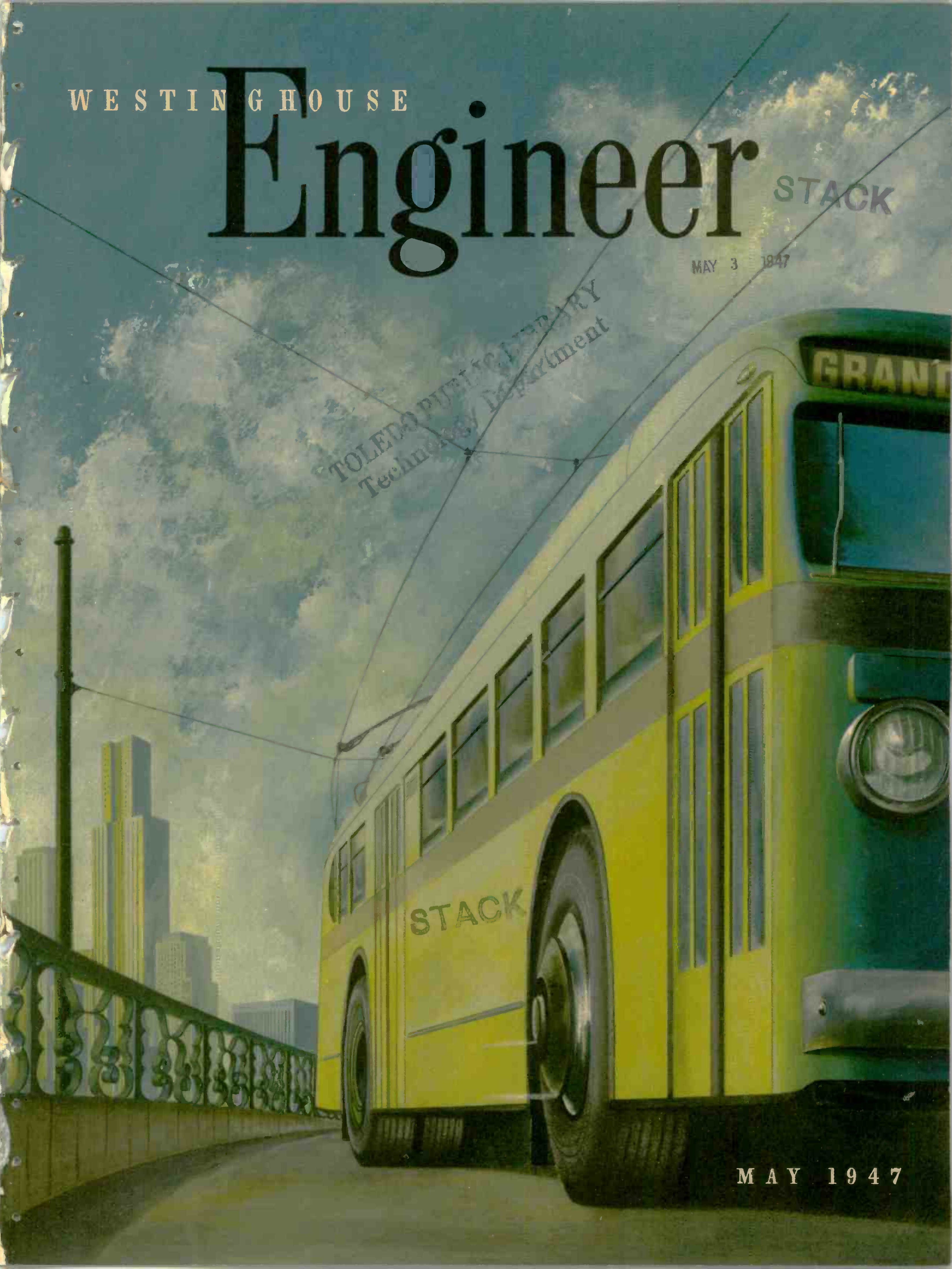
WESTINGHOUSE

Engineer



MAY 1947

When Metal Is Strained

A metal bar or shaft is an inscrutable object. Short of the yield point, it gives no visible indication of the pressure, or strain, or torque within. But just as human detectives can always find some trace of evidence of every act, so devices using the principle of the magnetic strain gauge can detect infinitesimal change in the metal itself caused by the load it carries. And they do this without any physical contact with the loaded piece.

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A magnetic strain gauge is a frugal instrument. It has to make the most of very little. It can detect a change in the length of a rod a few inches long under compression or tension of as little as a millionth of an inch. Or, as Mr. Wommack describes (p. 76), it can observe a twist in a torque-carrying shaft of but a few thousandths of a degree. A strain-gauge device delivering its findings to an oscillograph requires a motion of only three ten thousandths of an inch for full-scale deflection. Or used with a graphic meter, a full-scale reading results from a movement of but one thousandth of an inch.

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In the reception room of the Westinghouse Research Laboratories is a weighing scale that at first glance appears to be similar to the usual penny-in-the-slot platform scale. A person steps on the platform and his weight is indicated by a pointer moving past a scale. But this is not the usual spring-balance weighing machine. The weight on the platform simply stretches a round polished bar and that imperceptible bit of stretch is sensed by a magnetic strain gauge which moves the registering pointer to the correct weight within a pound.

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The magnetic strain gauge detects small changes in dimensions by the large effect they cause on the impedance of a magnetic circuit containing an airgap. Application of this principle to practical measuring devices is by no means new. They have been used in many forms for many years. Whoever used it first is probably lost to history.

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One of the early and most spectacular uses was the measurement of stresses in drive rods of electric and steam locomotives. Chatter caused by wheel slippage had caused breakage of side rods on some of the earlier electric locomotives. Tests were made on Norfolk and Western and on Virginian locomotives in 1923, 1924, and 1925, in which gauges clamped to the rods gave the necessary data on the dynamic stresses and vibration as the locomotives sped along with their trains. Similar tests were subsequently made to determine the effect of pulsating loads on the drawbar pull of both electric and steam locomotives.

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When main-line electrification was still young certain track failures were charged to the new, heavy electric locomotives. To clear up this point Westinghouse research men in 1929 went to the line of the Great Northern in the Pacific Northwest and mounted magnetic strain gauges on the rails on sharp curves. They were arranged to measure both vertical and lateral loadings caused by wheels and flanges of locomotives and their cars as they thundered by. These tests helped explain troublesome flange wear.

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Oil fields posed a chore for the sensitive gauges. The pump on the end of a string of rods a few thousand feet long imposes great stresses in the rod—enough sometimes to cause breakage. Also the stretch in such a long line of rods as it was raised and lowered by the pumping machine was known to be serious. On a well 3500 feet deep in Oklahoma strain gauges were applied in the rod string near the pump, about half way down, and at the surface. That a sensitive instrument could be made to ride on the rods as the pump operated two thirds of a mile below the surface and send back accurate indications is a tribute to the versatility and ruggedness of the strain gauge.

As the long line of pump rods is successively raised and lowered it stretches so that the vertical motions of the pump plunger and the walking-beam are neither equal nor in time phase. Because of this rubber-band effect the plunger sometimes actually moves more than the rods at the surface. For a constant 52-inch stroke at the surface the plunger 3500 feet below was found to move as little as 49 inches and as much as 65 inches, depending on the rapidity of strokes.

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The magnetic strain gauge is also being used extensively to measure "squeeze" in steel mills. A gauge is mounted in the mill housing so that as metal is forced between the work rolls the pressure is indicated. It serves thereby to warn against overloads as well as a means of both quality and quantity control of the rolled steel.

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Rotary cranes, when their booms are carrying an excessive load and are in the extended position, have been known to "fall on their face." Strain gauges built into the cranes have been used to warn against the approach of this condition.

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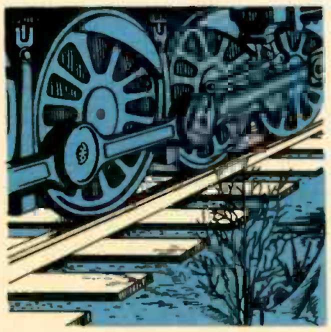
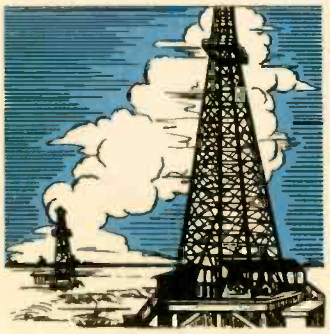
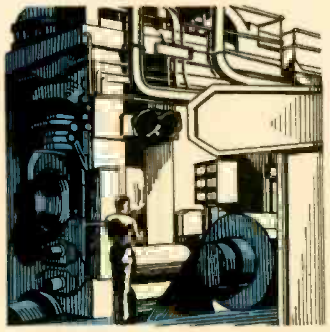
The torque transmitted by long propeller shafts of large ships has been studied with magnetic strain gauges. And now, with the torquemeter version of this same principle applied to aircraft, the strain-gauge principle in its various forms completes the circuit among the major types of public conveyances.







WESTINGHOUSE Engineer

VOLUME SEVEN MAY, 1947 NUMBER THREE

On the Side

The Cover—Possibly the best magazine-cover illustrations are those requiring the least explanation. On this cover artist Dick Marsh makes a point of the trolley coach, discussed in this issue by Mr. Woods. This picture, being highly pictorial—almost photographic—in comparison with the symbolic and impressionistic covers by Marsh in previous issues, indicates his wide technical versatility.

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The research, engineering, and manufacturing activities of the Westinghouse Company relating to various phases of atomic energy will be coordinated by a new committee for that purpose. The group is given general direction by M. W. Smith, Vice President in charge of Engineering, with the special assistance of Dr. J. A. Hutcheson, Associate Director of the Westinghouse Research Laboratory. Serving on the committee are R. C. Bergvall, Assistant to Vice President; J. H. Jewell, Manager, Industry Sales Departments; C. B. Campbell, Manager of Engineering, Steam Division, South Philadelphia; and H. W. Tenney, Assistant to Vice President, East Pittsburgh.

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One would expect the logging industry to be one of the last strongholds of the steam locomotive. Feeling the aggressive competition of the Diesel-electric, Potlatch Forest, Inc., operating in Idaho near Lewiston is replacing its steam motive power by three 70-ton Diesel electrics.

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Another Navy all-jet plane has been announced. It is the "Pirate", powered by a new-type Westinghouse jet engine. All the Navy cares to say about its speed is that "it is in excess of 500 mph."

In This Issue

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), Pennsylvania.

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The astronomical rise in transit industry passengers in the United States and Canada has city planners and traffic engineers groggy. Vehicles, suffering from a war-induced scarcity of parts and personnel, literally are bursting at the seams. Noiseless, clean and remunerative trolley coaches show much promise in breaking urban traffic bottlenecks.

The Trolley Coach—Its Place in Public Transportation

A trolley coach neatly sweeps around traffic blocks. Seattle trolley coach (top) loops back at the end of its run.

G. M. Woods
Transportation Engineer,
Westinghouse Electric Corporation

City planners and urban transportation officials in coping with the rapidly increasing passenger traffic have three types of surface vehicles at their command to use singly or in combination: streetcar, bus, and trolley coach. Of these three the trolley coach is the relative newcomer, but it is rising spectacularly in popularity. Passengers carried by trolley coaches increased from 68 million in 1934 to 1281 million in 1946, an increase of nearly nineteen times—and yet during the same period total passengers carried by all forms of urban transit increased only twice, from 12 billion to 23.5 billion.

Each type of transit machine has its advantages, its limitations. In some cases the zones of usefulness for each are clear cut, more often they overlap. This calls for a careful analysis to establish the relative grades of service rendered, and to ascertain which provides the greatest net revenue after paying all operating expenses and fixed charges. The economic elements that demand consideration are numerous. Hard and fast answers to each are impossible, even for a specific community. However, some general comparisons can be set forth.

Economic Considerations

The trolley coach lies between the streetcar and motor bus, both with respect to fixed charges and operating expenses. The average vehicle investment per passenger differs little for the three types. A 44-passenger trolley coach costs $16 000 and the 58-passenger streetcar costs $21 500. The motor bus, 44-passenger type and of comparable construction to a trolley coach, costs $15 000. While the cost of the motor bus is slightly lower per passenger than that of the trolley coach or streetcar, more spare buses are required, because their availability for service is much less. Service records from different areas show that the trolley coach availability is 97 percent compared to 84 percent for motor buses under similar conditions. Generally, five percent spare trolley coaches or streetcars and 15 percent spare motor buses are provided.

Trolley coaches and streetcars have greater capacity than motor buses in proportion to the number of seats because they generally have broader bodies, longer platforms, and wider doors. As a result, rush-hour loads are accommodated by fewer trolley coaches. The wider doors and aisles of the trolley coach facilitate passenger interchange, and increase schedule speeds; thus fewer coaches are required for a given frequency of service. The net effect is that the investment for trolley coaches may be 10 to 20 percent less than for motor buses or streetcars of equal service capacity.

The investment along the route varies with the type of vehicle. Double streetcar tracks and overhead structure cost from $100 000 to $130 000 per route mile. Trolley-coach overhead structure for two-way operation costs from $9000 per route mile, where existing streetcar overhead can be used, to $20 000 for all new construction of good quality. The motor bus requires practically no investment along the route.

The expenditure required for shops, car houses, garages and storage yards depends on the character of existing facilities, climatic conditions and the practices of the operating companies. Streetcars require tracks and overhead lines in car houses and yards while trolley coaches require overhead lines only; however, both streetcars and trolley coaches can be stored out-of-doors, even in the most severe climates. The prevailing practice for motor buses is to provide buildings wherever freezing temperatures are met. Therefore the cost of shop and garage facilities may be two to three times that of similar facilities for trolley coaches.

In many cities, substations already are available for trolley-coach service. In some cases power for trolley-coach operation is purchased from the local power utility at the d-c side of their substations. In either case, the cost of power for trolley coaches includes fixed charges of substations and their cost of operation.

Trolley Coach Earning Ability

The gross revenue earned by any transit vehicle is a measure of its service value to the public. If the transportation provided does not fill a real community need, it cannot endure. In Youngstown, Ohio, use of trolley coaches on lines serving one section of the city increased the gross revenue per vehicle mile 20 percent in three months. In Seattle, Washington, the transit system was completely modernized in 1940, with new trolley coaches and motor buses. The trolley coaches are used on the lines having the heaviest traffic and the most severe grades (for which Seattle is noted). Preceding modernization, operation showed a deficit each year, but after, the net revenue climbed steadily until when depreciation, taxes and interest had been met, it exceeded $2.5 million in 1944. Obviously gross receipts had been increased by war activity, but despite this, trolley-coach revenue exceeded trolley-coach expenses by $3 million.

In Providence, Rhode Island, in 1935 two streetcar lines using trolley coaches showed an increase in revenue of 33 percent on one line and 14 percent on the other. In 1936 a third line was converted to trolley-coach service with a 33-percent increase in revenue compared to an increase of 10 percent on similar car lines. Trolley coaches have an equally satisfactory earning ability on the Providence-Pawtucket system, showing an increase in revenue of 25.6 percent.

Operating Expenses

Operating expenses of trolley coach, streetcar, and motor bus vary widely, depending on climatic and road conditions, wage rates, and power costs. In the tabulation of operating costs trolley-coach expenses are based on information from 27 properties as compiled by the American Transit Association. Similar data on modern streetcars and motor buses are not available from this source because of the wide variety of sizes and types of vehicles used. Therefore, it has been necessary to base streetcar and motor-bus expenses on data collected from only those properties operating modern streetcars and motor buses of a comparable passenger capacity.

The life of the trolley coach is assumed to be 12 to 15 years (550 000 miles) but coaches 17 and 18 years old are still running. The life of the streetcar is ordinarily taken as 20 years (800 000 miles) although it is well known that they can be operated 30 years or more if physical condition alone is considered. Motor buses are normally retired after eight or ten years of service (300 000 miles) because, after that time, their maintenance expenses become prohibitive. In all types of vehicles, obsolescence is an important factor. Obviously, the charge against depreciation is at a rate inversely proportional to the expected life of the vehicle.

Trolley-Coach Electrical Equipment

The first "modern" trolley coaches using two 50-hp series motors were placed in service in Salt Lake City in 1928. Two

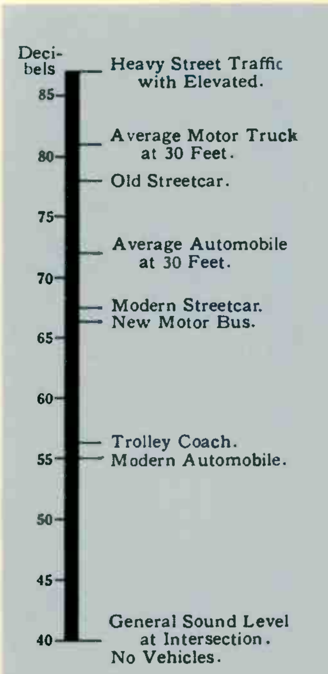
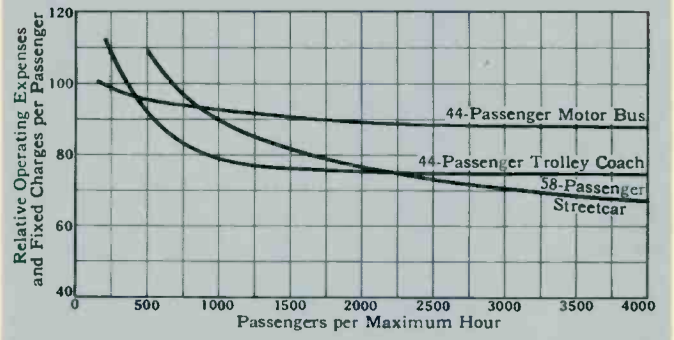
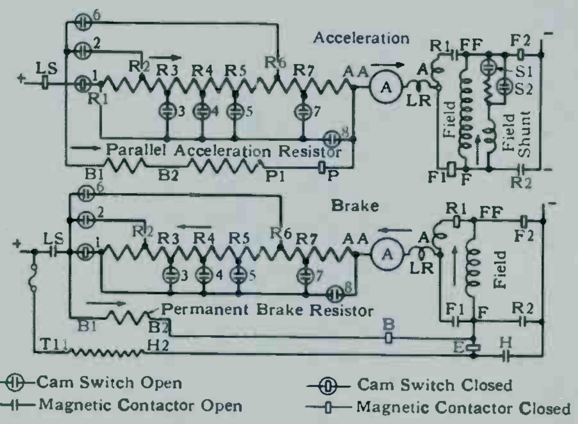


Fig. 1—Decibel ratings of street noises recorded in Cleveland and New York.

Fig. 2—In this family of comparative curves, the ordinates to the left are purely hypothetical figures. They do not represent dollar cost or percentages of any known values.

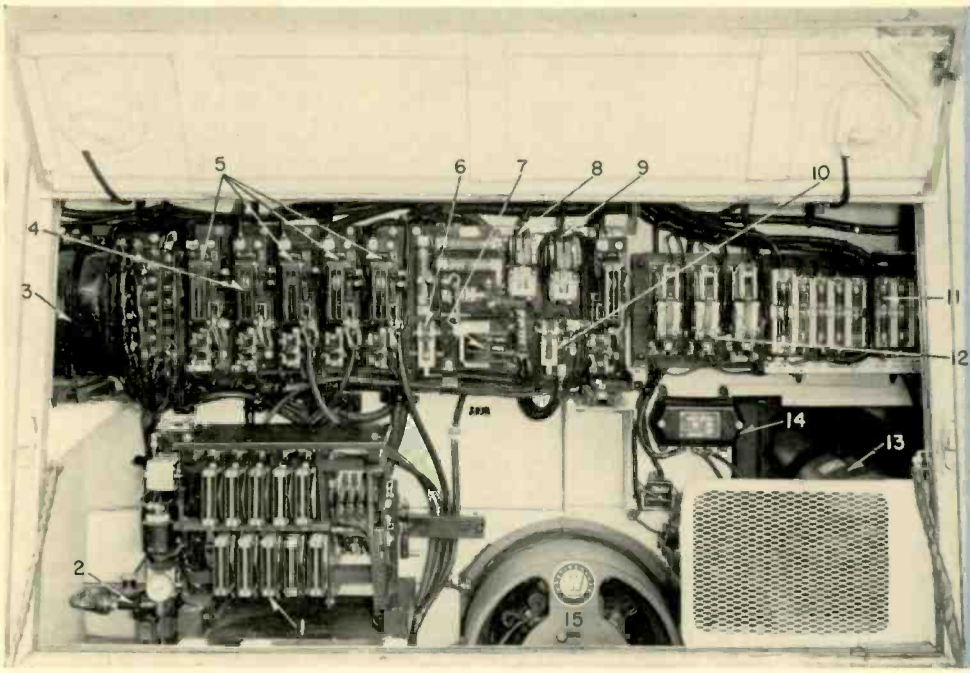




Sequence Chart

Notch		LS	P	B	E	F1	F2	R1	R2	1	2	3	4	5	6	7	8	S1	S2	MC	BC
Coast (Off)				O			O	O		O										Off	
Acceleration	1	O	O			O	O			O										1	Off
	2	C	O			O	O			O	O									2	
	3	C	O			O	O			O	O	O									
	4	C	O			O	O			O		O	O								
	5	C	O			O	O			O			O	O						3-4	
	6	C	O			O	O			O				O	O						
	7	C	O			O	O								O		O				
	8	C	O			O	O					O			O		O				
	9	C	O			O	O					O	O		O		O				
	10	C	O			O	O						O	O	O		O				
	11	C	O			O	O				O		O	O	O		O				
	12	C	O			O	O				O		O	O	O	O	O				
	13	C	O			O	O			O	O			O	O	O	O				
	14	O	O			O	O			O	O				O	O	O	O		5	
	15	O	O			O	O			O	O				O		O	O	O		
Shut Off	15	O	O			O	O			O	O				O		O	O	O	4-3	
	4	O	O			O	O			O		O								2	
	1	O	O			O	O			O										1	
Coast				O			O	O		O										Off	
Brake	4			O	O		O	O		O		O	O							Off	1
	13			O			O	O		O	O			O	O	O	O				2-3

Fig. 3—Main Electrocam circuit, acceleration and braking.



Electrocam trolley-coach control showing equipment mounted at the rear. (1) Electrocam controller (air-operated); (2) air-pressure regulator; (3) inductive shunt field; (4) brake contactor; (5) forward and reverse contactors; (6) rate relay; (7) limit relay; (8) braking field excitation contactor; (9) power resistor paralleling contactor; (10) overload relay; (11) fuse panels; (12) auxiliary relays; (13) blower motor; (14) regulator for 12-volt generator; (15) traction motor.

motors were used because, at that time, a single motor and a rear axle suitable for its use were not available. Also, since all streetcars had been propelled by two or four motors with series-parallel control, the same ideas carried over to the trolley coach. At that time the control was of the magnetic contactor type, non-automatic in acceleration, with automatic dynamic braking. The cutting of resistance from the dynamic-braking circuit was done by the same magnetic contactors used in acceleration; the contactors were controlled directly from a foot-operated master controller. During braking, the contactors were closed and opened by a secondary electro-pneumatically operated controller, known as a "sequence switch," which advanced under the control of a current-limit relay. The rate of braking was selected on a foot-operated brake controller.

The two-motor axle had included a worm gear through which each motor drove one rear wheel. Worm-gear life was short, axle breakage frequent, and brake maintenance excessive. Brake linings lasted 12 000 miles and rarely exceeded 20 000 miles. The new single-motor axle had double reduction hypoid (or bevel) gears and spur gears of conservative design, which promised long life. The axle shafts were more substantial with breakage reduced appreciably. Brake lining life was more than doubled.

The use of 50-hp and later 65-hp motors continued until 1936, when a new 125-hp series motor and a suitable axle for single motor drive were developed. This single 125-hp motor equipment saved 25 percent of the weight or 625 pounds, compared to the two-motor equipment. Maintenance was improved greatly. Since most of the control apparatus in use then was assembled on one panel instead of on several smaller units, installation was simplified, and accessibility and maintenance facilitated. This form of control differed from that of two-motor equipment in the elimination of the sequence switch and the use of two-section magnet coils on main circuit contactors. One section of coil closed the contactor and the other section then held it in the closed position through an *In* interlock on the contactor. The closing circuit was transferred by another *In* interlock to the closing coil of the next contactor in progression, and until all of the series resistance was cut out and the motor fields shunted.

The superior service afforded by single-motor equipment immensely broadened the field of trolley-coach application. In a short time trolley coaches were being used under more severe service conditions and at higher speeds. The service required of the friction brakes was increased and further reduction in brake maintenance became desirable. To meet the situation, the 125-hp motor was modified in 1938 to make its commutating characteristics suitable for the more severe dynamic-braking duty and to reduce its energy consumption; brake-lining life was increased to between 100 000 and 150 000 miles, even with the added braking demand.

Increased weights of coaches and their application to cities having severe grades, notably Seattle and San Francisco, made additional motor capacity necessary and a new 140-hp series motor was brought out in 1939. This motor is now used extensively on 40- and 45-passenger trolley coaches where grade conditions are severe and on one 56-passenger coach in Cleveland, Ohio, where grades are light. Its commutation is excellent, both in acceleration and braking; as a result, commutator and brush maintenance is low with constant braking effort exerted over a wide speed range.

Electrocam Control

In 1944 a radically different form of trolley-coach control, known as Electrocam, was developed. With Electrocam an electro-pneumatically operated cam controller is used for closing and opening the resistor- and also the field-shunting circuits. The cam switches are spring-closed, the closing sequence being fixed mechanically by the camshaft assembly. A material saving in space and weight is thereby effected. The complete Electrocam control equipment weighs 85 pounds less than the equipment it succeeds. It occupies less space, both horizontally and in depth. As a result of the smaller dimensions resulting from care in design of the apparatus, it is completely accessible for inspection and maintenance.

The small master and brake controllers are mounted under the floor of the coach near the front, and connect to the power and brake pedals by short links. These controllers, previously mounted in the side or rear control compartments, were connected to the pedals by means of long pull rods, shafts and levers which introduced friction and misfunctioning.

