WESTINGHOUSE

Engineer

Westinghouse Looks at Technical Progress

CROSSING the mid-century mark is something special. With this in mind we believe it profitable to review certain main features of the electric industry during the first half of our century in terms of Westinghouse participation and to peer as best we can into the remaining half. In so doing we find that a review of five decades of major power and electric apparatus is an excellent refresher course that aids immeasurably as we study the future. We need to be reminded of the doubts, uncertainties, hard work, flashes of genius, failures, and successes that surrounded every technical accomplishment now accepted without question as obvious. Such a review also suggests that many technical objectives that now appear to be but dreams will be realized.

Those of us at Westinghouse are proud of the record. It is, we believe, one rich in accomplishment and marks our Company as a leader from its early beginnings. Although we are proud of that accomplishment, we are at the same time humble. Our Company has been fortunate in being a part of the progressive, thriving electric industry and in having had among its ranks men of technical genius and leaders with imagination and financial courage. Then, too, Westinghouse has had the good fortune to develop within the favorable atmosphere of American free enterprise. This latter fortunate opportunity suggests also a continuing obligation: that scientists and engineers must not confine their concern to technology alone but must take an active, aggressive part in maintaining those institutions of free enterprise by which our nation has become strong.

Our technical leaders see no leveling off in engineering progress. They envision "still larger worlds to conquer." They admit to no ceilings in the field of electric apparatus or its use. And we intend, by aggressively working toward enlarged objectives, that Westinghouse will be a progressive company with which to deal in the years ahead.

Westinghouse, as one member of the electric industry, approaches the last half of this great century with sleeves rolled up, eagerly ready to tackle its part in helping make this a better world. We are confident that, in the year 2000, those who review the record of the twentieth century will write, "The last half was richer than the first."

GWILYM A. PRICE
PRESIDENT

WESTINGHOUSE Engineer

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Mid-Century Review and Forecast of Westinghouse Engineering

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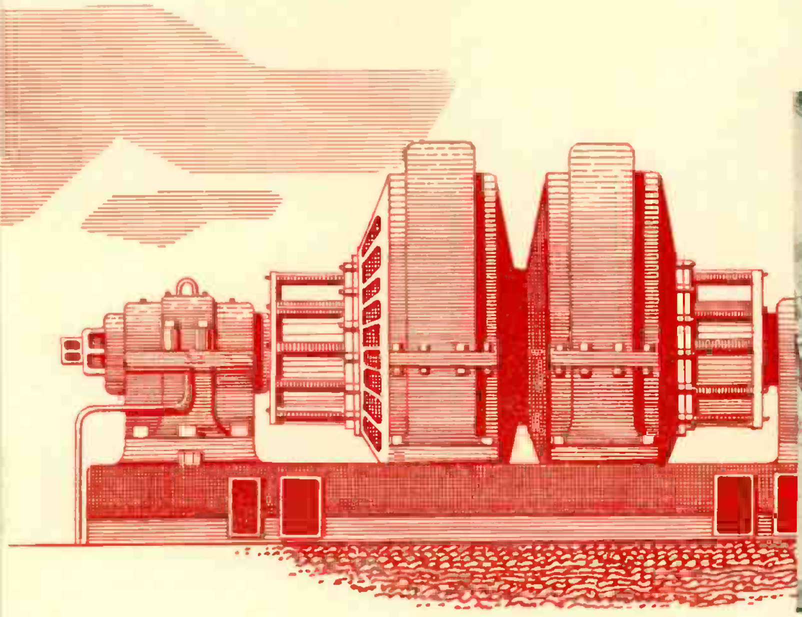
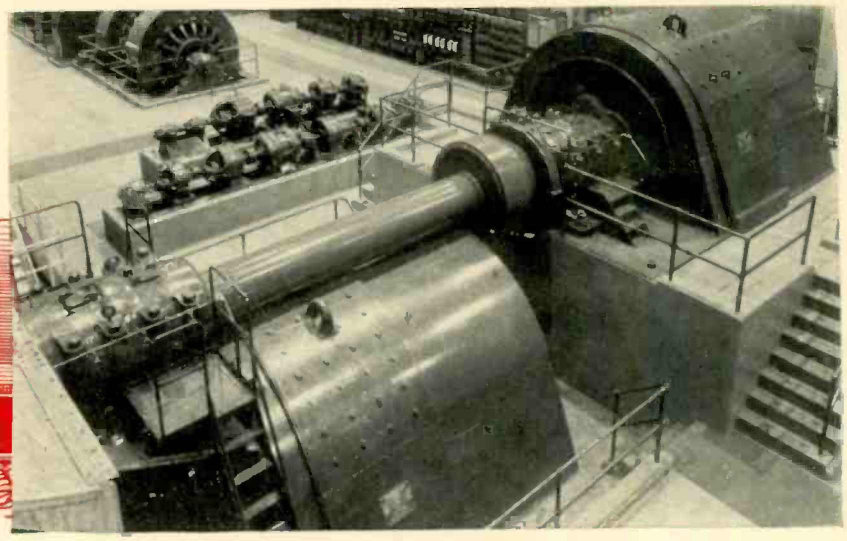
THE PRICELESS INGREDIENTS



1905—The first steel-mill main-roll drive



Modern twin-motor roll drive

ANY APPRAISAL of engineering, its past and its possible future, is of necessity written in terms of machines—things of steel, copper, varnish, tape—their constructions, ratings, and performance. But such a story, interesting and imposing though it be, is but the lesser part of the total story of technical progress. Other things, somewhat less tangible, more difficult to capture in words, are the more significant. The bigger story lies with the men behind the machines, the underlying, preceding research, the fundamental concepts, the know-how. How can one sum up the genius of the men—the Lamme's, Conrad's, Fortescue's, Hodgkinson's—who invented these things or sparked their development? How can one set down the importance of the numerous educational and training programs that have always been a part of the operation of a leader in the field? Or the vast sum of technical knowledge—printed, spoken, broadcast—contributed to industry as a whole for its advancement? Suppose we examine some of these less tangible ingredients of the application of power to industry.

Application Engineering—The generation and use of power are vastly more than so many turbines, generators, controls, motors, and so on. It is the unification of these things into coordinated systems; it is, in short, application engineering.

Unlike machines, application engineering was not invented; it has evolved in concept, scope, and organization as the natural consequence of industry's use of power. Its exact origins in the steam and electric power field are lost but its course has been indelibly written in the industrial history of the past half century.

At the dawn of the 20th century there were few application engineers. Few were needed. Electrification then consisted principally of substituting an electric motor for a steam engine or waterwheel driving a lineshaft. The main question was to select a motor big enough to do the job. Mostly this was done on the "plenty-big" basis.

Soon one of the fundamentals of electrification became apparent: the easy divisibility of electric power. Motors, unlike steam engines and waterwheels, can be readily disposed about a plant at will, in small sizes or in big ones. Cables are much easier to run than steam lines. It quickly became evident to plant managers—probably many of them independently—that savings could be made and plant operation improved if, instead of driving the plant's lineshaft by a single prime mover, it be divided into two or more sections, each with its own motor. Right then was born the prototype of the application engineer, for in that was the genesis of the industrial-plant electrical system. Coordination of motor sizes, speeds, and even their actual running became necessary.

In these embryonic years, application engineering as such was nebulous. The idea of a man specializing in electrification of certain industries did not take shape until shortly after the turn of the century.

