

A higher compression ratio, for better efficiency, requires more horsepower for the compressor, and hence more power from the turbine to drive the compressor. This additional power results in increased weight for both components. For those elements in which the gas pressure governs the thickness of the structural elements, higher internal pressure means heavier walls.

The effect of higher flight speed also increases engine weight because the air is forced into the engine at higher density. This means increased horsepower in the compressor and the turbine and higher internal pressure in the engine. At high speeds the temperature of the incoming air is raised as much as several hundred degrees F. This temperature rise is multiplied in the engine and may require the substitution of heavier materials for some of the light alloy components that cannot withstand higher operating temperatures.

Operation at higher altitudes requires larger combustion chambers to maintain flame stability and combustion efficiency, which also increases weight. Therefore, as operational altitudes and flight speeds increase, engines become heavier.

With increased requirements for auxiliary power from the engine, with more compressed air being tapped from the engine, and with the addition of further emergency safety provisions, engine accessories—gearboxes, pumps, controls, etc.—become heavier. Accessory weight consequently becomes a larger percentage of the overall engine weight. On early engines accessory weight averaged 10 percent of the total, but it has been as much as 30 percent.

**Frontal Area**

A small frontal area for a given amount of thrust permits a smaller engine package with lower drag, ideal for nacelle and wing installations. Where the engine is housed inside the fuselage, frontal area is not too significant if the engine fits entirely within the fuselage contours of the airplane.

Component improvements have brought about an increase in the amount of thrust obtainable from a given mass of air flowing into the engine. Other design refinements have resulted in better external streamlining of the power plant. Both factors increase the ratio of thrust to frontal area. But, here again, the need for more appendages in the form of additional or larger accessories partly offsets these benefits. However, the net result is still one of much increased power for the same engine frontal area, as shown in Fig. 3.

For centrifugal engines the thrust per unit frontal area has increased from a representative 225 lb per sq ft in 1944 to a typical value of 400 lb per sq ft in 1949. Axial-flow units, which started off with considerable variation, have now passed the mark of 600 lb per sq ft.

Several means of thrust augmentation have appeared. All are premised on the basic law of jet propulsion, namely, that engine thrust is the product of mass accelerated and velocity of exhaust. Hence, to increase thrust, either the mass or the jet velocity, or both, must be increased. Water injection, resulting in a cooling of the gases entering the turbine, permits the addition of more fuel without exceeding the permissible turbine inlet temperature. The water, as well as the additional fuel, increases the mass of gases exhausting from the nozzle. This form of augmentation, useful particularly for take-off, nets an additional thrust in the neighborhood of 20 percent.

Burning additional fuel in a tailpipe beyond the turbine (afterburning) increases the temperature and consequently the volume and velocity of the exhaust gases. This can yield some 40 percent additional thrust at standstill and more than twice this at higher flight speeds. While afterburner operation is expensive of fuel, it provides short bursts of terrific power. Thus, engines with afterburners are particularly suitable for interceptor-type aircraft where flash performance is desired.

### Centrifugal vs. Axial Flow

As more and more factual data becomes available, the violent controversy concerning the relative superiority of the two types of turbojets is subsiding. Each has advantages and shortcomings that govern its application. On the basis of typical performance, the frontal area of centrifugal engines is now some 50 percent greater (Fig. 3) than that of axial-flow engines. This differential is prohibitive for nacelle-type installation in high-speed aircraft. Early experience showed the centrifugal engine to be much lighter than its rival. However, this difference has now practically disappeared.

Considering "static, sea-level" performance—obtained in test-cell operation—the centrifugal engine compares favorably for pressure ratios up to four or five to one. This is about the maximum ratio at which a single impeller has, so far, operated efficiently. Increased pressure ratio—for lower fuel consumption—in a centrifugal design requires several impellers in series, which is generally less efficient because of the losses inherent in the curved ducts of the compressor.

Aircraft engines, however, are not built for static, sea-level operation, but for flight. At operational altitudes the centrifugal engine with a double-sided impeller (air passes on both sides of the impeller disc) suffers an additional loss because of the poor efficiency of the inlet ducting. Kinetic energy of the incoming air is lost in the plenum chamber at the inlet. This can increase fuel consumption by five or ten percent more than in the case of an axial inlet leading directly to the engine intake. This loss is avoided in centrifugal engines with single-sided impellers, but is offset by a larger frontal area.

Because of all these factors, the axial-flow design is replacing the centrifugal type in large power plants in which efficiency is the most important consideration. Centrifugal compressors continue to find use in smaller engines, such as for auxiliary drives, because they are cheaper to produce and because axial-flow compressor blading of small size is not as efficient. Combination designs, partly axial flow and partly centrifugal, also have advantages for some applications.

### Annular- and Can-Type Combustors

The two best-known forms of combustion chambers—the "can" type and the "annular" type—have been applied both in this country and in England. In the can-type combustor the air stream leaving the compressor divides into a number of diffuser passages leading to separate, approximately cylindrical, combustion chambers. The combustion products from these individual "cans" are then reunited in the turbine nozzle element. In the annular-burner design a single chamber surrounds the turbine shaft (Fig. 4).

Although the can-type combustor is simpler to design and evaluate, it has several disadvantages not found in the annular combustor. At high altitudes, the loss of flame in one or several of the individual combustors of a can-equipped engine results in severely irregular temperature distribution. Also, accumulation of fuel in the bottom cans might result in excessive temperatures when ignited. The single flame in the annular chamber avoids these difficulties and it is more readily maintained. For the same external diameter the lower gas velocities in the annular combustor promote better altitude combustion stability.

With annular chambers it is relatively easy to vary the radial temperature distribution of the gases passing into the turbine to get best temperature-stress relation, and, therefore, the lightest blades to carry the load. Near the tip of the turbine blade, where stresses are low, the temperatures can be permitted to run higher than near the blade root, where the stresses are high. This same slanted temperature distribution is obtainable by making the can-type combustors nonsymmetrical, but this complicates combustor design.

### Engine Development

Reciprocating aircraft-engine development has been characterized by what has become known as "make and break" procedure. Because of the inherent difficulties in predicting nonsteady conditions in a piston engine, they are customarily designed on the basis of the best available (often empirical) knowledge, relying largely on complete engine testing to bring out weak spots in the design and to carry out further engine improvements. In the reciprocating engine, the compression, combustion, and expansion processes all take place in the cylinder, but in the gas turbine these processes are handled by individual components, namely, the compressor, combustor, turbine, and exhaust nozzle, which can be studied separately. Thus, a closer analysis of the functioning of each individual component is possible.

In the case of the gas turbine, planned research and development of engine elements to accumulate basic knowledge for future designs gives a high degree of assurance that expected performance will be obtained. This fundamental approach is economic from the standpoint of effort as well as time. It frequently permits use of inexpensive models, rather than costly full-size components, to derive the data the designer needs. Admittedly, much proof testing of the finished product will always be required. Then, after a new engine comes to test, component refinements can be worked out by studying engine performance in detail.

#### Materials

One of the developments upon which the capabilities of the gas turbine depend is the progress in high-temperature alloys. Many of the forged and cast materials now being used in production engines are of prewar origin but have been gradually improved.

Early rotating turbine blades, where stresses as well as temperatures are high, were made of K42B alloy, Hastelloy B, and several others. To withstand blade vibration, materials must have high creep resistance and good fatigue strength at high temperature. Superiority of the newer alloys—Refractaloy alloy and some of the cast Stellites—at high temperatures is shown in Fig. 5.

Turbine discs (the rotating member to which the blades are affixed), on the other hand, must have high strength at only moderate temperature. Disc materials available in the early 40's, and since considerably refined, include 19-9-DL and Timken 16-25-6. Among the new arrivals, Discaloy alloy is outstanding for high-creep strength (Fig. 6).

One of the major contributions the turbojet engine has made to the turbine art is the large-scale use of precision castings. Precision-cast turbine blades were first used in superchargers, where they performed well. Their application to turbojet engines required much larger castings and imposed more extreme operating stresses on these parts.

The first precision-cast turbine and compressor blading appeared in the J-32 (9.5 A) turbojet engine. Vitallium and several other materials of the Stellite family have been used successfully. As of today, cast blading has been thoroughly proved in field operation.

Use of precision castings for blades gives the designer wide latitude in the choice of blade shapes. From this standpoint casting produces results superior to those obtained by the usual machining or rolling. New blade configurations can be obtained in experimental quantities quickly, thus allowing reasonably rapid verification.

**Fig. 8—Checking rotor clearances in low-power wind tunnel used in testing compressor models.**

Reliance on creep-rupture and fatigue testing to evaluate materials for use at high temperatures has been customary practice. Now, for the kind of operation to which gas turbines are subjected, additional attention is being paid to the effect of "thermal shock" (rapid heating and cooling cycles) on the behavior of parts such as turbine-nozzle vanes. Materials that are "brittle" under these severe conditions can easily crack in a relatively few hours. To obtain data under simulated service operations, a simple apparatus (Fig. 7) is used, in which a specimen is alternately heated to 1950 degrees F and air quenched. From such tests optimum material composition and heat treatments have been derived.

On the light-alloy side the most phenomenal development is the advent of titanium, which promises to have the strength of good steel at medium temperatures with only two-thirds its weight. It has good corrosion resistance and might find application in many jet parts that operate at moderate temperatures, that is, up to 800 or perhaps 1000 degrees F. Titanium can be produced in sheet form or as a forging; thus it has several natural applications on the "cold" side of the engine. As in the case of other light metals, further alloying of titanium will undoubtedly yield improved materials, having even greater strength.

### Compressor Research

The development of compressors of adequately high efficiency was one of the steps needed to make the gas turbine possible. Considerable progress is being made towards a better understanding of the function of gas-turbine blading. Much of the needed data can be obtained from model tests.

The use of simple models in a series of basic, low-speed

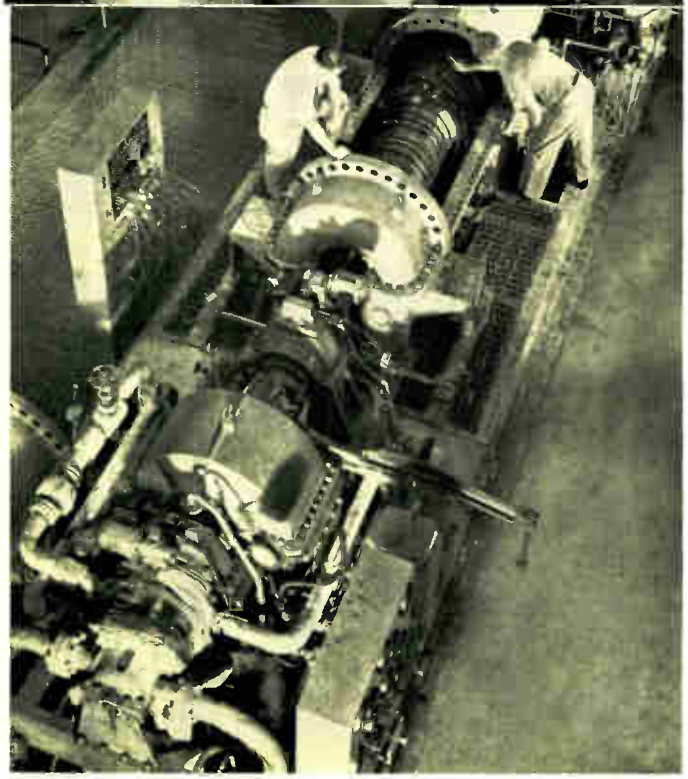
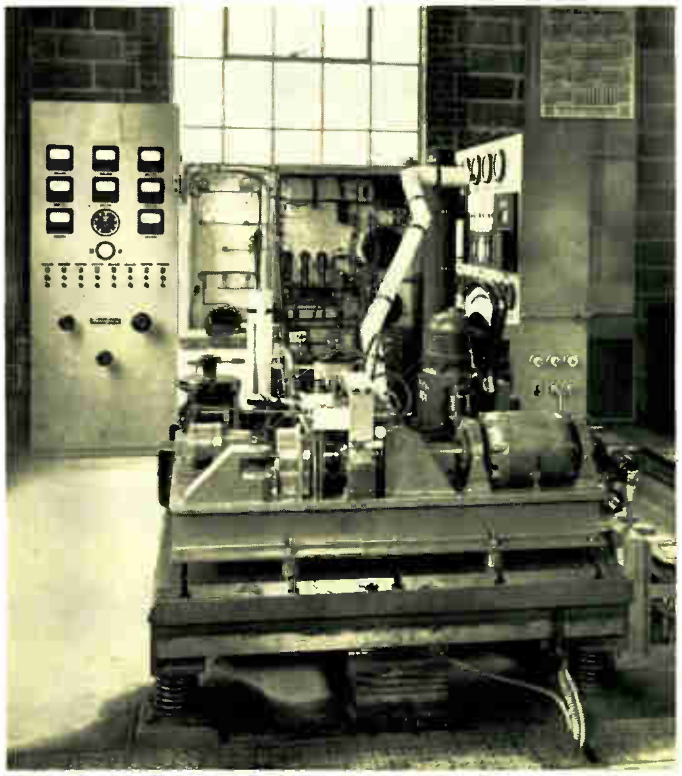


**Fig. 9 (left, below)—High-speed wind tunnel for testing turbojet compressor performance. Steam turbine, lower left, drives the compressor through dynamometer rig, center. Fig. 10 (below)—Turbojet bearings are subjected to widely varying loads, speeds and temperatures on this specially designed, 18 000-rpm test stand.**



tests to evaluate compressor-stage performance under conditions of operation well below sonic velocities is illustrated in Fig. 8. In these tests, variables such as blade spacing (pitch), blade setting (stagger), and blade section are being systematically explored. This work, requiring only low power for the test equipment, is followed by full-speed tests in which specific compressors as well as their individual stages are evaluated in detail.

In view of the weight and cost of compressor blading, emphasis has been placed on obtaining acceptable efficiency with a small number of blades. (This does not necessarily mean a small number of stages because there can be an arrangement of a few stages with many blades per stage.) It appears that large pressure ratios per stage can be obtained by turning the flow through a larger angle; however, so far this has involved increased energy losses and poorer efficiency.

### Bearing and Lubrication

In early turbojet operation the performance of the bearing and lubrication system was often one of the critical items that limited engine life. However, opposed to central-station and marine-turbine practice, in which the use of journal bearings is traditional, antifriction bearings have been a complete success in aviation gas turbines. Although some early American engines employed film lubrication, antifriction bearings are now practically universal. Engine-oil consumption in the turbojet amounts to only a fraction of a pound per hour. Experience with the "oil mist" system of lubrication indicated that it was difficult to apportion the proper amount of lubricant to each bearing through varying temperatures, pressures, and maneuvering demands. The use of "solid-oil lubrication" for bearings has alleviated this problem.

To evaluate bearing performance it is important to run bearings under controlled conditions. A testing machine (Fig. 10) designed at the Westinghouse Research Laboratories, permits running the test bearing under controlled temperatures up to 600 degrees F with thrust loads up to 20 000 pounds and radial loads to 12 000 pounds. Bearings are now as reliable as other engine parts.

### Combustion

Early experience with jet engines proved that at increasing altitudes, with reduced air density and lower ambient temperature, efficient combustion becomes more and more difficult to sustain. Under such conditions the efficiency of the combustion chamber can deteriorate severely and the flame might even go out completely. Several early engines ran into such operational troubles at altitudes below 30 000 feet. With continuing research and development it has been possible to increase considerably the altitudes at which the performance of the combustion chamber deteriorates.

Flame stability generally improves as gas velocity through the burner is decreased. Thus larger combustion chambers improve combustion, but combustor performance at these altitudes must be bought with increased size and weight.

One of the drawbacks of early combustion-chamber designs was their relatively short life, limited often to a few hours' operation. Careful attention to the structural requirements of combustion chambers has made possible a manyfold increase in combustor life. One of the most successful means of improving the mechanical reliability of combustion chambers has been the provision of a blanket of relatively cool air over

**Fig. 11 (Right)—Making connections on the upstream end of a sonic thermocouple traverse rig. This device permits rapid measurement of turbojet combustor temperatures to aid in determining altitude performance characteristics.**

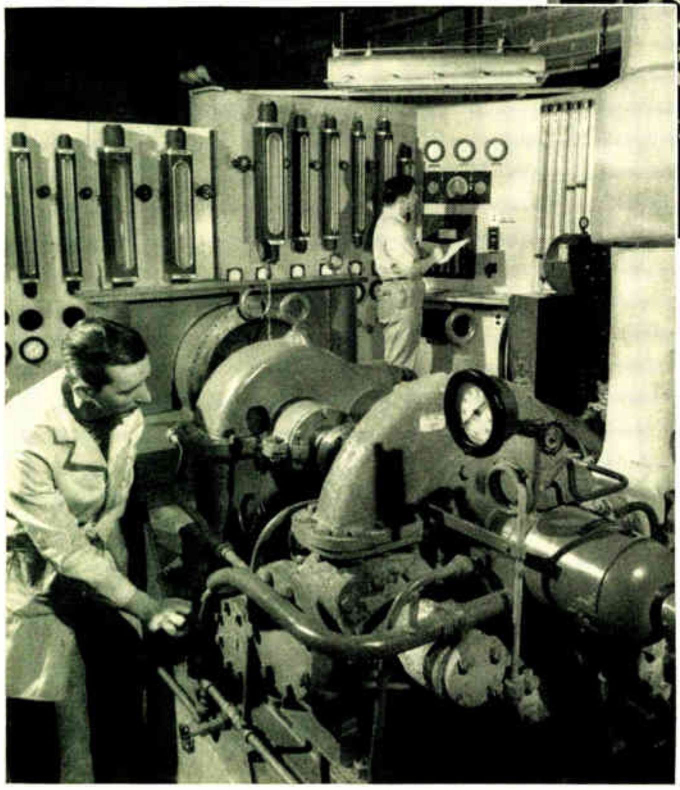


**Fig. 12 (Lower left)—Gear-drive testing is an important part of turbojet development although gears drive only the low-horsepower engine accessories. Minor defects are discovered and better working knowledge of these components is obtained from preliminary testing.**

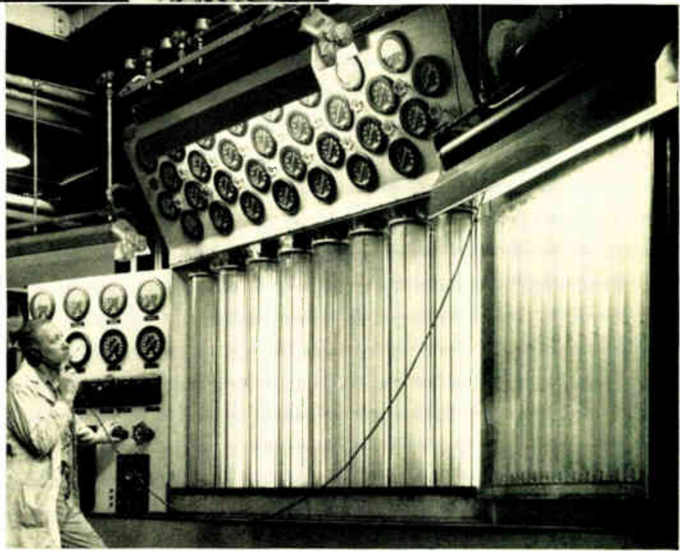


**Fig. 13—Test stand for investigation of fuel-system control components is shown during check of nozzle flow.**

the combustion walls. Thus the metal remains at moderate temperatures despite the close proximity of flame temperatures of some 3700 degrees F. Several combustors in production-type engines have operated through periods of 600 hours and were still fit for service.

### Control and Fuel System

Originally almost any system of getting fuel into the engine was permissible. Now the more complex systems must deliver fuel to the combustion chamber satisfactorily even at extreme altitudes, give safe engine control under any flight conditions, and yet require minimum attention from the pilot.

It must supply fuel in widely varying quantities throughout the operating range—from full load at sea level to cruising conditions at the ceiling altitude of the aircraft. This range can easily be 30 to 1. If fuel is fed to the combustion chamber through atomizing spray nozzles with fixed orifice, a 900-to-1 pressure variation is necessary to give a 30-to-1 variation in fuel flow. To obtain good spray characteristics, a certain minimum pressure is required; but with fixed orifices, pressures for sea-level, fuel-load condition become high. This is unfavorable to long full-pump life and requires fuel-spray nozzles of wide range.