Driver fatigue is reduced with Electrocam because the elimination of the friction of the long rods greatly reduces the required pedal pressure. The new arrangement saves some 150 pounds in weight of pull rods and their associated parts.

Overhead Lines and Collectors

Improvements in trolley coaches and their propulsion equipment were accompanied by corresponding improvements in current-collection apparatus and in overhead lines. The short trolley pole of the streetcar type gave way to a longer, more substantially based pattern. The increased length is a vital consideration, for a trolley coach can operate at a distance of 12 feet from a mid-point between the two wires. The trolley wheel with its swivel "harp" gave place to a swiveling bronze shoe with a renewable carbon insert. The benefits of shoe and insert are outstanding. They mean freedom from excessive wear of overhead wires and elimination of the expensive and objectionable lubrication previously necessary to offset the damaging friction. The new shoe is self-lubricating, reducing wire wear to a minimum.

Trolley-coach overhead lines differ from streetcar lines in the provision of two overhead wires instead of one wire with a rail return. Because the two wires are of opposite polarity, they must be insulated from each other, which introduces construction problems particularly at crossings and turnouts where positive and negative wires intersect. Another basic difference is found in the performance of the swiveling shoe of the trolley coach in following the trolley wire, compared to the standard trolley wheel of the streetcar. Streetcar trolley wire is accurately located with respect to the track at turnouts and curves. The track fixes the position of the car and the wire must be so located that the wheel follows it without rubbing or cutting. However, the path of the trolley coach varies and only the swivel action of the shoe permits it to adjust itself to the position of the wire. For this reason electrically operated frogs are used at turnouts to insure that the shoe follows the correct path. Grooved trolley wire instead of round, affording a smoother contact surface for the collector shoe, is now the accepted standard for trolley coaches.

An interesting innovation in trolley-coach operation is found in Atlanta, Georgia. On one of the lines serving a suburban section, "passing-sections" of four wires in each direction are provided for the operation of both local and express service. In a defined area, the express coaches pick up passengers only on outbound trips and discharge them only when inbound. The passing-sections, with suitable signals, allow the express coaches to pass the locals without delay.

Conclusions

Many reasons may be advanced for the preference of increasingly large numbers of transit passengers for trolley coaches. The trolley coach is quieter than either the streetcar or the motor bus. Like the motor bus, it loads and unloads at the curb. This practice not only contributes to the safety of passengers but also causes no obstruction to traffic flow in the center of the street.

Like the streetcar, the trolley coach is free from the odor of hot oil and exhaust gases. High accelerating rates are provided because the power supply is from a central station and is not limited by an individual power plant in the vehicle. Acceleration is without the interruption in torque common to motor bus gear shifting. Combined electric and air brakes give quick, smooth stops with maximum safety. Light and heat are ample because they are obtained from central station power. Electrically driven fans furnish adequate ventilation.

TABLE I—COMPARATIVE INVESTMENTS.
(Vehicles, Overhead Lines, Feeders, Shops, Car Houses, and Garages)

	Trolley Coach	Streetcar	Motor Bus
Moderately light service	$292 000	$766 000	$203 000
Heavy service	$1 956 000	$2 403 000	$1 870 000

No sharp line divides the proper fields of application for trolley coaches in the three types of surface public transportation. When total annual cost (fixed charges and operating expenses) is taken into account, it is found that under average conditions, the trolley coach is the most economical vehicle where the passengers to be transported in the maximum hours are more than 400–500 and less than 2000–2500. This is borne out in a study of Fig. 2 where the "cross-over" point indicates that for 2250 passengers per maximum hour, the 44-passenger trolley coach operates at an equal cost ratio to the streetcar. The ratio remains constant in favor of the trolley coach at lower passengers per maximum hour, and in favor of the streetcar for movements above 2500.

Trolley coaches are suitable for all but the lightest transit service in cities of moderate size. Also they have an equally important use as feeders of rapid transit and heavy street railway lines in larger cities. In 1945 they formed 13 percent of the total transit vehicles in cities of 250 000 to 500 000, four percent in cities of 500 000 to 1 000 000 and over one percent in cities over 1 000 000.

As a result of the increased earnings and low operating expenses of trolley coaches, their use has increased rapidly despite restrictions on expansion during the war years. In 1936 there were 1136 coaches in the United States and Canada. Today there are 6500 trolley coaches in service and on order. In the same period, the number of streetcars decreased from 37 180 to 25 250, or 5.1 per cent while motor buses increased from 26 800 to 52 500, or 95.89 per cent.

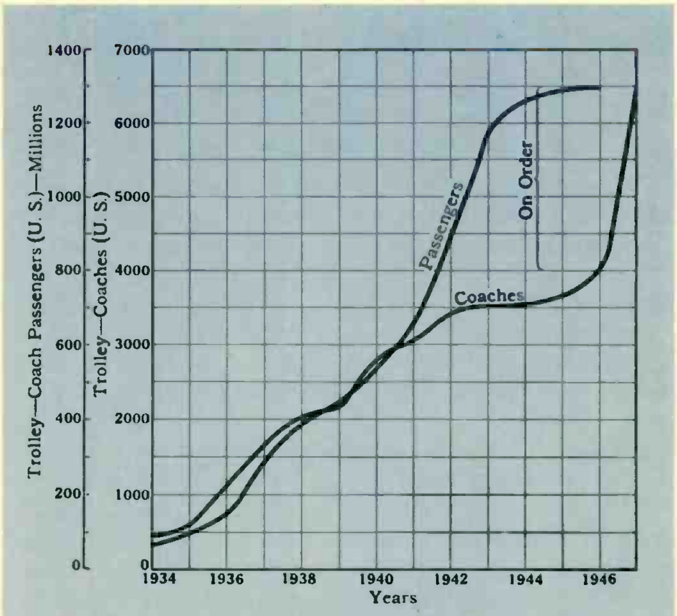


Fig. 4—Combined curve showing the disparity existing between coaches available and the millions of passengers who wish to travel in them. Even with the 2500 new coaches on order, they may be entirely inadequate by the end of 1947.

The Big Guns of Nuclear Physics

Wars are fought with many types of guns, each suited to a particular purpose. So, too, the nuclear physicist has a family of "guns" with strange new names—such as Van de Graaff generator, cyclotron, betatron, synchrotron, and linear accelerator—each with its merits and limitations, its place in the new science of nucleonics.

Dr. W. E. Shoupp, *Manager*
Dr. J. W. Coltman
Nuclear Physics and Electronics Department,
Westinghouse Electric Corporation

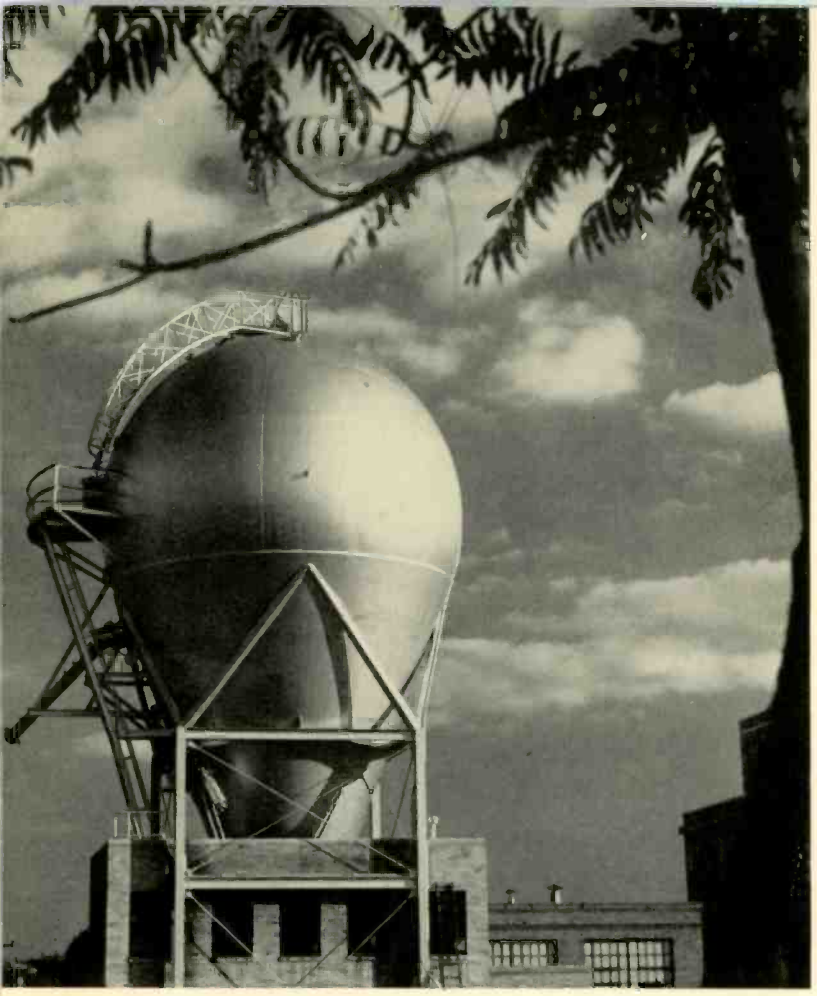


Fig. 1—The Westinghouse Van de Graaff generator.

Atom smashers are the major tools of the nuclear physicist. To explore the nucleus of atoms and to conduct nuclear reactions,* in contrast to chemical ones, the physicist must have means of creating nuclear bullets of enormous energy. His big guns for doing this are the atom smashers, of which several types are in common use or are being developed. These are in addition to several natural sources of nuclear-particle bullets, but the objective of each—natural or man-made—is to accelerate particles such as electrons (β particles), protons, helium ions (α particles), or deuterons, to extremely high velocities or to produce radiation of extremely short wavelength (high frequency.)

Sources of Nuclear Projectiles

When the principles of artificial nuclear transmutation became clear, it was evident also that considerably greater progress could be made if fast-moving particles were available in larger quantities to use as projectiles in the bombardment of elements. The development of ingenious and tremendously ponderous machines to produce high-speed particles for this purpose has been an important factor in the rapid accumulation of knowledge in the allied fields of nuclear physics and atomic energy.

A giant atom smasher weighing over 2000 tons is now being constructed at the University of California. These and similar "big guns" of nuclear physics vary greatly in principle and purpose, some being designed for tremendously high voltage while others are primarily intended for studies requiring a high order of voltage stability and a minimum of unwanted background radiation. All such accelerators are based upon the acquisition of exceedingly high velocities when charged positive ions fall through a potential difference of several million volts. The positive ions (the atom minus one or more electrons) of helium, deuterium, or hydrogen, when attracted by electrodes of increasing negative voltage, generally form the beam of bombarding projectiles. The positive ions originally are formed in an ordinary d-c gas-discharge tube and are drawn out of the discharge region into a vacuum tube containing electrodes to which an appropriate high voltage is applied. When a positive ion of charge e (coulombs) and mass m (grams) falls through a potential difference V (volts), the velocity (centimeters per second) acquired by the ion is given by the following expression:

$$v=\sqrt{\frac{2\ Ve\times10^7}{m}}$$

This formula is accurate only for speeds small compared to the velocity of light (3×10^{10} cm per sec). At higher speeds a formula derived from the theory of relativity must be used. When a proton, which is a positive ion of hydrogen, is accelerated by 1 000 000 volts it reaches a tremendous velocity. Substituting $V=1\ 000\ 000$ volts, $e=1.6 \times 10^{-19}$ coulombs and $m=1.66 \times 10^{-24}$ grams in the above equation gives an acceleration for the particle of 0.14×10^{10} cm per sec (31 000 000 mph). Although such particle velocities and energies appear high, they are still not sufficient for the projectile to overcome the inverse square law of repulsion that protects the nucleus from these projectiles. In fact, at such comparatively low energies, on a nuclear scale, atomic disintegrations are possible only because of a trick of nature that permits some of the projectiles to leak through the protective electric-potential barrier surrounding the nucleus and thereby cause nuclear disruption or transmutation.

Natural Sources of Nuclear Projectiles

Nature provided the first atom smashers. In fact it was the discovery of natural radioactivity by Becquerel and the Curies at the close of the last century that gave birth to modern nuclear physics. The behavior of radium and other radioactive elements led to the realization that the nuclei of the atoms themselves were breaking up and forming new elements, i. e., transmutation.

Of the various naturally occurring sources of nuclear projectiles the α-particles obtained from polonium (radium F) are the most valuable because they possess considerable energy and the attendant β and γ-radiations are weak. Further, the polonium can be easily separated from its parent materials

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*See "Nuclear Reactions," Dr. W. E. Shoupp and Hugh Odishaw, *Westinghouse ENGINEER*, November, 1946. p. 166.

by electrochemical processes. Intense sources of α-particles having a mean energy of 5.30 mev (million electron volts) are obtained from polonium. However, a more energetic though less intense source is obtained from radium C′ that emits α-particles having a mean energy of 7.68 mev. The energy of these particles is sufficient to cause nuclear disintegrations in all elements up to calcium ($Z=20$) except for the four more stable elements, H, He, C, and O.

The energy of the α-particles can be decreased by the insertion of absorbing materials such as foils of aluminum. The advantages of natural sources lie in their simplicity and small size while the disadvantages lie in the limited energy and intensity available. Indeed, a Curie of radium (representing an investment of over $25 000) emits only some 3.5×10^{10} α-particles per second, which corresponds to a beam current of only 0.011 microampere. Atom smashers generally deliver beam currents of at least ten microamperes, giving them an advantage of at least 1000 times over most natural sources.

The γ-radiation from substances such as thorium C″ has, until recently, been the most widely used natural source of electromagnetic radiation in the million-volt range. This source emits a monochromatic radiation having an energy of 2.62 mev. Ordinary radium sources are also used; however, the γ-radiation from radium consists of several lines having a mean energy of about 1.5 mev. These radiations are used for radiographic and medical therapy purposes and also may cause certain nuclear disintegrations that are called "photodisintegrations" since γ-rays are just high-energy light waves.

Neutrons from Natural Sources

Neutrons can be obtained from natural radioactive sources by indirect means. If beryllium is mixed with an α-particle emitting substance, such as radon, neutrons are emitted. These neutrons result from the disintegration of beryllium by the α-particles from radon by the following nuclear reaction.*

$$ {}_2He^4+{}_4Be^9\rightarrow{}_6C^{12}+{}_0n^1+Q $$

When one millicurie of radon is used, about 25 000 neutrons per second are obtained. Alpha particles from other substances such as thorium C″ or radium C′ can also be used. Such neutron sources, though feeble compared to the atomic pile and the cyclotron, are nevertheless simple and convenient to use experimentally. Neutrons can also be obtained from the photodisintegration of beryllium by the γ-rays from mesothorium.

The β-particles (electrons), though copiously emitted from natural sources, are generally of insufficient energy to cause nuclear disintegration (largely because of their small mass). Consequently they are of chief interest for therapy and analytical purposes.

High Voltage from the Atmosphere

Atmospheric voltage gradients of 10 volts per inch are not uncommon in most places near the earth's surface. During storms these gradients may rise to as high as 4000 volts per inch. Consequently in a gap 100 feet long a potential difference of 4.8 mev is obtainable. This potential difference is quite sufficient for the acceleration of atomic particles used in nuclear reactions if the voltage were harnessed and applied to a vacuum tube.

Attempts to do this have been made several times, and voltages up to 15 mev have been produced over a gap length of about 300 feet. However, this voltage source has not yet been applied to the acceleration of positive ions or electrons and has consequently been of little value to nuclear science.

The Surge Generator

High voltages can be generated by charging capacitors in parallel and then reconnecting them in series. Thus, if 10 capacitors are

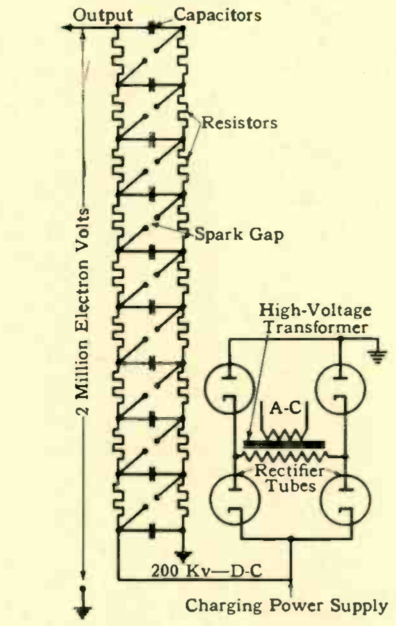

Fig. 2—With a surge generator a voltage equal to the sum of the individual condenser voltages is obtainable.

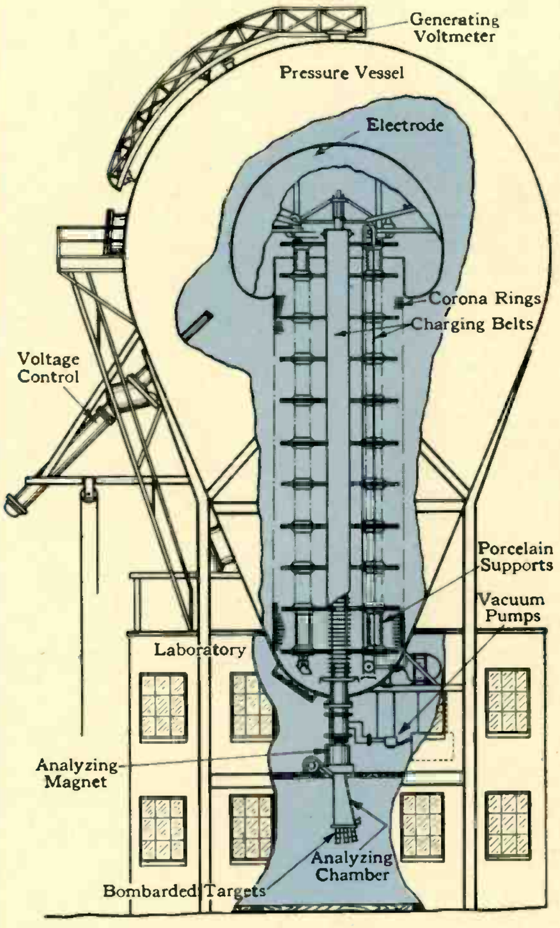

Fig. 3—In the Westinghouse type of Van de Graaff generator, moving charging belts carry electric charges to the inner spherical electrode, which is thereby raised to a potential of several million volts.

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*For an explanation of the formulas in this article, see "The Structure of the Nucleus," by Dr. W. E. Shoupp, July, 1946 *Westinghouse ENGINEER*, p. 118.

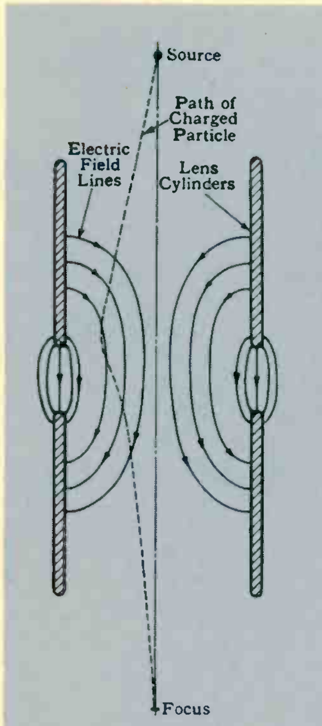


Fig. 4—Focusing action of a cylindrical electric lens in the Westinghouse atom smasher. The curved electric field lines between the charged cylinders deflect the particle first inward, then outward as it crosses them, but the increased speed of the particle after crossing the gap reduces the effect of the deflection.

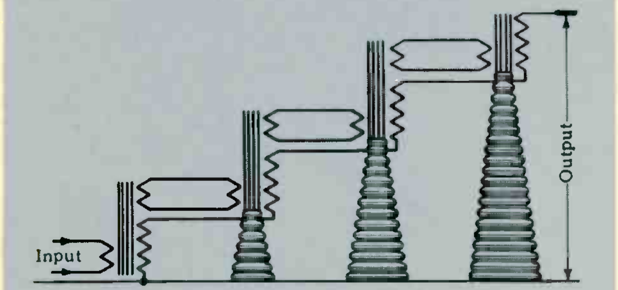


Fig. 5—The cascaded-transformer method of voltage generation uses a series of transformers, each driven from the preceding one. The burden of insulation is placed on the transformer supports instead of the interwinding material.

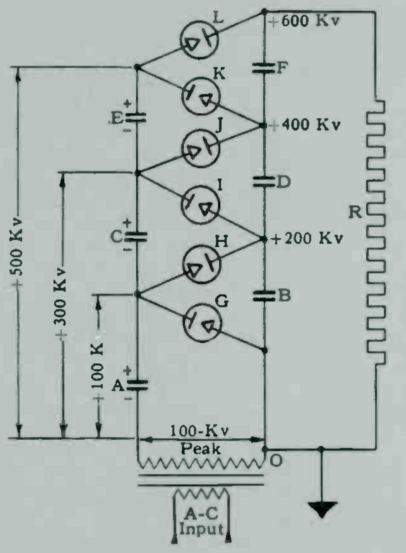


Fig. 6—The capacitor-rectifier voltage multiplier is an ingenious system that effectively permits the condensers at the right to be charged in parallel while they are connected in series.

charged to 200 kv while in parallel, they produce two million volts when connected in series. Voltages up to 2.5 million volts have been produced by this means and applied to an accelerating tube.

Capacitors are all charged in parallel through resistors, Fig. 2. When the proper voltage is reached, the spark gaps break down and offer a low resistance to current flow. When this occurs, the capacitors momentarily are connected in series, and the voltage is consequently high. However, as the capacitors discharge the voltage falls, the gap discharge is extinguished, and the machine is ready for another charging cycle. Several nuclear disintegrations have been produced in this manner.

The Electrostatic Generator

The modern belt-type electrostatic generator was originally devised by R. J. Van de Graaff in 1931. Since then various modifications have been made, although the general principle of building up a high voltage by carrying electric charges to a high-voltage electrode by insulating belts has not been changed. In the Westinghouse version of this machine, Fig. 3, an electrode 15 feet in diameter is mounted on an insulating tower at the center of a pear-shaped pressure vessel having a maximum diameter of 30 feet. This electrode is charged to a high positive voltage by a belt that carries positive charges up on one surface and negative charges down on the other. The charges are applied to the belt by corona points mounted near the belt surfaces and connected to d-c power supplies.

When the tank is at atmospheric pressure, electrical breakdown occurs across the 7½-foot gap at 1.2 million volts. However, when the tank is filled to a high pressure with dry air the breakdown voltage can be increased to four million volts. This voltage is applied to a vacuum tube at the center of the tank and a beam of positive ions of hydrogen (protons), deuterium (deuterons) or helium (α-particles) is accelerated down the vacuum tube.

The cylinders mounted within the vacuum tube aid in focusing these particles into a fine spot. The focusing action for charged particles of the gap between two cylinders of different potential is similar to that of a concavo-convex glass lens for light. As a charged particle enters the converging field between the two cylinders, Fig. 4, it is deflected towards the axis of symmetry of the system. As the particle passes into the diverging field region the field tends to deflect it outwards from the axis of the tube. However, in passing across the gap between the cylinders, the ion has been accelerated to a higher velocity so that the diverging deflections through the second part of the field are less than the convergence caused by the first part. The result of these two effects is a net convergence or focusing of the ion beam. The accelerated ions strike various nuclear targets placed within the vacuum tube at the bottom and nuclear disintegrations are observed to occur.

Machines of this type, as shown in Fig. 1, are particularly valuable for the detailed study of nuclear reactions where an accurately known steady d-c voltage is required. Because the voltage stability is better than 0.1 percent, most of the precision nuclear-physics measurements, so valuable to the theorist investigating the fundamental processes that occur in nuclei, have been done with machines of this general type.

Cascade Transformer

An obvious means of obtaining high voltage for accelerating charged particles is to use alternating current to excite a step-up transformer. At voltages higher than about 200 kv, however, the insulation problems in such a transformer become formidable. Increasing the thickness of the insulating material between the secondary and the core necessarily requires a large core window, with subsequent inefficiency in the transformer design. This difficulty has been overcome by arranging a series of transformers in cascade, so that each primary is energized from an extra winding on the preceding transformer. The schematic arrangement, depicted in Fig. 5, shows how the potential of each transformer is successively higher with respect to ground, while the potential difference across a single unit remains the same. Because the apparatus is bulky, and since the accelerating voltage for the particles is not constant, the cascade arrangement is little used at present.

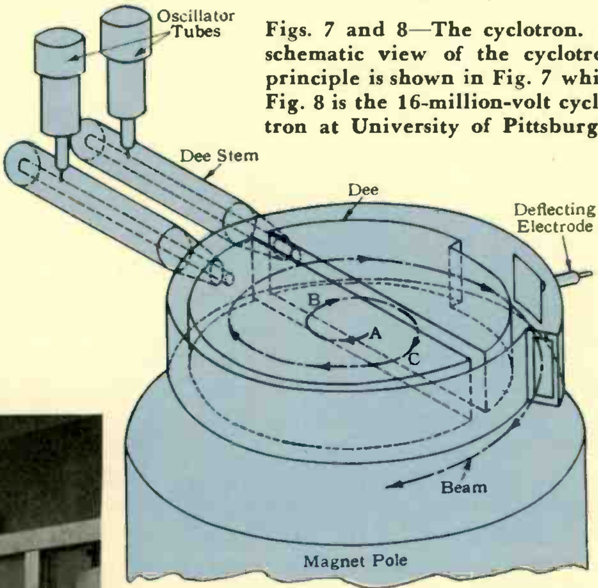
Capacitor-Rectifier Voltage Multipliers

A voltage-multiplying rectifier to obtain high voltage at constant potential was used by Cockroft and Walton in the first experiments on nuclear reactions produced by artificially accelerated particles. The operation of the circuit, shown in Fig. 6, is best explained by assuming that the capacitors are all charged to their full voltage as shown on the diagram. When the instantaneous transformer voltage is near zero, all potential differences are such that none of the rectifiers can pass electric current, their plates being negative with respect to the cathodes. As the transformer voltage rises, it carries the entire bank of capacitors *A*, *C*, *E* with it, until the potentials on the left are, respectively, 200, 400, and 600 kv with respect to ground. Since the right-hand bank of capacitors has discharged somewhat through the load *R* during this time, the potentials on the left are slightly higher than those on the right, and the three rectifiers *H*, *J*, and *L* recharge the right-hand bank of capacitors. On the reverse swing of the transformer, the left-hand bank of capacitors is recharged through rectifiers *G*, *I*, and *K*. The filaments of the rectifier tubes are ordinarily operated from a cascaded set of small transformers similar to the arrangement illustrated in Fig. 5.