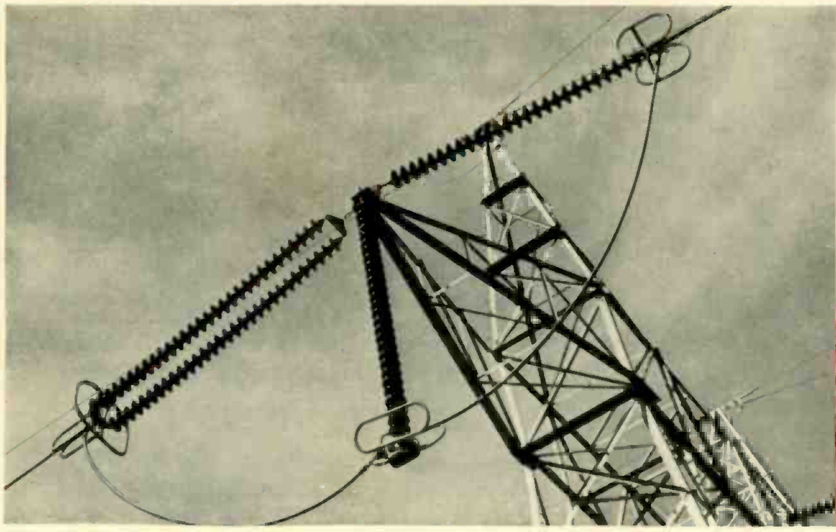
As industry got the feel of what electric power could accomplish, new ideas developed—and with the inception of each the application engineer became more of a necessity and his job enormously expanded. Motors were discovered to be more than merely convenient substitutes for older prime movers. Because of the comparative ease by which motors could be controlled and speed adjusted, operators saw how processes and products could be improved. This necessitated the selection of motors and control mechanisms based on an intimate knowledge of the particular problems of the plant and its product. Because the application engineer visited many such plants, he soon became an expert in that class of industry. In fact, not uncommonly, the application engineer acquires a better understanding of an industry and its problems than the owner or operator of a particular plant.

Somewhere along the line another concept appeared: that motors would speed up the whole plant operation, and hence output of product would be increased. Thereupon machine speeds began an upward climb that never ceased, a process superintended at every step by the application engineer.

Plant operators discovered another attribute of electric drive: it possesses—potentially at least—the possibility of

OF INDUSTRY ELECTRIFICATION

by A.C. MONTEITH



Tower top of experimental half-million volt line

Station and transmission line of 1911

interruption-free operation. And having sensed this, they began to develop processes requiring it, and then demanded of the application engineer that suitable equipment be provided. This has led to many operations, of which papermaking machines and electrolytic cells are examples, that run for long periods—even years—without interruption. Sometimes even a minute variation from normal is intolerable in product cost or plant maintenance. The application engineer has been asked to anticipate and guard against all manner of disturbances to production.

With the turn of the century came a new kind of industrial plant. This is the continuous-flow plant, well exemplified by the automobile factory in which many conveyorized operations must continuously work in harmony to effect a smooth flow of materials and assemblies without either interruption or accumulation. With such complex industrialized operations, plant-wide electrical systems—the product of application engineering—came into their own.

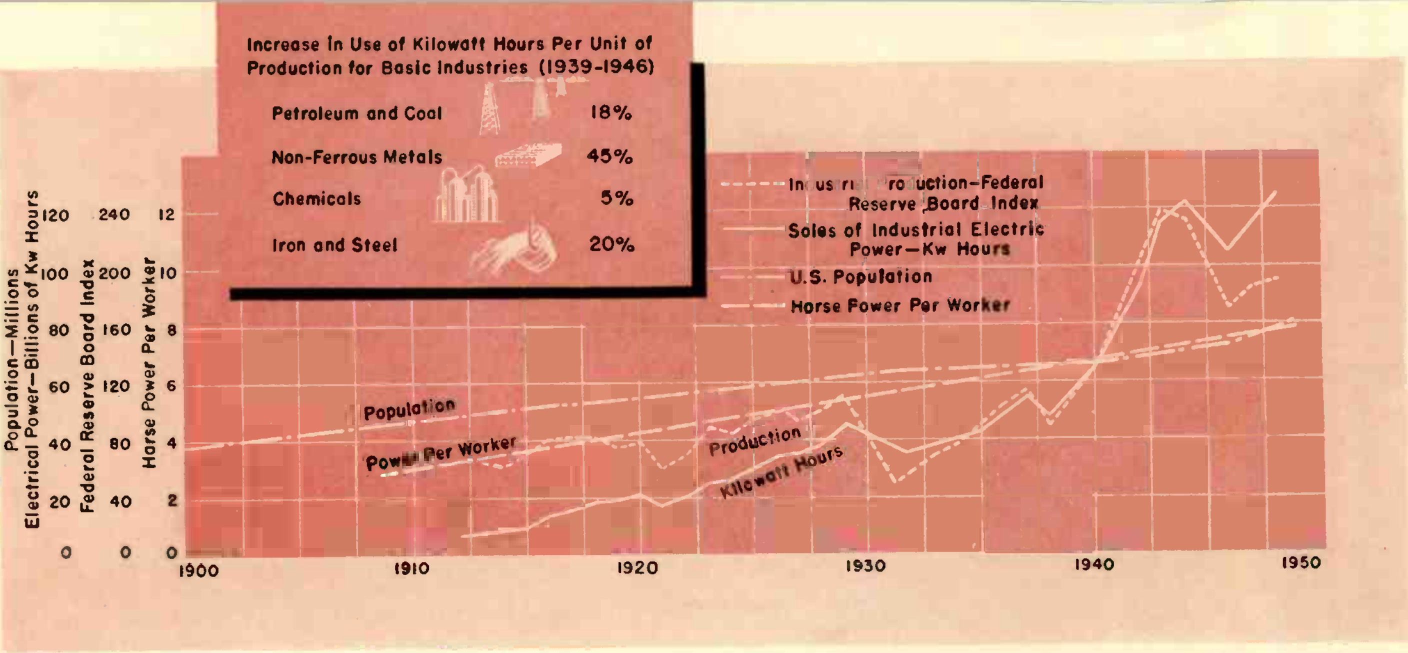
This general pattern of increasing use of and reliance on coordinated electrical apparatus has been followed by innumerable industries, large and small. None has been more outstanding than the *steel industry*. And it was one of the first. Electric motors made their debut in the steel industry in 1891 when a Pittsburgh mill installed three d-c motors to drive auxiliaries, one a grindstone. Not until after the century mark, however, did electricity invade the major domain of steam engines, the main-roll drive. This was in the same Pittsburgh mill, two 1500-hp, d-c adjustable-speed motors being applied to a light rail mill in 1905. The first application of motors to a reversing mill came two years later when a 4000-hp double-armature motor—which even today is a large motor—drove a 30-inch plate mill at South Chicago. Both historic equipments, incidentally, are still in regular service—which points up another basic quality of electric drive—its durability.

From these beginnings steel processing has gone on not only to almost complete dependence on electric power and control but also to using it for innumerable functions, processes, and products not possible without it. The first a-c adjustable-speed drive came in 1912 with two wound-rotor induction motors installed in a Canton, Ohio, mill. Here, to obtain speed control suitable for the products rolled, application engineers provided a rotary converter, a motor-generator set, and necessary control to make an adjustable-speed, main-roll drive now well known as the Kramer system.

Refinements of drive and control were called for by the steel producers. In the early days narrow strip was rolled without tension, except to make a tight coil. In 1922 Westinghouse provided the first electric motor and system for controlling tension when rolling strip. Without this the modern mile-a-minute strip mills would not exist.

Mill sizes and speeds were beginning to surpass the physical abilities of human operators to control. For example, until 1924 operators controlled reversing-motor drives by hand, being careful to avoid the too rapid acceleration and retardation that resulted in excessive trippings. This situation was then alleviated by a system of vibrating relays that automatically limited the current. This system, still fundamental, has since been improved by the replacement of the relays by the Rototrol rotating regulator.

Mill operators have, more and more, been relieved of direct control functions. The screw down, by which roll spacings are adjusted after each pass, became automatic in 1927. Electronic controls tackled one of their first industrial assignments in 1927, a set of "electric eyes" being arranged to open and close soaking-pit covers, allowing the crane operator to concentrate on his other tasks. The steady advance of apparatus specialization was again marked when, in 1930, each roll of a reversing mill was powered by its own motor, instead of the two rolls being driven by one motor and a gear. This system, which calls for accurate synchronization of d-c motor speeds, has been eminently successful and has since been extended to continuous plate mills. Tension of cold-reduction strip mills came under automatic control in 1933 with a device now considered crude but which laid the foundation for today's ten-



siometers, absolutely essential to the modern tandem mills producing tinplate and sheet. In three decades steel output has risen two and one-half times, the consumption of electrical energy by five times.