### Turbojet Future

Performance and reliability of aviation-gas-turbine engines in the past have been generally satisfactory and in most cases beyond expectations. In the future, proper planning, research, and development will undoubtedly bring forth engines that are superior from the standpoint of fuel economy as well as flight safety.

## Personalities IN ENGINEERING

Last June 21 the coveted "Spirit of St. Louis" medal, awarded annually by the St. Louis Section of the ASME for "meritorious service in the advancement of aeronautics," was given to *R. P. Kroon*. This focused attention on Kroon's aviation-gas-turbine accomplishments. To him belongs much of the credit for the present acceptance of the in-line type of jet engine with axial compressor. About one fifth of all turbo-jet engines produced in the United States this year will be from designs created under his supervision.

Kroon's career in the aviation-turbine field began on December 8, 1941 when, with the nation still stunned by the holocaust of Pearl Harbor, the U. S. Navy gave the green light to a program for developing an American jet engine. A group of ten men, with Kroon as their leader, became the nucleus of a team that—purposely isolated from European jet-engine practice—16 months later placed on test an axial-flow jet power plant. Today that engineering organization has grown to one of several hundred.

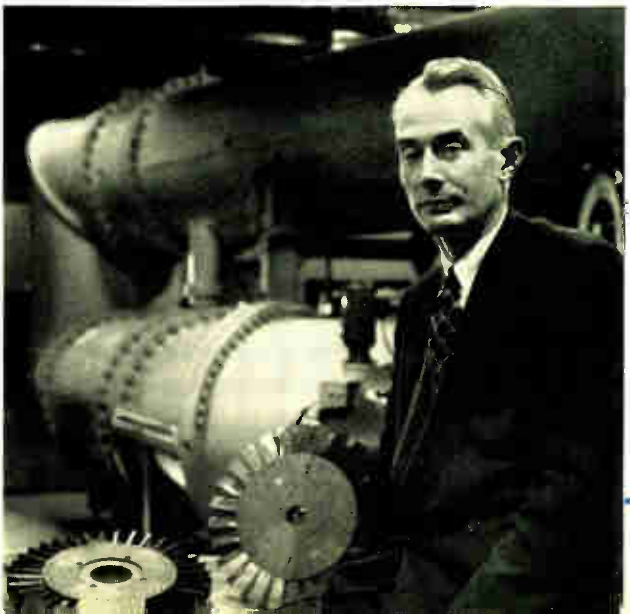
Kroon, a native of Holland, obtained his mechanical engineering degree from the Federal Technical Institute of Zurich in 1929. America seemed to him the greatest opportunity so he established a contact that led to his coming to Westinghouse. He entered the Westinghouse Student Training Course in 1931. Upon its completion he took a position at the Westinghouse steam-turbine plant. Here he had the opportunity to explore and discuss technical problems with such men as Soderberg, Timoshenko, Ormondroyd, and Karelitz, an experience he recalls with great satisfaction.

In addition to the steam-turbine business, the division undertook in 1935 to build the enormous supporting structure for the 200-inch Mt. Palomar telescope. It was realized that when the yoke was assembled with the telescope tube it would be slightly distorted by the enormous weight. Kroon worked out the mathematics and a method for stressing the components during machining and fabrication so that they would have precisely the right shape when assembled and loaded. Also, the telescope designers were much concerned over the effect that bearing friction of the 850 000-pound structure would have on the ultra-precise operation required of it. Following a suggestion of Francis Hodgkinson, Kroon created a design for an oil-flotation bearing that has only 1/600 part of the friction of the best ball bearing. A milk bottle resting on one side of the telescope yoke will turn it.

In the later '30's Kroon returned to turbine research, performing much fundamental work in the field of mechanics, particularly on resonant phenomena in blade structures. He became manager of the Steam-Turbine Experimental Division in 1937, which position he held until the switch to aviation turbines.

Kroon is a tall man. His stature would delight any basketball coach. His modesty is indicated by the fact that as we interviewed him for this sketch, he made no mention of his recent honor at St. Louis, his contributions to the big telescope, or his skill at the piano. It is perhaps his tact—supported by technical skill—that enabled him to maintain the confidence and respect of his associates as well as the Armed Forces. He is known among his associates for his consistent approach to every new problem, from the standpoint of basic fundamentals, also for his unusual interest in young engineers. His patience has enabled him to be an excellent teacher.

Several years ago he developed a keen interest in birds. His home in a four-acre wooded area in Delaware County, Pennsylvania, gave him a natural bird sanctuary, which he has equipped with numerous feeding stations. But his greatest interest right now is in a different type of bird—a man-made "bird" with speeds upwards of a thousand miles per hour. He wants to have a hand in the design of the engines for it. He probably will.



# *Magnetic Amplifiers* in Industry

**Long an outcast, the magnetic amplifier has finally come into its own. For years it lacked the qualifications of a practical industrial equipment; but now, with new core materials and rectifiers available for its use, and a new understanding of its role in amplifier society, it is finally being accepted with open arms as a useful, dependable, and nearly maintenance-free device.**

F. N. McClure, *Central Station Section, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania*

MAGNETIC amplifiers, which proved so valuable in servo-equipments during World War II, are being increasingly used as components in all sorts of control and regulating circuits. Today, engineers are uncovering potential uses for these static amplifiers in practically every electrified industry in the country.

Although the simple saturable-core reactor has been known and applied for years, the renewed interest in the use of magnetic amplifiers can be attributed to three major factors:

First, the self-saturating circuit, which makes possible high values of power gain, was little used and certainly not fully understood in prewar applications of magnetic amplifiers. The general feeling was that the increased power amplification obtained by adding feedback would result in increased time delay in a device that was already too slow. Actually, it has been found that feedback can be used to increase the ratio of amplification to time delay.

Second, the performance of self-saturating magnetic amplifiers depends greatly on the core material and rectifiers used. Recent improvements in these components have made it possible to capitalize on the self-saturating circuit. These new materials are largely responsible for the tremendously high gains now feasible.

And third, industry is ready for such a device. Certain applications stand out where an amplifier needs to be permanent and maintenance free. This is particularly true in heavy industries, such as steel and paper.

The effective application of modern magnetic amplifiers in industry depends upon a clear understanding of the operation of the self-saturating circuit, characteristics of core materials and rectifiers, and performance characteristics of the complete magnetic amplifier.

## Core Materials and Rectifiers

Better core materials and dry-type rectifiers now make magnetic amplifiers more useful in industry. New and improved core materials make possible higher amplification, which increases the flexibility of the device. The d-c magnetization curves for some of these materials is shown in Fig. 1.

Among these metals is Hipersil alloy, a grain-oriented silicon steel widely used in power and distribution transformers; it is particularly useful where relatively large amounts of power are involved and where low cost is important. Others are Hipernik alloy, Mu-Metal alloy, and Mo-Permalloy, the latter two having a considerably lower saturation flux density than the others.

Hipernik V alloy is another metal commonly used in magnetic amplifiers. It is similar to Hipernik alloy in composition, but differs in that it is drastically cold reduced and specially annealed. This special treatment results in a material that has an essentially rectangular hysteresis loop and a sharp knee that is reached at a low value of magnetizing force. These properties are essential in high-gain magnetic amplifiers.

Amplifiers using Hipernik V alloy have a higher amplification and a greater region of linearity than amplifiers using conventional magnetic materials, but due to the great amount of cold rolling involved, the high purity, and the special anneal, the material is more expensive.

Although the more expensive materials have characteristics desirable for magnetic amplifiers, the less costly alloys, such as Hipersil and other standard transformer steels, are adequate for many applications.

The rectifiers commonly used in magnetic amplifiers are the dry-type germanium and selenium varieties. Modern rectifiers are manufactured more uniformly than was possible previously; this is important because differences in rectifier characteristics affect amplifier operation. The rectifiers used should have low forward resistance and high back resistance since back leakage reduces power amplification. They should maintain these desirable characteristics with aging and exposure to environmental conditions.

## Static Characteristics of Magnetic Amplifiers

To show the effect of using different core materials in magnetic amplifiers, four amplifiers with toroidal cores of Hiper-

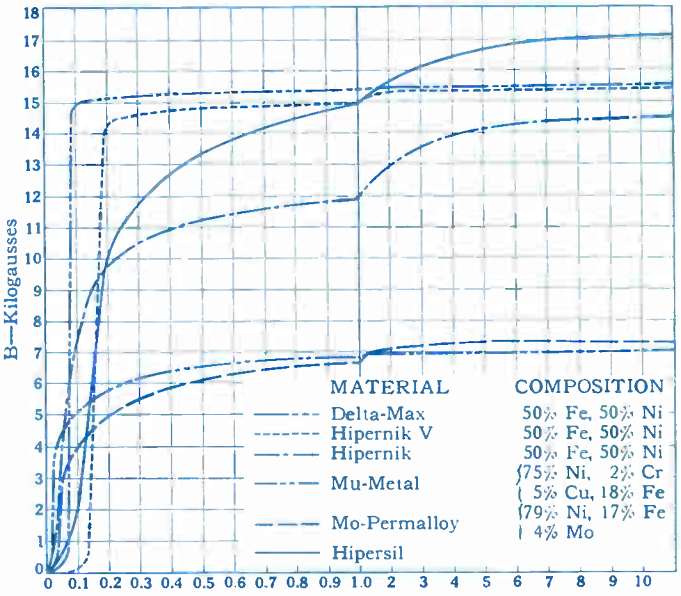


**Fig. 1—Shown above are d-c magnetization curves for some new and improved core materials now used in magnetic amplifiers.**

## Operation of the Self-Saturating Magnetic Amplifier

A self-saturating magnetic amplifier is one in which feedback provides increased amplification. Two common ways of accomplishing self-saturation are (1) by using additional windings carrying a direct current proportional to the load current, or (2) by placing rectifiers in series with the a-c windings of a parallel-connected reactor.

Two simple, self-saturating magnetic-amplifier diagrams are shown in Fig. 2. The upper circuit, which produces an a-c output, differs from a simple saturable-reactor circuit in that rectifiers are added in series with the two a-c windings. This type of circuit might be used to control an a-c relay.

The lower circuit is one of several self-saturating circuits that produce a d-c output, such as might be used to control some types of machine fields.

Standard rectifier circuits can be transformed into self-saturating magnetic-amplifier circuits by the addition of a saturable reactor. The lower diagram is basically a center-tapped transformer, full-wave rectifier circuit.

The operation of the self-saturating magnetic amplifier is most easily understood by analyzing the circuit shown in Fig. 3. This is a half-wave, self-saturating circuit, and is not practical because of the fundamental frequency voltage induced in the d-c circuit. For purposes of analysis, assume that the added impedance, $Z$, in the d-c circuit is sufficiently large to reduce the a-c current resulting from this induced voltage to some negligible value.

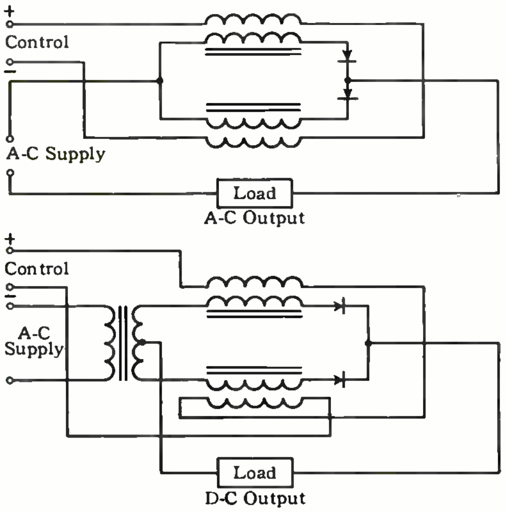


**Fig. 2—Two self-saturating magnetic amplifier circuits; above, with a-c output, below, with d-c.**

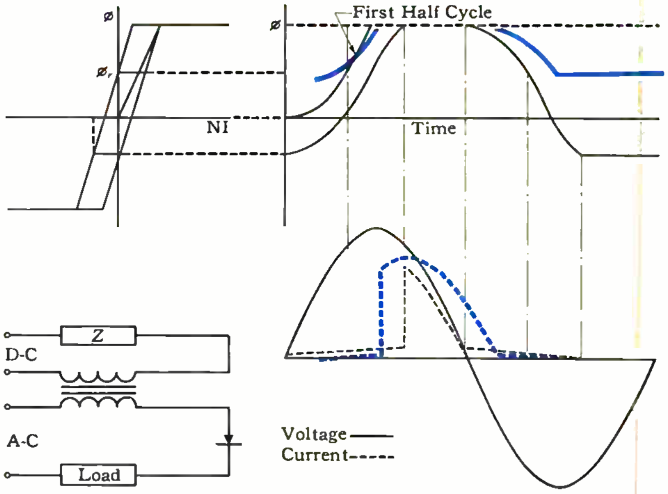


**Fig. 3—The self-saturating magnetic amplifier can be understood by analyzing the circuit above. Conditions with zero control current are shown in color; those with control current are in black.**

Other assumptions are:

1. Zero resistance in the a-c and d-c windings.
2. The load resistance is small in comparison with the unsaturated impedance of the a-c winding.
3. The rectifier is assumed to be perfect—zero forward resistance and infinite back resistance.

If a core material could have an idealized hysteresis loop, as shown in Fig. 3, the analysis would be simplified. Consider first the case of *zero control current.* The a-c circuit is closed at zero voltage at the beginning of a positive half cycle. As the supply voltage increases, the flux increases from zero, in accordance with the volt-seconds absorbed by the reactor, until saturation induction is reached. Up to this time the load current is limited by the high unsaturated impedance of the a-c winding. After saturation flux density is reached, the current is limited only by the load resistance and follows a sine wave. The current wave is not shown for the conditions during the full first cycle since this does not recur during subsequent half cycles, due to the effect of hysteresis. As the voltage and current decrease, the flux decreases along the upper branch of the hysteresis loop. When the load current reaches zero, the flux has a value equal to the residual flux, $\phi_r$. The current does not reverse during the negative half cycle of supply voltage because of the rectifier.

During subsequent positive half cycles of voltage the flux rises from an initial value, $\phi_r$, until saturation flux density is reached

nik, Hipernik V, Hipersil, and Mu-Metal alloys were tested. These were chosen as being representative of materials most commonly used. The four amplifiers were made as nearly alike as possible.

The transfer curves (output vs. input) of Fig. 5 show the effect of using these different core materials in self-saturating magnetic amplifiers. Although little is gained by using the better core materials in magnetic amplifiers without feedback, such is not the case when using the self-saturating circuit. The transfer curve of the Hipersil-alloy amplifier has a lesser slope than the others and, therefore, the amplifier has a lower amplification. The transfer curve for the Mu-Metal alloy amplifier is steep, indicating a high amplification, but the watts output is less than the others due to the lower saturation induction of the material. Although the slopes of the nearly straight-line portion of the transfer curves for the Hipernik and Hipernik V alloys are about the same, the transfer curve for Hipernik V alloy is nearly straight over a much larger range.

### Time Delay

There is an inherent time delay in magnetic amplifiers due to the inductance of the windings. Because in most cases the rise of load current with a suddenly applied control voltage is not exponential due to the non-linearity of the circuit, the term "time delay" is used rather than "time constant."

The time delay of an amplifier can be decreased by adding resistance in the control circuit (time constant$=L/R$). However, the addition of resistance results in reduced amplification. When high values of power gain are obtained by using self-saturation, the increased amplification is accompanied by increased time delay (Fig. 6). A change in the length of the (see curves in color). As described previously, the current up to this time is limited to a small value by the unsaturated impedance of the winding. At saturation the current rises sharply to a value determined by the supply voltage and the load resistance, and follows a sine wave. After current decreases to a value corresponding to the knee of the upper branch of the hysteresis loop, it is again limited by the unsaturated impedance of the winding. The current goes to zero when the flux reaches its initial value, $\phi_r$.

*With control current* in the d-c circuit, for a negative control signal, the value of flux at zero voltage at the beginning of a positive half cycle is determined from the upper branch of the hysteresis loop, as shown by the black curves in the diagram. As the voltage rises, it now takes a longer time for the flux to reach saturation, since the change in flux is proportional to the volt-seconds. The current rises from its initial small value at a later time than with zero control current, resulting in less average current through the load. Thus, the voltage appearing at the load can be varied from near zero to practically full supply voltage by varying the d-c control current from a small negative value to a small positive value. The output current is similar to that of a grid-controlled rectifier.

The effect of reverse current in the rectifier is apparent from this analysis. Reverse current during the negative half cycle of voltage causes the flux to reach a value less than that assumed in the preceding analysis. This increases the time required for the flux to reach the saturation induction, decreasing the average value of load current for a given d-c signal, thus decreasing the power amplification.

Although this analysis has been made for a simple half-wave circuit with idealized conditions, the operation and wave forms obtained with actual full-wave circuits are very similar. The oscillograms of Fig. 4 illustrate the load-current wave form obtained in a simplified, self-saturating magnetic amplifier using toroidal Hipernik V alloy cores.

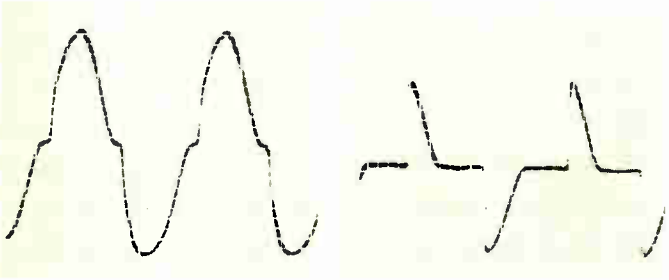


**Fig. 4—These oscillograms show sample load-current waves; left with zero control current, right, with a small negative signal.**

effective air gap causes a similar change in the amplification and time delay.

Although a change in amplification is always accompanied by a change in time delay, the relationship between the two quantities differs, depending upon the cause of the change.

## A Balanced Magnetic Amplifier

Many applications, such as voltage regulators, require a magnetic amplifier whose d-c output voltage reverses in polarity with a reversal of input. Such a circuit is shown in Fig. 7. The circuit consists essentially of two full-wave bridge-connected magnetic amplifiers arranged such that one side produces an output of one polarity, and the other produces an output of reverse polarity with a reversal of input. This circuit requires two machine fields, each capable of supplying full excitation. Bias windings have been omitted for simplicity. If space is not available in the machine for the oversized field, then the two fields in the diagram can be replaced with appropriate resistors and the machine field connected across the outside terminals. In general, such balanced magnetic amplifiers have a low efficiency.

## Applications

The magnetic amplifier is suitable for a large number of different applications. Many more may prove practical as the device becomes better known in industry and its capabilities and limitations become more apparent. Outlined here are but a few typical applications.

### Current Transductor

The current transductor[1,2] is a device that effectively transforms primary direct current into a secondary alternating current by d-c saturation of the core. It is essentially a magnetic amplifier in which the d-c ampere-turns are produced by the d-c bus passing through the cores, and the load is an ammeter. The current transductor replaces the conventional shunt in metering large d-c currents. It is made in ratings from 1000 to 100 000 d-c amperes.

The current transductor has several advantages over the conventional shunt. The hazard of shunt leads running from the bus to the instruments is eliminated. The cost of the leads is decreased, since small, conventional control wires can be used instead of specially insulated 1500-volt wires that require special treatment when passing through terminal blocks and onto swinging panels. The necessity for special calibration of each instrument with its leads is also eliminated.