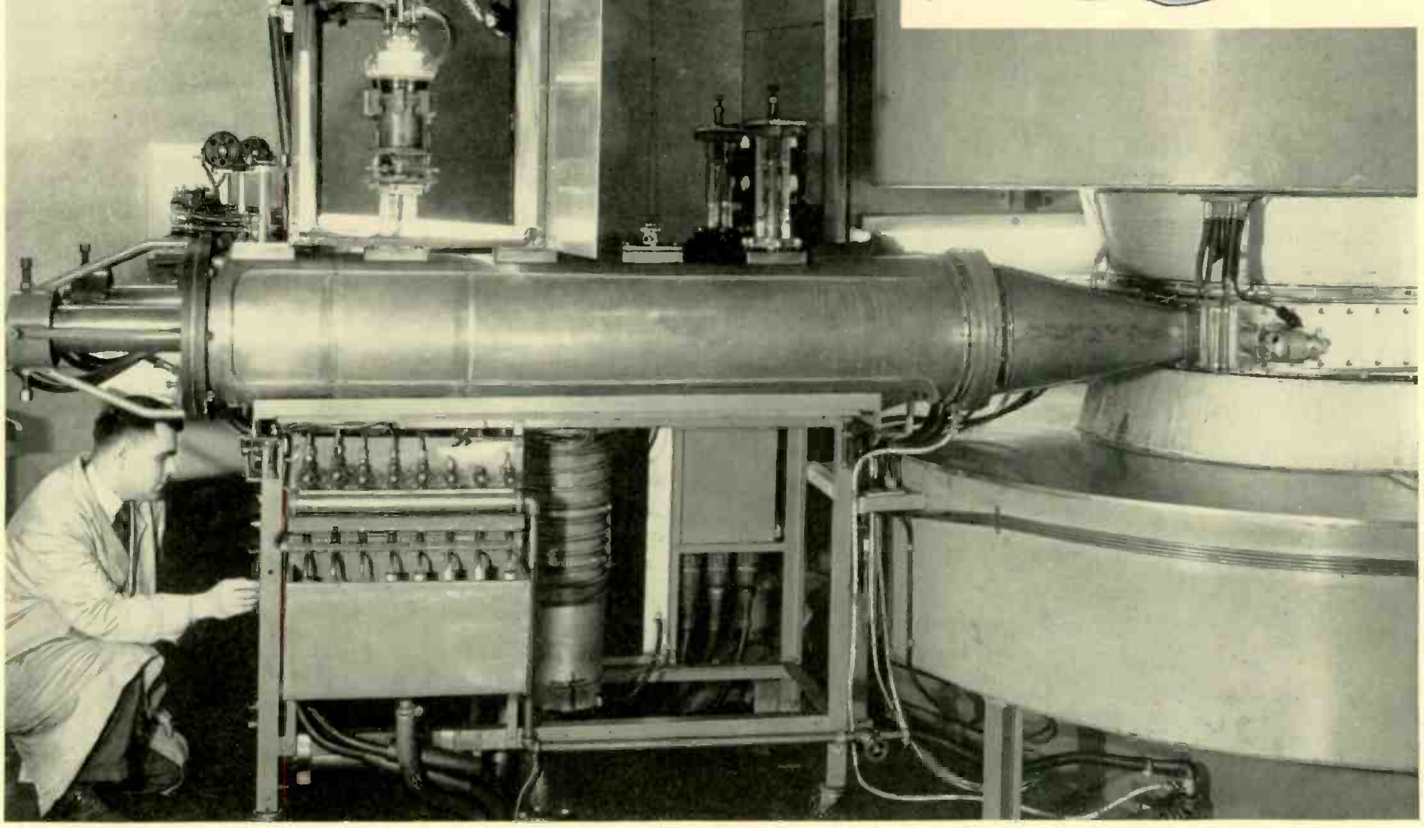
This apparatus, while not suited to the production of extremely high voltages because of the number of stages involved, can handle large ion currents and has been widely used where high yields from nuclear reactions are desired. A machine employing 22 voltage-doubling stages and delivering three million volts has been constructed by Cockroft and Walton in England.

The Cyclotron

The most widely publicized, and deservedly so, instrument for the production of high-speed particles is the cyclotron. This machine, synonymous in the popular mind with "atom smasher," in a few years has greatly extended the range of particle energies available for nuclear physics. Though other types of machines have advantages in certain respects, the mere "brute force" of the cyclotron, in its high voltages and



Figs. 7 and 8—The cyclotron. A schematic view of the cyclotron principle is shown in Fig. 7 while Fig. 8 is the 16-million-volt cyclotron at University of Pittsburgh.



relatively high ion currents has made rapid accumulation of fundamental knowledge possible.

The cyclotron put to practical use for the first time a new principle in the science of accelerating particles. Instead of supplying externally the entire voltage which a charged particle is to attain, the acceleration is provided in a series of pushes applied to the particle as it passes through a suitably charged gap, while magnetic means are provided to return the particle again and again through the same gap. The success of this method, as used in the cyclotron, depends upon the fact that a charged particle moving in a plane perpendicular to a uniform magnetic field describes a circular orbit at constant angular velocity, regardless of its speed. The force due to the magnetic field is given by $H e v$, where H is the field strength, e is the charge, and v the velocity of the particle. This force is directed at right angles to the velocity and to the field; that is, it acts as a centripetal force holding the particle into a circular orbit. This force, by the laws of mechanics, must be given by mv^2/r, where m is the mass of the particle, and r the radius of the orbit. Thus

$$\frac{mv^2}{r} = H\,e\,v \text{ or } \frac{mv}{r} = He \qquad (1)$$

Substituting ω = angular velocity $= v/r$

$$\omega = \frac{He}{m} \qquad (2)$$

Thus the angular velocity depends only on the charge and mass of the particle and on the strength of the magnetic field. Increasing the velocity of the particle merely increases the radius of the orbit, as can be seen from eq. (1).

This property of the particle in a magnetic field permits the use of a single accelerating gap, placed along the diameter of the circular orbit, with the assurance that the particle will pass the gap at specified instants, recurring at a constant rate regardless of its speed. The gap can be supplied with a voltage from a high-frequency alternating source, tuned to resonance with the particle rotation so that the accelerating voltage is maximum and at the proper polarity the instant the particle passes the gap.

Between the two poles of a large electromagnet of a cyclotron, Fig. 7, is a vacuum chamber within which are supported two D-shaped electrodes, which are formed much like a cake tin split along a diameter and slightly separated. This separation is the accelerating gap, and the high-frequency voltage is applied to the two D-shaped electrodes by the oscillator through the dee stems.

The ionized atoms of hydrogen or deuterium (protons or deuterons) are formed near the center of the chamber by an appropriate source, which can simply be a filament-and-grid system, the electrons from which ionize a part of the small amount of gas introduced into the chamber. A proton, for example, starting at A, is accelerated across the gap when the near dee is negative with respect to the far one. Once across, the proton describes a small semicircular path in the field-free region inside the dee, due to the action of the magnetic field. During this time the polarity of the dees is being reversed, and when the proton reaches the gap at B, it is again accelerated into the far dee. Its voltage, or velocity, being greater now than before, the semicircle is somewhat larger, but because of the constancy of the angular velocity as shown in eq. (2), the proton reaches C at the precise instant that the dee voltage is maximum and tending to accelerate the particle further. The proton thus proceeds in a series of ever-increasing semicircles, until the size of the orbit is sufficient to carry it through the window in the step formed in the far dee. Once outside, a deflecting electrode in the wall straightens the path so that the proton emerges from the chamber. During the course just described, other protons have been starting from the center, so that a pulse of protons is emitted each cycle of the driving frequency.

The cyclotron was first introduced in 1930, and in the subsequent years has gone through a remarkable development. The first working model was a few inches in diameter, and yielded 80 000-volt particles. The sixty-inch machine at the University of California is now able to produce deuterons with an energy of 20 mev. Since the field H is limited by the properties of the iron used in the magnet, the velocity obtainable for a given particle is directly proportional to the radius of the magnet, as eq. (1) indicates. Except for focusing considerations, the dee voltage is unimportant; if the voltage is low, the particle simply makes a larger number of revolutions and picks up a velocity sufficient to increase its orbit to the size necessary to escape through the window.

The Synchro-Cyclotron

The maximum velocity to which a particle is accelerated by means of a cyclotron is limited by the change in mass of the particle as it approaches the velocity of light. This effect, predicted by the theory of relativity, results in the angular velocity ceasing to remain constant as shown in eq. (2). Above a velocity corresponding to about 30 mev, the mass change is sufficient to cause the particles to get seriously out of step with the applied r-f voltage, and the cyclotron cannot function. This difficulty can be overcome by gradually lowering

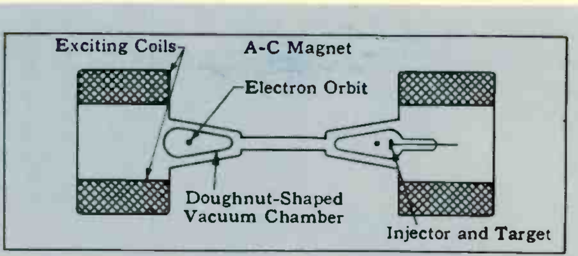


Fig. 9—In a betatron, during the time the magnetic field from the a-c magnet is increasing, the electrons are accelerated by the changing flux within the orbit, and are held at a constant radius by the increasing field at the orbit.

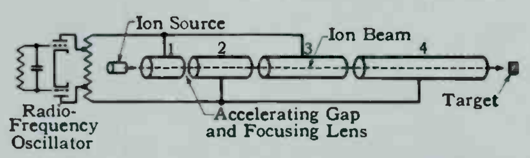


Fig. 10—In a linear accelerator driven by radio frequency, a charged particle accelerated across the first gap finds the voltage at the second gap in such a direction as to accelerate it to a still higher velocity until the final gap is reached.

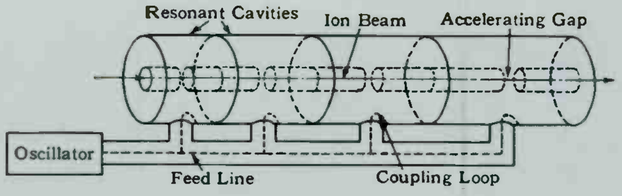


Fig. 11—In a resonant-cavity linear accelerator each gap is enclosed in a resonant cavity whose phase can be adjusted by changing the line length coupling oscillator to resonant cavity.

the frequency of the dee voltage as the particles proceed outward and gain speed. This means that a new group of particles no longer can be started each cycle, but a chosen set must be "escorted" throughout the entire acceleration process. The current output of the machine is thus considerably reduced, but the higher voltages obtainable more than make up for the loss. The 184-inch cyclotron at the University of California is to be equipped with frequency modulation, and is expected to produce 200-mev deuterons.

The Synchrotron

Another possible means of avoiding the change in mass difficulty is to vary the field H in eq. (2) as the mass increases. This is best accomplished by energizing the electromagnet with alternating current, and selecting that portion of the cycle in which the field is changing at the proper rate for the acceleration time. Further, the field can be changed so as to keep the radius of the orbit (r in (1)) also constant. The center portion of the magnet pole faces is then no longer needed, and considerable saving in magnetic iron and driving power can be effected. The gap can be formed by dees as in the cyclotron, or replaced by a high-frequency resonant cavity, which the particles traverse each cycle. Several machines of this nature designed for particle energies in the 300 mev range are now under construction.

The Betatron

The betatron, developed by D. W. Kerst in 1940, utilizes an acceleration principle quite distinct from any of the others yet discussed. In a closed circuit surrounding a region of magnetic flux, an emf is set up that is proportional to the time rate of change of the magnetic flux enclosed. This is true whether an actual wire circuit is present or not. If it were possible to keep charged particles in a circular path without interfering with their forward motion, large velocities could be obtained. By a careful analysis of the motions of electrons in a changing field, Kerst was able to shape the field so that stable orbits resulted.

As shown in Fig. 9, the changing field within the orbit, supplied by the a-c magnet, accelerates the electrons in accordance with the rule given above, while the field at the orbit increases just sufficiently with time to hold the radius of the electron orbit constant as the particles pick up speed. As in power transformers, the emf is only a few volts per turn, but the electrons make an enormous number of revolutions. At present, the electrons are not removed from the machine for target bombardment. Instead, toward the end of the cycle the orbit is slightly expanded by unbalancing the field so that the electrons strike the target placed within a vacuum.

The first betatron produced one million electron volts. The largest machine operating at present is capable of 100 mev, while the University of Illinois is now building one for 250 mev. The betatron is not suitable for acceleration of heavy particles, as the energy received depends on the number of turns made by the particle.

Linear Accelerator

Charged particles can be multiple-accelerated by means of radio-frequency voltages applied to a proper electrode system, as in Fig. 10. The two sides of a high-power, r-f oscillator are connected to alternate accelerating electrodes of the vacuum tube. When electrode 1 is negative, ions are accelerated across the first gap and enter the field-free region inside cylinder 2. If this cylinder is of the proper length, such that, by the time the ions emerge from 2 the r-f voltage has reversed itself. the ion again is accelerated by electrode 3, and so on down the electrode system. The individual acceleration voltages may be as much as 100 kv; therefore a 3-mev accelerator would have to contain 30 electrodes.

TABLE I—GENERAL COMPARISON OF PARTICLE ACCELERATORS

Name	Highest Energy Obtained Millions of Electron Volts	Highest Energy Proposed Millions of Electron Volts	Particles Accelerated	Characteristics
Cyclotron	20	20	Protons, deuterons, or helium ions	High voltage, high average current
Synchrocyclotron	200	300	Protons, deuterons, or helium ions	Very high voltage, low current
Betatron	100	300	Electrons	Pulses of electrons, very low current
Synchrotron	70	1000	Electrons	Pulses of electrons, very low current
Linear Accelerator	3	200	Electrons, protons, deuterons, or heavier positive ions	Pulses of charged particles. Moderate current.
Electrostatic Generator	5	10	Electrons, protons, deuterons, or heavier positive ions	Very steady voltage. Continuous current. High or low currents.

Since the velocity of an ion is increasing as it proceeds down the tube, the lengths of the electrodes must increase in a corresponding manner. In fact, until relativity corrections are required, these lengths vary as the square root of the electrode number. As the length of the electrode system approaches the wavelength corresponding to the radio frequency of the oscillator the constant phases shown on the diagram can no longer be maintained. Means must be provided for adjusting the relative phases of the electrodes. This can be done by using a resonant system, for example, a series of cavities as shown in Fig. 11.

Machines of this type now are being constructed for the acceleration of protons and electrons to as high as 300 mev. Their chief virtue lies in the fact that stages can be added indefinitely without encountering insulation difficulties. The cost is only directly proportional to the voltage obtained, whereas in machines of the magnetic type the weight, and roughly the cost, are proportional to the cube of the voltage. It seems likely that the super-power billion-electron volt machines of the future will be of the linear accelerator type.

Uranium Fission Piles

The uranium-fission pile was developed under the greatest secrecy during the war as the first step in production of atomic energy and atomic bombs. It takes its place as a "big gun" of nuclear physics because of the tremendous concentration of free neutrons within the pile. These neutrons are both byproducts and activators of the uranium-fission process. They can be used, in addition, to bombard any substance placed within the pile, thereby producing many types of nuclear reactions that can result in the formation of artificial, radioactive isotopes. By making a suitable aperture in the wall of the pile, an external beam of neutrons is obtained. The neutrons thus produced may not have any higher velocity than those obtained indirectly by bombardment of elements with charged particles, but the number of neutrons available from the pile is enormous compared to that from any other process. This source of neutrons assumes great importance for the quantity manufacture of many valuable isotopes not occurring naturally on the earth. Among these are plutonium, a new, man-made element, used in the atomic bomb.

Measuring Torque without Contact

K. L. Wommack
Motor Engineer,
Westinghouse Electric Corporation

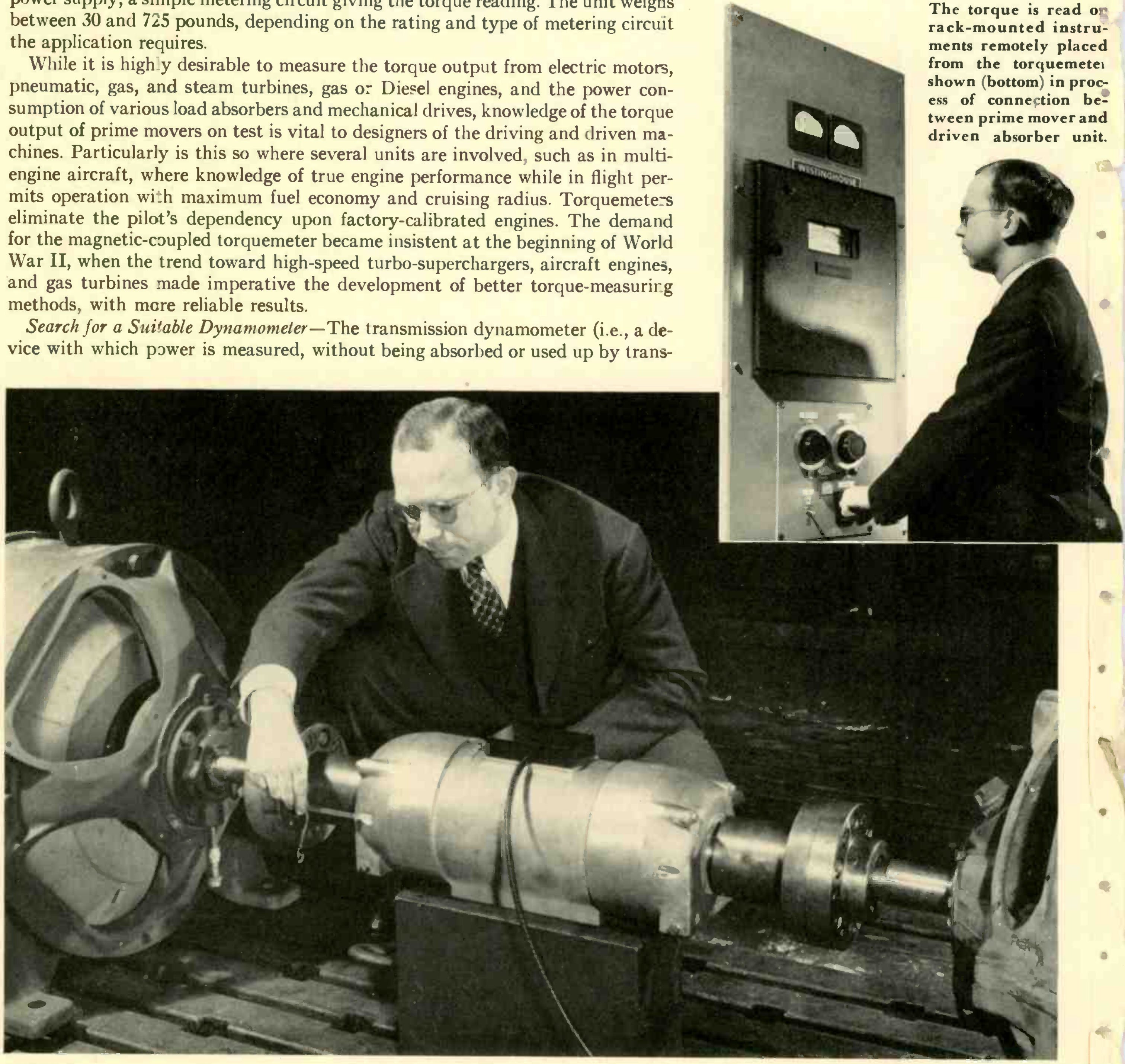
Accurate measurement of mechanical quantities is usually difficult, as compared with electrical ones. Measurement of torque transmitted has been particularly difficult. A new device, however, achieves this with only magnetic contact with the shaft.

Instruments for measuring electrical quantities are simple and exist in great variety. Just as amperes are measured in the transmission and absorption of electrical power, torque must be measured and known for all phases of mechanical power transmission and absorption. An instrument to do this efficiently and economically over the entire range of power-transmission machinery is known as the magnetic-coupled torquemeter.

The new instrument is a compact, adaptable device for measuring torque transmitted by a rotating shaft. In appearance it resembles a motor 10 to 25 inches long and 5 to 14 inches in diameter with a double-extended shaft, which may be coupled like a jackshaft between prime mover and power absorber. It is fed by an external power supply, a simple metering circuit giving the torque reading. The unit weighs between 30 and 725 pounds, depending on the rating and type of metering circuit the application requires.

While it is highly desirable to measure the torque output from electric motors, pneumatic, gas, and steam turbines, gas or Diesel engines, and the power consumption of various load absorbers and mechanical drives, knowledge of the torque output of prime movers on test is vital to designers of the driving and driven machines. Particularly is this so where several units are involved, such as in multi-engine aircraft, where knowledge of true engine performance while in flight permits operation with maximum fuel economy and cruising radius. Torquemeters eliminate the pilot's dependency upon factory-calibrated engines. The demand for the magnetic-coupled torquemeter became insistent at the beginning of World War II, when the trend toward high-speed turbo-superchargers, aircraft engines, and gas turbines made imperative the development of better torque-measuring methods, with more reliable results.

Search for a Suitable Dynamometer—The transmission dynamometer (i.e., a device with which power is measured, without being absorbed or used up by trans-



The torque is read on rack-mounted instruments remotely placed from the torquemeter shown (bottom) in process of connection between prime mover and driven absorber unit.

mission) found favor in installations such as aircraft and navel vessels where absorption dynamometers (i.e., where power is absorbed) are impractical. Various methods of measuring torque in rotating shafts have been studied.

When transmitted through a planetary gear, torque causes a reaction in the stationary gear. When transmitted through a single helical gear, torque causes a thrusting action. A method of measuring torque by these two phenomena is seldom used because of the difficulty of eliminating hysteresis and friction errors.

Torque applied to a shaft twists one end with respect to the other. The change in resistance of a conductor when stress is applied has been made the basis of successful torque-measuring devices. However, the necessary slip rings to pick up the electrical signal from the shaft are difficult to maintain in oily atmospheres, and at high speeds the voltage drop across the brushes becomes erratic.

The single-phase torquemeter depends for its signal upon the measurement of the phase angle between the a-c output from two generators spaced apart on the driving shaft. It requires too much shaft deflection for practical general application or for adequate metering.

Torque can be measured by using any one or more of several strain gauges. However, those depending on electrical energy have been limited by the slip-ring problem, while mechanical forms are limited by their low efficiency and complexity and limited speed range.

The magnetic-coupled torquemeter utilizes the principle employed in the magnetic-strain gauge,* which is shown in Fig. 1. Two stacks of **E**-shaped punchings are mounted on each side of a rectangular armature. When the coils on the center legs of the punchings are excited with alternating current, their impedances depend upon the reluctance of the magnetic circuits carrying flux. Because the air gaps constitute most of the reluctances, moving the armature towards one of the stacks varies the impedances of the coils in an opposite sense. When the two coils form two legs of an a-c bridge, a small motion of the armature causes a measurable change in the current through the metering circuit, giving an indication of the amount of movement. Because the torque signal from rotor to stator is transferred by magnetic flux, errors due to speed, atmospheric conditions, high accelerations, and infrequent maintenance are minimized.

As distinct from the strain gauge, a constant air gap has been added between the ends of the punchings and the coils of the magnetic-coupled torquemeter. This is the radial gap between rotor and stator, as shown in Fig. 2. The coils are mounted on the stator, which has replaced the outside portion of the iron cores, and a gap is left in the shells of magnetic material surrounding the coils just above the active air gaps.

The shaft has three equidistant flanges with rings of nonmagnetic metal shrunk over them. Pinned to these nonmagnetic rings are magnetic rings with projections of teeth on their adjacent edges that interlock to form the active or motion-sensitive air gaps, opening or closing and changing in length as torque is applied to the shaft. The two outer rings take the place of that part of the iron core within the constant air gap. The inner ring replaces the rectangular armature.

When the coils are excited with alternating current, flux passes around the shells, off the stator into the rotor, through the active gaps, and back into the stator. The active gaps are the major reluctance in the magnetic circuit, and therefore any amount of torque developed causes the impedance of one coil to increase and that of the other to decrease. If the coils form two legs of an a-c bridge, the unbalanced voltage is a measure of this torque.

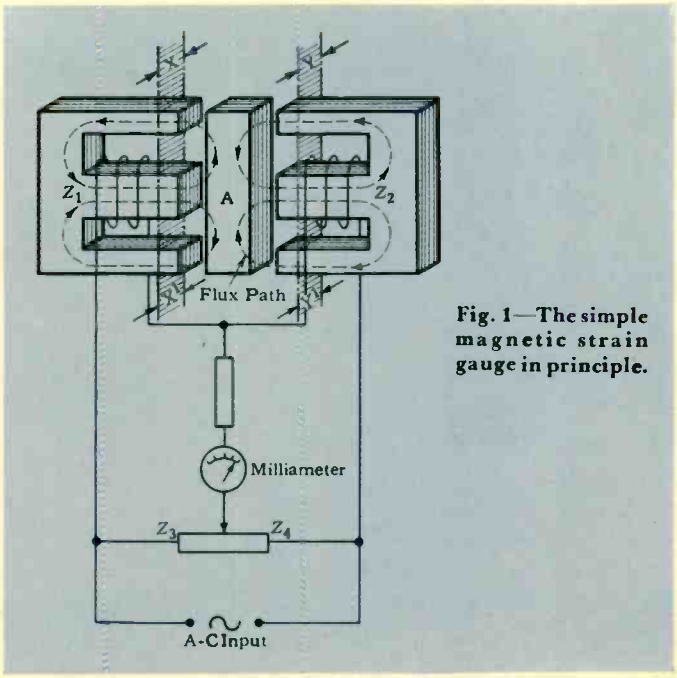


Fig. 1—The simple magnetic strain gauge in principle.