Papermaking has followed a similar pattern. Most paper machines in pre-electricity days were located on the banks of a stream so that a long lineshaft could be driven by a waterwheel or a steam engine. About the turn of the century, a motor or a steam turbine took the place of the waterwheel or steam engine. About 1909 the lineshaft gave way to several motors, each driving one section of the machine. Several steps have since followed to improve the control of the motor-speed relationships and to permit higher speeds, bringing us to the modern paper mill with its electronic regulators, separate generators for each motor, and an extreme degree of specialized drives for winders, calendars, as well as other parts of the paper machine itself. Today the papermaking industry uses an average 700 kwhr to make each ton of paper. Fifty years ago a machine making a sheet of newsprint 100 inches wide and running 600 feet per minute was considered big. Today sheets are produced 250 inches wide at a speed of 1600 fpm.

Coal mining, like steel and paper, found electric power indispensable. Even in 1900 the most important tools of the coal miner were the pick, shovel, sledge, and wedge. By 1910 more than 40 percent of the back-breaking job of cutting coal was done by machine and the time-honored mule was being retired in favor of electric locomotives, of which several thousand were in service. Between 1920 and 1930 semi-automatic coal-loading machines became common. Today nine tenths of all deep-mined coal is machine undercut and three fifths of it removed by mobile loaders and conveyors. The "continuous" mining machine, already beginning to appear, will continue the trend to greater output per worker that has doubled since 1900 and will continue the downward curve of accidents, now only one third that of four decades ago.

The *transportation industry* shows the fine hand of the application engineer and machine designer. This industry, acutely beset with problems of competition, regulation, outsize investments, and labor costs, has required the best this pair can offer.

With the railroads the application engineer has worked hand in hand to provide electrifications of 6491 track miles of heavy-traffic trunk lines, beginning with the New York, New Haven, and Hartford in 1907 and culminating with the electrification of the Pennsylvania between New York, Harrisburg, and Washington. This has required assistance in development of many locomotive types—d-c motor, motor-generator, and single-phase—and also it has entailed elaborate power supply and control systems to insure service continuity.

Marine—Practically the complete range of power apparatus and electrical application problems found in all industry are embodied in ships—plus many aspects peculiar to the sea, its atmosphere, its hazards, and its movement. Since fairly early in this century the application engineer has participated in the development and coordination of specialized equipment ranging from main propulsion machinery to the most modern of radar navigational aids. He has assisted in making practical use of many different main propulsion drives—geared-turbine, turbine-electric, diesel-electric, and electric coupling, with gas-turbine, and the atomic energy as future possibilities. Every modern ship has an electrical system—if even only for lighting and auxiliary service, but which on the larger vessels embodies problems of voltage regulation, protection, distribution as on a power system—both for direct current and, more recently, alternating current. Most of the problems of drives and their controls—for cargo handling, hoists, conveyors, refrigeration, fans, pumps, elevators—are present here along with the specialized requirements of shipboard service. In addition there are many problems unique to marine service of steering controls, navigational aids, communication services, and many sea-safety features.

Recently the counterpart of the marine application engineer is appearing for aircraft. With planes becoming larger and faster, the electrical systems are becoming sizable with large blocks of generated power, rigorous distribution and regulation problems, and literally hundreds of utilization devices—all with problems of weight and safety paramount.

The task of the *industry application engineer* is continuing to expand and now covers the industrial water front. The trend is for increasing use of electricity by the older, well-established industries, large and small. Also new ones are showing on the horizon. Synthetic rubber developed during the war. Production of liquid fuel from coal promises to be an enormous new industry using great quantities of electric power. With declining reserves of high-quality iron ore, methods of utilizing low-grade ores will become a mammoth business. The task of applying electric power to industry is not done, it is only begun.

In the *electric-power* industry itself the need for application engineering developed more slowly than in user industries. During most of the first two decades of this century each power station served only the area a few miles around it. They were small and for the most part independent of each other. Voltages were low. Lines were short and not so vulnerable to lightning. Besides, an outage every now and then was accepted as a matter of course. The power handled by the lines was small in comparison to their capacity. Not until shortly after World War I, when transmission systems were interconnected and voltages rose to today's high potentials, did the great, basic problem of central-station power generation, transmission, and distribution begin to require the attention of a large corps of specialists.

One of the first great achievements of this group was the invention, by Fortescue, of symmetrical components and the application of this branch of mathematics to the solution of the complex problems of polyphase networks. In truth, symmetrical components is as essential to the modern power system as the generator or transformer; without such calculation the analysis of complex systems would be all but impossible.

In the early 20's, as interconnections and the size of stations feeding them grew, the matter of instability—or the pulling apart of an interconnected system following some disturbance—became serious. A practical method for calculating power limits was developed and proved by laboratory and field tests. Many stability studies of particular systems have subsequently been made cooperatively by Westinghouse and utility engineers, to select the most suitable combinations of generators, transformers, transmission lines, and switchgear.

The concept that system outages can be reduced by quick clearing of short circuits and by high-speed reclosing of circuit breakers were developed by central-station specialists.

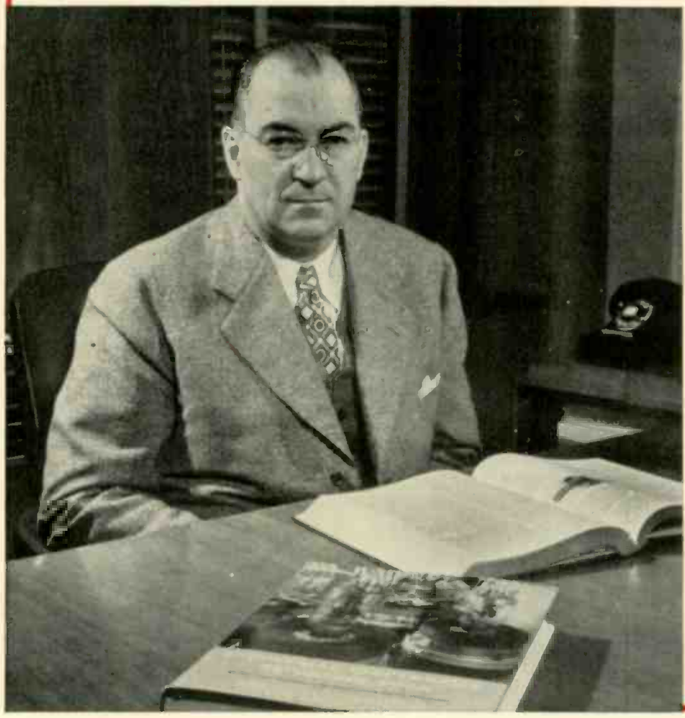
Similarly, the coordination of insulation, to avoid weak links in the electrical system, the analysis of the problems of generator and system grounding—all these and many more have been invaluable as the industry has developed in size.

For 75 years electric power consumption has doubled about every 12 years. The factors that have caused this are still at work—only more so. The country is growing. Industries are expanding and becoming more power conscious. The rising cost of labor—a natural result of the human demand for an improved standard of living—is compelling the use of more electrified equipment to enable a worker to produce more and, in this manner, to enrich his own life. An estimate made in 1947, when the national kwhr sale stood at 218 billion, predicted a total for 1957 of 374 billion. Now, three years later, it appears this total will be fully realized. In 1975—or 2000—it will be several fold larger. As the electric-power industry grows to meet these energy uses its problems will grow with it; higher voltages, larger blocks of generated power, better protection, improved distribution—and many more not yet sensed—will be posed, and solved, by the central-station specialist and operator working together, as in the past.

The Spread of Engineering Information—The close contact of a large engineering organization like Westinghouse with every type and variety of industry has other than physical consequences. It has resulted in the accumulation of an enormous fund of technical know-how. And this brings us to an interesting point. The electrical industry has been characterized by an outstanding fact: as much if not more than any other that can be named, this industry has widely and quickly disseminated its know-how. It has few "trade secrets." Findings of one electrical manufacturer or operator

A. C. MONTEITH

We have often observed that there are three main ways by which men rise to prominence in engineering: the beeline, the stepping-stone, and the expansion. Some follow the chosen branch of engineering unswervingly, rising to the top directly through it. Others progress from one specialty to another, using each in turn as a stepping stone to the next, but for the most part leaving the past behind. Some simply expand their interest to new fields, without dropping the old. They become broader in their engineering scope as they accumulate experience—such as A. C. Monteith has done. He was raised in a pulp and lumbering community in Northern Ontario, and obtained his electrical engineering education at Queens University at Kingston. Upon graduation in 1923 he went immediately to Westinghouse at Pittsburgh.