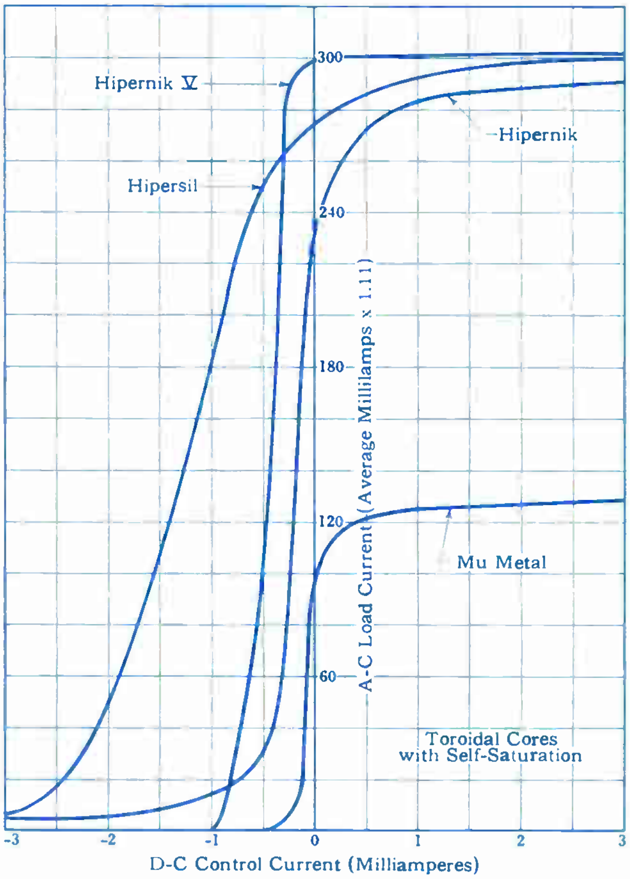


**Fig. 5—The transfer curves (output vs. input) of several self-saturating magnetic amplifiers utilizing different core materials.**

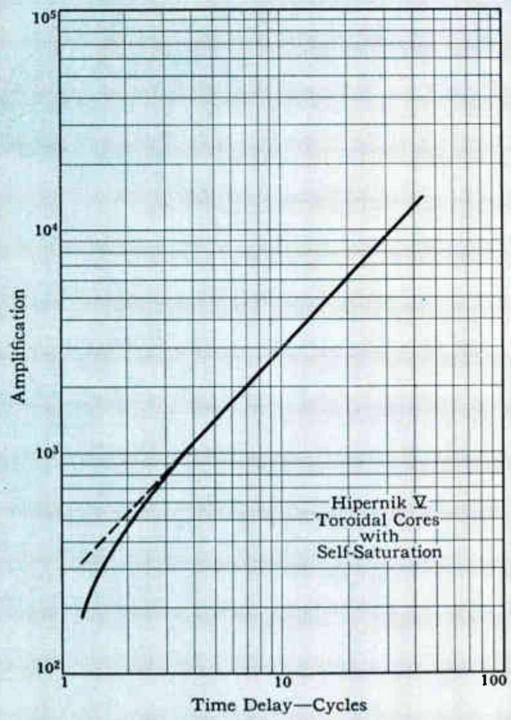


**Fig. 6**—The effect of increased amplification on time delay of a self-saturating magnetic amplifier.

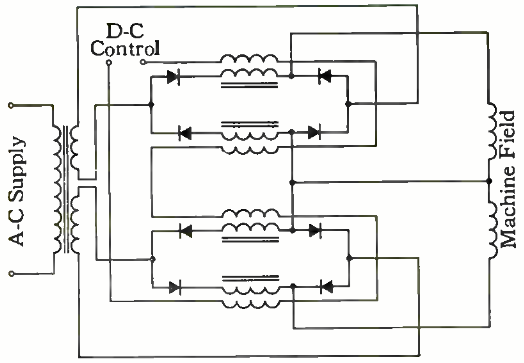
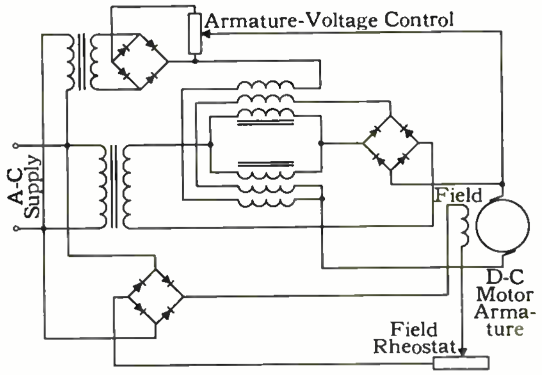


**Fig. 7**—The d-c output voltage of this amplifier circuit reverses polarity with reversal of input.



### Self-Regulating Battery Charger

The Rectomatic battery charger[1] is an automatic self-regulating Rectox rectifier. The charging rate is automatically varied by means of a saturable reactor, and is dependent upon the requirements of the battery.

In operation it maintains a battery at its correct voltage (2.15 volts per cell) within approximately ± one percent under any condition of load within its rating, at normal ambient temperatures. These limits are consistent with limits specified by battery manufacturers. The charger holds the battery within the above limits with a ± five-percent variation in supply voltage.

### Adjustable-Speed Control

Magnetic-amplifier control can be used to obtain a wide range of speed of a d-c motor supplied from an a-c source. The circuit is shown in Fig. 8.

The magnetic-amplifier, parallel-connected, a-c windings are in series with the motor armature through the load rectifier. A pattern voltage obtained at the armature-voltage-control rheostat is bucked against the terminal voltage of the motor through a d-c control winding on the magnetic amplifier. A resistor (not shown), in conjunction with a current transformer in the a-c supply circuit, compensates for *IR* drop. The device is essentially a modified voltage regulator that maintains constant back emf in the motor and, therefore, maintains constant speed for a given setting of the armature-voltage-control rheostat. Above the base speed of the motor, speed control is obtained with the motor field rheostat.

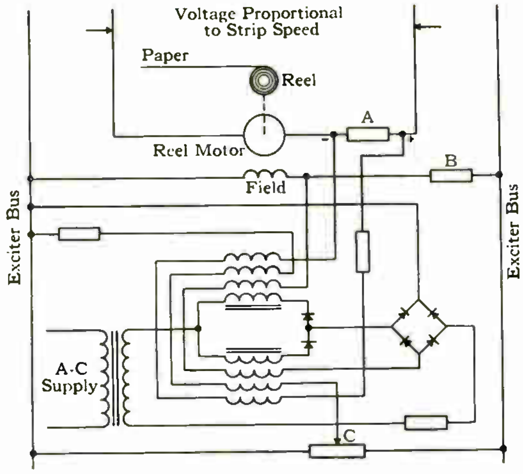
### Magnetic-Amplifier Reel Control

In the paper, textile, rubber, and steel industries many core-type reels are required to wind the material made along the processing line. The reel-drive motor is required to hold constant horsepower as adjusted by a regulator working on the motor shunt field. The magnetic amplifier is ideally suited to this type of regulating job because it offers economy and simplicity.

Consider the circuit of Fig. 9, which is a paper-mill magnetic-amplifier reel control. The reel motor receives its power from the same adjustable-voltage bus that supplies the entire processing machine. The voltage at the bus is proportional to the speed of the material being processed. The motor shunt field is excited from two sources. The exciter bus supplies the minimum motor field as adjusted by resistor *B*. The motor shunt field can be strengthened only by the magnetic amplifier.

The magnetic amplifier is self-saturating, using rectifiers in series with each of the parallel-connected a-c windings. Additional feedback is obtained by using feedback windings in series with the motor field. The current in the bias (pattern) winding is adjustable over a certain range by rheostat *C*. The voltage drop across resistor *A* in the motor armature circuit is applied to the control winding of the magnetic amplifier. The magnetic amplifier functions to hold the reel-motor armature current constant as the reel diameter increases from empty core to full roll.

Cores wound of Hipersil alloy and then cut to allow placement of the winding (type C) are used in the magnetic amplifier. The air gap at the butt joints of small type-C cores causes poor amplifier operation because of the large amount of

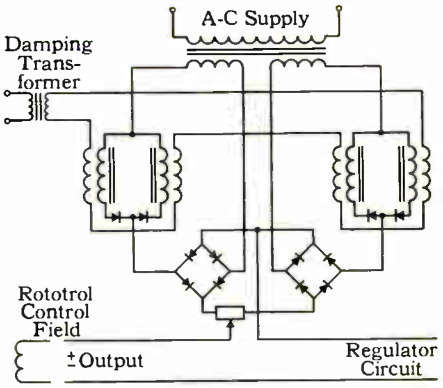


←

**Fig. 9—A circuit showing a magnetic-amplifier reel control for a paper mill. The amplifier holds the reel-motor armature current constant as the diameter of the reel increases.**

**Fig. 11—A magnetic amplifier as used in the regulating circuits of large a-c turbine generators. This is used to reduce the size of the damping transformer.**

→



←

**Fig. 8—The magnetic amplifier is useful in obtaining a wide range of speed control of a d-c motor supplied by a-c power source.**

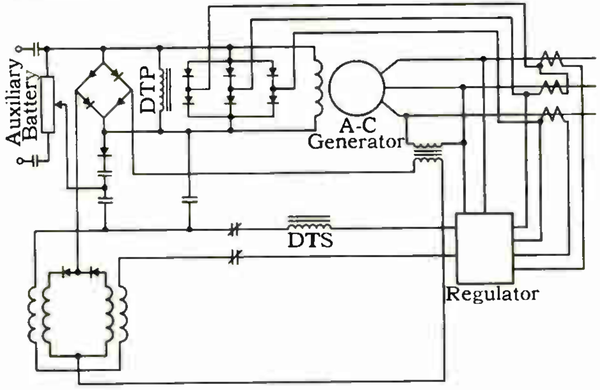


**Fig. 10—A static exciter and voltage regulator using a magnetic amplifier. This scheme can be used with a 60-kw, a-c generator and possibly in larger units.**

d-c power required to push flux across the air gap. However, in the larger sizes the air gap is small in comparison with the length of the flux path and their use results in a large reduction in amplifier cost.

**Voltage Regulators**

A static exciter and voltage regulator using a magnetic amplifier is illustrated by the schematic diagram of Fig. 10. This regulating scheme can be used with a 60-kw, a-c generator and possibly with larger units.

For starting, the contacts indicated as normally closed would be open, and the normally open contacts would be closed. Initially, a small current is supplied to the machine field from the auxiliary battery supply. This current also passes through the control windings on the magnetic amplifier. Thus the full voltage available at the transformer connected to the a-c generator terminals is applied to the full-wave bridge rectifier in the field circuit of the machine. As soon as the terminal voltage begins to rise, the machine field is supplied from this circuit. The auxiliary battery supply is needed only to supply a small initial field current. After the generator voltage reaches a predetermined value, the control can be switched to the static regulator circuit, which varies the amount of control current in the magnetic amplifier. Under load conditions part of the machine excitation is supplied by the current transformers in the a-c generator leads through a three-phase, full-wave rectifier.

The schematic diagram of Fig. 11 illustrates the use of a magnetic amplifier in a completely different capacity, namely, in the regulating circuits of large a-c turbine-generators. The amplifier is used to reduce the size of the damping transformer. Since the series impedance allowable in the regulating circuit is very small, an extremely large damping transformer would be required. However, by using the magnetic amplifier, a normal-sized damping transformer can be used. Amplifiers are balanced-bridge types with reversible polarity output.

## Other Applications

Magnetic amplifiers have been used as photo-cell amplifiers. replacing the sometimes erratic, sensitive relays normally used with photo-cells. The amplifier can be designed to have a snap-action operation similar to a relay, or it can have an output proportional to the amount of light. Magnetic amplifiers have been used in many cases to replace other sensitive relays. Snap-action operation is obtained by using feedback windings in addition to simplified self-saturation. Sufficient feedback is added to produce instability, and a small change in the d-c signal causes the output to change from minimum to maximum.

A two-phase motor can be controlled by a magnetic amplifier to form a tubeless position servomechanism.

Not all of the magnetic amplifier applications mentioned are commercially available—some are still in the experimental stage. Also, these are but a few of the many applications.

Magnetic amplifiers should not be considered as a cure-all for control and regulating problems. Each application has its own particular requirements and the magnetic amplifier should be considered along with other possible schemes.

REFERENCES

1. "Amplification by Magnetization," by F. N. McClure, *Westinghouse* ENGINEER, May, 1949, p. 92.
2. "The Theory of the Current Transductor and its Application to the Aluminum Industry," by T. R. Specht and R. N. Wagner, AIEE Paper 50-64.

# Coast Guard—Marine Police Extraordinary

**Where there are navigable waters you will find the Coast Guard. To perform its host of duties—of which only the more dramatic are popularly known—it has developed many special equipments, has pioneered in propulsion machinery and electric gear for its cutters, and has availed itself of every modern communication device for signalling and navigation tasks.**

The story of the Coast Guard is one of many parts. For one, the log books of its 160-year history are replete with episodes of courageous rescues, heroisms, and superhuman efforts that make the most imaginative of fiction thrillers seem pale. Its activities run the scale from the headline-making spectacular, as tracking narcotics smugglers, to the dullest of routine marine policing, as hunting sources of harbor-water pollution. Positions held by Coast Guardsmen cover the range from highly creative technical development to some of the dullest, loneliest, most unpleasant tasks man has conjured up, such as manning remote light ships. It is the story, too, of our oldest marine service (older, by eight years, than the Navy) yet a story of unparalleled efficiency and readiness—even aggressiveness—to adopt the latest devices in naval architecture, marine engineering, communications, and any other field that could improve its multitudinous operations. This is indicated by its recent announcement of an innovation—the remote-controlled lightship, illustrated on page 211.

The Coast Guard's numerous functions fall into three peacetime categories: law enforcement, marine safety, and special services performed in Alaska only. In all of this, it is a branch of the Department of the Treasury. In time of war, it assumes a fourth role, for then "as a military service and branch of the Armed Forces of the United States at all times" it automatically becomes a part of the U. S. Navy. (By Act of Congress, August 4, 1949.) Its wartime record is a story in itself.

### Law Enforcement

To say that the Coast Guard is charged with law enforcement gives scant notion of the variety of activities encompassed. On the dramatic side stand the prevention of smuggling and piracy and the enforcement of conservation laws, such as those aimed to prevent forbidden harvesting of halibut, fur-bearing seals, whales, sponges, certain migratory birds, and, in the days when ships' masts were vital in the national defense, even live oak trees.

Prepared by Charles A. Scarlott, based on information provided by members of the United States Coast Guard and the staffs of the Steam, Electronics, and Marine Divisions of Westinghouse Electric Corp. All photographs, except apparatus views, have been provided by the Coast Guard.

The bulk of its law-enforcement functions are more ordinary things. It enforces all navigation laws, and the regulations of the American Bureau of Shipping establishing load (Plimsoll) lines on vessels of United States registry, and it observes vessels at sea for overloading. It licenses all officer and crew members of our vessels and certifies the crew of all our vessels departing for foreign shores, thus preventing any modern form of shanghaiing.

The Coast Guard enforces all laws dealing with obstruction of navigable waters, the pollution of those waters by oil, and those relating to quarantine and to ships' pilots. A more pleasant chore is the patrolling of regattas. But the outstanding police function of the Coast Guard is the protection of customs revenue. Certainly this is its oldest function, the service having been initially created for this purpose in 1790, almost simultaneously with the birth of the Republic. This is one reason for the Coast Guard being an arm of the Department of the Treasury.

### Marine Safety

Better known aspects of the Coast Guard operation are those dealing with promotion of safety on all navigable waters—the sea, Great Lakes, and navigable rivers. But even many of these are all but unknown except to those involved.

*Accident Prevention*—Many of these services have to do with providing information of importance—often literally invaluable—to navigators both of ships and aircraft, i.e., information that will prevent mishap at sea. Until recent times such aids available to the Coast Guard consisted primarily of lighthouses, a few lightships anchored in strategic spots offshore, and light, bell, and fog buoys. Lighthouses, because of their striking locations, the beautiful simplicity of architecture, the lonely existence of their keepers and their exploits, have had great appeal to artists, to story tellers, and to people generally. To navigators they have been indispensable guideposts and means of warning during storms.

The Coast Guard now has charge of some 433 active lighthouses scattered at vital points along the 53 241 miles of sea coast of the United States and its possessions, and the 8300 miles of Great Lakes' shore line. However, this is fewer than the peak number of 776 that were in service in 1910, the year the lighthouse service was organized.

In addition to lighthouses, the Coast Guard provides and services many other types of shore and channel markers. These include 37 lightships, which are manned, powered vessels anchored at permanent points on shipping lanes, and equipped to indicate their presence by light, bell, horn, and—recently—radio. Also, a variety of anchored buoys issue their warning by means of lights, bells, and horns. A few have automatic radio-signal transmitters. Recently many of these buoys have acquired a curious modern touch. Pyramid-shaped recesses built into their upper structure enable them to reflect radar beams and thus be more readily identifiable by radar-equipped vessels.

Most of these aids to navigation have been limited in their scope to distances at which lights can be seen (essentially zero in the worst weather, when they are most needed) or sounds heard. This range has been multiplied many times by modern science. First came radio beacons, in 1921. A radio-beacon transmitter continuously broadcasts (literally) a coded long-wave signal. A navigator can determine the direction to this beacon by a receiver and a direction-sensitive antenna. By triangulation and contact with two such beacons a fix can be established that locates the craft. The reliable range of radio beacons varies from 10 to 200 miles, depending on the power of the transmitter. At present the Coast Guard maintains 186 radio beacons along the lengthy sea and lake coast lines of the United States.

The area of radio coverage has been extended greatly by the development, since the recent war, of Loran (*lo*ng *r*ange *a*id to *n*avigation). A coded long-wave radio pulse is broadcast at short intervals from a pair of transmitters some miles apart. The navigator measures the difference in arrival time of those two signals and thus establishes the line along which his position must be. Crossing this line with another established with respect to a second-known Loran signal gives him his exact fix.

With Loran the range covered is 750 miles in the daytime, and up to 1400 miles at night, when radio sky waves as well as ground waves are transmitted. With Loran a navigator can locate his position as accurately as by celestial means in clear weather—and do it in three minutes in any weather. The Coast Guard now has 30 pairs of Loran transmitting stations.

The most recent aid offered to the navigator by science is radar. Although radar is basically a ship-borne device, the Coast Guard has instituted coast-mounted adjuncts to increase ships' radar usefulness. One is the addition of microwave reflectors to buoys, as mentioned before. Another is Ramark (*ra*dar *mark*). This is a microwave signal contin-

## The Evolution of the Coast Guard

The United States was only 18 months old when the basic service of the present Coast Guard was created. The Navy that had helped bring independence had been disbanded at the end of the Revolutionary War (and was not re-created until 1798). Operation of cargo vessels in pre-Revolution days to evade duties and customs was something of a patriotic venture and had become a habit. But now it was smuggling. And besides, the treasury of the struggling young republic needed funds, and Alexander Hamilton, first Secretary of the Treasury, intended to get them. The First Congress, on August 4, 1790, empowered him to purchase and equip ten vessels for securing the "collection of revenues." This was called the United States Revenue Marine. (Curiously, some merchants objected because this implied their dishonesty. 'Twas ever thus!)

The cutters of the Revenue Marine helped run down French privateers in the undeclared war with France in 1798 and 1799, assisted in enforcing the embargo of 1807, had a full share in the War of 1812, helped suppress piracy and captured slave ships, assisted the Navy in the Seminole War that began in 1836, participated in the Mexican War, and fired the first shot of the Civil War in Charleston Harbor.

In 1863 the name "Revenue Cutter Service" was first used in an Act of Congress. In January, 1915 the Revenue Cutter Service and the Lifesaving Service of the Treasury Department were consolidated under the present title, United States Coast Guard. In 1939 the Lighthouse Service was transferred to it from the Department of Commerce. The organization as it stands today was rounded out in 1942 with the addition of certain safety-at-sea functions of the Bureau of Marine Inspection and Navigation (Department of Commerce).

**At left is the cutter *Tampa*, designed for off-shore patrol work, such as iceberg hunting. Above is the cutter *Ponchartrain*, (*Chelan* class) on duty at an international yacht race. Regatta patrol is an official U.S. Coast Guard function.**

uously transmitted from a shore point; when received by ship radar it shows on the screen as a white line pointing to the Ramark station, whose location is known by its code. The Coast Guard maintains four Ramark developmental transmitter installations.