Control Circuit—The control circuit consists of an a-c bridge and a metering circuit as shown in Fig. 3. A signal pick-up transformer takes the signal from the a-c bridge and passes it through a rectifier to the metering circuit. Inasmuch as the voltage from the torquemeter bridge cannot be conveniently balanced to zero, a constant bias is supplied to the metering circuit by another rectifier. The signal is measured by a milliameter, or, if larger indicators or recorders are required, the potential drop across a resistor carrying the unbalanced current is used. To measure this potential drop a millivoltmeter, preferably of the self-balancing potentiometer type, is used. Varying sensitivities are obtained by shunting the meters.

The rectifier circuits have stable temperature characteristics and swamping resistors minimize the effect of changes in the forward resistance of the rectifier. These swamping resistors are stable, and large enough in comparison to the rectifier resistance to make variations in it negligible.

The output of the torquemeter is directly proportional to the input voltage. If the voltage varies enough to produce objectionable errors in the readings, a voltage regulator can be used. The impedance of bridge and metering circuits is matched with the signal pick-up transformer for greater power output efficiency.

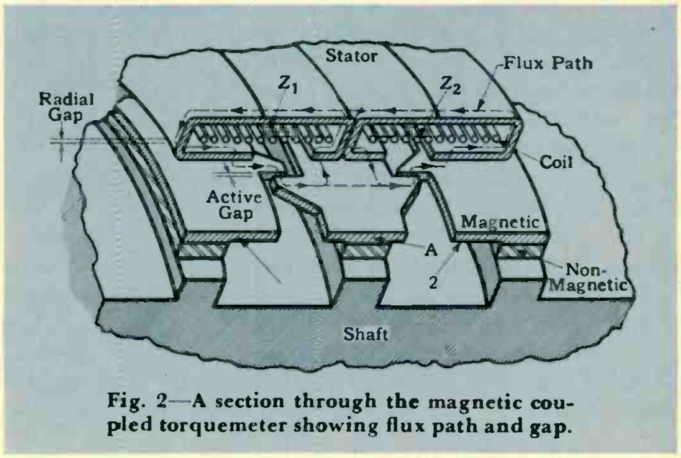


Fig. 2—A section through the magnetic coupled torquemeter showing flux path and gap.

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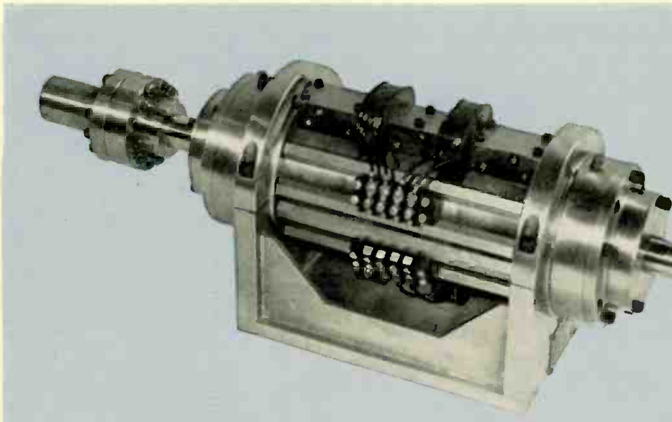
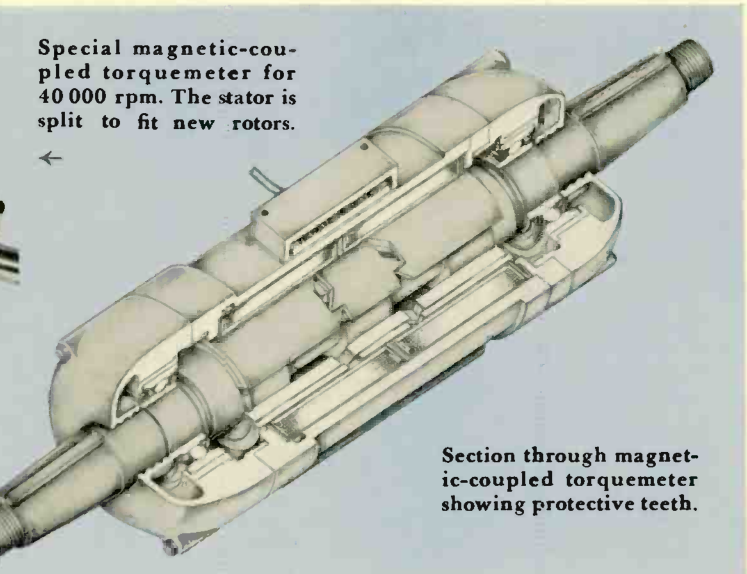
*"Laying Stress on Strains," by B. F. Langer, Westinghouse ENGINEER November, 1942, p. 129.



Special magnetic-coupled torquemeter for 40 000 rpm. The stator is split to fit new rotors. ←



Section through magnetic-coupled torquemeter showing protective teeth.

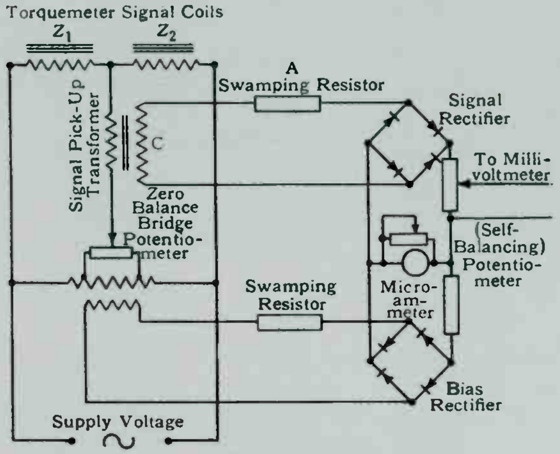


Fig. 3—Magnetic-coupled torquemeter alternating-current bridge control circuit.

Calibration—Because the output of the magnetic-coupled torquemeter is independent of speed, calibration can be made at standstill by clamping one end of the shaft and applying a known load on a known length of lever arm attached to the other end. If friction is absent, the torquemeter can detect changes in load as small as 0.1 percent of full load. Accuracies of ± 1 percent of rated torque can be secured with proper care and compensation for known effects. In aircraft torquemeters, variations in temperature and voltage supply are so extreme that a ± 3 percent accuracy is considered good.

Limitations—The maximum possible operating speed of the torquemeter is fixed by the hoop stress in the magnetic tooth rings, limiting speed of the ball bearings, and critical speed of the shaft. Heretofore, hoop stress has been a serious limiting factor because the rotor rings must be magnetically soft. However, a recently developed high-strength magnetic alloy has raised the allowable hoop stress 150 percent. Bearing speeds have been driven upwards by gas-turbine developments, leaving the maximum torquemeter speed equally limited by either the critical speed of the shaft or the ball bearings, depending on the application.

A more serious problem is ambient-temperature change. By changing the resistivity of the magnetic material, iron loss is altered and, with it, the output of the torquemeter. Careful use of temperature-sensitive resistors in the circuit can compensate for some changes in temperature. Holding the temperature of the unit constant with thermostatically controlled heaters solves this problem where demanded.

Forces on the shaft other than torque (i.e., thrust and bending) tend to balance. They have no influence on performance or accuracy of the magnetic-coupled torquemeter.

Applications—Magnetic-coupled torquemeters have found many uses. They are used to test high-speed motors (up to 10 000 rpm) and to measure the effect of design changes upon stray load loss. The possibility of automatically drawing speed-torque curves of a-c motors on production tests is seen.

The output from various constant-speed drives for aircraft generators is measured by using magnetic-coupled torquemeters. Aircraft engines have been ground-tested and flight-tested using them, and designs have been made for a torquemeter to be used as an operating instrument on gas-turbine propeller-driven aircraft.

The torquemeter can also be used to study the torsional vibrations in automotive-clutch drives and other machines where smooth power transmission is essential. It is suitable for frequencies up to about ¼ to ⅓ that of its supply voltage. The supply frequency cannot be increased indefinitely because iron losses in the pick-up limit the output. However, if a torquemeter is needed for studying torsional vibrations above 100 cycles per second, a power-supply frequency above 400 cycles must be used, and the output amplified to operate a recording oscillograph.

The torque required to stir a liquid is a function of the liquid's viscosity. Torquemeters can be used to measure and even to control the viscosity of varnishes, chemicals, and paints during manufacture, where nonuniformity and overprocessing would ruin the mixture. They may also prove suitable in the study of ship propulsion, automotive drives, gear and chain drives, rolling and paper mills, gasoline and Diesel engines, pumps, blowers, and machine tools.

Torquemeter Construction—The torquemeter is enclosed in a high-strength, streamlined aluminum frame, operates on high-speed ball bearings, and is adaptable to a variety of mountings. For applications covering wide ranges of speed and load, such as gas-turbine studies, a split stator torquemeter with changeable rotors is available.

The MC-1 type of magnetic-coupled torquemeter has a 400-percent overload capacity, obtained (on the larger units) by mechanical stops that protect the shaft and teeth from injury during starting. Nonmagnetic tooth rings close before the magnetic gaps and carry the load.

The magnetic-coupled torquemeter has been built in sizes ranging from 1 to 15 000 ft lb in capacity and at speeds from zero to 40 000 rpm. It is compact, simple, accurate, and requires almost no maintenance or special operating skills. Its indication of torque transmission is a valuable aid to designers and operators of power machinery.

Trends in Steam-Turbine Development

After the war recess, construction of large steam turbines began at an unprecedented rate. The present picture of these machines of major size is characterized by: the ascendency of the 3600-rpm unit; another new level of steam temperature and pressure to be followed by the customary plateau for consolidation of their benefits; and a conspicuous early success of the standardized-unit idea.

C. B. CAMPBELL • *Engineering Manager* • *Steam Turbine Division* • *Westinghouse Electric Corporation*

COMPARATIVELY little was heard during the war of the development of new steam turbine-generator units for stationary power plants, despite the indispensable role of this equipment in the war program. The major task then was to provide the propulsion turbines and electric-power generating units for an unprecedented number of ships of all types. While this demand was being satisfied, it was possible to produce only those stationary-plant turbines that government agencies found to be most urgently needed in support of the war effort.

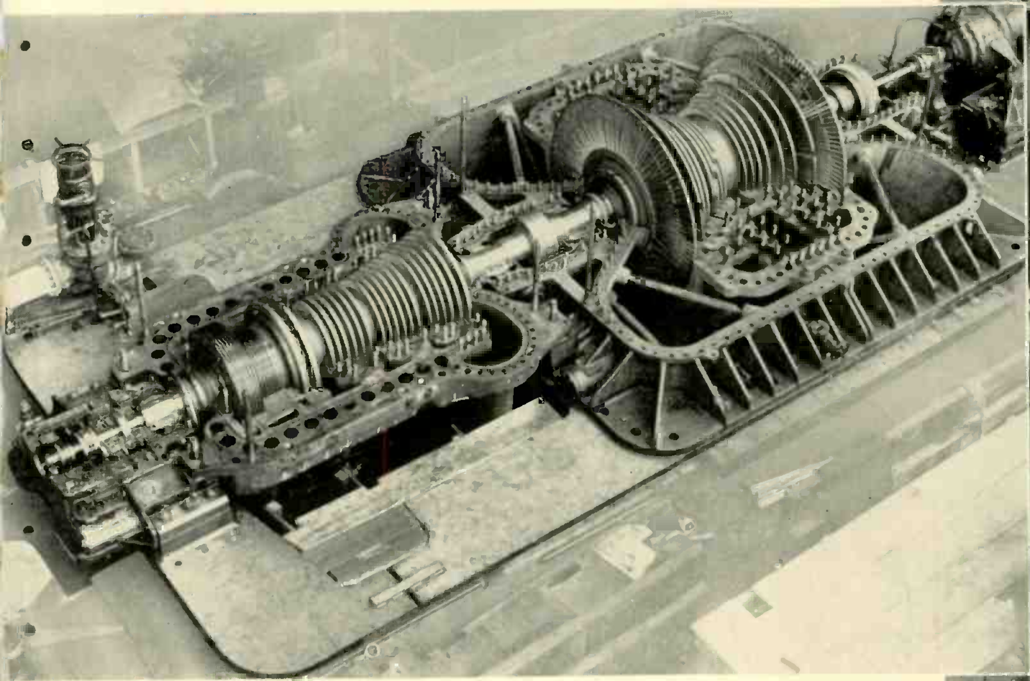
Now that production restrictions have been removed, the demand for stationary generating plant steam turbines is enormous. This is particularly true for units of 10 000 kw and larger, which is the group of machines discussed here. Production of these large turbines measured in combined kilowatt capacity will, for some time, proceed at a rate four times the average existing over the four years 1938 to 1941, inclusive, immediately preceding the war.

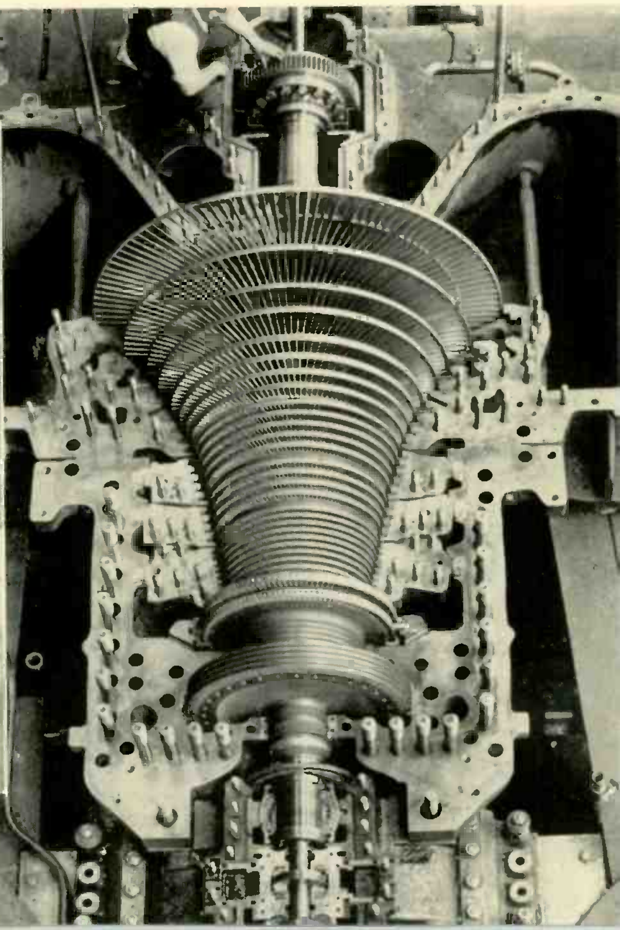
Throughout the war years record peak demands were encountered, along with greatly extended high-load demand periods. Nevertheless, essential power requirements were met. An uncommonly high degree of continuous operation was required of all operable generating units. Overhaul schedules were rather generally deferred. Short-time shutdowns were relatively infrequent, whereas in normal circumstances, they allow sufficient time for many minor maintenance tasks.

Steam turbines show no evidence of having suffered undue deterioration from operation under these severe conditions. In fact, their generally outstanding operating record during the war lends strong support to the conclusion that continuity of service, under intelligent surveillance, is distinctly favorable to the turbine. Intermittent operation, with its attendant extremes of turbine temperature and especially its transient nonuniformity of temperature distribution, is not conducive to the best mechanical performance.

Several million horsepower aggregate capacity of ship-propulsion turbines having been produced only recently, it is pertinent to inquire what influence this vast experience has had on current or near-future, large powerhouse turbines. The fact is that the direct influence is small. Land and marine turbines are based upon the same mechanical and thermodynamic design principles, but differ in arrangement, construction, and control details. Benefit results from the use of certain manufacturing processes developed for volume-production of marine turbines. Welding techniques will likely find broader application, not so much to reduce weight as to lessen production delays resulting from extensive repair of

Partial assembly of tandem-compound turbine and a single-casing turbine.





steel castings. Nondestructive material inspection methods have been stimulated and will carry over. The power-generation industry will benefit from a practical degree of standardization which was a factor contributing to the success of the marine-turbine program, and early recognized as such. In general, however, designs of power-plant turbines will be but little altered by the marine-turbine experience.

Large-turbine design practice has never been static, and probably never will be. The point has not been reached at which experience with large units in service no longer indicates the way to construction improvements of various degrees of importance. This is particularly true when, as is frequently the case, it becomes necessary to extrapolate beyond existing experience and then to consolidate the gains accruing from, for example, increases in machine rating at a given speed of rotation, elevation of operating steam pressures and temperatures, and the introduction of new materials or new manufacturing processes.

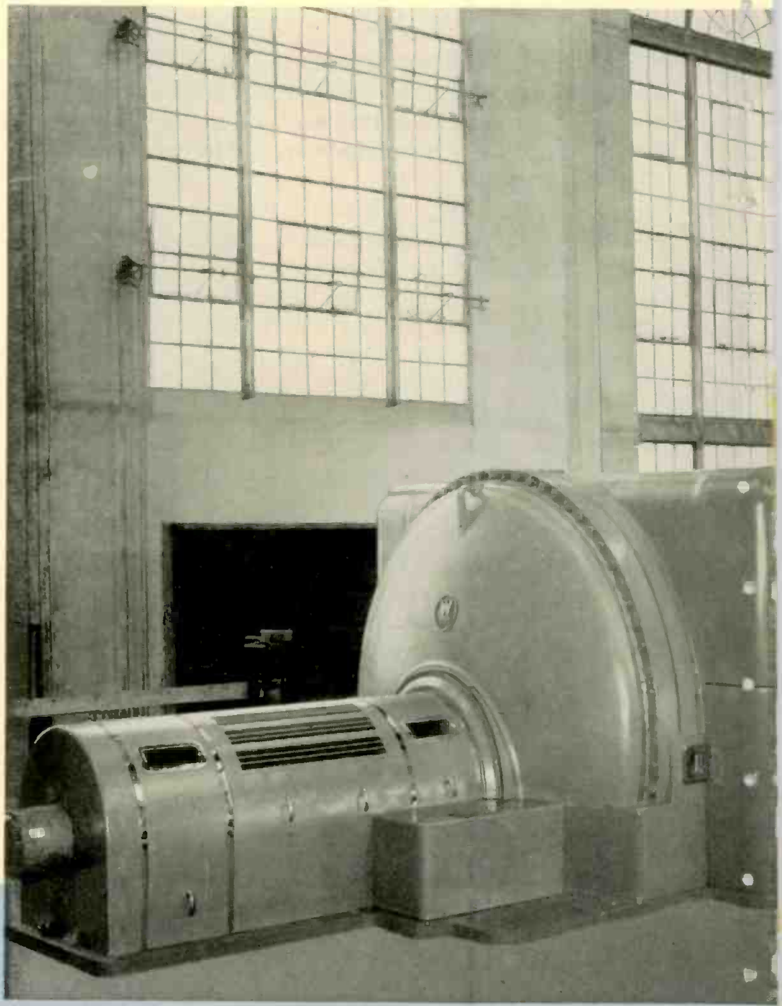
The Growth and Merit of High-Speed Machines

The maximum rating of 3600-rpm condensing turbines has grown rapidly. Not until 1929 was the first 10 000-kw, single-casing, high-speed condensing turbine produced. Subsequent developments by 1937 raised the limit to 25 000 kw, shortly followed by the two-element tandem turbine with double-flow exhaust blading to give a 65 000-kw rating, or 81 250-kw maximum output. These generating units have now accumulated several years of successful operating history, upon which is based the development now being made of two-casing, tandem, 3600-rpm turbines extending upwards to 100 000-kw maximum capacity. Several of these new and larger frame turbines are being designed, with shipments beginning within the present year.

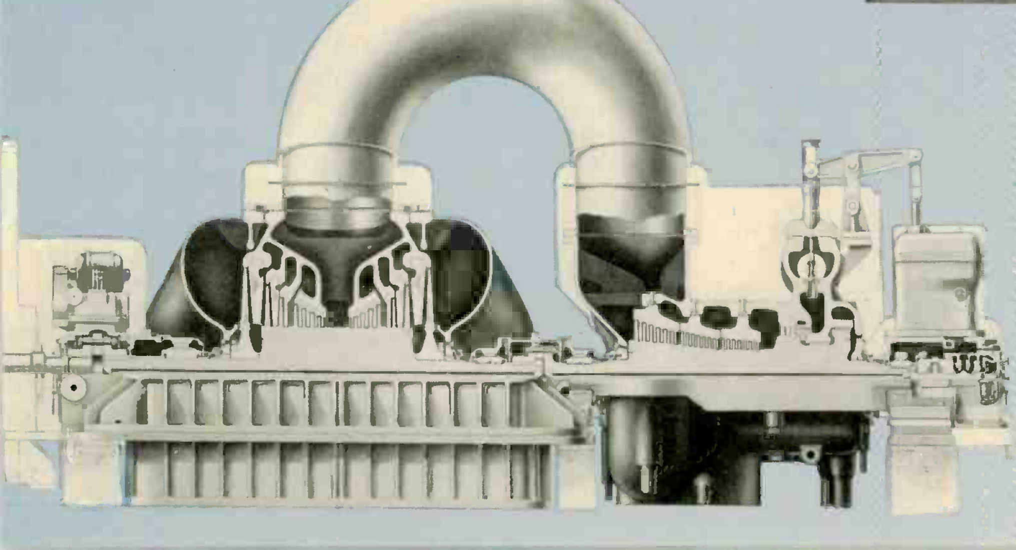
The extent to which the high-speed turbine has covered the large turbine field, and a measure of its acceptance by power companies, is evident from the fact that, of all stationary-plant units of 10 000 kw and larger shipped by Westinghouse since 1934, 89 percent operate at 3600 rpm. Also 95 percent of all large turbines now on order with Westinghouse, comprising 92 percent of the aggregate rating, are of the high-speed variety. The field for 1800-rpm units has thus been reduced to a relatively small number of large installations, and even there it is entirely possible that by further compounding of turbine casings the high-speed unit will become a competitor.

The primary factor determining the practicable limit to rating for condensing turbines at a given speed of rotation is the annular area for which reliable and efficient last-row blading can be produced. This is a matter of avoiding undue sacrifice in overall efficiency, which requires that the so-called leaving-energy loss, measured by steam velocity, be kept as small as possible. The successive major advances made in limit ratings coincide with the development of new and substantially larger exhaust-end blading. Each such step requires the utmost attention to the detail design of the blade from the standpoint of stress and control of steam flow, a thorough understanding and analysis of the vibration characteristics of the structure, and the production of costly new tooling.

In 1929 a last-row blade 17 inches long was developed to provide 20.8 square feet of annular area, with a blade-tip velocity of 1150 feet per second at 3600 rpm. This made possible the single-casing condensing turbine rated at 10 000 kw. A longer blade—20 inches—brought out in 1937 gave 26



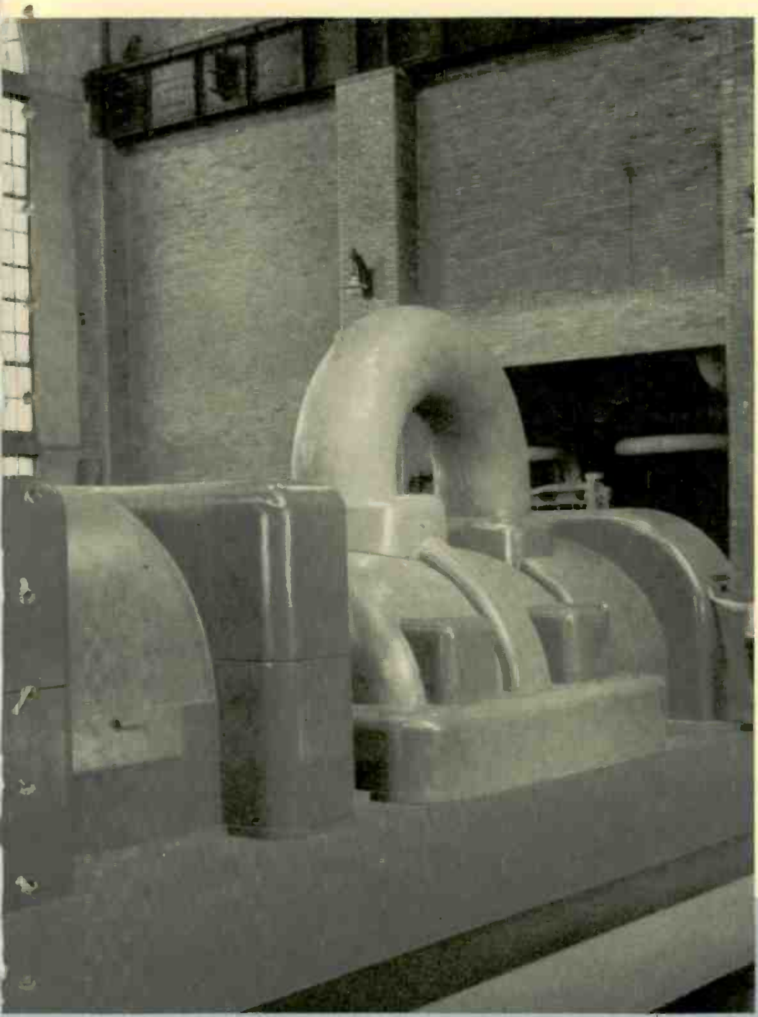
The view above shows a representative modern tand
of a tandem-compound and the single-casing steam t



The electric-power industry, after success
for its product during the war, finds itself
peacetime demand, for which new generati
speed. Although the industry has increa
lion kilowatts of 1935 it will be necessary

percent greater last-row annulus with a blade-tip velocity of 1260 feet per second. The most recent development—a 23-inch blade—effects an increase in area of 25 percent at a peripheral speed of 1370 feet per second.