Monteith considers himself particularly fortunate that he arrived in time to attend the graduate-student course while it was still under Lamme's direction. Monteith's first position was in the application group working on central-station problems. His beginning assignment was powerhouse auxiliaries. Although Monteith left that specific branch years ago, he can still discuss its problems expertly. Later, his attention turned to transmission-line problems, specifically lightning protection, and even more specifically, De-ion protector tubes. In this period he was associated closely with Dr. Fortescue. In 1938 he took charge of central-station engineering, followed in three years by the managership of the Industry Engineering Department, which includes not only the industry producing electrical power but also the many industries that use it. The circle of activity widened to include, in 1945, all of Headquarters Engineering and finally, eighteen months ago, the vice presidency of Westinghouse engineering. The Headquarters Engineering activity gave him responsibility for all the Company's educational programs, in which he has done an outstanding job. This led to his being named chairman of the committee on graduate-engineer education, which is the Committee on Professional Development of the Engineering Societies. This is but one of many professional society committees on which he has been genuinely active.

Last year his alma mater granted him an honorary doctorate degree in law. But we've never heard him called Dr. Monteith. It's "Monty." Prefers it, he says.

are quickly related to others via association papers, magazine articles, talks to engineering bodies. This has been so since the industry's beginning and doubtless has had much to do with its phenomenally rapid development.

Westinghouse has taken an active part in this sharing of technical information. It has long sponsored, for example, its own technical journal. *The Electric Journal*, begun in 1904, was succeeded in 1941 by the *Westinghouse* ENGINEER, which now appears in English, Spanish, and Portuguese. Such publications have helped establish high editorial standards of technical journalism.

In a representative year, some 450 technical articles by Westinghouse engineers appear in the more than 300 trade journals of the country. About 100 papers are presented before national technical societies.

Much technical know-how accumulated by Westinghouse has been published in book form. The "Characteristics of Transmission Lines" was a mid-20 classic. It later became the "Electrical Transmission and Distribution Reference Book," now a standard textbook in some 60 universities; many thousands of copies have been used by "students" in colleges and industry. Other examples of outstanding technical volumes include the "Industrial Electronics Reference Book" and one on relays called "Silent Sentinels." About 70 books by Westinghouse authors are currently in print, covering many phases of engineering, such as capacitors, induction motors, jet engines, electronics, servo-mechanisms, transformers, switchgear, and heat lamps.

Engineering Education is Continuous—The sharing of technical information by no means has been confined to articles, books, and speeches. Much of it has taken the more conventional forms of education. Paul W. Boynton, of the Socony Oil Company, states in his recent book, "Selecting the New Employe": "More than 50 years ago George Westinghouse, founder of the great company that bears his name, started a practice of surrounding himself with college graduates who had a requisite background in engineering education. In so doing, he became the first college recruiter." The spirit of Mr. Westinghouse has never been lost. Today the organization supports one of the most extensive programs of university relations recruitment, training, and continued education. Westinghouse has recognized its responsibility to industry and to the young engineer and has sought to help him for his engineering future. Approximately 15 000 men have received this training, which is a combination of practical work assignments and technical classwork. Outstanding among the training classes are the electrical and mechanical design schools. These schools are arranged to give young men of outstanding technical ability a tremendous amount of advanced fundamental learning quickly. These men are thus able to take responsibility quickly in matters of engineering importance. To date 600 young men have participated in the design schools.

In 1927 Westinghouse, together with the University of Pittsburgh, conceived the idea of joint sponsorship of evening study at the graduate level made both convenient and economical for technical men in industry. This graduate study program has grown until it now includes working arrangements with seven accredited universities in eight cities, serving 29 Westinghouse locations. In all cases work undertaken can include graduate credit leading to advanced degrees, although in most cases it has been to acquire special knowledge to assist him in his work or for its cultural advantages. Since its inception in 1927, the Graduate Study Program has had 9970 registrations of Westinghouse technical men, and 176 Master's degrees have been earned. Fifteen men have completed the necessary work and received doctorate degrees.

The recognition of an obligation to higher education is best illustrated by the extensive programs of scholarships, fellowships, and professorships sponsored by both the Corporation and the Westinghouse Educational Foundation. At any one time these programs may support up to 149 men on scholarships, 38 fellowships, and 5 professorships. Westinghouse has aided engineering schools in their efforts to keep teachers abreast of industry problems by providing summer positions.

This Mid-Century Issue—All these things, together with the following discussions of developments of major apparatus, give, we hope, a representative picture of the generation and use of power in this first half century in terms of Westinghouse participation in it. That picture, as presented in succeeding pages, however, is far from complete. Many equally interesting and important phases have been arbitrarily omitted in favor of fuller treatments of the selected ones. Conspicuous by their absence are such major equipments as those for use in the home, electric welding, vertical transportation, x-rays, electric furnaces, and many more that go to make up electric power at work today.

But no single volume can contain it all. Nor is it necessary. Our main objective is to review enough of where we have been to help us see where we are going. The look ahead in each of the successive chapters, while necessarily comparatively short in length, is the more important. Their purpose is not to set forth the future with finality, nor is any engineer willing to pose as a prophet. But, to peer into the future is good mental exercise. Furthermore it is important. At mid-century we are where we are because many of the pioneers five decades ago indulged in imaginative thinking. Undoubtedly 50 years hence some estimates set forth by the authors here will appear absurd—absurd because some turned out to be blind alleys and some because they fell far short of the actual. In any case, they set forth interesting goals and suggest that the next half-century is to be as full of opportunity, as rich in achievement, as interesting to experience as the one closing.

Application Engineering—Years Ago

Editor's Note: *The following are excerpts from a letter from C. W. Drake, Westinghouse application engineer, now ostensibly retired but lecturing at the University of Florida. In 40 years he turned in an outstanding record in the application of electrical apparatus to a wide variety of industries.*

"Looking back I wonder how we had the nerve to do the things we did. I still shudder about the first sectional paper-machine drive in 1909–10 with no sectional regulators. Who now would try to run several d-c motors in parallel under varying load conditions and guarantee not to tear a sheet of wet wall paper passing from one section to the other? I wouldn't. . . .

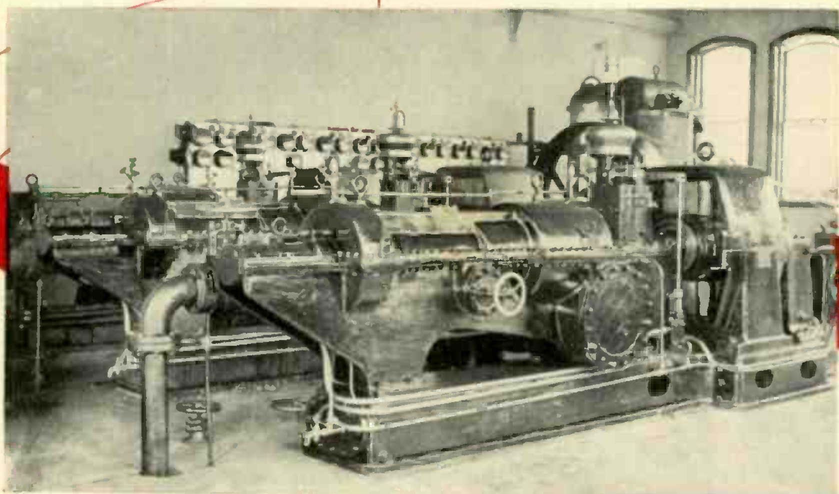
"Low-voltage alternating current was almost universally used in paper mills. In 1911 I suggested 2200 volts to the manager of a Pacific Coast mill and was nearly thrown out of the plant. With all the water and men barefooted, they were afraid of it. The installation, however, was made with proper oil breakers and wiring. Personal hazard was much less than with the open knife switches and fuses they were using on low voltage. . . .