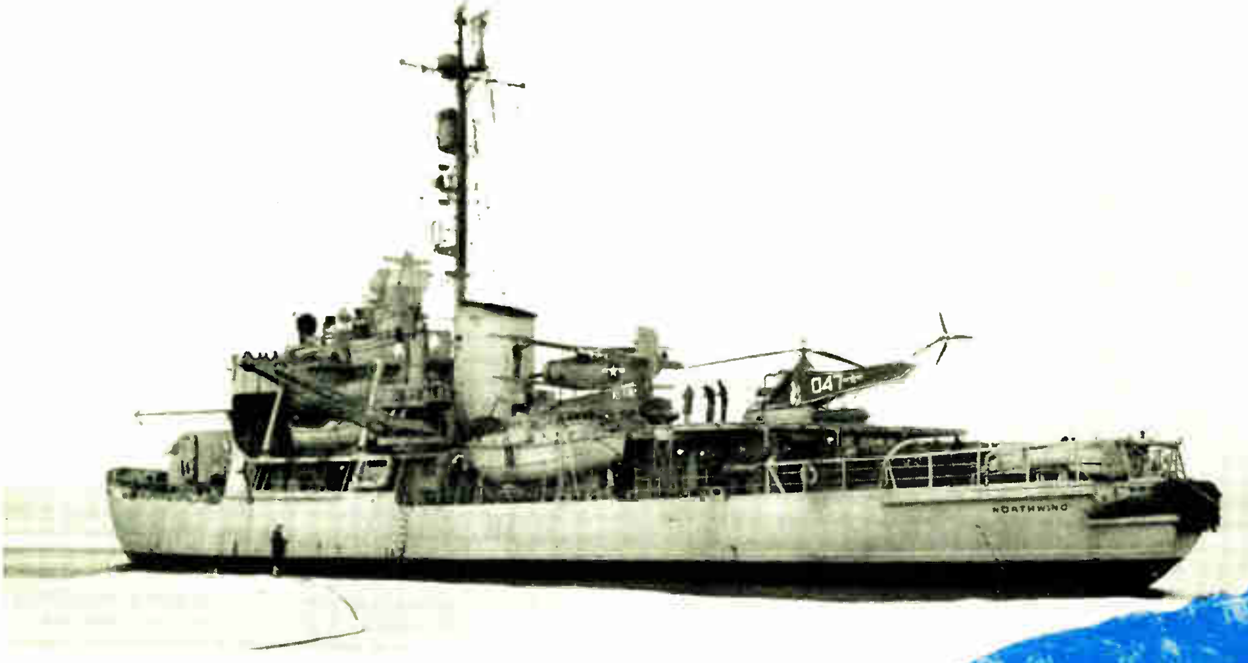
Coming into the picture now is Racon (*ra*dar bea*con*). This is an outgrowth of the war need for fighter planes to identify whether another plane was friend or enemy. It is a means by which one radar set sends out a beamed interrogating signal. The target radar replies with a proper identification.

Other quite different tasks are included in the family of things the Coast Guard does to help vessels avoid trouble. One is the routine matter of hunting down and destroying derelicts. A more dramatic chore is iceberg patrol. In 1913, shortly after the tragic sinking of the *Titanic* by an iceberg, the Coast Guard began its own ice patrol. Two years later a convention of maritime nations agreed to an International Service of Ice Observation and Ice Patrol, conducted by the U. S. Coast Guard. Except during the two wars, every ice season (March to as late as August) two cutters cruise an area of about 13 000 square miles off the Grand Banks of Greenland, athwart the shipping lanes of the North Atlantic. The cutters spot the icebergs, chart their course, collect ice information from other ships, and broadcast frequent reports. No attempt is made to destroy the ice, because no method is known, short of the warm Gulf Stream or an atom bomb. The number of icebergs migrating each season into this critical area varies from 13 to 1322, with an average of 377. The Coast Guard is rightfully proud of the fact that since the ice patrol began nearly 40 years ago only one serious collision has occurred, and that during World War II when the service was necessarily inoperative.

Another type of disaster-preventive service is the maintenance of weather stations, which have greatly increased in importance since the beginning of transoceanic flight. At present two such stations are maintained in the Pacific and 7½ in the Atlantic (one being operated jointly with Canada). At each, a cutter cruises continuously within an area ten miles square, gathering meteorological data and radioing it at frequent intervals to Radio Washington for transmittal to the Weather Bureau. Each cutter must remain in its 100 square miles for about 20 days, obviously regardless of weather—a monotonous operation, albeit an invaluable one.

Also on the accident-prevention side are numerous mer-

**The *Northwind*, one of the wind-class ice breakers, is seen here in Antarctic waters in one of the Byrd polar expeditions.**



**Above is the Coast Guard cutter *Campbell.* It is the largest of cutters, and, powered with 6200-shp geared turbines, has a range of 8000 miles. At right is the *Androscoggin,* a turbine-electric ship used in North Atlantic weather patrol.**

chant-marine inspection services. The Coast Guard establishes safety regulations concerning the design and construction of merchant vessels, provisions for safety and comfort of passengers and crew. This covers not only guidance in the original planning of all merchant-marine vessels, but also inspections of those in service. In addition, the Coast Guard examines and issues licenses and certificates to merchant-marine officers and seamen. In case of collision or other casualty, the Coast Guard conducts investigations, partly with a view to improving safety measures.

*Assistance in Disaster*—In addition to these services aimed to help avoid trouble, the Coast Guard comes to the rescue when disaster strikes. Best known is the Lifesaving Service established in 1871. It now comprises 165 active lifeboat stations. In the first 70 years of its service, 203,609 lives, and property valued at almost two billion dollars, were saved. Since 1941 an annual average of 5500 lives have been saved and 200 million dollars' worth of property preserved.

In 1831, Andrew Jackson's Secretary of the Treasury detailed seven cutters to patrol, in winter, the shipping lanes off our shores, and to give aid to any vessel in distress. Since then these cruises have been an important Coast Guard activity.

The weather stations, the winter-cruising cutters, and other Coast Guard services have, in addition to their specialized duties, been integrated into another class of rescue work. This is called Search and Rescue, formerly known as Air-Sea Rescue. This branch of the service has made several spectacular missions, particularly those involving transatlantic commercial aircraft. It coordinates all safety operations of government and private agencies, maintains ship and plane information centers, transmits and disseminates all distress information, and actively participates in search and rescue operations using cutters, airplanes, and helicopters.

Another duty of the marine-safety branch of the Coast Guard, although not directly related to policing or safety, was added in 1936—ice breaking. The Service was then directed to assist in keeping channels and harbors open by means of ice breaking in accordance with the reasonable demands of commerce. This function proved of incalculable value in 1941 when, with war impending and iron ore so vital, ice breakers opened channels in the Great Lakes earlier than at any time since 1855, permitting a new record in tonnage of iron ore moved in one season. Coast Guard ice breakers performed many other services in the North Atlantic during the war,

**The *Ingham* on one of its three-week turns of duty, cruising in a ten-mile square in the North Atlantic as a weather station.**

Even lifeboat stations have gone modern. This is one of the newer and more striking ones, located on Lake Erie, near Cleveland, Ohio.

Three crew members of the cutter *Mendota*, on ice patrol, watch a Coast Guard plane circle a glacier-born menace to navigation.

including the breaking up of the secret German weather station in Greenland. Ice breakers also have participated in three polar expeditions, including one of Admiral Byrd's trips to the antarctic regions.

The Coast Guard serves as a jack of all trades in Alaskan waters—even to the performance of Eskimo marriages, when requested. For the Navy, it acts as an intelligence arm; while for the Post Office it carries mail; for the Department of Justice it dispenses justice in isolated villages, and provides "floating courts" when necessary. It serves the Department of Interior in the transportation of teachers, natives and their supplies, makes sanitary and other inspections of Alaskan villages. It helps with the census, makes special hydrographic surveys, acts as game warden, and performs countless other chores as they arise.

### Coast Guard Cutters

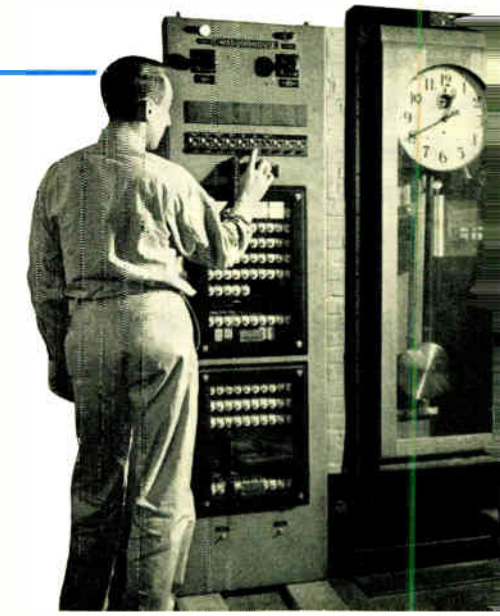
To discharge its multitude of enormously varied and widely scattered duties, the Coast Guard has required many types of vessels. Except for small boats, these have come to be known as cutters, although the term originally applied to a particular type of craft with very heavy keel so that it could carry plenty of sail, which gave it speed. On occasions, particularly in wartime, the Coast Guard has operated such vessels as it could obtain for its need, but for the most part the Coast Guard has developed its own special types. These include a wide variety of small craft, such as lifesaving boats, surf boats, motor launches, and lately the amphibious vessels such as the Dukw type. Also it has developed many larger vessels including a variety of general-purpose ships ranging from diesel-driven cutters 83 feet long to twin-screw turbine ships of 327 feet, and including buoy tenders, supply ships, lightships, ice breakers, and numerous others. In arriving at these highly specialized vessels the Coast Guard has rolled up a long record of pioneering in marine engineering. It has either initiated or performed basic development of many ideas that have since come into general marine use. This has been possible in large part because the Coast Guard has always been a relatively small, closely knit organization, and has had the good fortune to have had men of unusual caliber and foresight directing various of its activities.

To record all the outstanding technical pioneering ventures in the long history of vessels produced by the Coast Guard would be impossible in reasonable space. But several of modern times are illustrative.

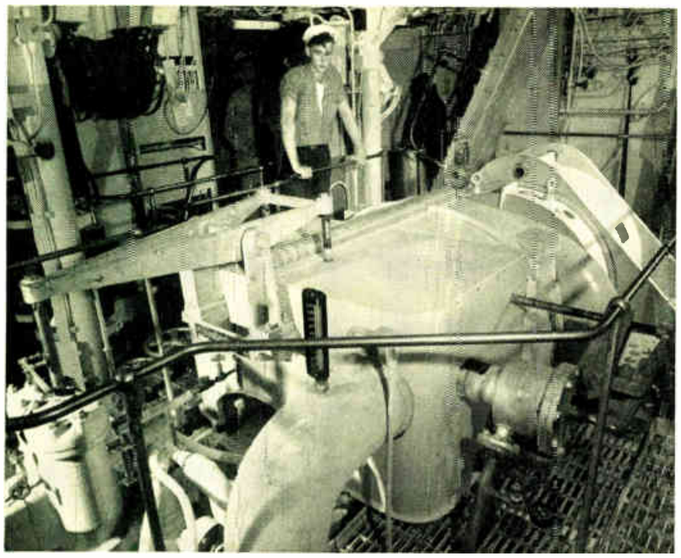
In 1921 the Coast Guard applied synchronous motors to alternating-current drive for ship propulsion. The 240-foot cutters of the *Tampa* class were equipped with a 2600-shp turbine-electric power plant driving the single screw. Propeller speed variation was obtained by changing the turbine speed. Synchronous motors, replacing induction motors, have since come into general use for a-c powered vessels, except for certain special applications.

In 1927, vessels employing diesel-electric drive were placed in service. These were of the 216-foot *Northland* class, which used two diesel-generating plants and a single 1000-shp direct-current propulsion motor. While these were not the first diesel-powered ships, they were noteworthy.

A year later the famous 250-foot *Chelan* class of cutter introduced the idea of a central-station type of plant for shipboard use. To effect fuel economies, the power for all ship



**The newest thing in lightships is this experimental vessel to be anchored off New York harbor. It will have no crew. Its three diesel-electric power plants, pumps, beacon, and other equipment are controlled from a shore station by supervisory-control signals transmitted by radio. Control equipment, shown here, is of the Visicode type as developed for power-line utility service.**



**In the engine room of the *Mendota* (*Owasco* class), shown in foreground is the turbine and in the background a 2600-kw generator.**

auxiliaries—lights, auxiliary motors, galley power, etc.—was taken from the efficient, main 3000-shp, a-c turbine-generator unit whenever the vessel was operating above two-thirds speed. At lower speeds auxiliary power was supplied by a three-unit set consisting of a turbine driving two generators, one alternating current and the other direct current. This system achieved its purpose of obtaining high efficiency, and has since been widely adopted.

The *Itasca* class, 250-foot, 3220-shp cutters, first built in 1931, utilized a-c driven auxiliaries. Here the use of a-c power for auxiliaries was carried even further, particularly to the operation of deck machinery. Induction motors were used for auxiliaries where possible and alternating current was used for lighting.

The first geared-turbine cutters were of the 165-foot *Algonquin* class, in 1932. This 1500-shp drive achieved an extremely compact power plant resulting from a construction of the geared turbine that involved no outboard bearing for the turbine. It made the cutter small and maneuverable.

In 1936 the 327-foot, twin-screw cutters known as the "Secretary" class appeared, of which the first was the *George W. Campbell*. These large, fast cutters, powered by 6200-shp geared turbines, were used in ice-patrol service.

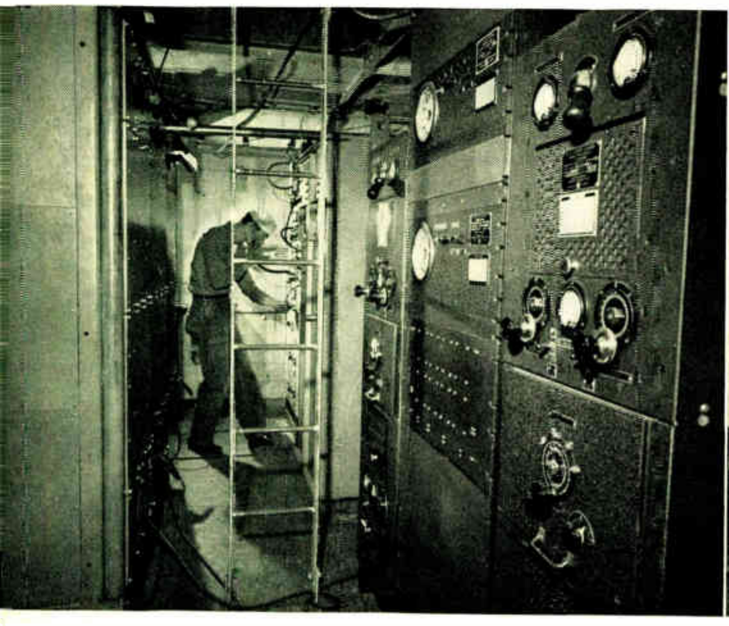
Pilothouse control was introduced with the a-c turbine-electric, *Owasco*-class, 255-foot cutters in 1945. In this system the actual control for all the ship's propulsion machinery is brought to the pilothouse. While more costly, it provides the ultimate in maneuverability. The *Owasco* cutters were 4000-shp, single-screw vessels and are now employed for weather stations. Speed control, as before, was by frequency variation, but here the use of frequency above 60 cycles was introduced. Full-speed frequency was 90 cycles. The higher frequency greatly reduces the machinery size.

The development that has led to the modern ice breaker is a long story in itself. There was the *Bear*, a wooden vessel built in 1874 and later strengthened for ice, which enabled it to do outstanding things in Alaskan waters. It was in 1897 that the *Bear* went to the rescue of whaling crews trapped by a premature winter. A small party from the ship traveled 1600 miles by sled, drove 400 reindeer overland for food, effected the rescue of the lost whaling men, and maintained order for four months until the *Bear* could reach them.

The diesel-electric cutters, the *Raritan* and *Naugatuck*, commissioned in 1939, were the first Coast Guard vessels designed primarily with ice-breaking characteristics. These were single-screw, 110-foot vessels. They were followed by those of the *Cactus* and later the *Iris* class.

But the story of modern ice breaking begins with those of the "wind" class, of which the *Northwind* was the first, being commissioned in 1945. Each vessel is 269 feet long. Its diesel-electric power plant develops 10 000 shp, delivered to two stern screws and one at the bow that pushes water forward under the ice, facilitating ice fracture. Such a vessel can break solid ice 5 feet thick at 4.8 knots or can open broken ice 10 feet thick by backing and ramming. These were the first diesel-electric vessels to employ parallel-connected generators, which allowed use of high-voltage (900 volts) direct current and achieved important weight reductions. Numerous technical features tried here have been proved sound.

The Coast Guard has become synonomous with efficiency, neatness, courtesy, and readiness to serve in any capacity for which it is equipped.



**Imagine a power station where circuits are adjacent to a tank car of gasoline; where the temperatures can change from 100 degrees to minus 30 degrees F in a few minutes; and where the whole station is subject to a minor earthquake several times a day. Add to this the routine functions of accommodating load changes and system surges, and of meeting switching requirements. These are the problems facing designers of modern aircraft electric-power systems. Yet the 24-volt d-c system, steadily improved, keeps pace with these many demands and provides complete service and protection.**

# D-C 24-Volt Aircraft Electrical Systems

J. D. Miner *and* B. O. Austin
*Aviation Engineering Department,*
*Westinghouse Electric Corporation,*
*Lima, Ohio*

Amazing vitality has characterized the 24-volt electrical system now in use on more than 90 percent of the commercial and military airplanes of this country. Disparaged and written off time and time again, the 24-volt system has come back stronger than ever. Advances in equipment design, fault protection, and overall system reliability have steadily extended its application to all but the heaviest military requirements. Even on those few airplanes where military needs dictate the use of a-c systems, the ubiquitous 24-volt d-c system is found, alongside the main a-c system, still doing those vital jobs for which it has no real competitor. For example, d-c operating coils are used on the great majority of the control relays for the a-c system. Failure of the d-c supply may result in partial or complete loss of the main a-c system.

Aircraft electrical power systems combine the functions of generation, system protection, and positive control in a few compact, integrated units. The principal objective is continuity of service. Also, as with everything on an airplane, minimum weight and low maintenance are necessities. Designed within these strict requirements, the systems must perform certain functions:

1—Connect generators to the bus when polarity is correct and when generator speed and output voltage are within the proper ranges for operation.

2—Disconnect the generators from the bus when speed is below that which permits the generator to deliver power.

3—Disconnect the generators from the bus when a fault—overvoltage, ground, or generator reverse polarity—occurs on the system.

4—Remove generator excitation when a fault exists or the generator builds up with reversed polarity.

5—Provide accurate load division between the several generators of the system.

6—Provide fault indication.

7—Function automatically except when in manual control.

8—Provide for trip-free manual reset when power is not available for electrical reset.

### Previous "Systems"

In an article published only four years ago,[1] the 24-volt system was described as consisting of generators, voltage regulators, reverse-current relays, and a "distribution system." Sole omen of the modern concepts of aircraft protection about to be developed was a discussion of the advantages of multiple feeders, in which it was pointed out that such feeders were of value when open circuits, such as would be caused by gunfire, were anticipated.

Previous systems omitted many of the essential functions of an electrical system. The only protection against overvoltage was battery load; batteries, by being large in comparison with total system capacity, prevented extensive overvoltage damage to the electrical equipment. However, this occasionally resulted in electrolyte boiling out of batteries, exposing the structure to sulphuric acid, with attendant problems of aircraft maintenance.

Other characteristics of the systems of 1946 were equally unsatisfactory. The use of multiple generators was well established, but paralleling was generally crude, inaccurate, and a constant source of trouble. Fault protection consisted of the fortuitous condition that either faults burned clear or the electrical system went dead. Occasionally, however, a small restriking arc at a fault caused trouble by burning away sections of the airplane structure.

If the reverse-current relay operated properly, reversed generators (see "Polarity Reversal," left) stayed off the line and no immediate difficulty appeared. As long as electrical loads were small, the battery could usually carry on until an

*Polarity Reversal*—On aircraft-type generators, polarity reversal is a frequent cause of trouble. These generators, which can build up in either direction according to the polarity of the residual flux in the field, are particularly susceptible to reversal because of the normally low residual voltage of a wide-speed-range machine. During operation at high speeds, the magnetic flux is small and a relatively low value of reverse excitation will cause polarity reversal. Many early generators were, in effect, over-compounded, either because of inaccurate neutral setting, or because the interpoles were adjusted to overcome saturation at low speed and, therefore, became too strong at the higher speeds. This would allow a transient reverse current to reverse the machine. Extreme care is taken to make sure that present generators are not over-compounded at any point in their speed or load range. Even this does not guarantee against reverse polarity. For example, if a generator field is opened at high speed, the transient reverse current will set up a residual flux in the interpoles that can generate enough circulating current in the armature coils under the brushes to reverse generator polarity. Thus, because of the very nature of aircraft generators and their conditions of operation, it is necessary that this inherently troublesome problem be guarded against.

airplane with all generators out could reach the next airfield. But if the reverse-current relay did not function, the result could easily be a disastrous fire.