Each of these increases to new size limits has been made only after extended operation at the preceding ceiling in a large number of machines. Such operation has not always been entirely free of difficulty, but it has invariably led to a solution of the problems encountered before venturing further. This is the situation as it now exists with the 20-inch blade, with which ample experience will be obtained before proceeding to higher levels. In making these progressive steps in exhaust-blade construction it has been found unnecessary to adopt new materials for blading or rotor, or to raise stress values appreciably. Probably several years will elapse before further increase in blade dimension can be considered.



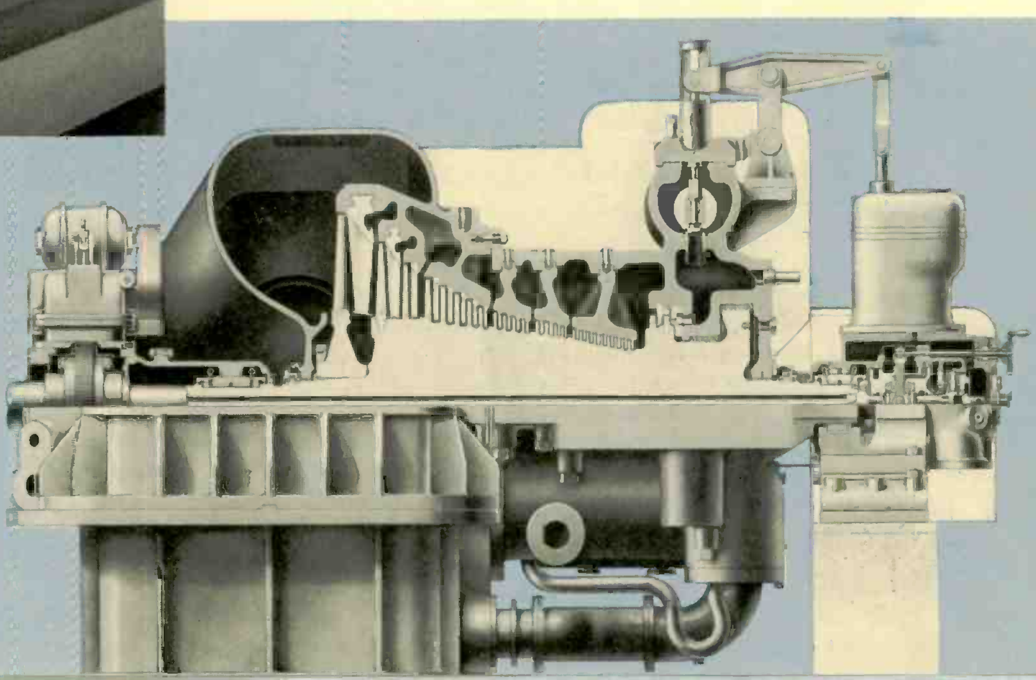
-compound turbine-generator unit. Sectional views
rbine, covers removed, are shown at left and right.

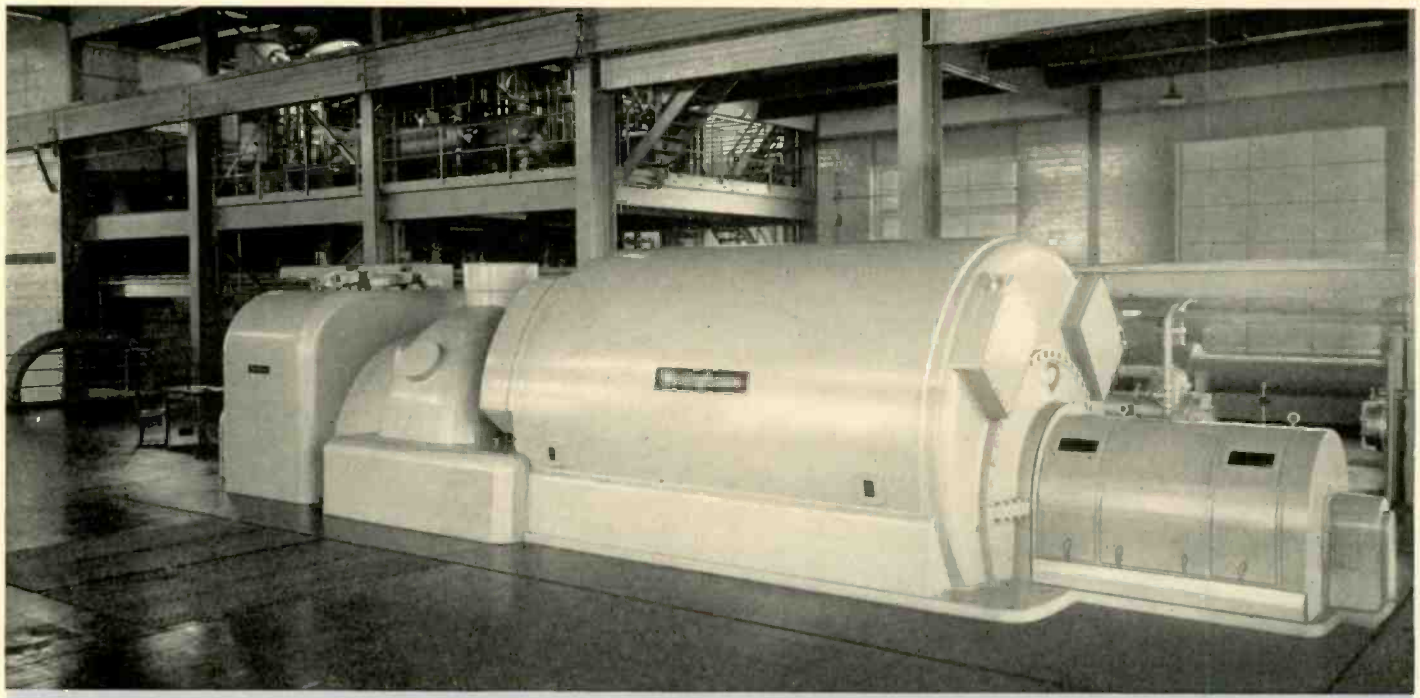
lly meeting unprecedented requirements
aced with an even larger and astounding
capacity is being added with all possible
ower more than a third since the 36 mil-
add another third to this again by 1950.

The above growth of limiting exhaust-blade annulus accounts directly for only about one half of the increase in maximum rating of high-speed turbines effected since 1929. The remainder is partially accounted for by the reduced steam flow through the last-row blade annulus, particularly with higher operating steam pressures, because considerably more steam is extracted for regenerative feed-water heating than was the case 18 years ago. Modern operating steam pressures and temperature make available some 25 percent more heat energy per pound of steam, as compared to 1929 levels, with a corresponding reduction in steam flow per unit of output. Further, each of the preceding factors permits of materially increased velocity of the steam as it leaves the exhaust blade annulus for a given percentage overall leaving loss.

The exhaust-blade annular area of a 3600-rpm turbine can never equal that of an 1800-rpm unit of similar arrangement. The relationship is about 1 to 4, at comparable stress levels. However, as long as the requirements of large-turbine buyers can be met at the higher speed, important advantages from use of the high-speed machine accrue to the power-generation industry. These include materially decreased weight of the complete turbine, and reduced weight and dimensions of most of the individual parts of the assembly. These factors facilitate procurement of materials as well as the manufacturing processes, and also reduce the required foundation mass and plant crane capacity.

These are minor considerations, however, compared with the contribution made to the successful use of elevated steam pressure and, even more particularly, temperature. For a given general arrangement of turbine, doubling the speed of rotation reduces the rotor and casing diameter by 40 to 50 percent. Thus, peripheral velocity of rotating parts is not doubled when rotating speed is doubled. Other factors being equal, reduced diameters permit a corresponding reduction in thicknesses of casing walls and bolting flanges. In turn, this leads directly to a structure that responds more quickly to the wide changes in steam temperature, with smaller transient gradients in metal temperature, which produce distortion, temporary or permanent. For the same reason, the higher speed turbine can be started from cold or partially cooled condition, and be put on the line relatively quicker. Further, smaller blading diameters in the early stages of the turbine are conducive to improved efficiency of energy conversion when handling the relatively small volumes of steam associated with prevailing elevated pressures. Growth of the 3600-rpm turbine is therefore based upon sound fundamen-





A 20 000-kw, single-case, hydrogen-cooled, high-speed turbine generating unit in a power station in the Southwest.

tals, which have been verified by a wide and extended service.

The Worth of High Pressures and Temperatures

Plant thermal economy is enhanced by elevating both steam pressure and temperature. The history of these steam conditions shows that between incremental increases in either or both are plateaus of some duration to allow thorough development of equipment for the new condition before proceeding to the next.

Superposed turbines have generally led the way in the elevation of steam pressures, reaching 1200 psi nearly twenty years ago at moderate temperatures, and arriving at 1600 psi at 950 degrees F in 1942. Most of the new, larger condensing turbine installations are being designed for steam supply at 850 psi, 900 degrees F total temperature, a condition well established by as much as ten years' operation. A much smaller number will use 1250-psi steam at 950 degrees F, supported, also, by several years of plant operating history. The forward-looking steps being taken currently are to 1500 or 1650 psi at 1000 to 1050 degrees F total temperature. Specifically, a condensing turbine rated at 40 000 kw is being designed for1650 psi, 1000 degrees F, another for 100 000 kw at 1500 psi, 1050 degrees F, and a third for 65 000 kw with 1450 psi, 1000 degrees F and with intermediate-pressure, boiler reheat to 1000 degrees F. Each will operate at 3600 rpm, tandem compounded with double-flow, low-pressure blading. The reheat unit, a recommended procedure, will have three turbine elements, not two, in tandem.

Practical limits of operating steam pressure and temperature ultimately may be determined by the turbine, or by the steam generator, superheater, piping, or auxiliaries. The economical limits are a function of equipment cost and demonstrated availability for service, fuel costs, load factors, etc. A new plateau is likely to be established on the time curve of both steam pressure and temperature, at the levels for which the new turbines are now being designed. Assuming that operation with 1050-degree F steam proves practical and economical for plants of high load factor, as is probable, the corresponding steam pressure could be advanced from 1500 to about 1800 psi without particular difficulty insofar as the turbine is concerned.

Some simple rules are useful in making preliminary approximations of the value of increasing temperature or pressure. Plant heat rate, i.e., Btu heat value of fuel consumed per unit of electric power generated, is reduced about three percent for each 100 degrees F increase of steam temperature at constant pressure. On this basis a plant employing 1250 psi, 950 degrees F has a 4.5-percent lower heat rate than one with 850 psi 900 degrees F. Also 1500 psi at 1000 degrees F may result in additional reduction of about 3 percent. Further, for estimating purposes, it can be assumed that a properly selected, single-stage intermediate reheat to the initial steam temperature brings a 5 percent reduction in heat rate. Likewise with such reheat, comparable heat rates are obtained with 150 degrees F reduction in initial steam temperature. These comparisons are but approximations, subject to variation in a specific case and are not applicable independent of unit size or equipment arrangement.

It is our opinion, based upon metallurgical and economic considerations, that 1050 degrees F operating temperature will not be exceeded in the early future. Also, if fuel prices continue their upward trend, an increasing number of the desirable reheat installations will be made at 950 to 1050 degrees F steam temperature level.

The Growing Acceptance of Standard Turbines

A substantial measure of standardization has now become available in the large-turbine field, and has attained considerable buyer acceptance within the past year. Proposed jointly by AIEE and ASME, six ratings of condensing, 3600-rpm turbines from 11 500- to 60 000-kw rating, inclusive, are included. With each of the four lower ratings—11 500, 15 000, 20 000, and 30 000 kw—standard units have fixed inlet steam conditions consistent with pressures and temperatures existing in many turbines purchased recently for each such capacity level. The 40 000- and 60 000-kw standard turbines each have two optional steam conditions, one 850 psi, 900 degrees F, the other 1250 psi, 950 degrees F. The higher one 1250 psi, 950 degrees F, is above that of most recent purchases. All frames have specified and fixed steam-extraction points for feed-water heating, whether or not actually used, and each has a specified maximum guaranteed capability output of 110 percent of rating with an absolute exhaust pressure of 1.5 inches of mercury with all extraction points in full use.

The standardization program presupposed that each manufacturer would provide his desired contingency marginal steam-flow capacity, over and above that required by the guarantee of maximum kilowatt capability. About 105 percent of maximum-load steam flow is customarily provided. It so happened that the first standard units considered were for installation in the South. This disclosed that in such warm climates the condenser circulating water is not cool enough to give the standard exhaust pressure of 1½ inches of mercury absolute. Standardized turbines were therefore designed to provide ample steam flow to meet the specified capability guarantee with standard steam pressure and temperature conditions, but with the exhaust pressure increased to 2½ inches mercury absolute. Other factors being the same, this higher exhaust pressure coincides with a 17 degrees F increase in circulating-water temperature. This variation makes it possible to furnish a standard turbine without sacrifice in the standard guaranteed output for practically any location in the United States. For plants that do obtain the lower exhaust pressure, the contingency marginal steam-flow capacity is, in effect, increased two or three percent, depending upon the particular unit and steam condition selected. With 30 percent of the standard turbines sold recently destined for installation in the South, this provision appears well justified.

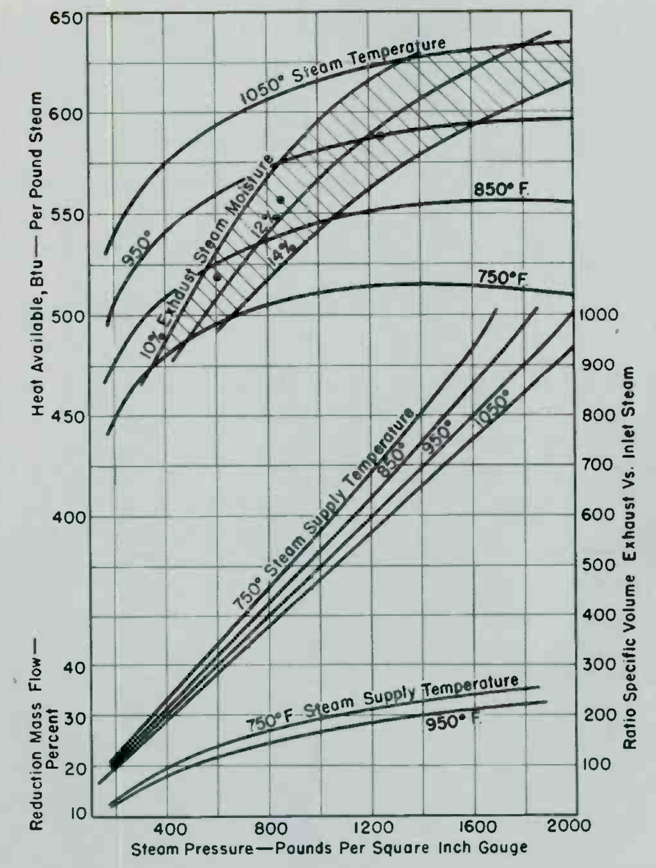
Several factors can properly make the purchase of standard turbines inadvisable, such as duplication of old units or connection into an existing steam header system not coincident with adopted standards. Nevertheless, the acceptance of standardized turbines has exceeded expectations. Of all turbines on order with Westinghouse in March to drive 60-cycle generators of 10 000 to 60 000 kw inclusive, standard units account for 40 percent of the number of units with 48 percent of the aggregate rating. As of last March, orders placed with Westinghouse for standard turbines were ratings of 11 500, 20 000, 30 000, 40 000, and 60 000 kw, with only the 15 000-kw standard unit as yet not applied. The total standard units on order aggregate 1 231 500-kw rating in 29 turbines. It is of interest to note that, of the 17 standard units rated at 40 000 and 60 000 kw, where alternative inlet steam conditions are offered, only one specifies 1250 psi, 950 degrees F steam.

Standardization means repetition in manufacture and the installation of thoroughly demonstrated equipment. After completing the initial design of each frame it permits immediate issuance of ordering and manufacturing information for all major and detail parts of the complete unit, except possibly the oil piping, if, indeed, the popularity of a given frame size has not warranted building for stock. Simultaneous manufacture of several duplicate standard units gives substantial assurance against delay, occasioned by possible rejection of a large casting or forging. Under normal circumstances—with turbine-manufacturing schedules not severely crowded as at present—the standard machine should be produced in less elapsed time than is required for the non-standard unit. Time saving will include that required for special development, and all that accrues from stocking of major parts. Correspondingly, plant design for general arrangement and for foundations can start immediately to match any accelerated production schedule that may accrue from standardization acceptance.

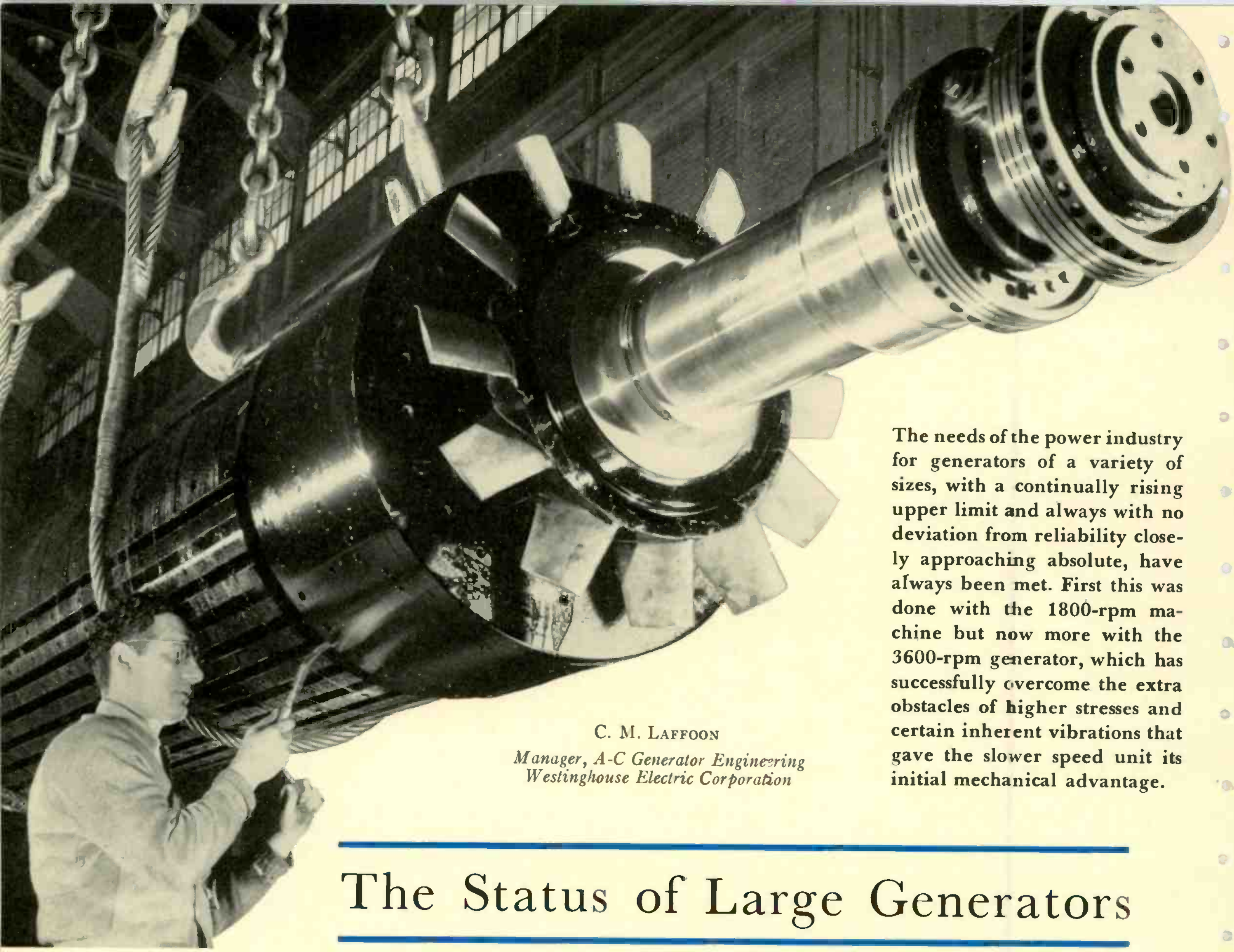
One of the logical results of reasonable activity in the purchase of standard designs is lower cost. Anticipating standards acceptance, and to stimulate consideration of standard machines, a price reduction of several percent was immediately offered so that early buyers would not be required to underwrite the savings of those who followed. The protracted time span from order date to shipment date, (with the need of careful cost reviews and adequate study of manufacturing methods) limits the economies of standardization until some time after appreciable shipments of standardized machines.

To be effective, standards must be flexible enough to meet developments. Present standards provide reasonable latitude for the anticipated continued upward trend in steam conditions selected for new installations. The largest standard unit rating—60 000 kw—was determined by the then existing maximum last-blade annular area. Subsequent development of new and larger last-row blading will, after satisfactory demonstration in service, make consideration of larger standard units possible.

Turbines of 3600 rpm to cover practically the entire field, combined with a good measure of standardization, will go a long way toward meeting current demands for rapid expansion of central-station power-plant generating capacity.



These curves show the influence of steam moisture and temperature on heat available for different inlet steam pressures. The center family of curves provides information as to the increase in volume of exhaust steam or inlet steam for the different initial pressures. The two bottom curves show approximate reduction of steam that must be handled by the exhaust for systems regenerated for feed-water heating a fairly high pressure point. All these curves are based on a standard of 1½ inches of mercury absolute exhaust pressure.



The Status of Large Generators

C. M. LAFFOON
Manager, A-C Generator Engineering
Westinghouse Electric Corporation

The needs of the power industry for generators of a variety of sizes, with a continually rising upper limit and always with no deviation from reliability closely approaching absolute, have always been met. First this was done with the 1800-rpm machine but now more with the 3600-rpm generator, which has successfully overcome the extra obstacles of higher stresses and certain inherent vibrations that gave the slower speed unit its initial mechanical advantage.

THE power-generating industry, hastening to keep pace with rapidly rising requirements for power, finds its only serious problem in connection with generators one resulting from the fact that so many are needed at once. It has available to it large a-c generators of proven dependability in all sizes—including the largest necessary, and even some standard units that simplify the problem of buying, lower the cost, and shorten the period between purchase and power delivery.

During the past decade the two-pole generator for large ratings has been thoroughly demonstrated as adequate. Its efficiency, reliability, and suitability for operating conditions compare favorably with units for 1800 rpm. The smaller and lighter rotating parts of the 3600-rpm turbine and generator greatly facilitate manufacturing, installation, and maintenance operations. At present single-shaft, 3600-rpm generators for ratings up to and including 80 000 kw or 100 000 kva at 0.8 power factor, and 90 000 kw, 105 800 kva at 0.85 are being built. A small number of 1800-rpm units are being built for 75 000 kw and higher at 0.8 and 0.9 power factor.

Before the two-pole generator could be built in the large central-station sizes solutions had to be found for certain problems inherent in the two-pole machine in addition to those that result from the higher speed. The double-frequency vibration problem was a major one but has been satisfactorily disposed of. Double-frequency rotor vibration, which is caused by the unequal rigidity of the rotor on its two major axes, has been eliminated without introducing rotor magnetic saturation. Uniform rigidity in the plane of the poles and at right angles to them is obtained by transverse slots machined into the pole faces. The double-frequency vibration of the stator core is kept within tolerable limits by using rigid cores, the laminations of which are tightly clamped together so that the built-up body functions as a solid cylinder.

Transmission of vibrations from the stator core to the housing, foundation and station parts has been reduced to a negligible magnitude by flexibly supporting the stator core with respect to the frame housing. The amplitude of these double-frequency vibrations transmitted to the foundation is barely measurable, and is comparable with that prevailing for four-pole generators. Some noise is transmitted from the stator core through the intervening air to the stator housing. The noise level of a 3600-rpm unit is somewhat higher than that of an 1800-rpm unit of comparable rating, but well within acceptable limits.

Hydrogen is now generally used as the cooling medium for all two- and four-pole turbine generators rated at 20 000 kva and more. Oil-treating equipment removes moisture, and other entrapped gases from the oil supplied to the hydrogen sealing glands. Sealing glands and the oil-treating equipment have performed satisfactorily and no troubles have been experienced. The hydrogen consumption for units operating at 0.5 pound pressure has been appreciably below the maximum expected value of 100 cubic feet per day. The oil-treating equipment represents an appreciable investment; elimination for the lower ratings, therefore, is attractive. Consideration is being given to development of sealing glands and methods of operating them that will make it possible to dispense with oil-treating equipment for small machines. If conservative clearances are provided and a reasonable amount of oil is passed through the seals, it is expected the consumption of hydrogen, while it will increase, will not be excessive.

Ratings of turbine generators assume a hydrogen pressure of 0.5 pound per square inch. For the past several years Westinghouse turbine generators have been made for operation up to 15 pounds hydrogen pressure with an attendant 15-percent increase in rating. Experience of several years with the higher pressure indicates that satisfactory operation at this upper range in gas pressure has been obtained with reasonable hydrogen consumption. With machines designed for this range of coolant pressure the machine can be operated either at the 15 percent additional rating or at the nominal rating with lower temperatures. The good performance record of such machines at the higher pressures suggests the future need to consider fixing the nominal ratings on the basis of a higher gas pressure.

The new AIEE-ASME jointly sponsored standards for 3600-rpm, central-station turbine generators have been available for more than a year. The standards are limited to ratings, characteristics, and performance. The nominal ratings are based on using the gas-cooling medium at atmospheric pressure or slightly above for the hydrogen-cooled units. A generator rating increase of 15 percent has been given for operation at 15 pounds hydrogen pressure. Ratings and rating characteristics for standard units are given in table I.

Designs and manufacturing tools for all but the two smaller sizes of standard generators are complete; it is expected that these two smaller sizes will be added this year. Supplementing the AIEE-ASME standardization for these ratings additional standardization covering primary construction features, location and arrangement of gas coolers, type and location of main lead terminals, terminal boards for temperature indicating devices, auxiliary equipment for treating the gland sealing oil, and drying the gas, and hydrogen-control equipment have been made by each manufacturer.