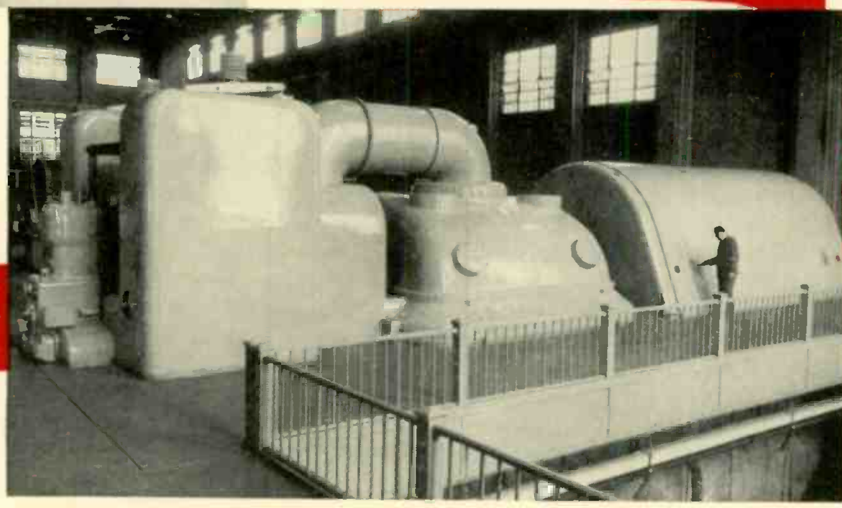
"I recall helping install, in a West Virginia paper mill, about 1905 or before, one of the first and largest linestart motors. I believe it was a 400 hp squirrel-cage. No suitable starter was then available, so they would ask the station operators to hold in the breakers and throw the motor on the line."

Central-Station Steam-Power Generation

Its Past and Its Prospects

by D. W. R. MORGAN





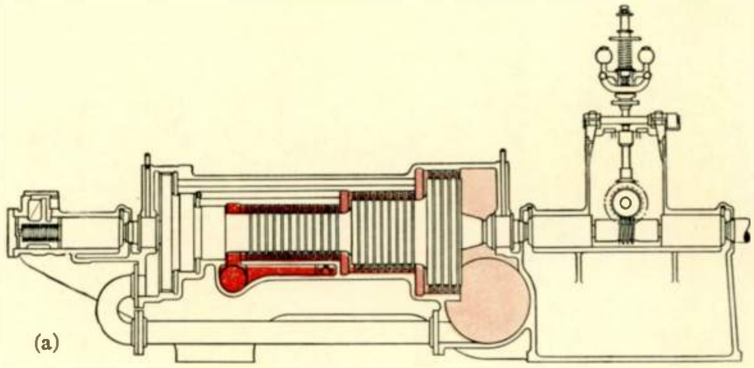
IN THIS country the steam turbine and the twentieth century arrived together. The first turbine for central-station service began operation early in 1900 in the plant of the Hartford Electric Light Company. It was a 2000-kw, 1200-rpm condensing turbine, far exceeding in capacity any unit previously built. Now, 50 years later, the modern high-speed machines currently going into service have 50 times this capacity, and larger, slower machines have been running for many years.

George Westinghouse had been marketing a single-acting, high-speed engine, but was interested in developing a rotating engine. He had, in fact, experimented for years with a displacement rotary engine, but the results never satisfied him. His entrance into polyphase-current generation heightened his desire for a rotating prime mover, so when word came of the success of Sir Charles A. Parsons in developing a steam turbine he immediately had it investigated.

This negotiation had three important results. In 1895, an agreement was reached for the exclusive American rights for the Parsons-type steam turbine. In 1896, the Parsons Company supplied to Westinghouse a 150-kw, 5000-rpm turbine and d-c generator. As the third important result, Mr. Francis Hodgkinson, one of Parson's leading turbine engineers, was persuaded to cast his fortune with the Westinghouse Company. He was destined to become, in truth, the "Dean" of the steam-turbine industry in the United States.

The first Westinghouse-produced turbine was one for 120 kw to drive directly a 5000-rpm d-c generator. It saw service in 1896 with the Nichols Chemical Company, but difficulty with the generator caused its return to East Pittsburgh to be rebuilt for 3600 rpm as a test-floor exciter set. However, experience with it paved the way for the first successful com-

Top photo shows 400-kw turbine-generators for Westinghouse Air Brake Co., installed 1899. Lower, 100 000-kw turbine-generator for Buffalo Niagara Electric Corp., installed 1948.



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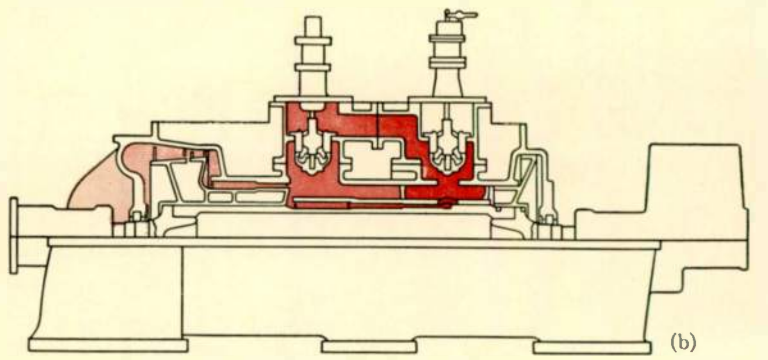


(b)

mercial steam-turbine installation in this country, at the plant of the Westinghouse Air Brake Company in Wilmerding, Pa. In a modernization of that plant, several single-acting engines that drove line shafting were to be replaced with the new a-c polyphase motors. To provide power for them, three 400-kw, 3600-rpm, 60-cycle, condensing turbine-generator units were installed. In their quarter century of service these machines established service records that did much to promote acceptance of the steam turbine. Sixty-six of this class were built without important change in design. The success at Wilmerding led directly to the Hartford central-station machine, five times larger, next year—1900.

Although the Hartford machine ran for eight years, it experienced difficulty because of thermal distortion of the turbine casing, which was extremely large for its day. This experience caused temporary abandonment of the idea of building a turbine larger than 750 kw within a single housing or case, in which the inlet end is at full steam temperature while the exhaust end is comparatively cold. The expedient adopted was to divide temperature drop between two machines, a high-pressure section and a low-pressure section in separate housings but on the same shaft. Several of these two-case, tandem-compound machines were built in capacities up to 1500 kw between 1901 and 1904, and performed well. Interestingly, several of these units had provisions for extracting the steam after it had gone part way through the turbine and reheating it with live steam from the boiler. But at the time, this proved uneconomical and was abandoned. Reheat, accomplished in a different way, is again in favor.

By 1904, operation of the Hartford turbine showed how to overcome the distortion difficulties. Single-case designs were re-established and rapidly went forward to capacities far beyond any then visualized. A family of these was developed and several hundred built for ratings of 750 kw at 3600 rpm to 3000 kw at 1200 rpm for 60-cycle service, and up to 7500 kw at 750 rpm for 25-cycle generators. By the end of the first decade the basic forms of steam turbines were established.

The Steam Exit Problem

The inlet end of a steam turbine, where the steam is at maximum pressure and it is hot enough for the blading to be faintly visible, would seem to dominate designers attention. Not necessarily so. The exhaust end, where the situation is less dramatic, has always presented serious problems and always fixes the economical maximum capacity of a condensing turbine at a given speed.

The designer of the exhaust end of a turbine inevitably is confronted with several opposing, unyielding physical facts. They have to do with providing exit space for the spent steam, which, having passed through many stages of blading and diminished in pressure and temperature, has grown to prodigious volume. In a 1050-degree, 1500-pound turbine with back pressure of 1.0-inch mercury absolute, each pound of steam at the inlet occupies about one half cubic foot. A few hundredths of a second later and 20 feet away, it has multiplied in volume more than a thousand times—to 575 cubic feet. For a 100 000-kw turbine, that means a flow through the last stage of over five million cubic feet of steam and water vapor per minute. This enormous volume must leave this final row at a low velocity so that the wasted kinetic energy is small. As a result the exhaust annulus, which is the doughnut-shaped area swept by a blade of the last row, must be extremely large. This requires very long blades with high tip speed and terrific centrifugal forces that endeavor to throw the blades out from their roots. In a modern 3600-rpm turbine the 23-inch last-row blades have a tip velocity of 1380 feet per second. Although at standstill each blade weighs less than seven pounds, at this speed it experiences an outward pull of 33 tons. The successive steps taken to provide ample exhaust annulus for ever larger outputs at a given speed, and keeping well within the limits of strength of available metals, constitute one of the important chapters of turbine history.