The advent of larger airplanes, having from two to six 300-ampere generators, brought new difficulties. No longer was the battery sufficient to control generator voltage or to supply even essential loads for any length of time; paralleling of generators became even more critical, and positive, selective fault protection was a necessity. Various overvoltage schemes were improvised following several near disasters, but it was not until Northwest Airlines inaugurated the Martin 2-0-2 airplane in 1947 that provision for overvoltage protection was

*Overvoltage*—If overvoltage, caused by the generator, exists on the bus, that overvoltage is sensed by *OVC* and resulting overcurrent by *OVS*. The flux produced by *OVS* adds to that from *OVC*, closing the contact *OV*. Current then flows through *FRTC*, tripping contacts *FR*1, *FR*2, and *FR*3. *C*1 and *C*2 disconnect the generator and *TIL* indicates the outage. If this generator is not the cause of the overvoltage, *OVS* opposes *OVC* and the generator is kept in operation, except under very light load. Under light load, although the generator may be disconnected momentarily due to reverse current, it is automatically reconnected when the faulty section of the system is removed.

*Reverse Polarity*—Under some conditions, despite the tickler resistance, the generator might build up with reverse polarity. Current through the rectifier and *FRTC* prevents connection or continued operation of the generator. This trips the field relay, disconnects the generator field, and opens *C*1 and *C*2. The voltage appearing across *C*1 and *C*2 is thus minimized.

*Reverse Current*—A reversed generator causes reverse current in *DR*2, which opens *DR* and, in turn, *C*2. *DR*1 prevents reclosure of *C*2 until the generator voltage is again 0.5 volt greater than the bus.

*Trip-free Operation*—The field relay is trip-free when either electrical or manual reset is used. Recycling or teasing is prevented during reset operations.

| | |
|---|---|
| ***BL*** | **Ballast Lamps** |
| ***BUP*** | **Backup-Protection Relay** |
| ***BUPC*** | **Backup-Protection Relay Coil** |
| ***CP*** | **Carbon-Pile Regulator** |
| ***C*1, *C*2** | **Contactor Operating Coils** |
| ***DR*** | **Differential Relay** |
| ***DR*1, 2, 3** | **Polarized Differential-Relay Coils** |
| ***ERC*** | **Equalizer-Relay Coil** |
| ***ER*1, 2** | **Equalizer Relay** |
| ***FP*** | **Feeder Protective Relay** |
| ***FRRC*** | **Field-Relay Reset Coil** |
| ***FRTC*** | **Field-Relay Trip Coil** |
| ***FR*1, 2, 3** | **Field Relays** |
| ***GF*** | **Ground-Fault Relay** |
| ***GFP*** | **Generator-Feeder Protective-Relay Coil** |
| ***GP*** | **Generator-Feeder Protective Switch** |
| ***GF*1, 2** | **Ground-Fault Relay Coils** |
| ***GS*** | **Generator Switch** |
| ***OV*** | **Overvoltage Relay** |
| ***OVC*** | **Overvoltage-Relay Coil** |
| ***OVS*** | **Overvoltage Selector Coil** |
| ***REC*** | **Regulator Equalizer Coil** |
| ***ROC*** | **Regulator Operating Coil** |
| ***R*2** | **Calibrating Resistance** |
| ***SF*** | **Shunt Field** |
| ***SW*** | **Series Field** |
| ***TIL*** | **Trip-Indicator Lamp** |
| ***TR*** | **Tickler Resistance** |

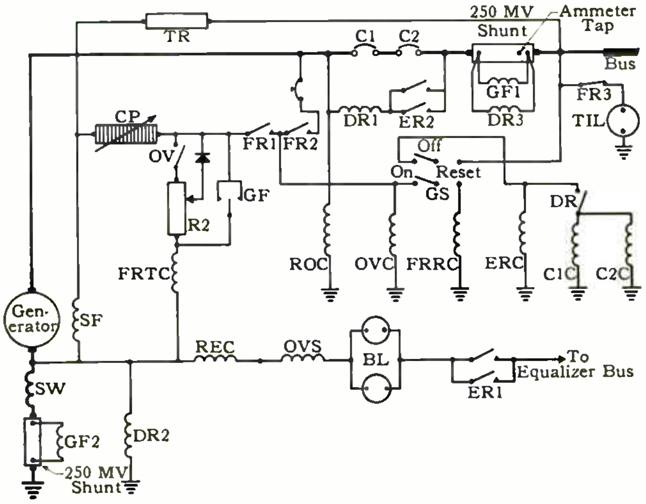


Fig. 1

**Ground Faults**—**A fault in the generator, its leads, or in the feeder bus is sensed by the differential relay coils, *GF*1 and *GF*2. As soon as the current through the two shunts differs; *GF* contact closes, tripping the field relay and shutting down the generator. *TIL* indicates the outage.**

***Backup Protection*—The backup coil *DR*3 on the differential relay trips at 100 amperes reverse current and opens *DR*. This opens *C*1 and *C*2 and disconnects the generator.**

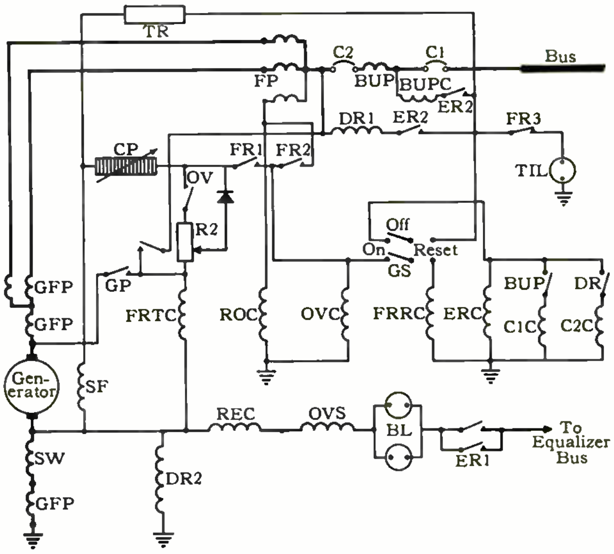


Fig. 2

***Ground Faults*—Fault in the generator windings or leads is sensed by the differential current relay, *GFP*, which then closes the contact *GP* and energizes *FRTC*. This trips the field relay, opening *FR*1 and *FR*2, which shuts down and disconnects the generator. Similarly, a fault in the feeders is sensed by the *FP* relay coils, which then close contact *FP*. This trips the field relay and shuts down the generator as before.**

***Backup Protection*—Should *C*2 fail to open, when generator is stopped, the backup relay will trip at 100 amperes reverse current, opening *BUP* and *C*1, disconnecting the generator.**

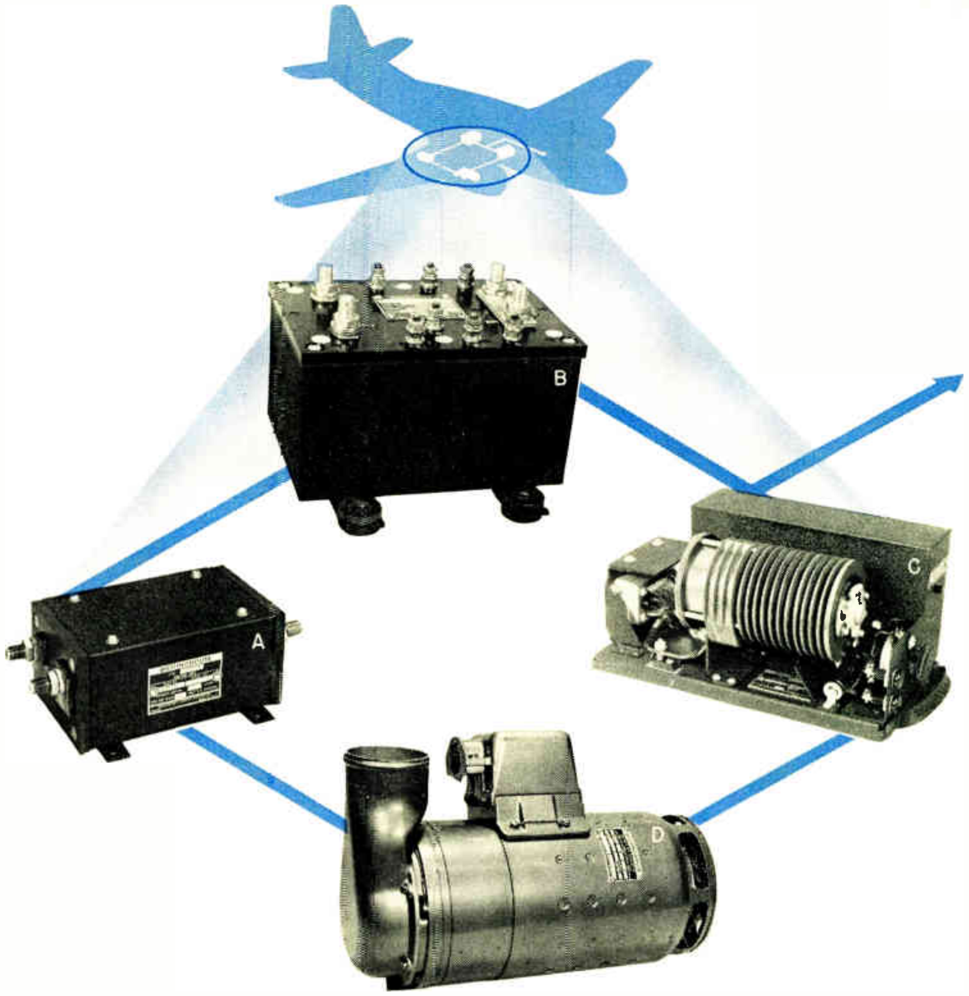


**Fig. 3—The basic units of a modern d-c power system: (a) generator and feeder ground-fault relay, (b) dual contactor, feeder fault relay and back-up protective assembly, (c) the plug-in type control panel assembly, which is the heart of the system, and (d) a typical aircraft generator, the d-c, 300-ampere, wide-speed-range unit. One of these three-unit control systems is required for each of the generators.**

made by using a relay that sensed bus voltage.

## A Protective System Develops

Two basic circuits that accomplish the required functions and yet comply with the manifold requirements and limitations of aircraft service were developed. They incorporate a decade of steady advancement embodying the co-operative thinking of equipment designers, aircraft builders, maintenance personnel, military planners, and commercial operators. The pros and cons of the two are somewhat controversial, but the important point is that in both circuits sound fundamental design and careful coordination of components have been joined to provide adequate, effective, and reliable protection for both the electrical system and the aircraft itself.

Both circuits provide continuity of electric power despite faults occurring in one or more generators, feeders, or in the controls. Faults are isolated, minimizing damage to equipment and preventing fires, and positive and selective overvoltage protection is provided. In addition, the component parts are grouped for convenient and economical installation and maintenance.

In both systems fault protection is obtained by comparing the current fed to the bus with the current returned from the structure to the negative generator terminal. A system, based upon balancing the voltage drops across two shunts, is shown in Fig. 1. Here appreciable energy is dissipated in the shunts, although the voltage drop in each is only 0.25 volt at full load. When a fault occurs, the difference between the low shunt voltages operates a remotely located sensitive relay. But casualty to one line of a dual feeder doesn't give a fault indication unless a ground also results. A system based on current balance relays is diagrammed in Fig. 2. The fault-sensing relays are rugged and operate without power loss and without local heating. Casualty to one feeder gives a fault indication and shuts down the generator associated with that particular feeder.

### Overvoltage Protection

Overvoltage, which can cause considerable damage, is one of the most frequent faults. The usual cause is over-excitation of a generator because of some fault in the regulator circuit or because of malfunctioning of the regulator itself. Because all overvoltage relays are connected to the common bus, provision must be made to select and remove the faulty generator from the bus without disturbing the others. This selectivity is obtained by providing a bias coil in the overvoltage relay connected into the equalizer circuit (Figs. 1 and 2).

The voltage supplied to the equalizer circuit by each generator on the system is produced by current through the series windings and is directly proportional to generator current. Current in the equalizer circuit changes the calibration of the voltage regulators and the overvoltage relays. The regulators are biased to reduce excitation of those generators producing more than their share of load current and to increase excitation of those producing less. Thus, the equalizer circuit reduces current unbalance to a low value. Simultaneously, the operating point of the overvoltage relay associated with the over-excited generator is dropped and the operating point of all other overvoltage relays is raised. The offending generator is removed even under load conditions that prevent an actual overvoltage on the bus. The bias coils keep the relays on normal generators from tripping whether the voltage rises or not.

### Parallel Generators

Current in the equalizer circuit shifts the regulator operating points to equalize the load currents on all generators. The higher the voltage used, the more precise the load balance of the generators. However, the larger the equalizing voltage, the more the system voltage is depressed if one generator is operating below the speed at which it contributes current to the system. If the generator is disconnected entirely, the equalizer relay for that generator opens and the system voltage remains normal. An equalizing signal of two volts at full-load current is made possible by using the voltage existing across the generator series winding, and by using ballast lamps to decrease equalizer sensitivity as large values of unbalance are reached. The ballast lamps heat up with high current and, because of the high temperature coefficient of tungsten, introduce sufficient resistance to limit equalizer action.

### Reversed Generator Protection

With properly adjusted under-compounded generators, most conditions tending to reverse polarity are handled by the field tickle resistor—a resistor that connects directly to the bus and maintains a low voltage of correct polarity on the generator field. It is impossible, however, to guarantee that a generator will never reverse polarity, or even to guarantee that, in the instant the generator was switched off after a shop check, the polarity did not reverse, which would lead to improper installation. This is no reflection on generator maintenance or design, but merely a characteristic of the low residual voltage normal to a generator that operates over an extremely wide speed range. Earlier systems kept a reversed generator off the bus but the operator knew only that the generator would not come on. Now, tripping of the field relay by a reversed generator gives a fault indication so that the difficulty can be corrected.

### Dual Contactors

Reliable operation of the main contactor is of paramount importance. Failure of this element makes all other features futile. When one or more of the control relays detects a signal, the main contactor must connect or disconnect the generator and bus as required. The conventional aircraft contactor uses two circuit breaks in series. However, use of a dual contactor with two contact bridges, and, consequently, four breaks in series, is strongly recommended. In addition to the possibility of mechanical failures and contacts that weld, the circuit might arc over continuously under overvoltage conditions. With only two breaks (unless accessory blowout devices are used) there is little margin in arc-interrupting capacity at system voltage and normal altitudes.

The dual contactor consists of two complete and independent contactors; failure of one contactor does not affect the operation of the other contactor. (No piece of equipment can be made absolutely trouble-free, but probability of simultaneous failure of two contactors is so remote that it can be ignored.) The dual contactor, which is located in the fuselage at the bus, also takes care of the high voltage that can result from a field-to-armature fault at the generator. Such a fault bypasses all protective devices, and the dual contactor, with an interrupting ability in excess of 100 volts, removes the generator from the bus even if it cannot save the generator from burning itself up.

### Short Bus

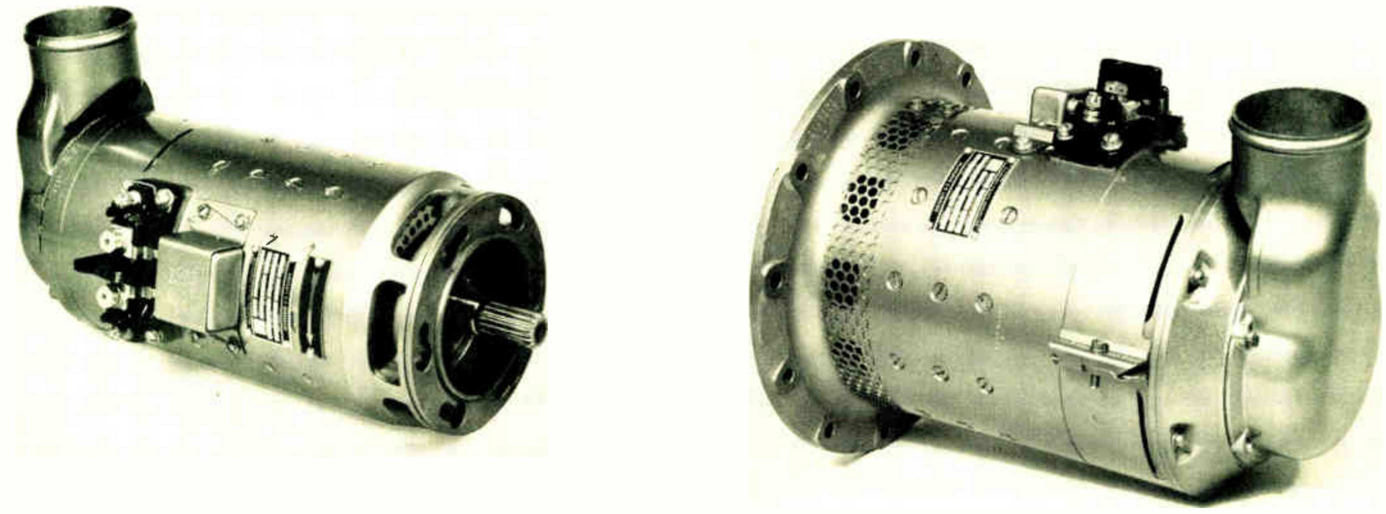
Only a sectionalizing arrangement, with a protective system for each generator, such as described here, can provide complete fault protection. Since the one objective of all aircraft electric-power systems, hence all protective schemes, is to maintain voltage on the bus, fault protection for the bus itself is not provided. However, a short bus, which minimizes liability to damage from flexure and vibration of the aircraft structure, can be designed so that a fault is possible only when, due to some external cause, the plane completely disintegrates.

## The "Packaged" System

The 2-0-2 airplane utilized the first electrical system in which the control components were assembled into a compact unit. Until this "packaged" system was developed, these individual components were installed in any location that suited the airplane designer. The voltage regulator, overvoltage relay, field relay, and some of the contactor controlling relays are all mounted on a single panel. Those not incorporated are the rugged current-balance relays used with the current-balance system, and the backup relay used with the dual contactor. Generator-ground fault protection was originally provided by a nacelle-located fault relay and contactor. On later installations, fault relays were located at both the generator and at the bus end of the generator feeders, and with these relays, a single or dual contactor at the bus furnishes protection against both generator and feeder faults. It might be expected that a system to provide all of the features which have been described would be both bulky and heavy. Not so—the complete set of control equipment required for each generator is compact and weighs only about 15 pounds.

Maintenance men originally feared that fault protection and automatic control equipment would be too complicated Experience showed, however, that this equipment is relatively simple and trouble free. Maintenance of the protective-system equipment is far simpler and more economical than mainte-

**Fig. 4 (left)—This 300-ampere, wide-speed-range d-c generator has the new button-hole-type mounting flange. Fig. 5 (right)—A 400-ampere wide-speed-range generator.**



nance of the airplane and equipment to accomplish the same degree of reliability. Few laymen appreciate the extreme flexibility of aircraft structures. The wing tips of a large airplane may actually droop five or six feet when the airplane is resting on the ground as compared with the position of the wings in flight. Hence, cables in the structure are subjected to considerable chafing and vibration. Inspecting this wiring and reinsulating danger spots is a tremendous job; it would be impossible to provide, through maintenance, the reliability obtained as a matter of course with a modern protective system.

### Component Characteristics

The overvoltage relay employs a dashpot in the magnetic circuit to provide a time delay. With the dashpot in normal position the relay magnetic circuit is extremely inefficient and requires very high voltage (over 200 percent) for operation. Under creeping overvoltage conditions, the dashpot plunger slowly reduces the reluctance of the magnetic circuit until, in the final position of the plunger, the relay operates in the range of 31 to 33 volts. The net result is that an inverse time-voltage characteristic is obtained that prevents nuisance trips at high transient voltages, and yet gives reliable tripping if 31 to 33 volts is maintained for an appreciable time. This relay now has had several years of successful operation.

The field relay must open the highly inductive generator field circuit under all operating conditions. Its main contact must interrupt 40 to 50 amperes at 150 volts up to altitudes exceeding 50 000 feet. Normally this field relay is electrically reset, but it could be mechanically reset if the battery were dead and there were no power on the bus. Current through the rectifier trips the field relay if a generator builds up with reverse polarity. A recently developed field relay combines mechanical and electrical trip-free operation without added interlocking relays.

Improvements in carbon-pile voltage regulators have largely eliminated former difficulties with these devices. Stable operation, long life, simplified maintenance, increased capacity, and better operation over the wide range of environmental conditions encountered have all been achieved.

### Generators

Although advances in power systems have occupied the spotlight, there have been real, if less spectacular, advances in generating and utilization equipment. Several are worthy of special comment.