The acceptance of the AIEE-ASME standard turbine generators has been good. Further, the advantages of overall standardization by industry and manufacturers have exceeded the early expectations. Directly, it has made possible lower prices, shorter manufacturing time, and a better machine. Because final generator outline drawings, outline supplement and other drawings, are available for each of these machines they can be incorporated in the original negotiation proposal, made a part of the purchase contract, and later verified and certified after the order is awarded. This expedites the concurrent design of the generating station.

For the manufacturer, the new standard line makes it possible to stock primary elements such as rotor forging at different stages of completion, structural steel plate, electrical steel sheet of suitable size, and auxiliary equipment purchased from outside suppliers in anticipation of actual orders. Essential manufacturing information can be issued to the manufacturing department much more quickly. Now, with the large volume of generator construction, acceptance of the new standard line has prevented the development of a serious bottleneck in engineering design and drafting. Acceptance of the manufacturers' standards as well as the industry standardization program is likewise of great benefit in shortening the period between purchase and delivery. It would be helpful if unified manufacturing standards were to be adopted for additional items not covered by the AIEE-ASME standards and thus make possible further advantages to both builder and user. Meanwhile manufacturer and purchaser can cooperate so that by the end of 1947 most of the turbine-generator units within the standard-rating range will conform to the standards. Repetitive manufacture of turbine generators and auxiliary equipment, from available designs and manufacturing equipment, has the same order of importance as improvements in design and construction, in reaching a goal of lower costs and shorter deliveries.

When the new standards were being formulated, a user group representing utility systems of the larger cities, which normally require turbine generators above 60 000 kw, believed that the larger machines should be designed for lower power factor and higher short-circuit ratio. Twelve 3600-rpm turbine generators rated at 65 000 kw, 81 250 kva, 0.8 power factor, 0.9 short-circuit ratio, (or an equivalent rating) are now either in operation or under construction. Several 3600-rpm generators for ratings of 80 000, and 90 000 kw at 0.8 and 0.9 power factor for 0.9 and 0.85 short-circuit ratio re-

TABLE I—COMPARATIVE RATINGS OF PRESENT STANDARD 3600-RPM TURBINE GENERATORS WITH HYDROGEN AT LOW PRESSURE AND HIGH PRESSURE

Unit Size	Rating at 0.5 lb/sq in. Hydrogen Pressure				Capability at 15 lb/sq in.				Number Units[2] On Order[3]
	Kw	Kva	P-f	Scr[1]	Kw	Kva	P-f	Scr[1]	
1*	11 500	12 940	0.85	0.8					1
2	15 000	17 650	0.85	0.8					0
3	20 000	23 500	0.85	0.8	22 000	25 900	0.83	0.7	5
4	30 000	35 300	0.85	0.8	33 000	38 850	0.83	0.7	13
5	40 000	47 100	0.85	0.8	44 000	51 800	0.83	0.7	9
6	60 000	70 600	0.85	0.8	66 000	77 600	0.83	0.7	17

[1] Short-circuit ratio.
[2] Some units do not have standard ratings.
[3] As of March 1, 1947.
*Air cooled only.

TABLE II—COMPARATIVE RATINGS OF 3600-RPM TURBINE GENERATORS UNDER CONSTRUCTION LARGER THAN PRESENT STANDARD

Unit Size	Rating with Hydrogen at 0.5 lb/sq in.				Capability with Hydrogen at 15 lb/sq in.				Number Units Sold
	Kw	Kva	P-f	Scr	Kw	Kva	P-f	Scr	
7	65 000	81 250	0.80	0.9	81 250	93 500	0.87	0.78	3
8	80 000	100 000	0.80	0.9	100 000	115 000	0.87	0.78	5*
9	100 000	125 000	0.80	0.9	125 000	143 750	0.87	0.78	0

*Includes two generators at equivalent ratings for different p-f and Scr.

TABLE III—RATINGS OF PROPOSED VERY LARGE HIGH-SPEED GENERATORS AT THREE GAS PRESSURES

Unit Size	Capability at 25 lb/sq in. Hydrogen Pressure				Capability at 15 lb/sq in. Hydrogen Pressure				Capability at 0.5 lb/sq in. Hydrogen Pressure			
	Kw	Kva	P-f	Scr	Kw	Kva	P-f	Scr	Kw	Kva	P-f	Scr
10	125 000	147 000	0.85	0.8	116 500	137 000	0.85	0.85	91 250	107 000	0.85	1.0
11	150 000	176 500	0.85	0.8	140 000	165 000	0.85	0.85	109 500	129 000	0.85	1.0

spectively are being built. As a result 3600-rpm turbine-generator units for ratings above 60 000 kw are being projected and developed as needed. The ratings and characteristics of the three unit sizes now considered are shown in table II.

Although several 1800-rpm turbine generators of 75 000, 80 000, 100 000 kw and above are being built, it is expected that in the future most units up to and including 100 000 kw will be high-speed machines. In considering the 3600-rpm turbine generator for 100 000 kw and more, it is necessary to take maximum advantage of the highest quality forgings procurable for the rotor and retaining rings, to provide the most effective ventilation for the rotor winding, and to have a coordinated rotor design in which the materials and construction are adequate to withstand the continuous and alternative forces and stresses imposed on the component parts by rotation and thermal cycling. In meeting the higher ratings it is also necessary to increase the power factor, reduce the short-circuit ratio, and to increase the hydrogen gas pressure.

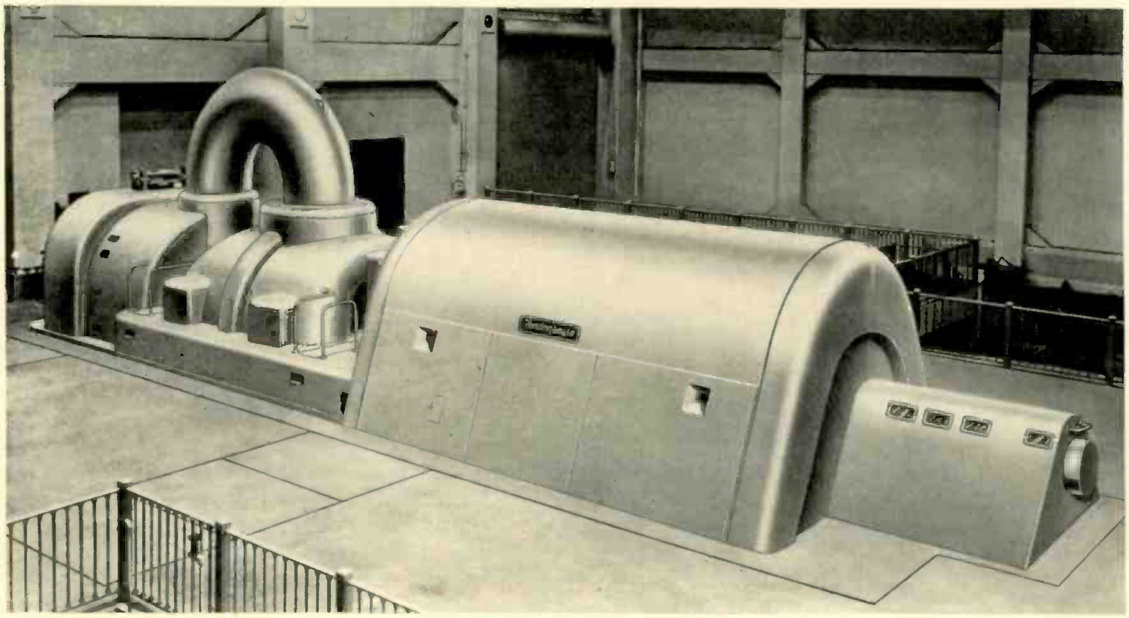
For large machines, consideration is being given to gas pressures up to 25 or 30 pounds per square inch. Experience indicates that approximately one-percent increase in rating can be obtained for each pound increase in hydrogen pressure up to a total pressure of 25 pounds, after which the rate of increase tapers off. The nominal rating has been based on 0.5 pound per square inch hydrogen pressure and an increase in rating specified if higher gas pressures are employed. Since the stator and rotor windings and the stator core respond differently to the ventilation at the higher gas pressures the actual temperature conditions are somewhat unbalanced when operating at the higher pressures. For the largest ratings, it is proposed to design the unit for maximum rating at the highest practical pressure, and then specify the ratings for the lower gas pressures.

The mechanical construction of a turbine generator designed for 25 or 30 pounds gas pressure is different and more costly than that for 15 pounds. The housing for the stator will require thicker walls and heavier welds. The joints between end bracket halves, and between the end brackets and the cylindrical housing sheet require much heavier flanges with larger and increased strength bolts. The increased flow of oil to the sealing glands requires more oil-treating capacity. It is further anticipated that some increase in gas consumption will result.

The projected ratings and characteristics for 3600-rpm units for ratings in excess of 100 000 kw are shown in table III. For these units it is expected that shaft-mounted, high-pressure, propeller-type blowers will be used to circulate the hydrogen. The design will allow the same factor of safety for stress loadings, vibration, performance efficiency and reliability, and thermal margin as for smaller units.

For the ratings given in table III it is further recommended that two departures be made from present practice with respect to the voltage of the stator and rotor windings. Because of the limitation in the current-carrying capacity of the main lead terminals, it is recommended that the most economical voltage be used for each rating. This would be the voltage that would normally result from the use of single-turn half-coils, and the winding Y-connected in two parallel or two-winding circuits. The most economical potential falls between 13 800 and 18 000 volts, terminal-to-terminal. To reduce the magnitude of the excitation current to be handled by the collector rings and the exciter, the excitation voltage should be 375 or 500 volts. Two 81 250-kva, 3600-rpm generators are now being built for a 375-volt excitation system.

Most Westinghouse 3600-rpm generators in service and under construction are provided with direct-coupled, 3600-rpm main and pilot exciters. A few units, however, are being built without direct-connected exciters, but will use either 1200-rpm, motor-driven exciter sets or electronic excitation. One electronic excitation system is in operation at the Springdale Station of the West Penn Power Company and is performing satisfactorily. Three generator units are being built with electronic excitation systems in which the electric power is supplied to the electronic equipment by direct-driven, six-phase auxiliary generators. While acceptable performance of these electronic excitation systems from the standpoint of reliability and availability is anticipated, the facility with which direct-connected exciters may be serviced and the ready accessibility to brushes and brushholders provided, may conceivably go a long way to retain operator approval of a known and tried excitation means. The initial cost of the electronic excitation system is much higher than that of the direct-coupled or the motor-generator exciter. The performance of these electronic excitation systems, with their course along the "development plateau" just started, will be watched with considerable interest by the central-station industry.

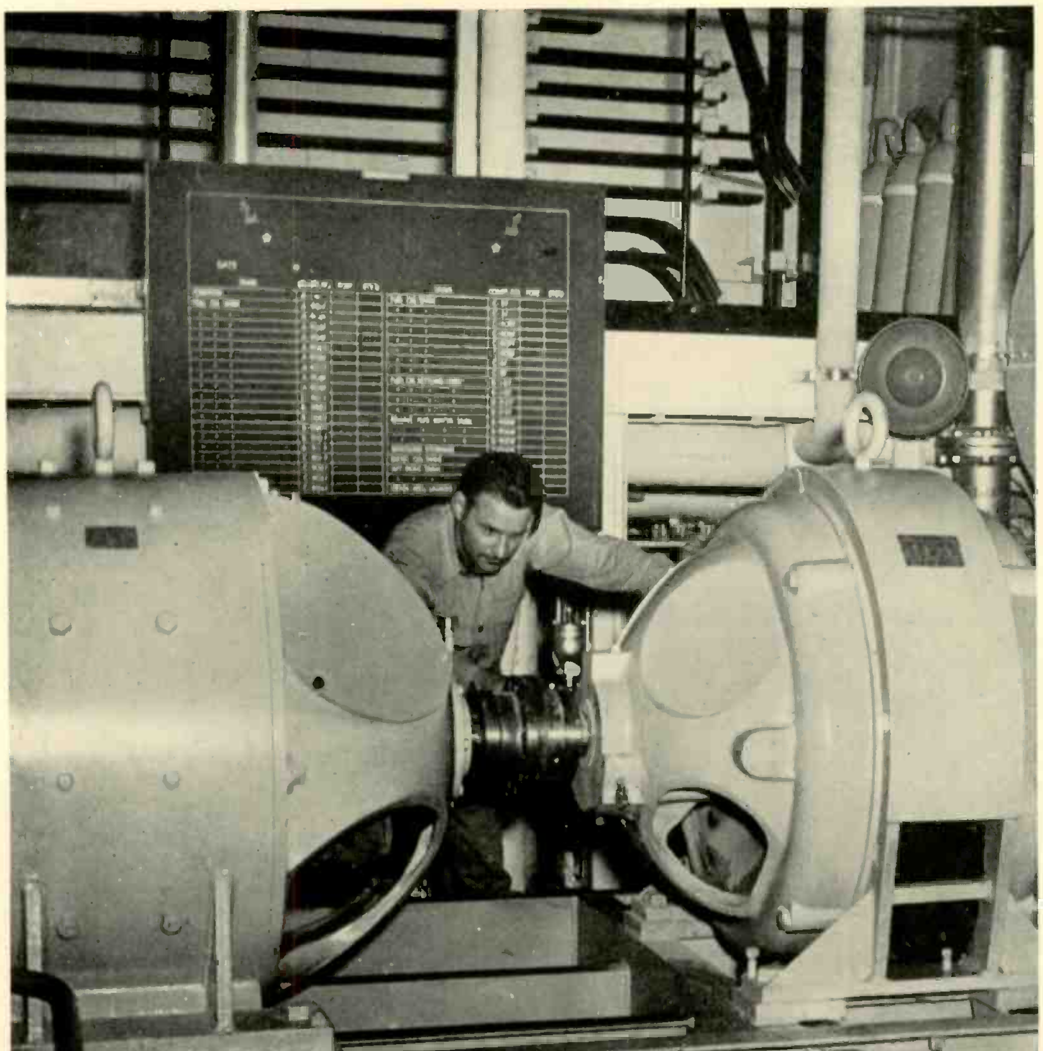


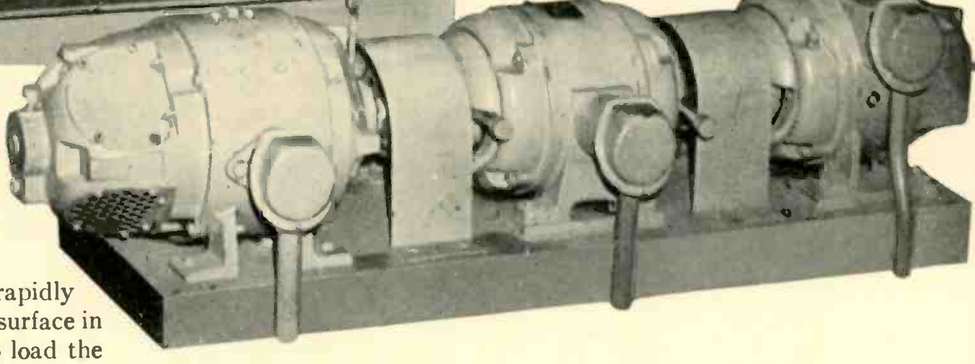
A representative modern large tandem-compound turbine generator for operation at 3600 rpm. It employs a direct-connected exciter. The streamlined generator housing gives little evidence of the presence of the heat exchangers employed in the hydrogen-cooling system in use here.

Rototrol Reduces Size of Ship Drives

Reminiscent of the stone that tamed Goliath is the Rototrol, the little motor-generator set that curbs the high torque swings on a-c drives for ships. With Rototrol, propulsion machinery is considerably reduced in size, allowing designers of machinery to save space and weight for payload cargo.

S. L. Lindbeck
Marine and Aviation Section, Industry Engineering Department, Westinghouse Electric Corporation



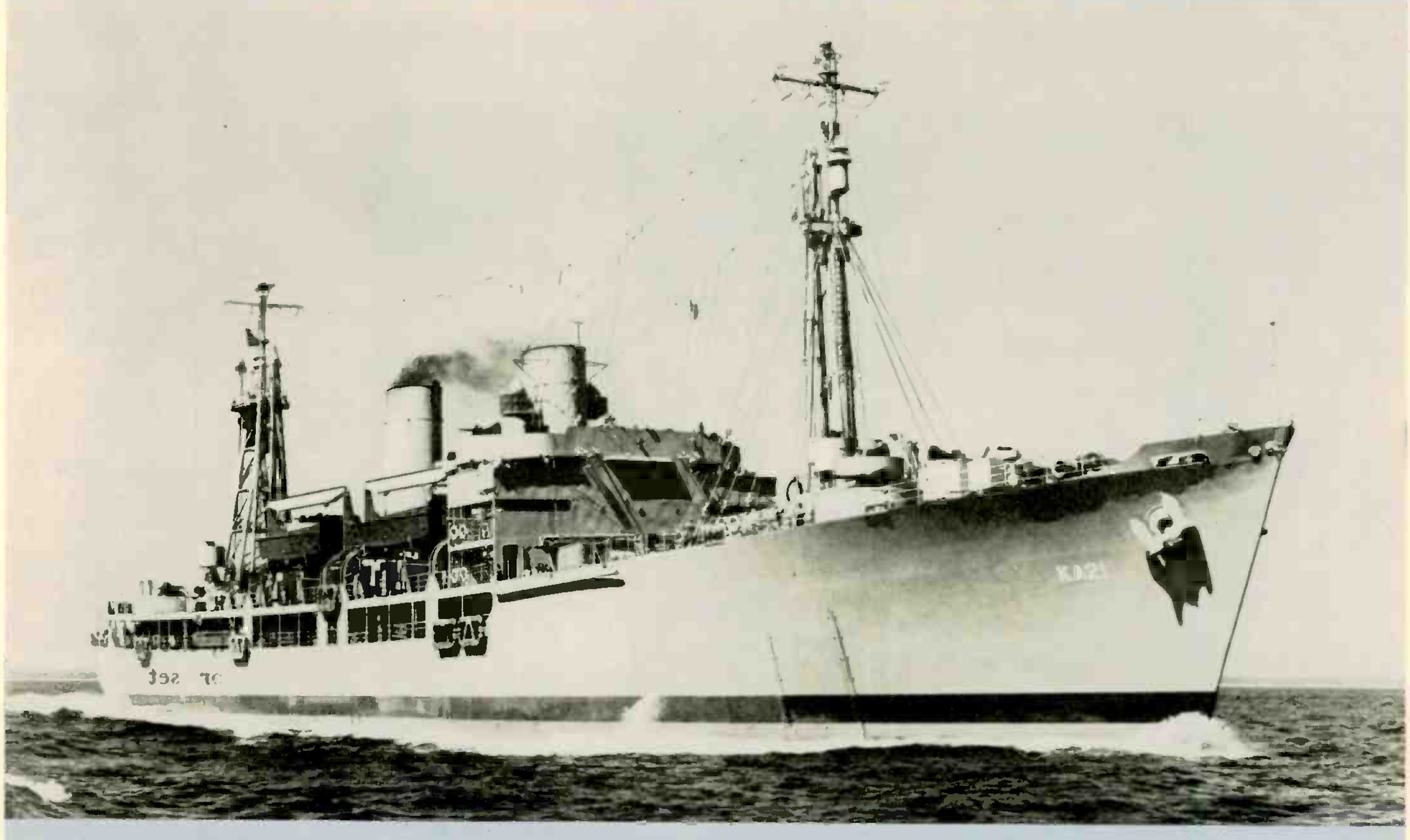


The small, three-unit Rototrol control, shown at the right, excites the 90-kw propulsion exciter and the 250-kw general ship service generator, above. Exciter and generator are on one shaft.

The propeller power requirements of a ship change rapidly during maneuvers, or when the propeller breaks surface in heavy seas. Twin-screw vessels have a tendency to load the inboard screw heavily on turns. The peak propeller torques reach 125 percent or more of full-load torque, depending upon the type of vessel and service. If these transient high-torque demands are limited in some way so that the motor and generator ratings can be determined by load and normal overload requirements the propulsion machinery can be smaller and lighter. Rototrol control of the motor excitation provides means by which this may be accomplished.

Sixty-four transport vessels built for the United States Maritime Commission in 1943 and 1944 were fitted with Rototrol excitation systems for their turbine-driven electric generators and synchronous-motor propulsion equipment. The speed of the propeller is determined by the speed of the generator which, in turn, is controlled by the steam-turbine governor. Actually, the governor on the steam turbine maintains the generator speed constant at any given setting. The transports are twin-screw vessels of 6800 tons displacement with two independent 3300-hp synchronous motors located in separate engine rooms. A substantial saving in weight was easily possible with Rototrol excitation control. The propulsion motors and generators on each ship weigh sufficient to effect a net saving of 20 000 pounds for each vessel.

Two methods of providing for load surges are available. One, used until a few years ago, was to design the equipment to carry the maximum expected load with a safe margin, requiring that the motors and generators be designed to operate at approximately 125 percent torque without pulling out of step and stalling. The other method is by rapid and sensitive excitation control. This is possible because the torque limit of an a-c generator and motor system increases with increase in the field current. For the usual a-c ship drive, comprising a synchronous generator and synchronous motor, the pullout torque is approximately proportional to the product of motor and generator field currents. When motor and generator fields are supplied by a single exciter, the necessary 25 percent mar-



One of the cargo transports in which the Rototrol control described in the article is fitted.

gin above rated torque can be provided by approximately 15 percent increase in excitation voltage. If the field current of only one machine is raised, the proportional increase must be twice as great. The transport drive utilizes the change in motor line voltage and current with load to vary the excitation voltage with load automatically.

As shown in the simplified circuit diagram, field of constant strength, No. 1, provides a base value of excitation voltage, which is either strengthened or weakened by the action of the regulating fields, Nos. 2 and 3. Field No. 2 is energized by a current transformer in the motor-armature circuit. Field No. 2 is proportional in strength to the motor current, hence an increase in propeller load results in an increase in strength of field No. 2 which is added to the basic excitation provided by No. 1. Field No. 3 is a differential field that responds to voltage divided by frequency. This is usually referred to as a "volts-per-cycle" response. The desired action is obtained by the use of a reactor in series with the field rectifier. The reactance is large compared to the resistance in the circuit. The current is thus proportional to motor voltage and inversely proportional to frequency.

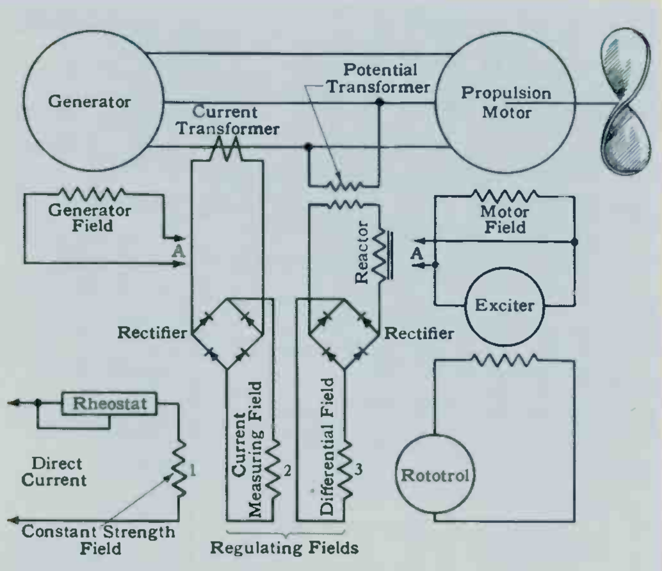


Fig. 1—Simplified circuit diagram of a typical Rototrol control system for ship propulsion.

At normal full load, the current and voltage measuring fields are approximately equal and opposite and hence nullify each other. An increase in load increases the motor current and reduces motor voltage, meaning an increase in strength of field No. 2 and a decrease in strength of field No. 3. The net result is a large increase in excitation and an increase in pull-out torque limit. Under all operating conditions, a considerable margin of torque capacity is obtained, although tests have indicated that operation is possible with the machines running under conditions that would result in loss of synchronism if fixed field current were used.

The Rototrol circuit used on the transports is simple and reliable. No mechanical devices in the control system such as relays or switches are employed. Except for slight compensation required at long intervals due to aging of the rectifiers, no periodic adjustment or maintenance operations are necessary. The Rototrol generator is of the same construction as a standard d-c machine and can be maintained by any operator familiar with conventional d-c motors and generators.

The results to be expected with controlled excitation of synchronous machines were determined by laboratory tests before the construction of these vessels. In addition to the study of ship-propulsion systems, the performance of Rototrol control of synchronous motors on large power systems has been investigated. Rototrol control is not limited to marine applications. Where fitted to industrial synchronous motors subject to variable loads, important improvements in pullout-torque rating, efficiency and power-factor characteristics are obtainable.

PR Plating—A New Tool for Electroplaters

Fabrication of a part is only one phase before its use—it must then be sold. Before this can happen it must first be plated and polished to a high degree of brightness. That takes money—and time. PR plating shows the way to a significant saving of both—and to a superior plated product.

GEORGE W. JERNSTEDT

Manager, Electroplating Projects Department, Westinghouse Electric Corporation

IN the production of brightly finished plated parts, the subsequent buffing and polishing amounts, usually, to between one half and two thirds of the total cost. This serious and entirely disproportionate outlay spurred development of a process, revolutionary in theory and yet simple in application, that produces a brighter and smoother plate—a prime requisite—and at a greatly enhanced plating speed.

The development is known as Periodic Reverse-Current Electroplating, and, as its name implies, is a reversal of the plating current under specified optimum timing conditions with respect to both chemical composition of the bath and timing. It will be referred to as PR plating throughout.

Weaknesses of Unreversed Direct-Current Plating

The problem associated with conventional systems of unreversed direct-current electroplating, heretofore centering around the high cost of finishing (buffing and polishing) stems, for the most part, from basic deficiencies in the systems as a whole, rather than the mechanics of finishing.