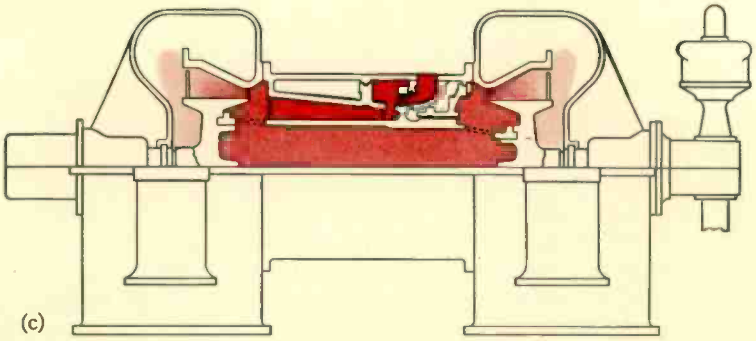
At any time blade velocities are limited by the physical properties of available rotor and blade materials, and by the strength of known rotating-blade fastenings. In early machines this limit was about 400 feet per second at mean blade height, which is the mid-point of the exposed portion of the blade. This low speed made it difficult to provide a last-stage annulus of sufficient area for other than small output. The most obvious means of obtaining larger blade dimensions for increased economical rating was—and still is—to decrease speed of rotation. This permits a corresponding increase in rotor diameter and blade height, i.e., larger annulus without exceeding allowable stresses. Thus, turbines were built for 7500 kw in 1907 by reducing speed to 750 rpm.

This practice is occasionally followed today for the same purpose, but fortunately several developments have combined to raise greatly the limit of allowable blade speeds. The figure now stands at 1025 feet per second, in contrast to the 400 of fifty years ago, and this limit will be raised further.

Division of the exhaust flow into two or more parallel paths is another way to provide adequate exit space for increasingly larger volumes of steam flow at the exhaust end of the turbine. Low-pressure turbine stages have been built in double, triple, and even quadruple exhaust flow to provide these multiple parallel steam paths, each passing only one half, one third, or one fourth of the total steam volume. The single-case, double-flow, low-pressure construction was introduced in 1907. It was used until about 1924 in numerous machines at 3600 rpm up to 6000 kw, and at 1800 rpm, 35 000 kw.

Cross-compounding is an additional approach to the exhaust-area problem. This involves two (or more) shafts—usually a high-pressure turbine driving a generator at one speed and its exhaust steam crossing over to a separate low-pressure condensing turbine and generator running at a lower speed. This construction appeared in 1914 with the turbines of 30 000 kw for the Interborough Rapid Transit Company

For space reasons this discussion is confined principally to central-station-type steam turbines. Turbines for marine use and industrial drives, blowers, gears, and related equipments are equally important and have had as interesting development, but are arbitrarily omitted.



(c)

(a) The construction, simplified, used for the historic Westinghouse Air Brake turbines, which comprised the first commercial installation of the Parsons-type turbine in this country. (b) Between 1904 and 1909 about 400 turbines of this single-case construction were built. The design continued popular for several years. (c) Machines of this arrangement were built in sizes up to about 35 000 kw between 1907 and 1924. It was one of the earliest examples of single-case turbine construction with double-flow exhaust.

of New York. Here the total heat drop was divided between two separate turbine elements, each driving its own 25-cycle generator. These high-pressure sections operated at 1500 rpm and the low-pressure, double-flow units at 750 rpm. Advantage was thus taken both of multiple-flow exhaust and of large exhaust-blade annuli available only at a speed lower than appropriate for the high-pressure element.

Ability to reduce speed of the low-pressure turbine relative to that of the high-pressure turbine in order to obtain greater exhaust annulus is the major advantage inherent in cross compounding. Excluding marine propulsion, the number of cross-compound turbines produced is relatively small, being confined to the largest ratings of a particular period; later development made it possible to build the same capacities in the simpler and smaller tandem-compound (single-shaft) higher speed machines. Twenty years ago cross-compound machines had grown to 165 000 kw (1800/1800 rpm) with an installation in Hell Gate Station in New York.

Three modern cross-compound turbines are of particular interest. In Burlington Station, Public Service Electric and Gas Company of New Jersey, a 100 000-kw unit was installed in 1943 to operate with steam at 1250 psi, 950 degrees F. Appropriately for these conditions, 3600 rpm was selected for the high-pressure turbine, driving a 50 000-kw generator. The low-pressure turbine consists of two double-flow sections in tandem driving a 50 000-kw, 3600-rpm generator.

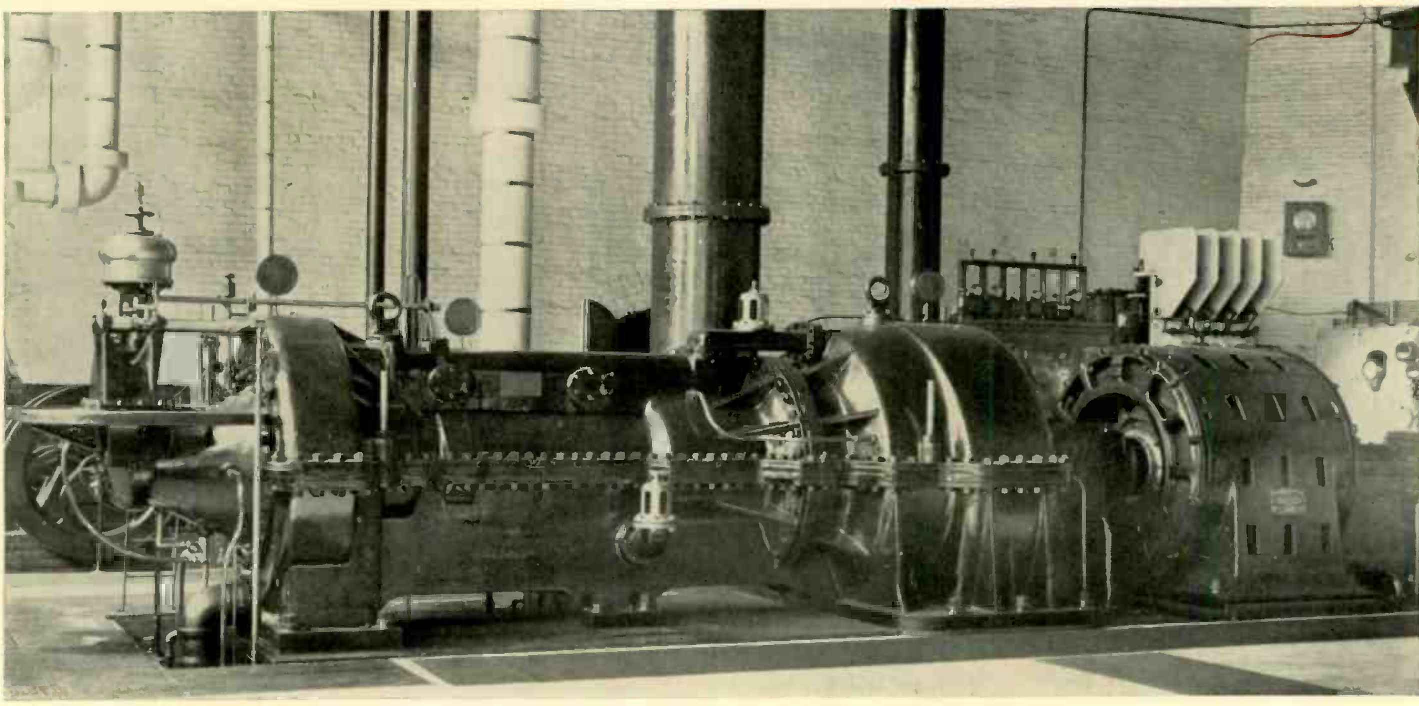
Progress in generators and turbine blading has been such that this rating is now being obtained without resort to cross compounding, i.e., with single-shaft units. In 1947 and 1948 two 150 000-kw (3600/1800 rpm) cross-compound units were installed in the Southwark Station of the Philadelphia Electric Company, for 850 psi, 900-degree F steam. A 150 000-kw (3600/1800 rpm) cross-compound turbine to operate with 1800-psi, 1050-degree F steam is being completed for the new Ridgeland Station of the Commonwealth Edison Company.