The "buttonhole" mounting flange, first introduced on the 300-ampere generator for the Martin 2-0-2 airplane (Fig. 4), is in wide use. Mounting studs for generators are notoriously inaccessible and the buttonholes convert the standard mounting arrangement into a sort of bayonet mounting that reduces installation time from hours to minutes. No increase in overhung moment is necessary as is the case with practically all types of "quick-attach-disattach" mounts.

Modern generators are provided with "fixed-position" brushholders. All adjustments are made at the factory; in the field, parts can be scrambled at will without appreciable change in the original test performance. This requires great precision in manufacture to avoid instability due to incorrect brush position, and to assure good commutation. All modern aircraft generators are built with pole-face compensating windings for good commutation and satisfactory efficiency over the wide speed ranges required. Some of the larger machines employ commutator bars of Cupaloy alloy, (copper-chromium-silver), an alloy having high strength at elevated temperatures.

Present generators must operate from sea level to 50 000 or 60 000 feet. No entirely satisfactory solution of the altitude-brush problem has been found. Best results are obtained with electrographitic brushes impregnated with barium fluoride. These give fair performance at sea level, excellent performance from 30 000 to 45 000 feet, and good performance up to 60 000 feet, providing generator rating is decreased as the altitude increases above 40 000 feet.

In recent years mechanical problems of generator design have overshadowed electrical problems. The largest reciprocating engines now in use subject engine-mounted accessories to tremendous vibration. To complicate matters further, top speed rotation, which was once required only for a few seconds during take-off, is now cruising speed of jet engines.

Bearing failure is probably the most serious difficulty encountered with generators, both as to frequency of failure and seriousness of the consequences. Using a nitrided liner for the bearing seat at the drive end of the generator and using precision bearings closely fitted to the housing liners produce best results. Fits must be maintained from line-to-line to 0.0003 inch tight for satisfactory life. The use of rubbing seals to keep grease in the bearings and engine fluids out has also proved beneficial and greatly extends bearing life under certain operating conditions.

Ratings of 30-volt generators (nominal rating of machines on a 24-volt system) in current use are 100, 200, 300, and 400 amperes. Speed ratings are tending to be standardized at the Army-Navy specification values. "Wide-speed-range" generators operate from 3000 to 10 000 rpm with full rating available from 3500 to 8000 rpm. "Narrow-speed-range" generators operate from 4000 to 10 000 rpm with the full rating available from 4500 to 8000 rpm. Full current is available at minimum speed but an output of only 26 volts is required. Voltage regulation must be maintained over the range 8000 to 10 000 rpm, but continuous operation over this range is not generally encountered. Weights vary from 28 pounds for the narrow-speed-range, 100-ampere generator to 69 pounds for the wide-speed-range, 400-ampere generator.

The applications for electric power on modern aircraft appear endless, and far too much space would be required to do justice to even such a limited subject as motor applications. Trends in aircraft motors are toward strict adherence to environmental conditions and toward absolute compliance with radio-interference specifications. Elaborate test facilities are necessary to qualify motors and motor-operated devices for approval under basic military motor specifications. Operation under extreme temperature conditions is customarily obtained. The chief difficulties appear under the tropical conditions rather than extreme cold (winterization). Vibration ambients, explosion resistance, exposure to sand, dust, oil, and extreme humidity cycles can be handled very satisfactorily. Radio noise presents more of a problem, especially on some very high intermittent ratings, but some sort of filter, possibly quite elaborate, usually brings the motor down to the required values for radiated and conducted noise.

Evolution of the 24-volt electric power system to its present form has given aircraft complete and dependable protection. It is evidence of the usefulness of this basic system.

REFERENCES

1. "Direct-Current Power for Aircraft," by J. C. Cunningham and H. E. Keneipp, *Westinghouse* ENGINEER, March, 1946, p. 57.
2. "Aircraft Electric Power Protective Systems," by B. O. Austin, AIEE Paper No. 47-222.
3. "Control and Protection of Aircraft D-C Power Systems," by B. O. Austin, AIEE Paper No. 46-180.

# Power-Transformer Investment Can Be Reduced

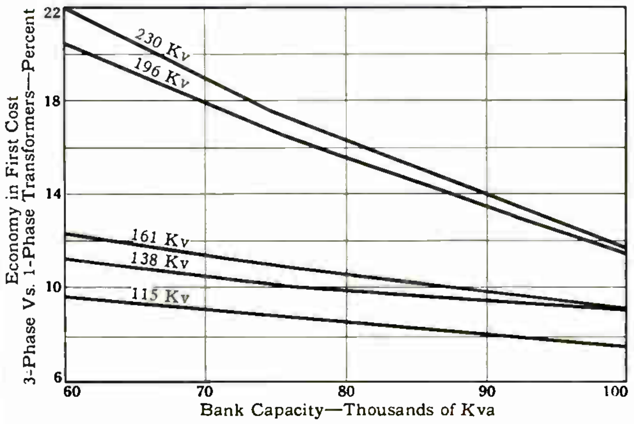
**The transformer, a static device, is, for all its 65 years, not static as to progress. Improvements that increase reliability, better methods of forced cooling, new insulation concepts, and other gains can be taken into account by the engineer under pressure to hold investment in new power transformers to the minimum. This is true of banks at generating stations, at the step-down ends of lines, and on sub-transmission lines. By comparison with a transformer bank of only a decade ago, the investment today may be only 50 percent as much, depending on the circumstances of the installation.**

F. L. Snyder, *Manager, Transformer Division, Westinghouse Electric Corporation, Sharon, Pa.*

Progress in power-transformer engineering has in the last ten years been such that it can be applied to reduce the investment in generating-station and substation transformer installations by one half, and by as much as two thirds in extreme cases. Some power companies are doing exactly that.

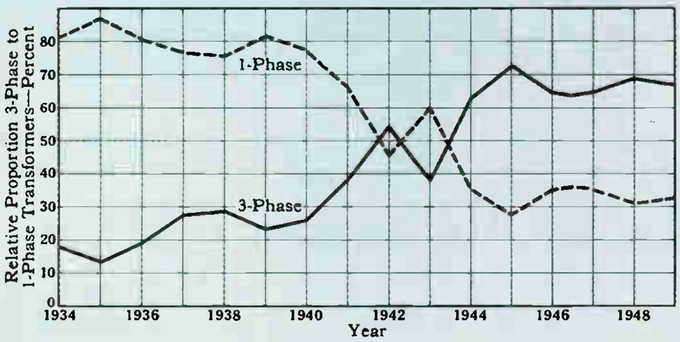
### Generating-Station Transformer Bank

Ten years ago the average generating-station transformer bank was made up of three single-phase units with a spare, such as the installation shown in photo *A*. Assume a 75 000-kva, 138-kv transformer bank. Following the practice then in vogue the transformers would have been straight self-cooled and would have been insulated for full line voltage. The cost



→

**Fig. 1—The approximate cost relationships of three-phase and one-phase transformers for different voltages.**



←

**Fig. 2—The proportion of three-phase transformers has risen from 15 percent to nearly 70 percent of the total in 15 years.**

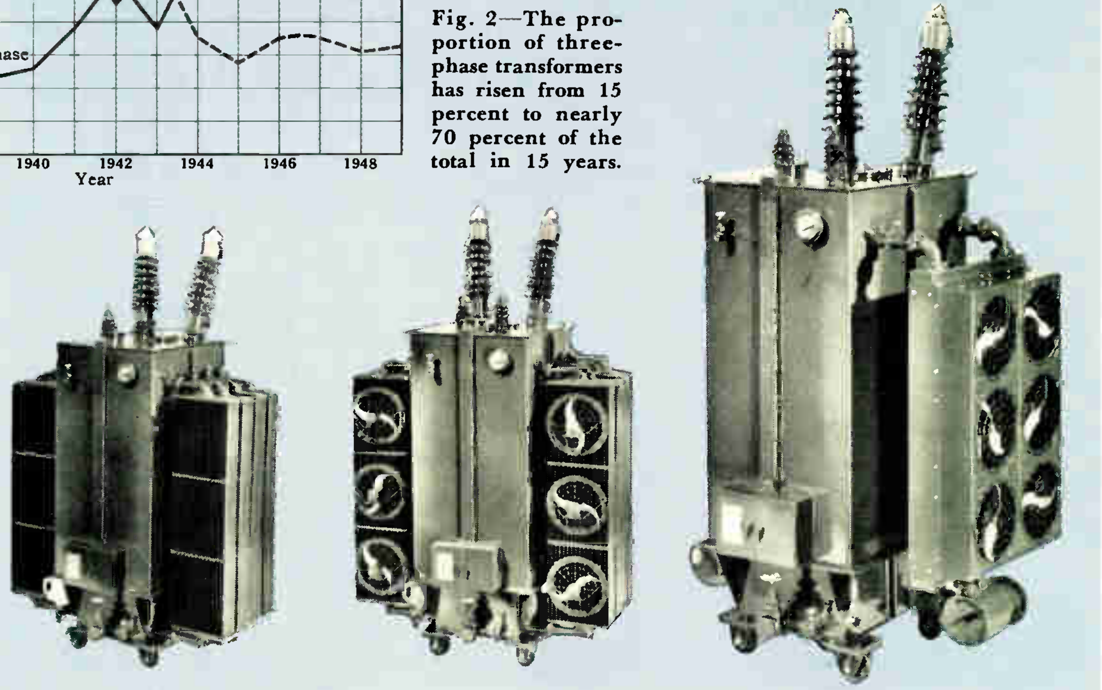
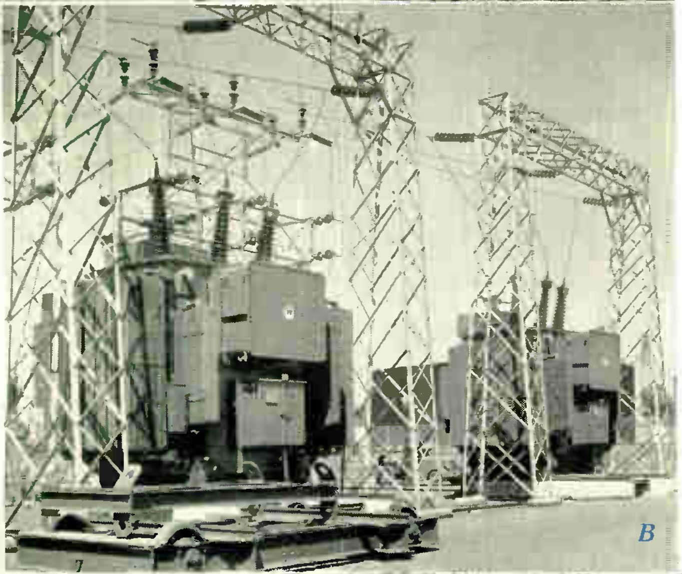


**Fig. 3—As of 1948, forced-oil transformers constituted 44 percent of the total built by Westinghouse, while forced-air-cooled and self-cooled transformers comprised 25 and 31 percent, respectively.**

*A*—A decade ago transformer banks commonly comprised 4 single-phase units. *B*—(center) Later, 2 three-phase units were used as at this 50 000-kva station on the West Coast.



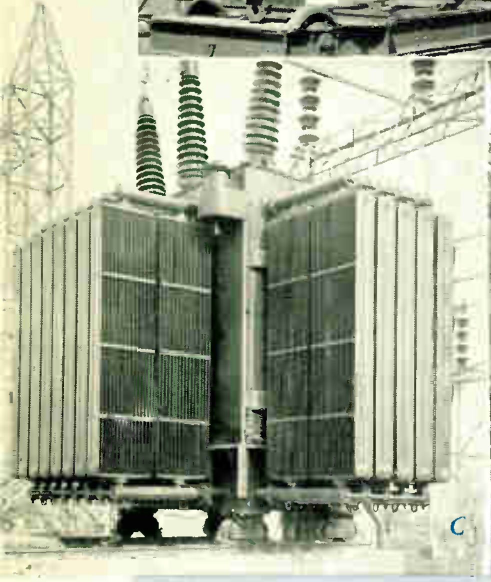
of the transformers, at today's prices, would be $322 000. This transformer bank has the advantage that it could be used on any kind of a system, that is fully insulated, grounded solidly, through a Petersen coil, or through a resistance or a reactance. The spare unit maintains service continuity when one of the three units gets into difficulty, although a brief outage occurs while the spare unit is moved physically into position and is being switched into the bank. With this type of bank the designer does not need to know much about the application of the transformer, and the user needs to know little about the transformer design. Everybody is happy with this conservative arrangement that provides a high degree of insurance—providing plenty of capital is available.

Assume, however, that all of the $322 000 required to buy such a transformer bank is not readily available. What can be done to reduce the cost of this transformer bank without reducing the total bank capacity?

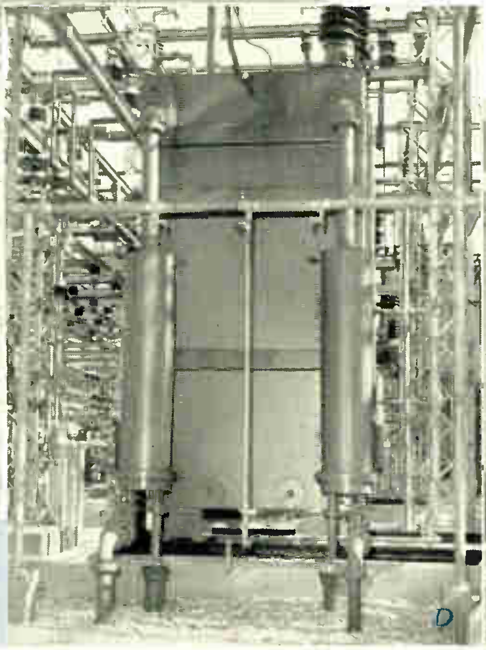
*Two Three-Phase Units*—A big step in reduction of capital investment can be taken by employing the principle of phase combination. For example, the bank can be made up of two three-phase transformers instead of four single-phase units, as was done in photo *B*. This reduces the cost from $322 000 to $271 000. The saving is $51 000, or 15 percent. Should one of these three-phase units get into trouble, 50 percent of the rated transformer-bank capacity remains. This is usually sufficient to carry the entire station load until the system can be rearranged to make up the drop in capacity at this station from another source. For example, the one transformer can carry the entire station load for at least one hour without appreciable loss of life. Furthermore, if the three-phase transformers are equipped with thermal relays, such as the TRO, the maximum capacity can be obtained automatically from the transformer still in service, and without danger of burning out or unduly reducing the life of the transformer. Furthermore, if the switching and relaying is properly engineered, this station will not go off the line when one transformer gets into trouble. The load gradually can be reduced as additional capacity from other parts of the system is brought into action.

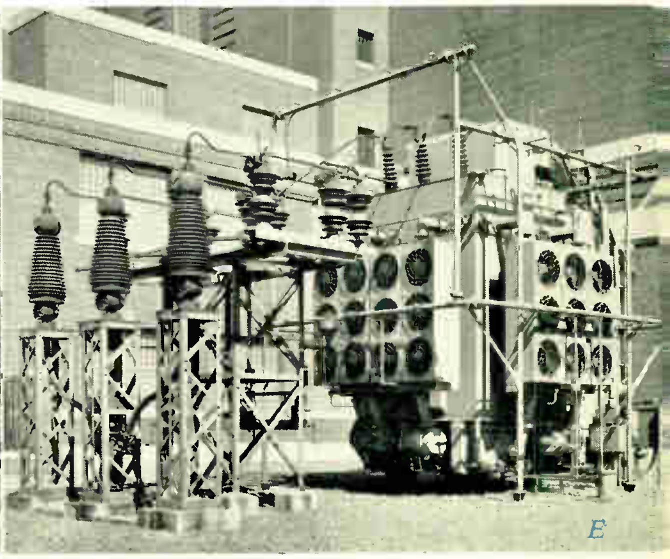
*One Three-Phase Unit*—If the station has several generators, or if the single generator is not too large a part of the total system capacity, the cost can be still further reduced by using one large three-phase transformer, as shown in photo *C*,

*D* (left)—A water-cooled, three-phase transformer of 50 000 kva. *E* (below)—A 105 000-kva, three-phase, forced-oil-cooled transformer in the East.



*C*—A typical three-phase, 40 000-kva transformer on a Missouri utility system.





instead of two smaller three-phase transformers. This brings the cost down from $271 000 to $231 000, or 15 percent, or an overall economy by comparison with the four-unit bank of 28 percent. The economy of this step for different voltages is given in Fig. 1. Obviously with this scheme there is no spare capacity should trouble develop in the transformer. However, it is well to remember that, on the average, the outage time of the transformer is much less than that of the generator. While there can be no absolute assurance that the transformer will never fail, the calculated risk is extremely low. Many modern generating stations are being installed with only one three-phase transformer per generator, as Fig. 2 shows. In fact, the largest three-phase transformer manufactured in this country (photo *F*) is in such a station.

*Water Cooling*—Use of a water-cooled transformer instead of a straight self-cooled transformer further reduces the overall cost. External water coolers for large, high-voltage transformers, introduced three years ago, are reviving interest in water-cooled transformers. Therefore, if adequate cooling water is available, the cost of the three-phase transformer can be lowered from $231 000 to $193 000 by using water-cooled transformers instead of self-cooled transformers, thereby reducing the capital investment by $38 000, or 17 percent. An example of this is photo *D*.

*Forced-Oil Cooling*—If cooling water is not available or if air-cooled transformers are preferred, further reduction in capital cost can be achieved by forced-oil cooling. Oil is pumped through external heat exchangers and through ducts in the core-and-coil assembly, instead of flowing by thermosiphon action through conventional external radiators. Note that this is forced-oil cooling of the transformer and not forced cooling of the oil only—there is a lot of difference between these two ideas.

Forced-oil cooling reduces the cost of transformers from $193 000 to $163 000, thereby again reducing the capital investment by $30 000 or 15 percent. An example of this is photo *E*. The popularity of the forced-oil cooled principle is shown in Fig. 3.

*External Water Cooler*—We have by no means exhausted our cost-saving possibilities. Further reduction in cost from $163 000 to $149 000, or 8 percent, can be achieved by using an external water cooler instead of an external air cooler for forced-oil-cooled transformers, as is done in photo *E*. But this move, and the others that have gone before, has almost exactly halved the investment required for a four-unit bank of single-phase transformers.

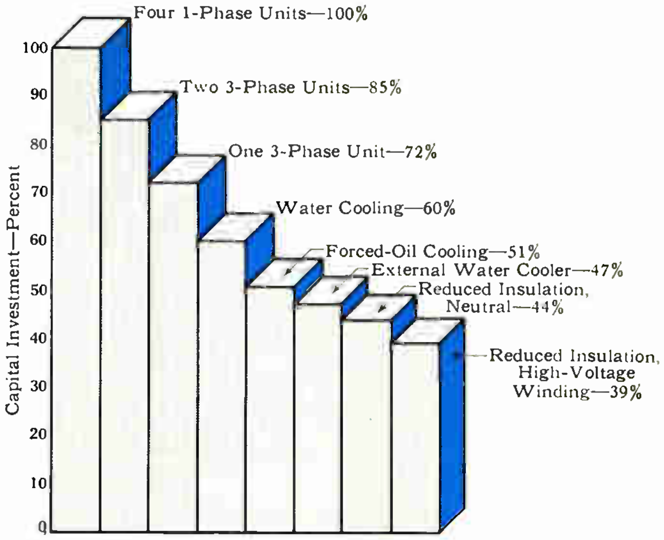
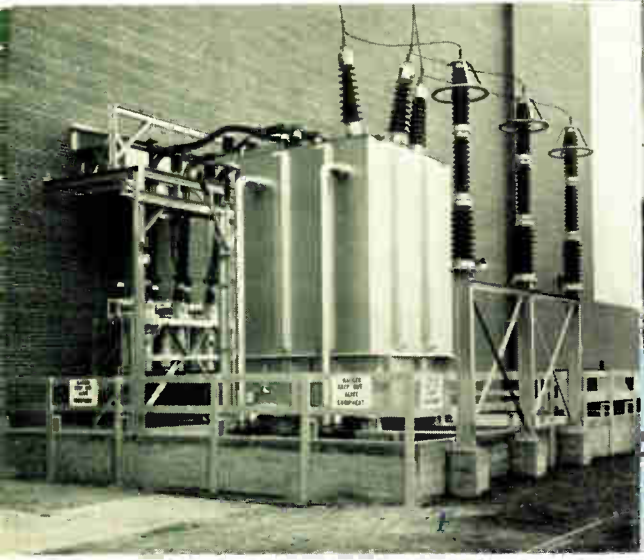


**Fig. 4—Summation of possible reductions in investment cost of generating-station transformer banks.**

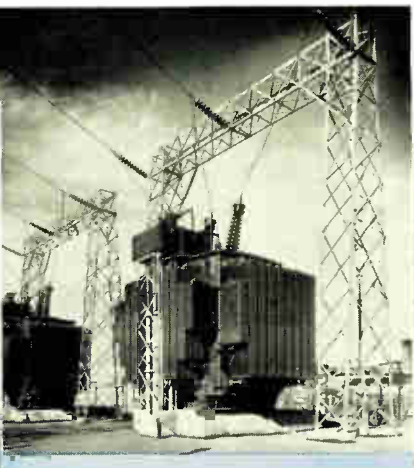
If forced-oil-cooled transformers are used, the impedance and losses are higher than with straight self-cooled or straight water-cooled transformers. The increases in losses and impedances are not, however, too important for generating-station transformers because they are usually capitalized at lower values than for step-down units since the losses are not supplied over the transmission lines.