These basic deficiencies resulting in nodules, roughness of plate, dullness, porosity, corner build-up, corrosion susceptibility, long have plagued the industry. They have limited the amount of plate that can be deposited, so that serious difficulties are encountered when metal deposits of even five mils (0.005 inch) thickness or greater are attempted. The electrodeposits become progressively more nodular, rough and nonuniform in thickness, often occurring as coarse crystalline coatings, or coatings having the appearance of tree branches. Uniform flow (unreversed) direct-current electroplating tends initially to deposit sound metal, but the plate becomes progressively poorer in structure and smoothness as more metal is deposited.

The Theory of Ordinary Electroplating

The theory underlying conventional forms of electroplating requires that by electrolysis—using an electrolyte as a "carrier" or "transporter"—metal dissolved from an anode is deposited on the cathode, i.e., the base member or material to be plated. This is accomplished in the following manner: steady, uninterrupted direct current so dissociates the atomic structure of the anode that electrons at the cathode attract

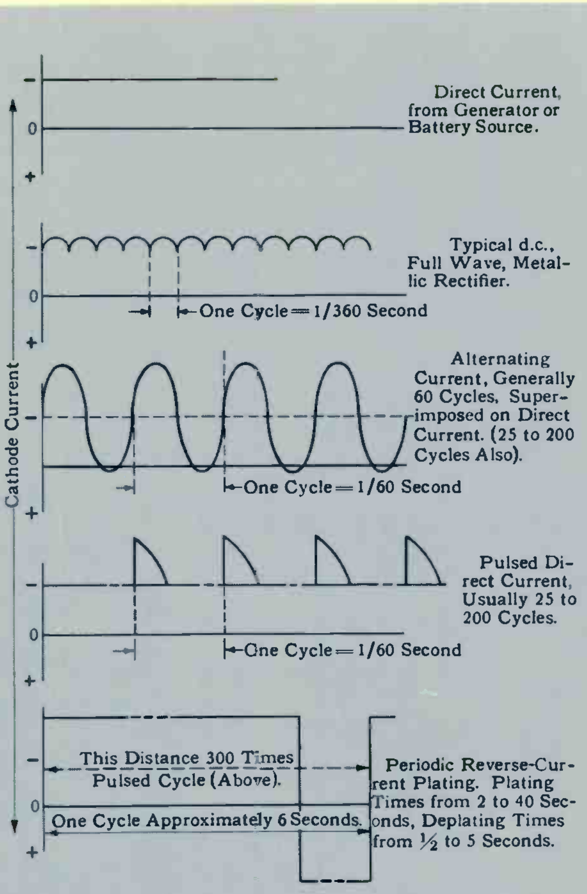


Fig. 1—Graphical presentation of different plating systems. Results of the first four are similar. The fifth shows that the length of the overall cycle (plating and deplating) is 300 times that employed in the first four. The actual number of coulombs employed in the reverse period is sufficient to deplate 20 to 40 percent of the metal deposited in the plating or first part of the cycle, and efficiency is correspondingly aided.

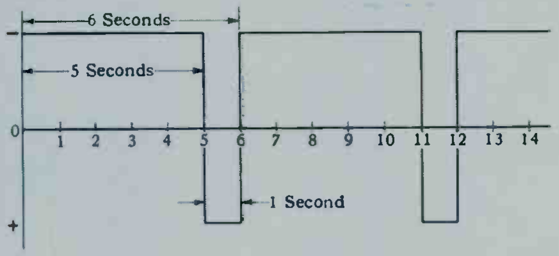


Fig. 2—Theoretical current wave for PR plating using five seconds of plating, and one second reversal.

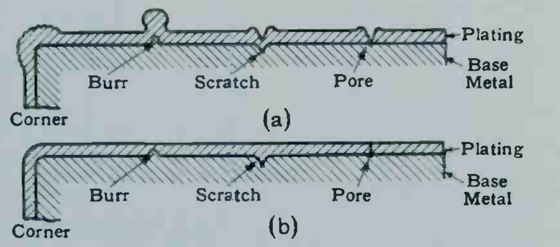
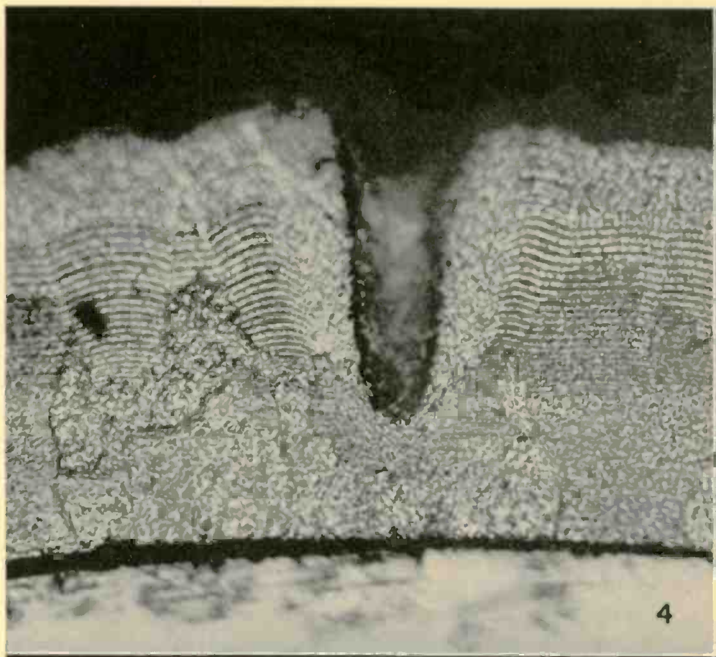


Fig. 3—(a) shows the results of unreversed direct current, and (b) the benefits to be expected from PR electroplating with properly timed, current reversals.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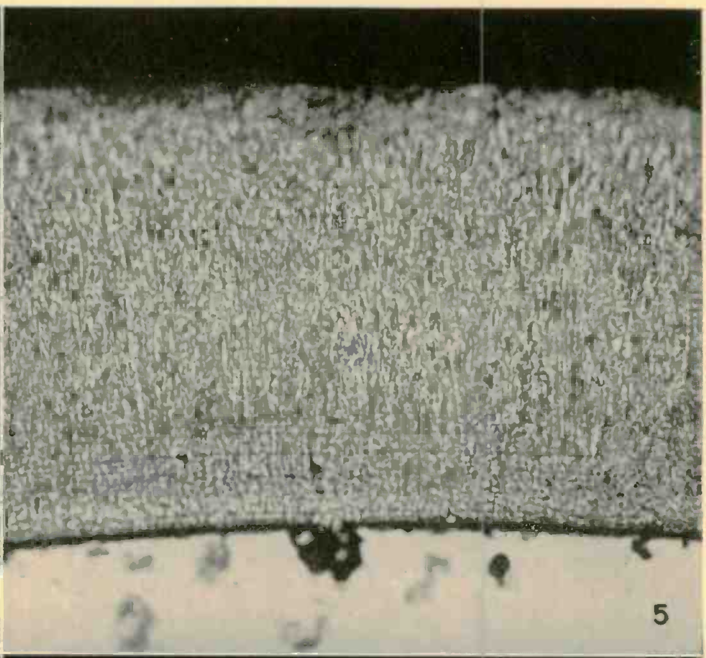
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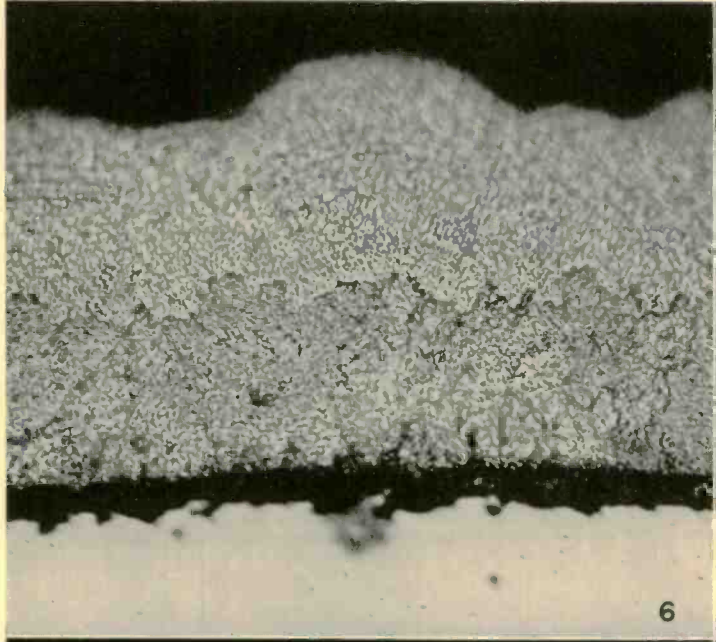
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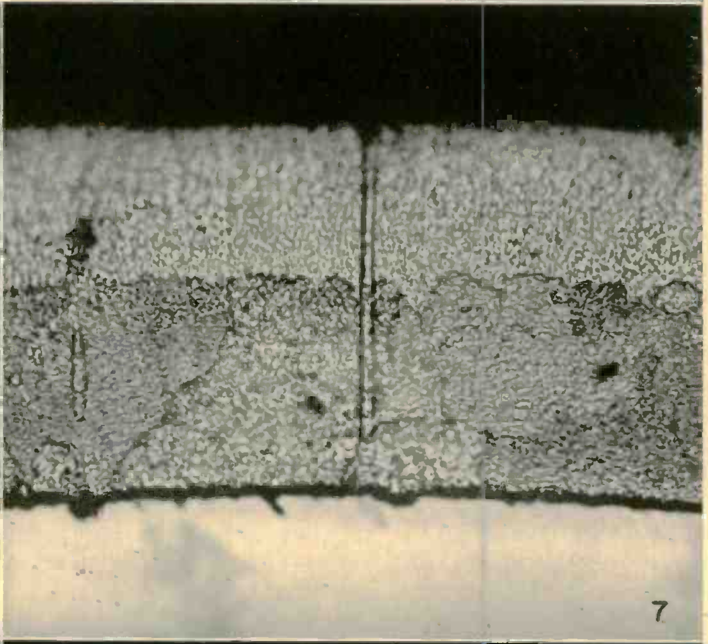
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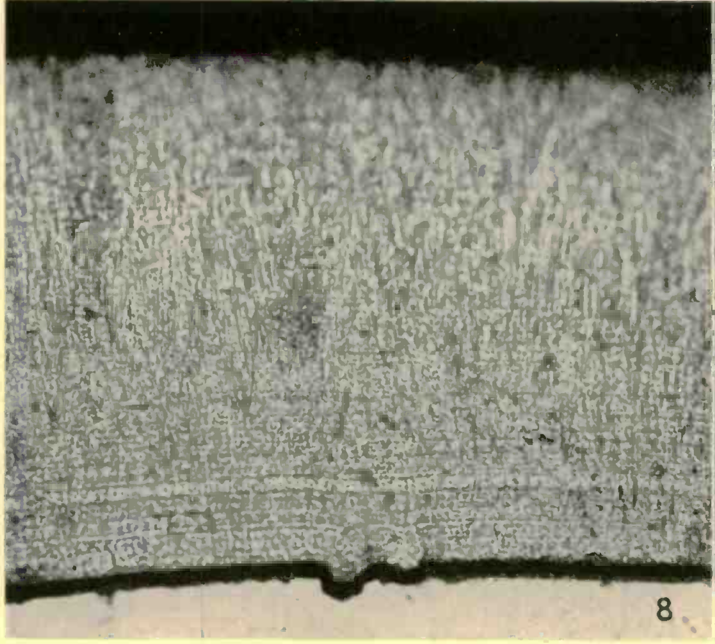
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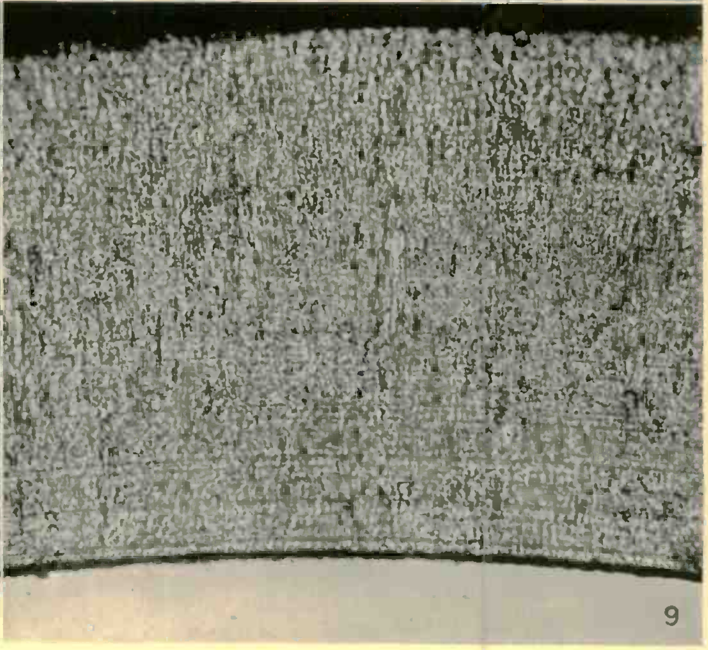
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Comparisons of metals plated by unreversed direct current and by the PR system are shown in Figs. 4 and 5. The pore in Fig. 4 and the striations or series of dark lines are missing from Fig. 5, which shows a deposit made from the same bath but reversing the current periodically 3½ seconds cathodic, ¼ second anodic. Ordinary, unreversed d-c, high-speed copper plating, even with rapid filtration and agitation reveals many imperfections. Microscopic roughness and nonuniformity in the base metal result in Fig. 6. A cross section of a gas bubble pore is shown in Fig. 7. With the same solution and procedure, but using PR plating, Fig. 8 shows how the copper quality has been improved. A scratch on the base metal has been filled after 0.001 inch of copper has been deposited. The uniform quality of PR plated copper from base to outer edge of deposit is shown in Fig. 9.

the positively charged ions traveling from anode to cathode, or already at the cathode. When they meet, the ion ceases to be positive since it has received an equal and neutralizing electron, and becomes instead a particle or atom of its original chemical structure, adhering to the cathodic base member as such.

The basic limitations of this method, as exemplified in practice, are threefold: (1) excessive reduction in the concentration of metal ions in the solution adjacent to the cathode, and the building up of too high a concentration of undesirable ions at both electrodes, (2) a defined limit on the current density, (i.e., "dissociating speed") which is governed by the rate of electro-chemical reaction at the electrodes, (3) polarization—an indirect result of number one. All three can be explained as follows:

In electroplating a metal using a particular electrolyte, a limit to current density is reached when the electrolyte immediately adjacent to the base member becomes so depleted in the metallic ions it is carrying or supporting that further increases in current do not produce proportional metal increases. Thereafter water in the electrolyte begins to decompose, depositing a film of hydrogen or causing high concentrations of undesirable ions adjacent to the surface of the metal. Known as polarization this film insulates the surface and greatly diminishes the amount of metal deposited by a given quantity of electricity. Plating speed ordinarily is controlled so as to prevent or minimize this condition.

The PR Electroplating System

Reversing the current passing through the anode element and the cathode base member makes the base member become the positive pole during reversal. The electronic theory given for conventional plating is changed only in direction — the ions in migration in the electrolyte travel on an opposite path. Since ions now are given off from what was the cathodic base member, but which is now the anode, they are carried through the electrolyte to the new cathode (before the current reversal this was the anode), where they meet electrons which change them into atoms. They revert to their original chemical structure and redeposit themselves.

Were the reversal to be held for long periods the newly plated metal would disintegrate completely. However, the reversal is of short duration, frequent repetition of the cycle serving to build up a plate quality superior to anything previously obtained from straight unreversed direct current.

In effect, the PR system makes it possible both to improve surface smoothness and brightness, and to enhance the body quality of the deposit. This occurs because of the electrical "back-stroke" feature of the reversed current cycle. PR plating continuously refines the grain structure of the deposited metal. The random structure of ordinary, unreversed plating, revealed by the photomicrographs as gaps and lines or striations, is smoothed out to a cohesive, integrated whole. The deposits made with PR plating are more dense and of greater homogeneity, well bonded, and displaying greatly enhanced physical properties of strength and elasticity. Porosity flaws are markedly reduced, and corrosion resistance improved.

Two additional advantages appeal to platers. One is the absence of inferior plated metal resulting from (a) burned electrodeposits, (b) nodules, (c) exaggerated build-up of metal at corners or sharp points, (d) the presence of defects caused by burrs or scratches existing in the base metal. The second, enhanced smoothness, is most significant. With the new process it is possible to produce a plate considerably smoother than the surface of the base member to which it is applied. As an example, 0.0015 inch of copper has been applied to shot-blasted steel without evidence of the roughened base showing through, and despite the thin plate deposited.

The process is particularly applicable to depositing thick, dense copper coatings. It is possible to electroform parts such as an engraver's plate, in a cyanide solution, thus avoiding the limitations of the acid copper bath with its poor throwing power and double current requirements. Throwing power describes a plating system's efficacy in depositing metal in recesses or distant parts of the base member, as compared to the rate at which near or protruding parts are coated. The current required to deposit copper from an acid bath is double that required to deposit copper at the same rate from a cyanide bath. In an acid solution, copper is divalent, requiring two electrons to discharge the ion, whereas in cyanide solutions, it is monovalent, that is, requires only one electron to discharge the ion.

With PR plating, the plating portion of the cycle can be carried out at greater current densities, and therefore greater rapidity. To deposit 0.016 inch in thickness of copper on watthour magnets using high-speed copper-cyanide barrel or "tumbling" plating with unreversed direct current, requires 7 to 10 hours. Using rack plating where the base member is held stationary in a rack, the time has been cut to some five hours, but the plate then is so nodular as to be pebbly in appearance. With the new process a superior deposit has been produced in less than four hours, and occasionally this can be done in 3½ hours. Possibly, following future developments, the time could be cut to about two hours.

Almost any thickness of plate, even up to ¼ inch, can be produced without undesirable surface flaws. Even here, the speed of plating can be increased without sacrifice of quality.

In operation for some time at an automobile plant, PR plating has reduced the cost of finishing a part from 50 to 25 cents, while the deposited copper has been increased from slightly over 0.001 inch to 0.0030 inch.

Several improvements have been developed to increase the field of application of PR plating. Details of various commercial applications are being worked out as rapidly as possible. These may include unique uses such as the plating of deeply recessed areas or the apparent reversing of the throwing power rule. Throwing power ability, when referring to unreversed systems, concerns the uniform plating of shallow recesses and protuberances. Under these conditions a protuberance or edge will plate faster and with more metal than a recess; to get at the recesses requires an increase in current density. These limitations disappear with PR plating, because, at the moment of reversal (and using purely hypothetical numbers) three ions may travel from an edge, and only one from a distant recess.

Applications

The PR process can be applied by several methods. The most obvious is to reverse the current at the electrolyte tank. This is accomplished by means of low-voltage contactors with a timing device. Another method is to reverse the field current in the generator, which is done by a timer similar to the one employed in the low-voltage reversing method and which operates relays of suitable size to carry the generator field current. A large contactor suitable for low-voltage, high-current application is now being constructed.

Best results are obtained from PR plating when a cycle is used in which the plating current is applied for a period of from two to forty seconds, and the reverse current for a period of from one half to five seconds. This reverse-current period is sufficient to remove the inferior metal plated while the work was cathodic. Repetition of the cycle builds up the plate to any desired thickness.

The reversal of current deplates from ten to fifty percent of each increment, depending on the duration of the reverse current. The amount to be deplated per cycle is regulated in accordance with the desired quality of both increment and overall deposit of plated metal.

It would appear that, with a reverse or deplating current cycle, the overall efficiency would be reduced as compared to continuous direct-current plating. For example, with a six-second plating cycle consisting of five seconds plating time and one second deplating (reversed current) time, the net amount of metal deposited would appear to be no more than could be applied in four seconds or two thirds of the time using uninterrupted, unreversed current. This apparent time loss is largely hypothetical for the loss, if such it may be regarded, is compensated by other factors, i.e., 100-percent efficiency in the plating, even where, in the unreversed, uninterrupted process, the efficiency is normally of the order of 80 percent or lower.

The reverse current is so brief that it results in a high density of metal ions near the plate; the plating part of the cycle is expedited and the subsequent plating efficiency improved. This effect compensates, in part, for the current consumed in the reverse part of the cycle. Actually, the amount of metal plated is not far short of that deposited for the same time and current density, using unreversed, uninterrupted direct current flow, as in ordinary systems.

Electroplating using the PR process can be done in conventional electrolytes, although preference exists for the cyanide baths, such as copper cyanide. Brighteners such as sulphonic acids or long-chain betaine compounds are added to some ordinary, unreversed systems as organic additions to refine the metallic grain size. Sometimes they are added to reduce surface tension, and for this the aryl sulphonate baths are used. Brighteners can be left out of a bath when using the PR system, although they help in some cases. The full benefits of PR plating may not be evident at normal operating conditions of the bath. Where this is indicated, changing such factors as temperature, metal concentrations, bath acidity or alkalinity, etc., will result in considerable improvement.

PR plating works much better with some electrolytes than others. A definite and substantial improvement is evident in most acid baths such as nickel chloride, and with the alkaline baths such as an electrolyte of copper cyanide. It is in the cyanide baths, however, that results with the PR process are outstanding: smoother, brighter, and more corrosion-resistant coatings are produced in almost every case.

Experience with various metals other than copper shows that the electrolytes most suited for the new process are, in general, of the cyanide type, such as silver, zinc, cadmium, and gold. Brass although not a satisfactory bright-plating metal, works very well and even can be made to plate bright entirely without addition agents.

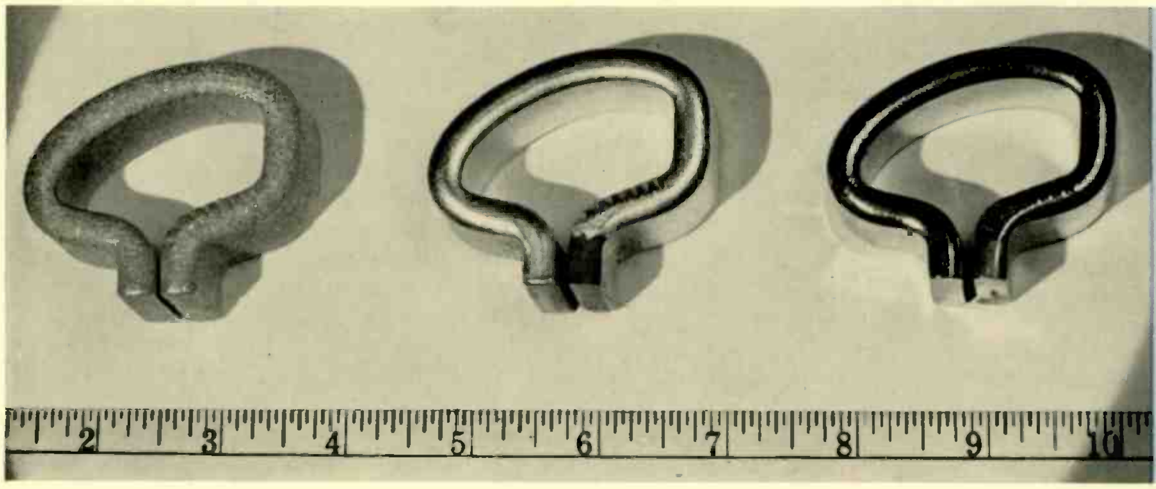
The suggestion has been made that, by reversing the current for a small fraction of a second, depolarization could be accomplished and better plating obtained. This procedure has been tried but no significant benefit was found, nor was any improvement noted in the deposited metal.

Conclusions

While PR plating is not a panacea for all plating ills, already it has proved itself to be an exceptionally worthwhile tool in some of the largest copper-plating installations in the country. In general, it results in one or more of the following:

1—Increases the rate of plating
2—Increases the density of the metal deposited
3—Improves the brightness of the surface
4—Applies plated metal smoother than the base metal
5—Allows heavier deposits
6—Decreases porosity
7—Provides better metal distribution.

The process is flexible and any one particularly desired feature can be emphasized. The PR system produces a fundamentally different type of deposit. The plate is composed of numerous minute increments of sound metal of high quality resulting in a materially improved product. Moreover, the process, in general, provides greater flexibility of solution control and operational tolerances than do other systems.

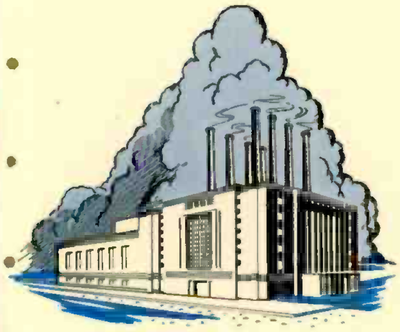


Plating evolution of a watthour meter magnet. The magnet on the left has had 7-10 hours conventional plating with a tumbling motion. Five hours with ordinary plating, but using a stationary rack motion, is shown at center. The fine quality of PR plating (right) obtained in 3½ hours shows distinctly.

Unit-Type Generating Station Networks

The secondary network power supply to auxiliaries in stations where a generator and its transformer are operated as a unit gives that added measure of reliability for which the distribution system is noted. The added cost and complexity are negligible factors compared to the benefits derived from its flexibility.

JOHN S. PARSONS • *Distribution Engineer* • *Westinghouse Electric Corporation*



A SECONDARY network system, in plants where each generator and its step-up transformer are treated as a unit, can be devised to supply all auxiliaries in the station. In cost, such a system would be comparable to that of others, and would have the added advantage of service reliability and flexibility for expansion as station capacity increases in step with increased power demand.

The simplest and least expensive connection of primary feeders to supply the network is shown in Fig. 1. Each of the network feeders F_1, F_2, and F_3 is tapped off the leads of a generator through a three-pole, gang-operated disconnect, (D_1, D_2 and D_3) preferably of the load-break type. Each feeder and its associated network transformers should have sufficient capacity to carry the auxiliaries of the largest generator without overloading. Feeder F_4 provides the supply from the system so that the station can be started. It utilizes the transformer T_1 and high-voltage breaker B_1 of generator 1 for connection to bus 4 and the system. To make feeder F_4 independent of generator 1 it is necessary to install breaker B_{1a}. The capacity of feeder F_4 and its associated network transformers should be equal to that of one of the other primary feeders. With the amount of capacity in the feeders and network transformers mentioned above, our studies indicate that no serious overloading of any part of the system occurs, although the various feeders do not load equally at times.