Turbines from 1901 to 1904 were tandem compounded to simplify the casing and rotor design rather than to provide sufficient blade flow area. In 1917 the tandem-compound turbine appeared again, this time providing double-flow, low-pressure blading for large outputs. The largest Westinghouse single-shaft machine is rated 165 000 kw at 1800 rpm. Since going into service in 1935 in the Richmond Station of the Philadelphia Electric Company it has turned in an extraordinary record of continuity of service.

Factors other than increase in blade length have contributed to the increase in maximum sizes of turbines. One of these was the general adoption of the *feed-water heating cycle*, which, although long known, came into general use about 1922. Extracting a portion of the expanded steam part way through the turbine and using it to heat the water going to the boiler materially increased the thermodynamic efficiency of the steam power cycle with but minor change in turbine design. Because of feed heating, about one fourth of the steam is diverted from the low-pressure stages, the exhaust steam flow is reduced by this amount or the rating increases.

The large *rise in inlet steam pressures and temperatures* has

The first central-station steam turbine installation was this 2000-kw unit in a plant of the Hartford Electric Light Company.



been even more effective. By comparison with the 500-degree, 200-pound steam common in 1915, the 950-degree, 1250-pound steam now in general use has raised the available heat energy by 50 percent, meaning a corresponding increase in available rating for the same last-stage annulus.

Expansion Principle

The impulse-reaction turbine. The Parsons' turbine brought to the United States utilized only the straight reaction principle, with steam admitted all the way around each stage. This results in an inlet annulus that, with relatively small volumes of steam at the high-pressure end, calls for short blades. The running clearance at the blade tips, which must be allowed to avoid rubbing, is relatively constant and almost independent of blade length. The shorter the blade the larger the proportion of the steam that leaks around the end of the blade and escapes doing work. This spells loss in efficiency.

The most obvious direct solution to this leakage problem was to adopt smaller rotor diameters and correspondingly longer blades to obtain a smaller percentage clearance and leakage-path area. However, the heat-energy for optimum efficiency per stage varies with the square of the blade velocity. Therefore, reduction of rotor diameter and blade velocity rapidly increases the number of blading stages required, and hence the length of the machine. Early in turbine history, even before throttle steam pressure and temperature had begun their upward trend, this handicap in straight reaction turbine construction was recognized.

In 1907, therefore, Westinghouse introduced the combination impulse-reaction turbine, a construction still used in most large turbines. In this an impulse-type stage is substituted for many reaction stages of short blading. This construction avoids high leakage losses.

Impulse-type stages at the turbine inlet have an advantage in addition to their favorable effect on efficiency. They make possible the inlet of steam through several independently controlled valves and nozzles instead of around the full periphery of the stage. Ability to admit steam by closing some nozzles entirely instead of throttling all of them, called partial admission, improves efficiency at light loads.

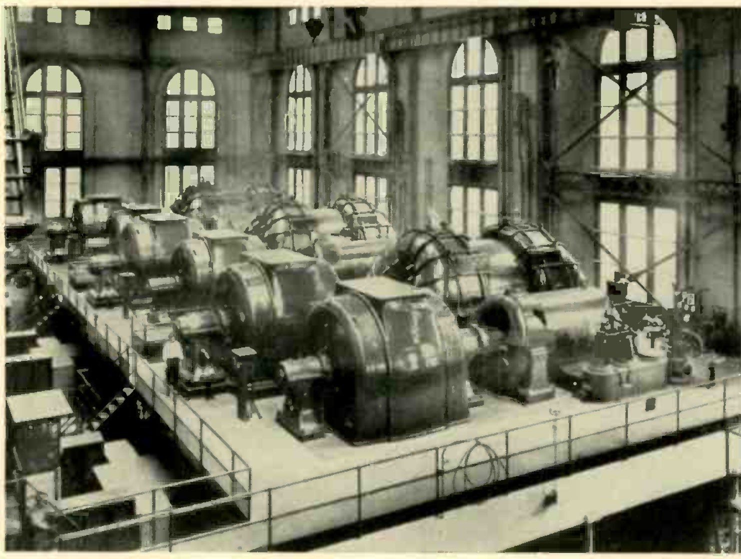
Partial admission to first-stage impulse wheels served its purpose well for many years. Then the superposed turbine appeared on the scene—bringing with it a new degree of severity of duty on the first-stage blading. This type of high-speed turbine, installed in an existing plant originally equipped for medium or low steam conditions, took steam from a new high pressure and high temperature and expanded it to inlet conditions of the old turbines. This method of modernization permitted raising the efficiency of older plants and was popular during the late 30's. These machines called for enormous quantities of steam—far more than customary. About 40 percent of the complete expansion heat energy is available to the average superposed turbine, so its steam flow is 2½ times as large as a condensing turbine of the same kw rating. As a result the impulse blades are comparatively long. At light load, with some valves full open, others closed, i.e., partial admission, these long impulse blades during each revolution sweep into and out of jets of great mass moving 3000 feet per second. The effect is a rapid succession of sharp hammer blows. Under some conditions of service, the impacts are certain to correspond to a blade harmonic.

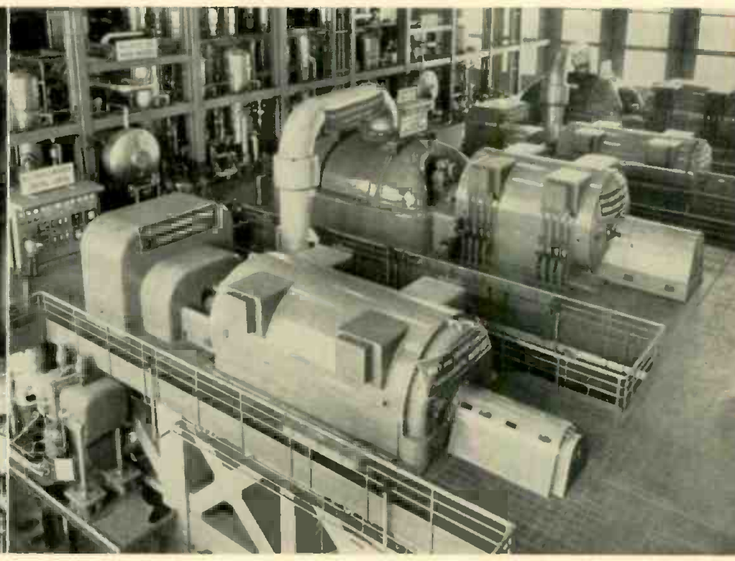
As a result, some blades on early superposed turbines failed by fatigue. A complete solution to this problem was obtained only after extensive experimentation on test turbines in the shop and finally on a full-scale unit installed for test purposes alone and operated under superposed turbine conditions in the Schuylkill Station of the Philadelphia Electric Company. By means of a light beam sent in through the shaft and up to the blade tip and back, the blades were made to write a record of their actual vibration under all conditions.

Many blade constructions were tested. The one that proved to be fully the master of this situation consists, as shown in the illustration, of the complete assembly of three individual blades joined by welding or copper brazing under a controlled atmosphere. Actually such construction is more than adequate, and has been used in but a few more recent high-temperature machines. The problem in the early superposed turbines was solved by less extensive departure from previous practice. The most important result of this exhaustive study was the basic data obtained for future guidance.

Blade Evolution

The "front line" in a steam turbine is the blading. In a sense all other components of a turbine are merely necessary auxiliaries that enable the blades to do their work. Modern blades have, by a long evolution, come to be beautifully finished, precision parts, highly efficient for the job to be done. They are the result of the combined intensive efforts for many years of metallurgists, fluid-flow specialists, and mechanical engineers. That evolution has been in several directions: the





metal used, blade shapes, and methods of fastening or roots.

The first blades were drawn of brass, but these were soon superseded by phosphor bronze and five-percent nickel steel, depending on the stress to be met. As turbine powers and steam temperatures rose, phosphor bronze became inadequate and in 1921 was replaced by manganese copper. Stainless steel appeared in cutlery about the time of World War I. While attractive as to physical properties, it is hard to work, but it led to a study of similar alloys that resulted in low-carbon, 12-percent chrome-iron blading. This was introduced by Westinghouse in the mid-20's and is still the material generally used throughout the industry with great success. With higher temperatures in the offing, intensive research is under way to develop a new superior blade material or improve on the 12-percent chrome iron.