The greater voltage drop through the transformer, due to the high impedance, can be compensated by using a higher primary voltage. This increases the kva rating of the transformer slightly but it does not appreciably offset the savings offered by the use of forced-oil-cooled transformers.

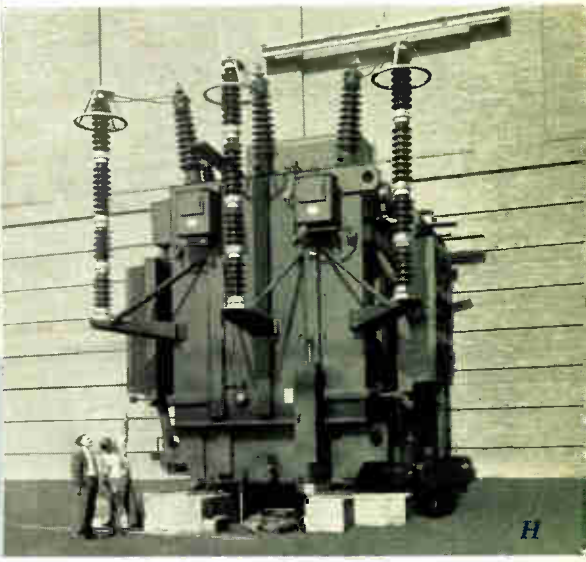
*Reduced High-Voltage Neutral Insulation*—If the transmission system is effectively grounded, it is feasible to use reduced insulation in the high-voltage neutral for any of these transformer combinations. In the case of the forced-oil water-



***F*—The largest transformer built in the United States is this 145 000-kva, three-phase unit. It uses external water coolers.**

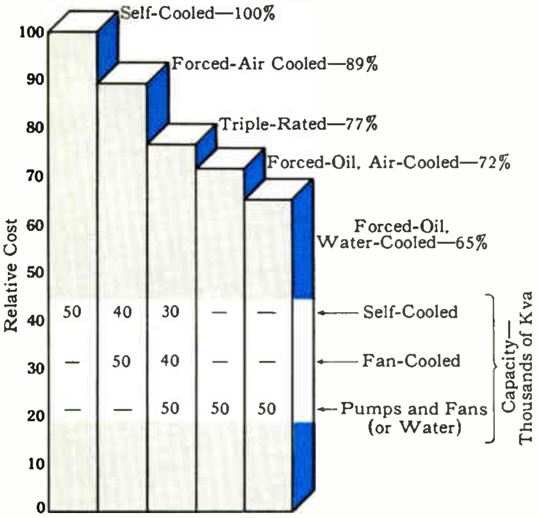


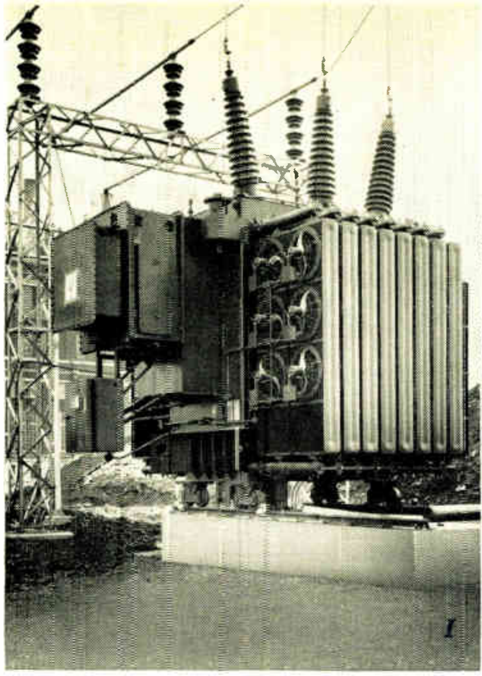
***G*—These 25 000-kva, three-phase units on a California system have reduced insulation in high-voltage neutrals.**



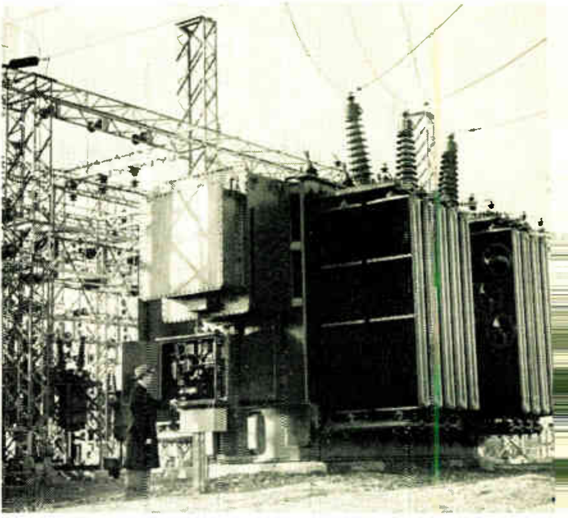
***H*—An example of transformer with reduced primary-winding insulation is this 110 000-kva, three-phase unit.**

**Fig. 5—A comparison in cost and performance of 50 000-kva, 115-kv, three-phase transformers of different principles of cooling.**





*I*—**A triple-rated transformer—25 000/33 000/41 667 kva—at 161 000/13.8 kv.**



*J*—**A 115/69-kv step-down transformer with a load tap changer at a utility substation.**

cooled (FOW) transformer (photo *G*) this pares the cost from $149 000 to $142 000. This represents a savings in investment of five percent.

*Reduced Primary-Winding Insulation*—If the system is solidly grounded, and if the dynamic and switching surge voltages can be limited to about 80 percent of their nominal values, reduced insulation can be employed in the entire high-voltage winding of the transformer bank. A further reduction in capital investment from $142 000 to $127 000, or 10 percent thereby obtains. A combination of these two principles, that is, solidly grounded neutrals and reduced insulation, results in a total reduction in cost of any of these transformers by approximately 15 percent. Such a transformer installation is shown in photo *H*.

While we are concerned here with transformers only, the economies elsewhere about the station resulting from the use of reduced insulation level should not be overlooked.

This principle cannot generally be offered to system voltages below 115 kv because the lightning-arrester coordination problem usually does not permit it.

To realize full advantage of the principle of insulation coordination in reducing capital investment, it is necessary to use arresters having a dynamic voltage rating of about 80 percent of the maximum line voltage. The arrester should always be as close to the transformer as possible. If the rise in dynamic voltage on the transmission line when the breaker is opened exceeds the voltage rating of the 80-percent arrester, it may be desirable to connect a 100-percent arrester on the line side of the breaker and an 80-percent arrester directly to the transformer terminals. The 80-percent arrester protects the transformer when the breaker is closed while the 100-percent arrester protects the breaker when the breaker is open.

When a generating-station transformer installation can be planned to incorporate all of these principles of phase combination, cooling, and reduced insulation levels, the first cost or capital investment will fall from $322 000 to $127 000. This is a total reduction of approximately $195 000, or 60 percent (summarized in Fig. 4), and is achieved without reducing the rated capacity of the transformer bank. In addition, appreciable reduction results in land area, foundations, installation costs, and maintenance. The total of these items may result in as much savings as that for the transformer itself.

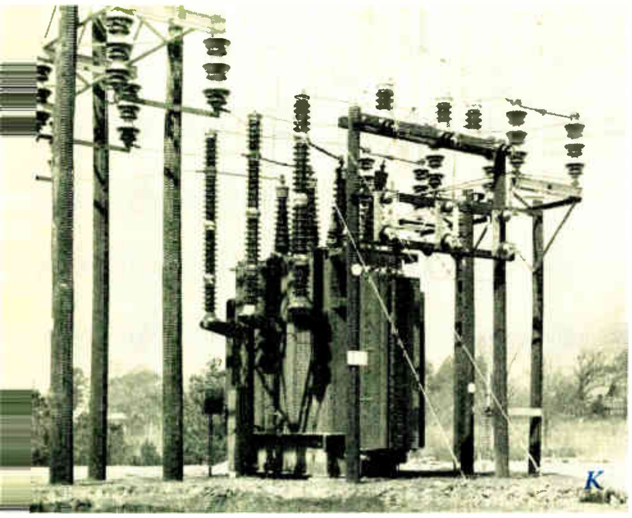
### Step-Down Stations

The engineering principles set forth for generating-station transformers are equally applicable to those used at the receiving end of the lines. Assume that the kva capacity of the step-down bank at the switching station is also 75 000 kva, and that the transmission voltage is 138 kv, and that the sub-transmission voltage is 69 kv. The cost of four single-phase units for this station will be $381 000.

*Phase-Combination*—Again using the principle of phase combination, the cost of one three-phase, straight self-cooled unit with solidly grounded neutral and reduced insulation is $275 000, or a reduction in capital investment of 28 percent.

*Triple-Rated Transformers*—The economy-minded step-down station designer has some other tricks available to him. For example, the triple-rated transformer, photo *I*, is particularly applicable to step-down transformers, because it offers a compromise between the straight self-cooled transformer and the forced-oil-cooled transformer as far as losses and cooling are concerned. It has the additional advantage that it can be operated as a straight self-cooled transformer for 60 percent of its maximum rating. It can carry 80 percent of its maximum rating with the fans running, and its full maximum rating with both the fans and the oil pumps running. The losses are less than with the forced-oil-cooled transformer, but not as low as with the straight self-cooled transformer. The capital investment required is reduced from $275 000 to $201 000, which means an additional reduction in capital outlay of 27 percent. A comparison of triple-rated transformers with others is given in Fig. 5.

*Load Tap Changers*—Considerable savings in capital investment can be made in step-down transformers if load tap changers are built into them to obtain bus regulation rather than installing separate voltage regulators on the individual sub-transmission lines running out from such stations. The combination of the step-down transformer and the load tap changer (photo *J*) built into an integral unit usually saves



*K*—A 115/105-kv, three-phase autotransformer of 62 500-kva installed on the lines of a Southern system.

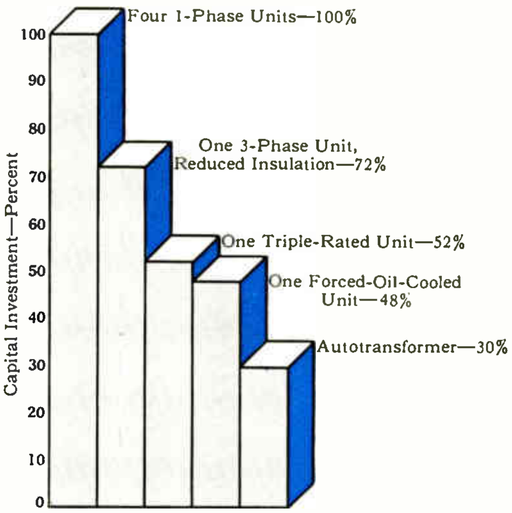


**Fig. 6—Summation of possible transformer-investment economies at step-down stations.**

about ten percent in capital investment over that of a separate step-down transformer and a separate voltage regulator. Many of the large high-voltage step-down transformers now produced are equipped with load tap changers.

*Autotransformers*—When stepping down to the sub-transmission voltage, if both the transmission system and the sub-transmission system are effectively grounded, substantial additional saving is effected by use of autotransformers instead of two-winding transformers, as was done in photo *K*. If the transformer is used, say, to step down the transmission potential from 138 kv to 69 kv, the cost of the forced-oil-cooled, two-winding transformer (wye-wye connected with a tertiary for suppression of third-harmonic voltages) to perform this transformation is $183 000. The cost of an autotransformer to perform this same function is $116 000 or $67 000 (37 percent) less. In addition, both the losses and the impedances are materially reduced.

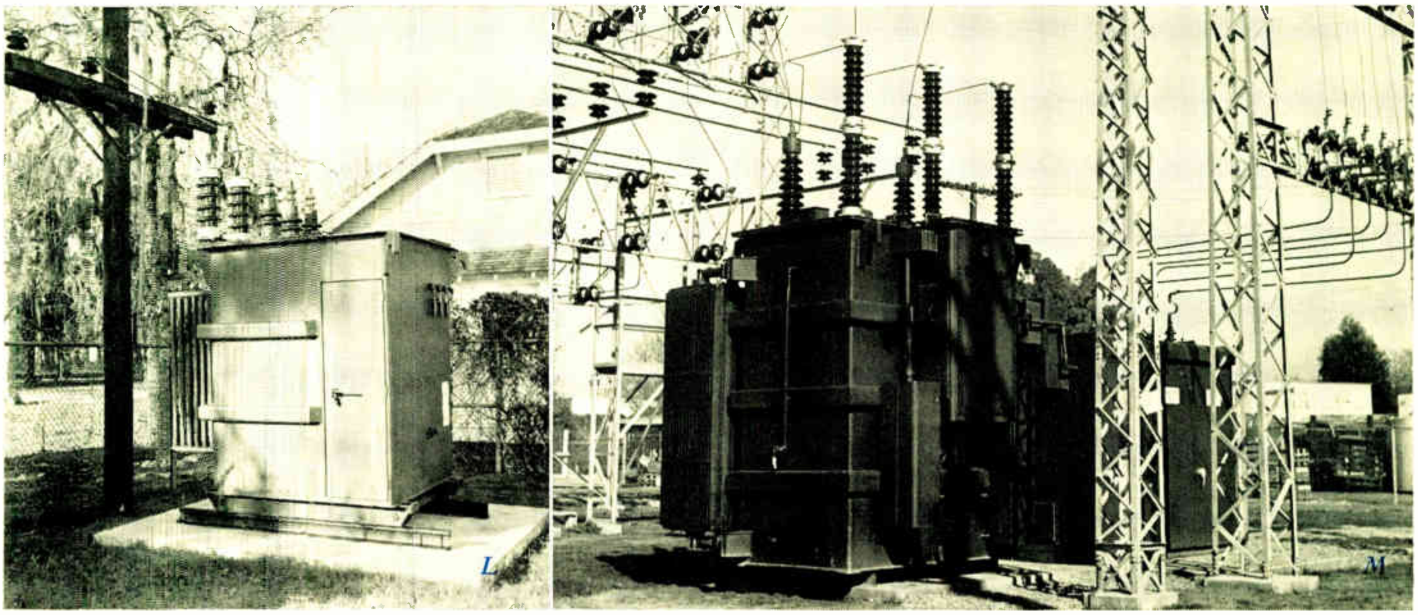
Certain precautions, however, must be observed in making such use of autotransformers. For one thing both system neutrals should be effectively grounded. Secondly, a phase rotation cannot be obtained through the transformer. And, third, if the ratio of transformation is relatively high, for example, 138 to 115 kv, the transformer is not self-protecting under short-circuit conditions. External impedances may have to be introduced in order to protect the transformer against a system short circuit.

In summation, again, Fig. 6, when it is possible to utilize all the possibilities mentioned, the economies become outstanding. The $381 000 cost for the step-down station of four three-phase units is $106 000, or only about 30 percent as much. Again, in addition to the savings in capital investment, there will be appreciable savings in installation costs.

### Sub-Transmission Step-Down Transformers

Significant economies can also be effected at the step-down points from sub-transmission to distribution lines by taking advantage of modern transformer engineering. Ten years ago such transformer banks would also probably have been made

**L (left)—A 1000-kva CSP power transformer for single feeders on a Texas utility company system. M (right)—A 4000-kva unit substation on a Pacific Coast utility system. High voltage: 69 kv. Low voltage: 12 kv.**



up of single-phase transformers with a separate voltage regulator, high- and low-voltage circuit breakers, high- and low-voltage lightning arresters, suitable metering and relaying equipment, all tied together and supported by an elaborate steel framework. Today many such substations consist of a CSP power transformer (photo *L*) or they might consist of a unit substation transformer as shown in photo *M*.

The advantages of this newer equipment are legion. Briefly they are: lower overall cost, less space, much improved appearance, better coordination, and greater mobility. The total savings in capital investment resulting from the use of unit substations over the use of conventional substations depends upon the type of unit substation used, as well as upon the system of accounting used.

It is obviously not practical to take advantage of all of the principles discussed on any one power installation, but it should be possible to take advantage of one or more of them in most applications of large power transformers.

• • •

# What's NEW!

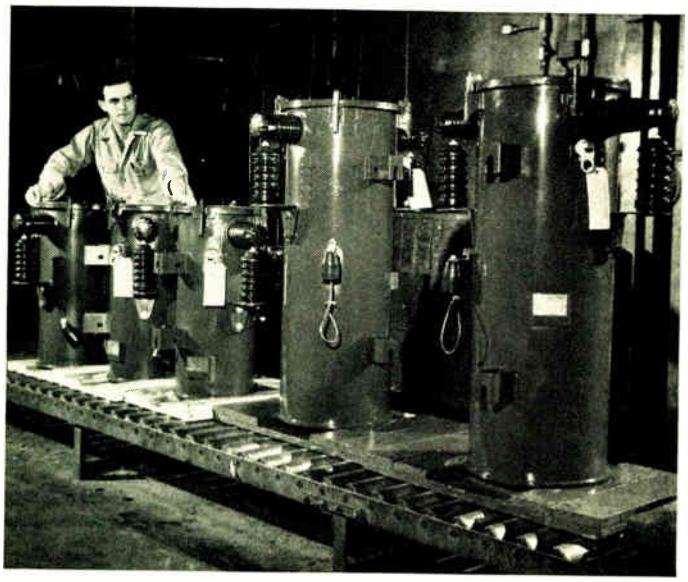
## Making the Good Better—A New CSP Distribution Transformer

An improvement in De-ion arresters for distribution transformers has led to a major improvement in the physical form of the transformer itself. Until recently CSP distribution transformers for 5000-volt service and less were made in two forms. One (for 37½ to 100 kva) was the cylindrical tank with circular cover, and bushings entering the tank through welded-on pockets near the top. The other (for 25 kva and less) was the cylindrical tank capped with a large rectangular upper section and with leads entering from beneath the overhang. In both, the arresters were mounted inside the tank.

The development of an external arrester, which would eliminate the need for a series resistor, has proved successful and the first application is shown in cover-mounted bushing transformers employing a series gap at the line electrode. A further development of this external arrester has made possible the new CSP distribution transformer (type RW) with high-voltage bushings mounted on the side wall of the transformer tank.

This transformer has several important service features. It employs the so-called disconnect construction, by which connection to the high-voltage line is made simply by inserting the primary conductor from either side of the bushing and turning an insulated knob. No tools are required. The gripping strength of this connection far exceeds previous ones. In plan view the transformer is smaller in the area adjacent to the crossarm than either of the types it replaces, giving better crossarm clearance and more working space for the lineman. The high-voltage bushing has been located a sufficient distance from the hanger lugs to allow the breaker handle to be placed between the lug and the bushing. This makes the breaker handle easily accessible to the lineman, and eliminates the need for reaching around the bushing to operate the handle.