A primary-feeder fault results in shutting down one generator. For example, a fault on feeder F_3 causes unit 3 to be disconnected from the system by the opening of breaker B_3. The faulty feeder F_3, however, can be disconnected quickly from the system by opening disconnect D_3. Service from unit 3 can then be restored, since its auxiliaries can be supplied from the secondary networks under such contingencies.

Electrical interlocking is necessary to prevent an attempt to synchronize any of the generators through the network or networks. The network protectors associated with feeder F_3 must be interlocked so that they cannot close unless breaker B_3 is closed. The protectors associated with feeder F_2 must be interlocked so that they cannot close unless breaker B_2 is closed. And the protectors associated with feeder F_1 must be interlocked so that they cannot close unless breaker B_{1a} is closed. Also breakers B_1 and B_{1a} must be interlocked so that breaker B_{1a} cannot be closed unless breaker B_1 is closed. These interlocks, with the exception of the interlocking between breakers B_1 and B_{1a}, are necessary on any network system for supplying power-station auxiliaries unless all network feeders are taken from a common bus.

A more expensive arrangement of primary feeders is shown in Fig. 2. This method needs an additional high-voltage breaker B_4 for the auxiliary supply and a transformer T_4 large enough to supply all auxiliaries of the largest unit. The transformer may step down to the generator voltage if all auxiliaries are supplied at 460 volts. By this means the network transformers connected to feeder F_4 are duplicates of those connected to feeders F_1, F_2, and F_3. However, if some auxiliaries are supplied at 2300 volts, as is sometimes the case, transformer T_4 may step down to 2300 volts and the network transformers connected to feeder F_4 step down from 2300 to 460 volts. Such an arrangement saves a double transformation from the voltage of the station bus 4 to 2300 volts. In this case the network protectors on feeders F_1, F_2, and F_3 must be interlocked with their associated generator breakers B_1, B_2, and B_3 so that they cannot close until their associated generator breakers are closed, thus preventing synchronization through the network.

The primary-feeder arrangement of Fig. 2 provides greater overall station reliability than does that of Fig. 1, because a fault on feeder F_4 does not interfere with the operation of the

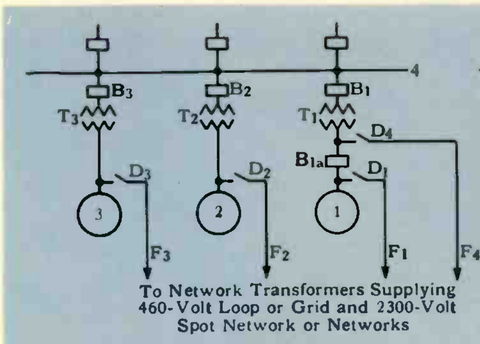


Fig. 1—Simple method of network supply for powerhouse auxiliaries.

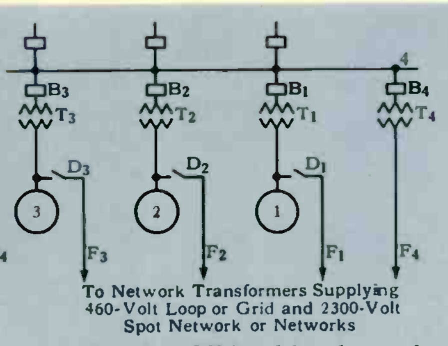


Fig. 2—An additional breaker and transformer increases reliability.

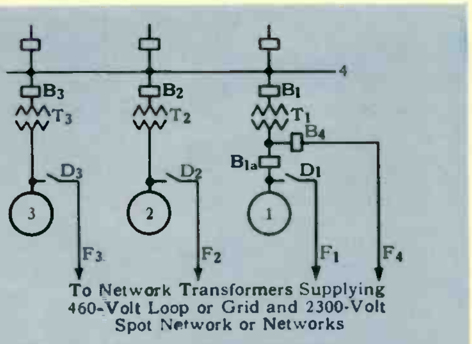
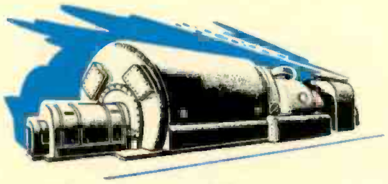


Fig. 3—Comparable reliability can be obtained with only an extra breaker, B_4.



station, whereas, in the case of the arrangement of Fig. 1 such a fault would cause the short-time shutdown of generator 1.

The scheme of Fig. 1 can be made comparable in reliability and at less cost to the scheme of Fig. 2 by the addition of breaker B_4 as shown in Fig. 3; the arrangement of Fig. 3 then is similar to that of Fig. 1. The interlocking to prevent synchronizing through the network is the same for the schemes of Fig. 3 and Fig. 1. The arrangement shown in Fig. 3 is the one usually recommended.

Should greater station reliability than is provided by Fig. 3 be desired, breakers can be used in place of disconnecting switches, D_1, D_2, and D_3. When this is done a generator will not be shut down by a fault on network feeders F_1, F_2, F_3 or F_4. This arrangement results in a considerably more unjustifiably expensive auxiliary supply system than that of Fig. 3. Where breakers are used instead of disconnecting switches, D_1, D_2 and D_3, each of them should be interlocked with its associated generator breaker B_{1a}, B_2, or B_3 so that it cannot be closed until its generator breaker is closed. Also breaker B_{1a} must be interlocked so that it cannot be closed until breaker B_1 is closed. With this arrangement it is unnecessary to interlock the network protectors with their associated generator breakers. When the station consists of a single unit the primary feeder arrangement should be similar to that for generator 1 of Fig. 2, or preferably Fig. 3. The only interlocking required in this case is between breaker B_{1a} and its associated network protectors on feeder F_1.

The short-circuit currents on a 460-volt network for supplying power-plant auxiliaries must be considered when the system is designed, otherwise the fault currents may run considerably higher than on a radial system and the cost of the load breakers then becomes excessive. The interrupting duty on the load breakers can be kept within reasonable limits by the influence of various related factors. These include the percentage of the auxiliary load of one unit supplied at 460 volts, and the number of generator units whose auxiliaries are supplied from a single network, which has a bearing on the number of primary feeders and the extent or area of the 460-volt network. The number of primary feeders determines the amount of network transformer capacity required to supply a given load. If no spare transformer capacity is required in a network system to take care of the condition of one primary feeder out of service, the maximum fault current on a network system will often be less than on the usual radial system using one or two large transformers.

TABLE 1—INTERRUPTING RATING OF LOAD CIRCUIT BREAKERS IN 460-VOLT NETWORK FOR SUPPLY OF GENERATING-STATION AUXILIARIES

	Maximum Demand of Auxiliary Load per Generating Unit, Kva		Interrupting Ratings of Load Circuit Breakers, Thousands of Amperes							
Rating of Turbo-Generator, Kw	2300 Volts	460 Volts	One Unit Max.	One Unit Min.	Two Units Max.	Two Units Min.	Three Units Max.	Three Units Min.	Four Units Max.	Four Units Min.
100 000	6500	6200	75	25						
50 000	3000	2060			50	15	50	25	75	25
50 000	1750	3310					75	25		
50 000	2700	2500	50	15						
25 000		2500	50	15	50	25				
10 000		1200			25	10				

Minimizing the interrupting duty on the load breakers can be provided for in three ways: (1) limiting the amount of load supplied from any one secondary loop or grid to a reasonable value, (2) supplying the secondary networks from three or four primary feeders, (3) keeping the size of the network transformers down to an economic limit based on the installed cost of transformers, protectors, secondary loop or grid secondary radial runs from the grid to the motors. The network transformers should in most cases have an impedance of 10 percent. The interrupting duty on the load breakers can at times be further reduced by tapping the load circuits from the loop or grid through limiters, and locating the load breakers near the motors which they control, so as to take advantage of the impedance of the radial-load circuits.

A definite relation between maximum short-circuit current on a secondary network and the total connected transformer capacity cannot be stated. Table 1, however, gives load-breaker interrupting ratings in terms of the auxiliary load per generator and the number and size of the generators whose auxiliaries are fed from one network. This information is taken from studies for actual stations and indicates the short-circuit ratings of the load circuit breakers required in a generating-station auxiliary network.

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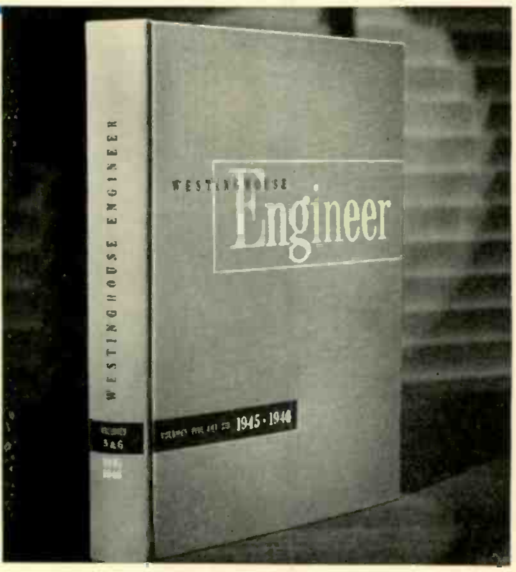


STORIES OF RESEARCH

And Now Hiperco

The tantalizing fact that cobalt is the only element having the ability to raise the magnetic-saturation characteristic of iron has been known for 32 years. While cobalt's ability is all important in the design of rotating electrical equipment, its use as an alloy posed other problems which until recently went unsolved. Intensive research, under the guidance of Dr. T. D. Yensen of the Westinghouse Research Laboratories established a treatment process that promises to effect savings of from 10 to 15 percent in the weight of motors and generators.

One of the problems arising from the use of cobalt-iron alloy in its previous form was its brittleness in the punching and stamping operations required in the fabrication of motor and generator stators and armature cores. Under the radically different treatment method conceived by Dr. Yensen and fully developed by J. K. Stanley of the Laboratories, the cobalt-iron sheets are produced sufficiently ductile to withstand all usual stamping and punching operations. The new alloy, called "Hiperco," has been made commercially in six-inch strip in two thicknesses of 0.017 inch and 0.025 inch. In the laboratory the material has been reduced to 0.003 inch without difficulty and can be punched or stamped readily in the cold-rolled condition.

By adding small amounts of other elements, the electrical resistance is raised to two or three times that of iron without appreciably lowering the saturation value. After annealing for prolonged periods in a protective atmosphere, the magnetic values are enhanced so that the permeability of the alloy, at magnetizing forces common to motors and generators, is about 15 percent higher than for other magnetic materials. At 20 000 gausses and 60 cycles (129 000 lines per square inch) the losses in a 10-mil sheet are one third that of silicon iron.

The new alloy is an invaluable addition to the family of Westinghouse magnetic materials: Puron, Hipersil, Hipernik, and Conpernik. Hiperco's particular value lies in aircraft applications where its superior characteristics permit substantial weight saving.

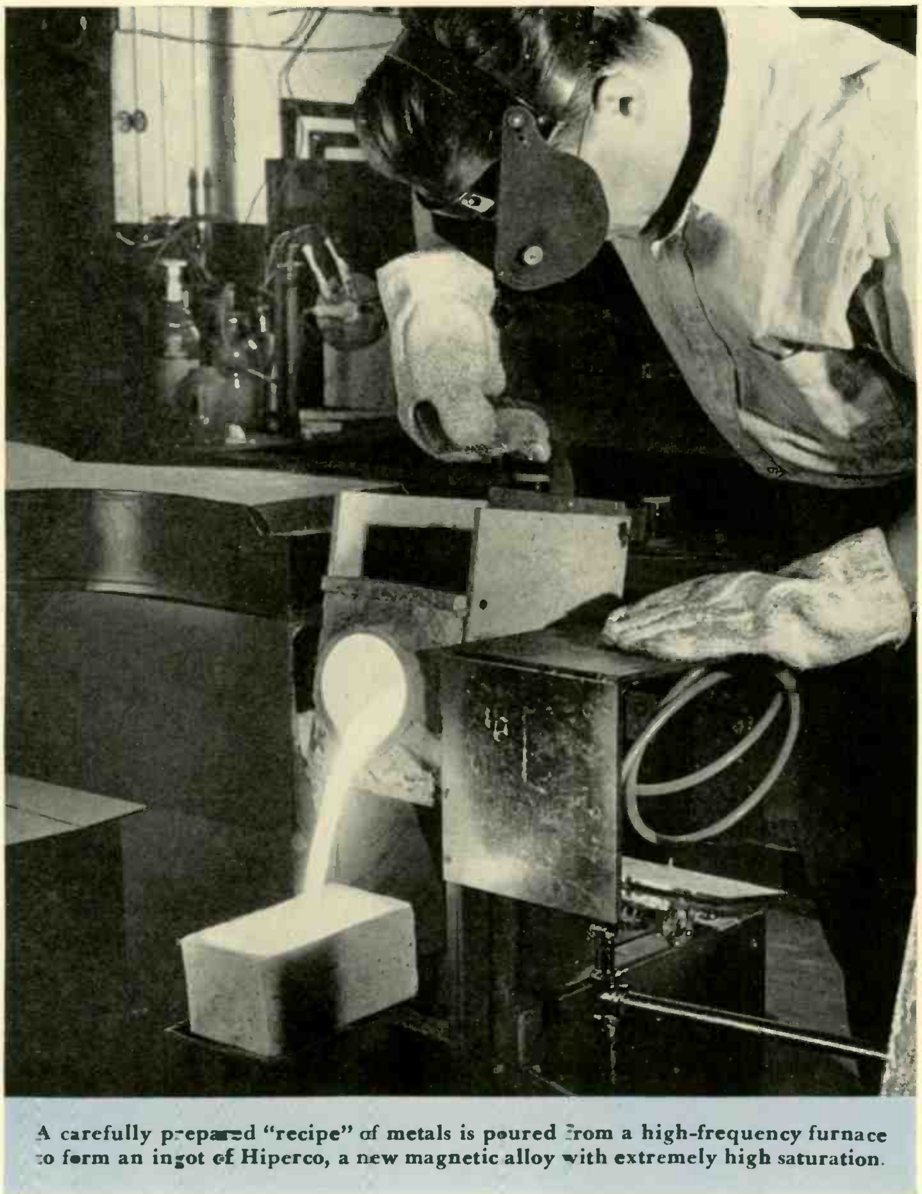
Rolling Their Own

A new and valuable tool has been added to the repertory of magnetic engineers at the Westinghouse Research Laboratories. It is a Sendzimir precision cold strip mill capable of rolling the hardest alloys to a paper-tissue thinness of 0.001 inch or even to 0.0005 inch.

From a production standpoint, the new mill is just what is needed in rolling Hiperco, the new magnetic alloy developed recently by T. D. Yensen and J. K. Stanley of the Laboratories. An extremely hard cobalt-iron alloy, Hiperco is too tough for the conventional mill to roll thinner than about twenty thousandths of an inch. For aircraft generator use—Hiperco's chief field of application at present—strips with a maximum thickness of 10 mils are required, mainly because eddy-current losses go up with the square of the thickness. With the new Sendzimir mill, the new alloy can be rolled to any desired gauge.

Even more important, the new mill enables research men to probe into the magnetic properties of very thin-gauge alloys. An urgent need exists for increased knowledge concerning the magnetic behavior of such alloys, used, for example, as cores in high-frequency transformers. In television the fidelity of the signal response may well be tied in with the magnetic properties of the alloys used. Research men are anxious to find out how much association exists—and why.

With the Sendzimir mill it is possible to roll to thicknesses of one half a mil (0.0005 inch; this sheet of magazine paper is 0.003 inch—six times as thick). Such super-thin gauges may make it possible to measure the size of magnetic "domains" in ferromagnetic materials—those regions of magnetic saturation in which all the atomic magnets are believed to be pointing in the same direction. A further un-



A carefully prepared "recipe" of metals is poured from a high-frequency furnace to form an ingot of Hiperco, a new magnetic alloy with extremely high saturation.

derstanding of these domains is important to modern theories of magnetism.

The work roll of the Sendzimir mill is astonishingly small in diameter, as compared to conventional work rolls, measuring just 7/16 inch in the one installed at the Research Laboratories. Herein lies the key to the mill's precision rolling, because such small diameters provide a much superior "roll bite"; a maximum amount of work is done in reducing the strip to the required thickness. With the conventional rolling mill, employing work rolls eight inches and up in diameter, the roll bite is considerably less, and much energy is wasted in merely flattening out, rather than thinning, the strip.

Almost absolute rigidity is maintained in the Sendzimir mill, a necessary requirement to insure uniform thickness throughout when rolling very thin strip. The two work rolls "float" in contact pressure between four drive rolls, which in turn are backed up by four more support rolls. The whole roll assembly is held firmly by a solid steel housing. The rolls of the conventional mill are usually supported on bearings placed at the ends of the rolls, using one pair of back-up rolls, with the result that, under great pressure, a "bowing" effect takes place.

The roll mechanism of the Sendzimir mill has all the precision of a watch, with tolerances of 0.001 inch observed in the grinding of its parts. With the tungsten carbide used in the work rolls, Westinghouse research engineers expect little wear or tear for a long period of time.

The purposely thin-walled "lid" goes on as dynamics experts at Westinghouse Research Laboratories prepare to explode whirling, white-hot gas-turbine disks.

Dugout Laboratory

The jet engine and the atomic bomb are alike in at least one respect. While no doubt exists that both work, many unsolved questions in connection with their operation, and many problems difficult of mathematical solution still remain. That is why dynamics engineers at the Westinghouse Research Laboratories will resort to the somewhat violent tactic of whirling gas-turbine disks at terrific speeds and under very high temperatures until they literally fly apart.

From these studies—conducted in a special, explosion-proof dugout—research men hope to amass a wealth of fundamental information about the behavior of turbine disks over a wide range of operating conditions. Temperatures, for example, may vary up to 400 degrees F between the periphery of the disk and a point only two inches away. Stresses in general are greatest at the center and fall away rapidly at the periphery, while creep rate is most pronounced in a zone near the edge.

All of these variables make the problem enormously complicated. In fact, the calculations required to formulate theoretical assumptions are so complex that many of them have to be worked out on the famous calculator at the Massachusetts Institute of Technology. Now research men want to see how closely their theories come to fact.

The "dugout" laboratory is a special test pit sunk well below the floor level. The disk is attached to the shaft of a high-speed motor capable of rotating at speeds up to 35 000 rpm, while electric resistance heating coils provide temperatures up to 1400 degrees F. Heavy sand bags completely ring the disk, which, during the test, is covered with a thin-walled steel hood. The hood is made purposely thin so that flying fragments of the disk after it explodes will not be damaged and thus prevent close scrutiny of the kind of rupture or break involved.

It is planned to make temperature measurements with both radiation and contact thermocouples. The latter presented a very difficult problem. With the disk whirling at 35 000 rpm, any heat-measuring device attached to the perimeter would be under a centrifugal pull of some 190 000 times its own weight. Even if it weighed but a fraction of an ounce, it would have to be fastened strongly enough to resist a pull of several thousand pounds. However, with special welding, research men believe they have this problem solved.

The basic data gathered in these tests should be of great value to the metallurgist in his search for better high-temperature alloys and to the design engineer in the development of more efficient gas turbine equipment.

PERSONALITY PROFILES

This is not the first time *C. B. Campbell* and *C. M. Laffoon* have been teamed together. They have appeared on the platforms of many technical societies and before many power companies with presentations of their respective specialties, which are always paired. Both have been in their fields for a long while. Laffoon began work on large a-c machines soon after coming to Westinghouse from the University of Missouri in 1916 and is now in charge of this activity. Campbell, a native of Michigan and a graduate of its state university in 1919, has been continuously engaged since then in design and applications of steam turbines. Like Laffoon, Campbell is a department manager.

* * *

S. L. Lindbeck's seafaring experience had been restricted to rowing a boat or paddling a canoe, prior to 1945 when he was elected to sail as a manufacturer's representative in a cargo-type transport on a voyage to Cuba. The electrical equipment fitted in the vessel had been his particular coordination problem, with emphasis on the Rototrol system of excitation control of the ship's drive. His marine experience plus his present assignment as West Coast aviation contact engineer may be said to give him a three-medium expression in which to apply his knowledge of Rototrol control.

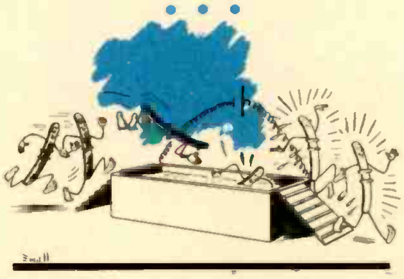
Lindbeck, a native of San Francisco, graduated from the University of California at Berkeley with a B.S. degree in electrical engineering. He obtained his Master's degree at the University of Pittsburgh in 1944. Since joining Westinghouse in 1941, all his time had been taken up with marine equipment engineering, until a year ago when he switched to aviation applications of Rototrol control.

* * *

Drs. W. E. Shoupp and *J. W. Coltman*, whose names last year appeared on these pages over important, separately authored articles, are now co-authors in the final of a group on nuclear physics. In the interim both scientists spent a hectic but not altogether unprofitable period resulting from the preparation of automatic registration equipment for the two atom bomb tests at Bikini. Now they have the added satisfaction of preparing, for a peacetime role, the Westinghouse 4 000 000-volt Van de Graaff generator, which shortly will be devoted to the more productive aspects of nuclear studies rather than the destructive one typified by the atomic bomb. Dr. Shoupp, as head of electronics at the Research Laboratories, is in charge of the rejuvenation and extensive modifications required.

Since Coltman's article on the magnetron microwave generator, November, 1946, he has been placed in charge of the x-ray group of the Electronics Section.

* * *



George W. Jernstedt's career, since joining Westinghouse in 1937, takes on the nature of a one-man crusade against corrosion, tarnish, and rust. His unbroken string of developments can be started at beryllia plating where beryllium oxide is deposited on silver or copper to ward off tarnish. Similarly his pre-dip process for phosphating enhances the normally good qualities of Bonderizing. Bright-alloy plating, another of his credits, results in superior finishes from alloys of copper, zinc and tin.

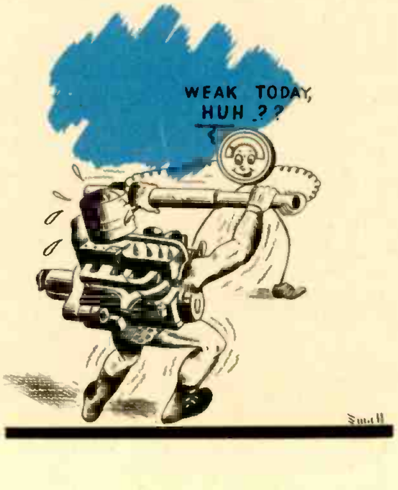
Obviously Jernstedt, although a newcomer to these pages, is no novice in his art. He graduated from Newark College of Engineering in 1937 with a B.S. degree in chemical engineering, at the same time resuming studies through post-graduate work in physio-chemistry and electrochemistry at Polytechnic Institute of Brooklyn. In 1939 he was awarded the Westinghouse Lamme Scholarship with which he obtained his Master's degree after a year at Michigan State. In March, 1946 he was appointed Manager of Electroplating Projects.

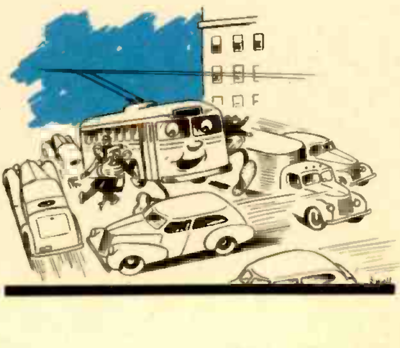
* * *

It does happen that one sometimes goes hunting for deer and comes home with a bear. This, in a sense, happened to *K. L. Wommack*. He was clearly headed for a career in the air-conditioning business. His father had been a refrigeration engineer in Winston-Salem, North Carolina, so it was natural that when Wommack went to North Carolina State he would study mechanical engineering, with special emphasis on heating and air conditioning. During the summers, prior to graduation in 1942, he worked for the Carrier Corporation in such occupations as draftsman and service man. Sheepskin in hand he came to Westinghouse in 1942, taking the graduate student course. As seemed preordained, he transferred to the Springfield, Mass., plant, then the center of Westinghouse air-conditioning activities. Then international events began to have their effect. The need was more for young research engineers than for air-conditioning experts. Wommack was assigned to work with B. F. Langer of the Research Laboratories on the problem of developing a torquemeter for military airplanes, which led to the device about which he now writes. Thus Wommack aided in the initial research on this interesting instrument as well as guiding it through actual production designs and development. He also had a hand in other strain gauge developments, i. e., rotary cranes. These provide a warning against tip-over caused by boom overloading.

* * *

George M. Woods, a native of Pine Grove Mills, Pennsylvania, started work with Westinghouse in 1911 after obtaining his B. S. in electrical engineering from Pennsylvania State College. In 1913 he transferred to Transportation Engineering and since then has been constantly associated with city transit. For his many sales and engineering contributions in this field, Woods is well known among the operators of city transit systems. His experience in development and applications of motor and control equipment for transportation vehicles includes the modern, silent, swift and popular PCC cars. Trolley coaches have been a particular subject of Woods. His association dates to the days of their original inception, 1921–1922, through their emergence as an important urban carrier in 1928. His most recent experience concerns the vast modernization of the rapid transit trains of the New York Subway. Woods has authored many technical papers relating to city transportation services.





Precision Mill

for precision iron. The inset picture is not a close-up of a fine watch, but a side view of the rolls of the Sendzimir mill below, now in service in the Westinghouse Research Laboratories for accurate rolling to paper-thin gauges magnetic irons of the Hiperco type and other still experimental transformer irons. (See p. 95.)