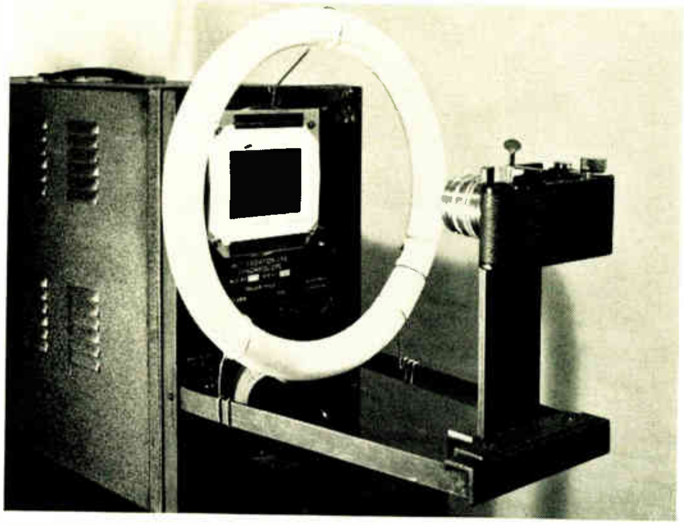
**The new CSP distribution transformer with external arrester.**



The completely round tank with round cover provides more effective gasketing and sealing of the transformer and simplifies removal and installation of covers on transformers. A series gap isolates the arrester from the line both electrically and mechanically. Protective porcelain parts cover all live high-voltage terminals, which is particularly important where birds and squirrels are a problem. All porcelains are made larger where they pass through the tank and hence are stronger mechanically than those employed on previous pocket-mounted units.

## Tracing a Trace

A photographer using a camera with a ground-glass viewing screen customarily uses a hood, or cloth, to block incidental light, so that the picture he sees is formed only by light passing through the lens. In making photographic reproductions of traces on cathode-ray oscilloscopes, the same procedure is used—except on the other end of the camera. Here a hood is used to block from the camera lens all but the light from the trace. The resulting print shows only a white trace on a black background; all information as to scales, test conditions, and calibration must be kept



**Camera and lamp in place for reproducing oscillograph traces.**

---

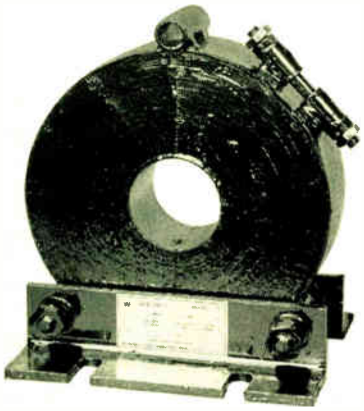
Any inquiries relating to specific products mentioned in this section should be addressed to the *Westinghouse* Engineer, 306 Fourth Avenue, P. O. Box 1017, Pittsburgh 30, Pa.

separately and later noted on the photograph for reference.

A novel new method of recording oscilloscope traces, plus all necessary information—on one photograph—is now being used by research engineers at the Westinghouse Lamp Division. The question is, essentially, how to illuminate the area surrounding the face of the cathode-ray tube without "washing out" the relatively faint trace in a photograph. This is done by using a 32-watt, circular fluorescent lamp, placed about four inches from the oscilloscope and surrounding the face of the tube. Because it is difficult to balance three different shades of gray (to the camera)—those of the trace, the calibration lines on the oscilloscope screen, and the background of the screen—a calibration screen made of fine silvery wire is placed in front of the tube. This is fastened lightly to a rectangular mask, on which scales, test conditions, and other pertinent information is recorded. Then with the lamp output lowered slightly (by lowering the electrical input or by covering the fluorescent tube with some translucent material such as nail polish or colored cellophane) the trace, calibration screen, and mask can be recorded on one photograph. If extreme detail is required, a single film may be exposed twice—once for the trace with the illumination off, and once for the scale with the illumination on.

## Impedance-Matching Reactors

Transformers to be operated satisfactorily in parallel must have identical impedances. The same is true for parallel secondary networks. To match impedances a paralleling reactor can be added in series with the apparatus of lower impedance.



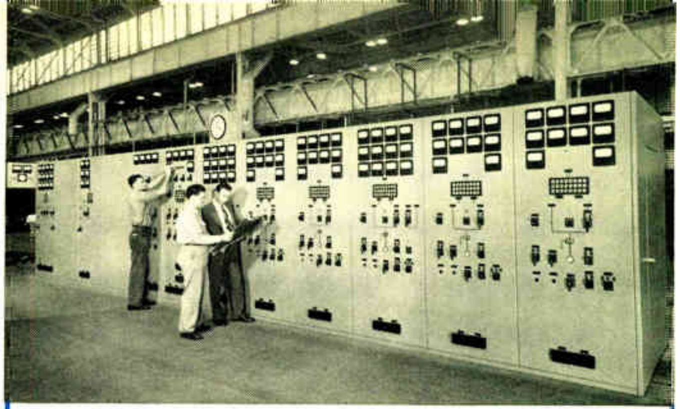
**Reactors, such as this, are used to permit paralleling of transformers or secondary networks of unmatched impedances.**

A new type of paralleling reactor—small, light in weight, easy to apply, and of definitely improved appearance—has been developed. It resembles a doughnut. The core is wound spirally, like a roll of adding-machine tape, is split into two halves to obtain the required air gap and for application around the conductor, where necessary. The two halves are then closed and held tight by a steel band. Gap spacing can be varied slightly to obtain precisely the desired characteristics. A ring introduces about one-percent reactance or 1.2 volts drop at 60 cycles. Two or more reactors can be stacked side by side, using tie bolts through sleeves welded to the clamping band for rigid attachment, when necessary to obtain greater reactance than a single ring provides.

The standard reactors (type WR) are designed for a wide range of currents. Each application must be specific in requirements, since a definite and fixed relation exists between the frequency, current, and voltage drop. Any one design and air-gap adjustment gives only one set of characteristics; however, the design is such that with an increase in current due to overload, the voltage drop increases in the same ratio as the current increase, up to approximately 150-percent current. Currents above 150 percent of rating cause the magnetic flux in the core to saturate and the voltage drop does not increase as rapidly as the current.

Reactors are available for any specified current from 450 to 2000 amperes to give 1.2 ± 10 percent volts drop at 60 cycles. For currents below 450 amperes, the proper characteristics can be obtained by using two or more turns of the conductor through the reactor. For higher voltage drops, two or more of these reactors can be employed.

These rings weigh from 40 to 43½ pounds each, depending on current ratings.



## Grand Coulee Switchboard

**This switchboard, shown above getting finishing touches and a final once-over in the shop, is now installed at Grand Coulee Dam. There it controls six 108 000-kva generators in the right Power House.**

## DeLuxe Colors for Fluorescent Lamps

Color wields a strong influence in the selection of any item of merchandise. To provide the best color rendition of such merchandise and food—as well as the human complexion—two new colors of fluorescent lamp have been developed. These are called the deluxe cool white and the deluxe warm white.

Both lamps are made possible by a new phosphor, which yields a balanced color output all the way out to the deep red end of the spectrum. The improvement in color is accomplished at some expense in luminous efficiency (initial lumen output is about 40 percent less than standard lamps), so the highly efficient standard-color lamp will still be needed for ordinary applications.

These deluxe lamps are the same in physical appearance as the standard lamps, and are now available in limited quantities in 20 and 40-watt sizes (T-12). Other sizes will be made soon.

To simplify identification of these new deluxe-type lamps, the high-efficiency-type lamps will henceforth be called the standard cool white (instead of the "4500 white") and the standard warm white (instead of "warm white").

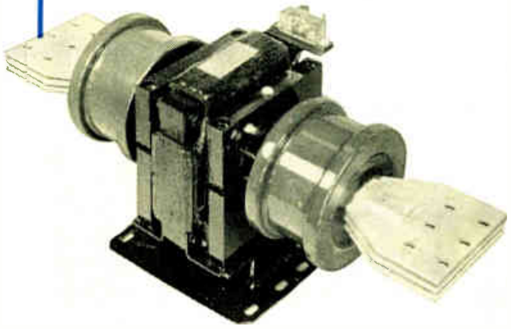
## New Slimline Lamp

Recently added to the Slimline series of fluorescent lamps was a 48-inch length, which lends more flexibility in the application of these lamps. The complete series of T-12 Slimlines now includes a 48-, a 72-, and a 96-inch size, all of which are available for a loading of either 425 or 600 milliamperes.

Like its longer counterparts, the 48-inch Slimline is of the starterless, instant-start variety. It has the usual single pin base, and is available in three colors—designated white, standard cool white, and daylight.

## Instrument Transformer

**In only about ten months a new type of indoor, high-current instrument transformer with all-porcelain insulation has achieved popularity. It is a through-type unit, with the heavy-current conductor passing through a sturdy porcelain sleeve bushing, which forms the major insulation of the transformer. Over the full line of ratings the accuracy is as good, and in many cases better, than other types of transformers used for this service. This transformer (type UP) is built for currents from 1000 to 5000 amperes at 5, 8.7, and 15 kilovolts.**



## CSP Power Transformers, Junior Editions

The completely self-protecting substation, known as the CSP power transformer, has been an extremely popular packaged unit for single-feeder service since 1937. But the smallest CSP power transformer is 1000 kva. On the other hand, the CSP distribution transformer, now beginning the second million in production, is four years older, but the upper limit of ratings for the three-phase variety is 150 kva. Between these two values is a wide gap in ratings. Herein, as it happens, lie the sizes needed by small rural communities or small factories. A single-feeder substation with CSP features and in intermediate ratings in a packaged unit has not been available for such application. That gap has now been closed by the development of CSP power transformers in three ratings, 300, 500, and 750 kva and with primary voltages of 34.5, 46, and 69 kv (with secondary limited to 100 amperes).

The problem has been to obtain smaller versions of the CSP power transformer, with no sacrifice of the protective and operating features, at reasonable cost. So the transformer designers went bargain hunting, so to speak. To replace the high-capacity and expensive circuit breaker they picked up from their associates in the Switchgear Division a three-phase recloser (GR) developed for rural pole lines. The same tap changer as used on pole-top regulators, but modified for three-phase service, gives the high-quality but lighter duty service required of the smaller units—at a significant cost saving. Lightning protection for both windings, high-voltage protective links, overload relays, metering and auxiliary power supply are included.

**Two models, one being of the junior CSP power transformer.**

## Sunnyvale Impulse Generator

**Exploding with the sound of a high-powered rifle, man-made lightning strikes from source to ground. In the background is the 2 400 000-volt impulse generator recently installed at the Sunnyvale, California plant of Westinghouse. Alternating current (440 volts) is stepped up by a special transformer to supply two 50 000-volt vacuum-tube rectifiers, which convert it to direct current for the capacitors. The 24 banks of capacitors are charged in parallel and then discharged in series. The process of fully charging the surge generator takes from 20 to 30 seconds; it can then be discharged at will by an operator in the control room. This surge generator will be used to test large power transformers.**

## Continuous Viscosity Controller

A chain is no better than its weakest link; likewise, a process is no better than the least exact of its variables. Viscosity control—amidst precise control of temperature, pressure, flow, density, and so forth—has been a weak link in control of production flow processes, such as the preparation of varnish, dope, and resin. Manual checks of viscosity consist of extracting a portion of the substance, running it through a viscosimeter in a laboratory, and then making the necessary correcting adjustments. This requires both time and skilled personnel. Also, it cannot detect and compensate for rapid viscosity changes that can occur in a continuous-flow process.

None of the many devices developed to check viscosity have provided continuous measurement that allows the incorporation of automatic recording and control to maintain desired viscosity. Now, the Materials Engineering Department of Westinghouse has developed an automatic viscosity controller and recorder to accomplish these objectives. Viscosity is measured continuously by passing a small portion of the fluid through a measuring tube at constant temperature and at a constant velocity; from this tube it returns to the main mass of fluid. Thus, in accordance with Poiseulle's equation, the pressure drop across the measuring tube is proportional to change in viscosity. The pressure differential is converted to an air pressure in a differential pressure transmitter and amplified. Thus a Bourdon pressure gauge calibrated in viscosity units and placed in the line indicates viscosity continuously.

The pressure can be impressed across a standard controller for actuation of valves, pumps, solenoids, etc., to correct the viscosity to the desired value. Also by simple additions to the basic equipment, the apparatus can be made to perform many other operations, such as automatically turning heat on or off, and emptying or filling reactor vats at the proper time. By the use of two of these measuring tubes operating at different temperatures, the viscosity index (rate of change of viscosity with change of temperature) of a liquid can likewise be measured, recorded, and controlled in a continuous process.

The use of a continuous viscosity controller not only improves the product by continually testing and controlling viscosity without human error, it releases trained personnel for more important work. Six units have been operating for several years, controlling the viscosity of wire-enamel solutions.

# News in Engineering

### Better Gases for Lamps

Gases once considered rare, but now available in sizable quantities, are proving valuable as a fill for fluorescent lamps. Two years ago krypton was first used and was responsible for a significant increase in efficiency. Now, even better gases have been found in two different mixtures of krypton and other inert gases.

One such mixture, half krypton and half argon, is now being used in a new 90-watt fluorescent lamp (60-inch, T-17) with resultant advantages. Krypton's contribution is high efficiency, whereas the argon leads to easier starting and better operation in a cool room. This lamp supersedes the 85-watt all-krypton lamp introduced two years ago. Despite the 5-watt increase in lamp rating, the net increase in wattage consumed by ballast and lamp is only 3 watts, because of reduced ballast loss due to a lower operating amperage. Thus the new 90-watt lamp, whose output is 4860 lumens, actually produces 5 percent more lumens for 3 percent more total wattage. Research has shown that the 50-50 mixture is optimum for a high-power lamp.

For lower power lamps, however, a gas mixture of ¾ krypton and ¼ neon gives best results. Such is the combination in a new 25-watt fluorescent lamp. This lamp has an initial output of 1430 lumens.

### Photoflash Calculator

In one simple setting of a new photoflash calculator, flash photography enthusiasts can determine the proper exposure for all types of black and white or color film. These tables recommend professionally accepted lens apertures for various shutter speeds and flashbulbs, without mathematics or guide numbers. This calculator is now available at photolamp dealers.

### Air-Insulated Transformer for Resistance Furnaces

Electric resistance furnaces that use Globar elements require a power supply susceptible of providing various voltages. A new family of tap-changing transformers has been created for this purpose. They are built in six sizes between 15 and 75 kva. Two no-load tap controls—a coarse and a fine adjustment—provide output voltages from 270 down to 70. Use of Hipersil cores makes for compactness and light weight.

### New Insulation Gives Lower Loss Current Transformers

Users of air-insulated current transformers are the recipients of some improvements developed by paper manufacturers. A new variety of crepe paper has been made available that lends itself better to taping of coils of the irregular shapes found in these transformers. This insulation, impregnated with a special, high-grade asphalt compound, has a power-factor of less than five percent, much lower than previous paper insulations. Then, with a covering of varnished cambric tape and a final dip in Thermoset baking varnish, a final product is achieved that has good appearance and extra-ordinary moisture resistance. This type of insulation is applied to all Westinghouse (type C-T) air-insulated instrument transformers (up to 800 amperes).

### To Cope with Rising Rural Loads

Some systems faced with overloaded rural lines or the necessity of making lengthy extensions to rural lines are adopting the comparatively simple solution of raising the voltage—in fact about doubling it. Rural service has seldom exceeded 12 470 volts or 13 200 volts grounded wye. Some rural lines are being changed for 24 900 volts grounded-wye service. To do this requires only a change in insulation and transformers.

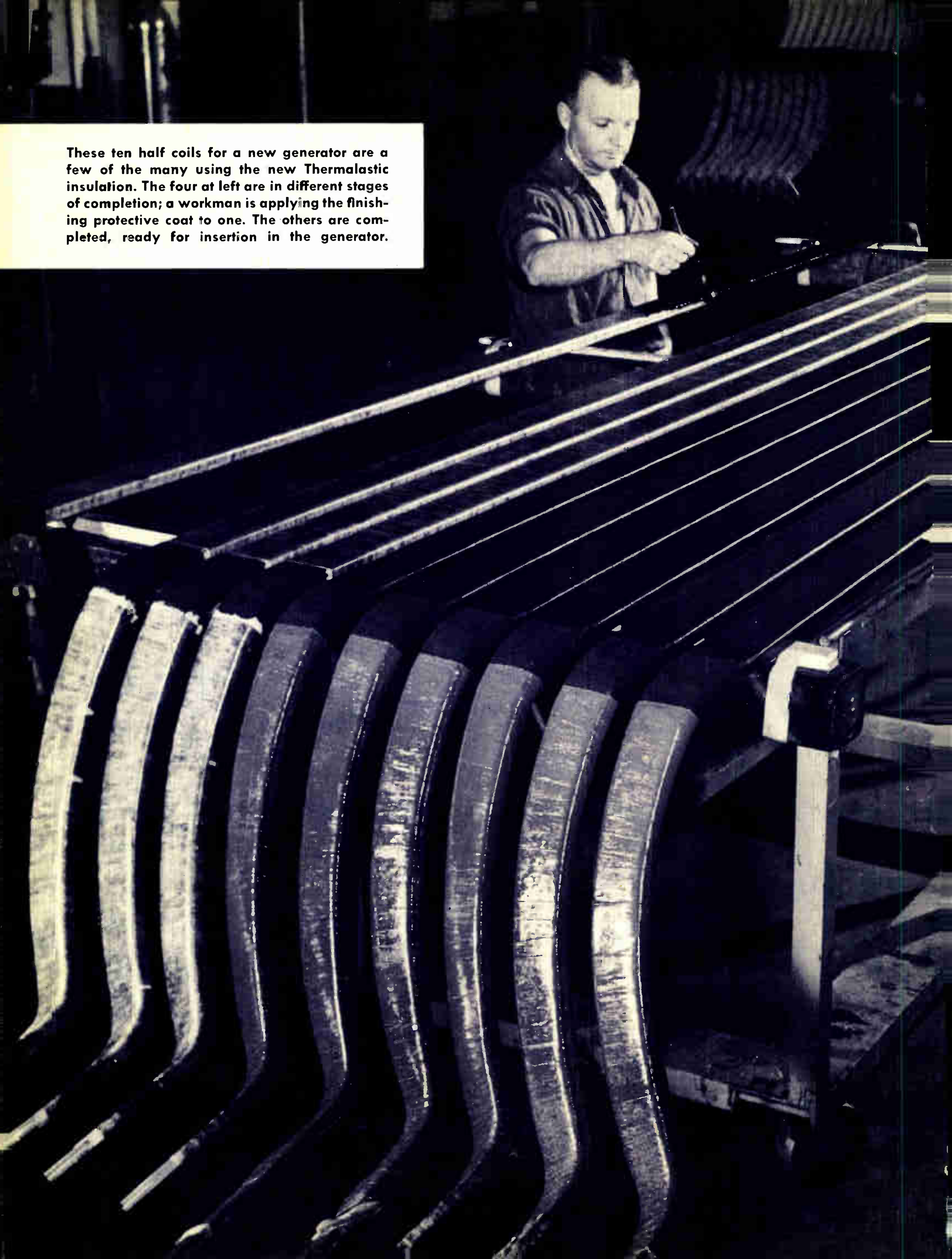
A new CSP distribution transformer has been created especially for this service with built-in protective devices and operating features characteristic of it, but with a high-voltage insulator, stronger both electrically and mechanically. Physical dimensions of the new transformer exceed only slightly those for existing transformers for 12 470-volt wye service. These 24 900-volt grounded-wye transformers are built in the full range of distribution transformer sizes from 3 to 25 kva.

# Personality Profiles

Our readers will find several familiar names in this issue. All except one of our authors have previously written at least one story for us. These include: *Frank L. Snyder*, manager of the Westinghouse Transformer Division; *J. D. Miner*, manager of the Aviation Engineering Department at the Lima works; *F. N. McClure*, an industry engineer in the Central Station Section; and *R. P. Kroon* (whose personality profile appears on page 200).

The one exception is *B. O. Austin*, who teamed up with Miner in authoring the story on aircraft electrical systems. Perhaps one factor tells more about Austin than a multitude of words. He has to his credit well over 50 patents, more than two thirds of which are now in use or have been at some time since their issue. This points to the fact that Austin is both an original and a practical engineer.

His work has been largely in the field of transportation control, ranging from electric railway equipment to aircraft control. Austin came to Westinghouse in 1914, straight from North Carolina State College, from which he had just obtained a B.S. degree. In 1915 he left the company to operate a consulting engineering business in North Carolina, but returned to Westinghouse in 1918. For over 20 years thereafter he was concerned with design engineering on transportation control apparatus. Then in 1942 he was moved to the Lima, Ohio, plant, where he became section manager in charge of the engineering of aircraft control apparatus, the position he now holds.



These ten half coils for a new generator are a few of the many using the new Thermalastic insulation. The four at left are in different stages of completion; a workman is applying the finishing protective coat to one. The others are completed, ready for insertion in the generator.