Because of the high centrifugal forces of many tons acting to pull the blades out of their fastenings, the root structure is a matter of greatest interest. Early constructions involved dovetail roots, compound tapered side wedges, and separate spacers. These underwent numerous variations until, as steam temperatures and loadings increased, progressive crushing of the dovetail root surfaces took place. This led to roots with various abutment surfaces like an inverted letter T, as shown in the illustration. Spacers are now made as an integral part of the blade. These are entirely adequate even today.

As reaction blades grew longer some means of stiffening them by bracing one against the next became necessary. For many years the blades were pierced a short distance from their outer end and a lashing wire run through the opening and fastened to each blade by mechanical means or silver soldering. In 1935 shrouded-blade construction was adopted for central-station turbines generally, and except for the very long low-pressure reaction blades, these proved sufficient. Additional stiffening, if required, was achieved by welding struts to the blades. But the welding introduced local heating so that this practice has given way to one in which abutments are formed integral with the blade during forging. These abutments are then joined by welding, without the blade proper becoming overheated.

In the last stages of a turbine it is not uncommon to find 10 to 14 percent moisture in the steam. With blades moving through this cloud of moisture droplets, erosion of the leading edges becomes a problem. In 1929 Westinghouse experimented with two large turbines equipped with combinations of bare blades and blades to which shields of hard metals had been attached. The efficacy of stellite shields in reducing erosion was so clearly demonstrated that they are now generally used on low-pressure blading in the moisture region.

The Effects of Improved Metals

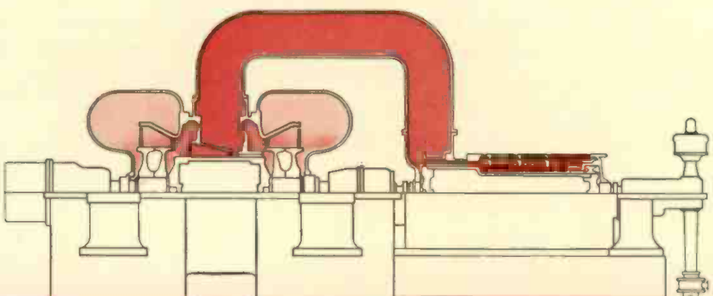
Credit for the tremendous growth of turbine capacities, speeds, and adaptability to service with elevated steam pressure and temperature is in part due to significant progress by the steel industry and to a broad field of metallurgical development. Early turbine rotors were built up of relatively small steel forgings and castings, the components being assembled with shrink or pressed fits, supplemented by bolting or shrink bars. High-quality, carbon-steel castings and multi-piece rotors were adequate at low speeds and with low temperature.

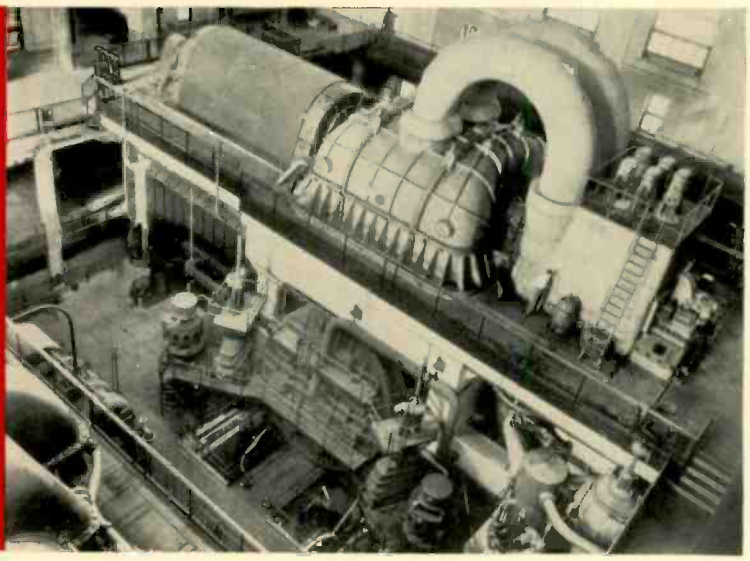
However, the limits of multi-part construction were finally reached, forcing attention to the development of forging techniques capable of producing a single-piece rotor. In 1921 Westinghouse introduced solid-forged rotors in multi-stage units of medium size. Development continued until it became possible to make single-piece carbon and alloy-steel rotor forgings for the largest machines.

This development was outstandingly important. Not only did it enhance turbine reliability but also, by the elimination of assembly fits, it removed one barrier to the building of rotors of today's high-speed, high-temperature large turbines.

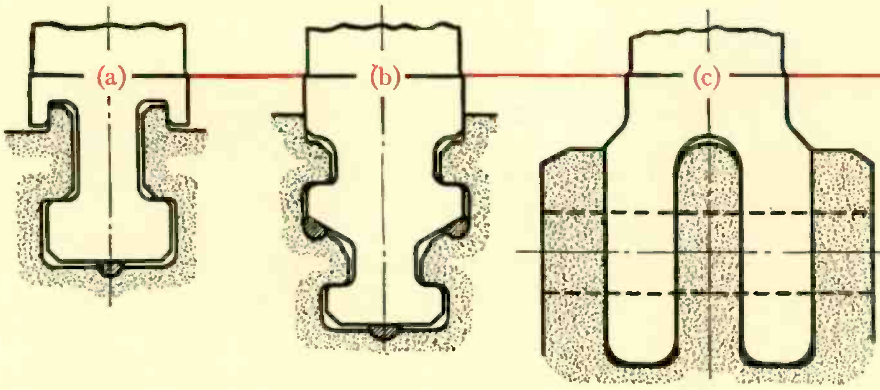
Iron castings were adequate for turbine casings, throttle valves, and other steam containers until about 1912 when temperatures increased above 500 degrees. The phenomenon of cast-iron growth was then encountered. This apparent intercrystalline growth was accompanied by marked loss of strength. This is bad enough anywhere, but in turbines, with their many close-fitting parts, permanent growth of some members clearly leads to trouble.

Carbon-steel castings then came into use for temperatures above 450 degrees. Thereupon all went well until operating





For the larger ratings—up to 50 000 kw—the double-flow, two-case tandem machine (above) came into vogue in 1917. The 30 000-kw, 25-cycle machines (far left) of the Interborough Rapid Transit Company were among the first large cross-compound units. The two 150 000-kw units (left) in Southwark Station, Philadelphia Electric Company, are representative of modern cross-compound construction. The largest of the single-shaft generating units is the 165 000-kw unit installed in Richmond Station, Philadelphia, in 1936.



The impulse (a, b, c) and reaction (d, e, f) blades used, shown left to right in order of increasing severity of duty. Blade (c) also shown below, is the one developed for the severe partial-admission duty as a result of optical studies of blade vibration. Reaction blade (d) is applicable for most stages, with (e) for larger blading. Reaction blade (f) is used for condensing-turbine exhaust-end blades having the greatest centrifugal loading.

temperatures reached 825 degrees. "Creep" became a new obstacle. This is the gradual and permanent "stretching" of metal, depending in amount on the particular metal, stress, temperature, and time. A tremendous amount of research has catalogued the creep properties of steels and many alloys, so that it is now possible to apply a particular material to operate at such stress and temperature level as to give required life. Small quantities of molybdenum are particularly effective as an alloying element to resist creep, and are now used generally above 825 degrees.

More recently the phenomenon of "graphitization" appeared in metal adjacent to welds. This is essentially a carbide destruction followed by intercrystalline consolidation of graphite. It causes loss of strength and susceptibility to shock failure. Graphitization can be inhibited by certain precautions taken in the steel mill, and by certain additive alloying elements such as chromium. Alloys containing molybdenum and chromium have satisfactory creep properties and graphitization resistance for general use up to 1000 degrees.

Above 1000 degrees F it has been deemed desirable to adopt much richer alloys rather than to design the cumbersome structures that would be necessary to keep the stresses and corresponding creep within bounds. Castings and forgings of stainless steel—18 percent chromium, 8 percent nickel, and with columbium stabilizer—are used in the 1050-degree machines. The much higher coefficient of expansion and poor heat conductivity of stainless steel impose design changes.

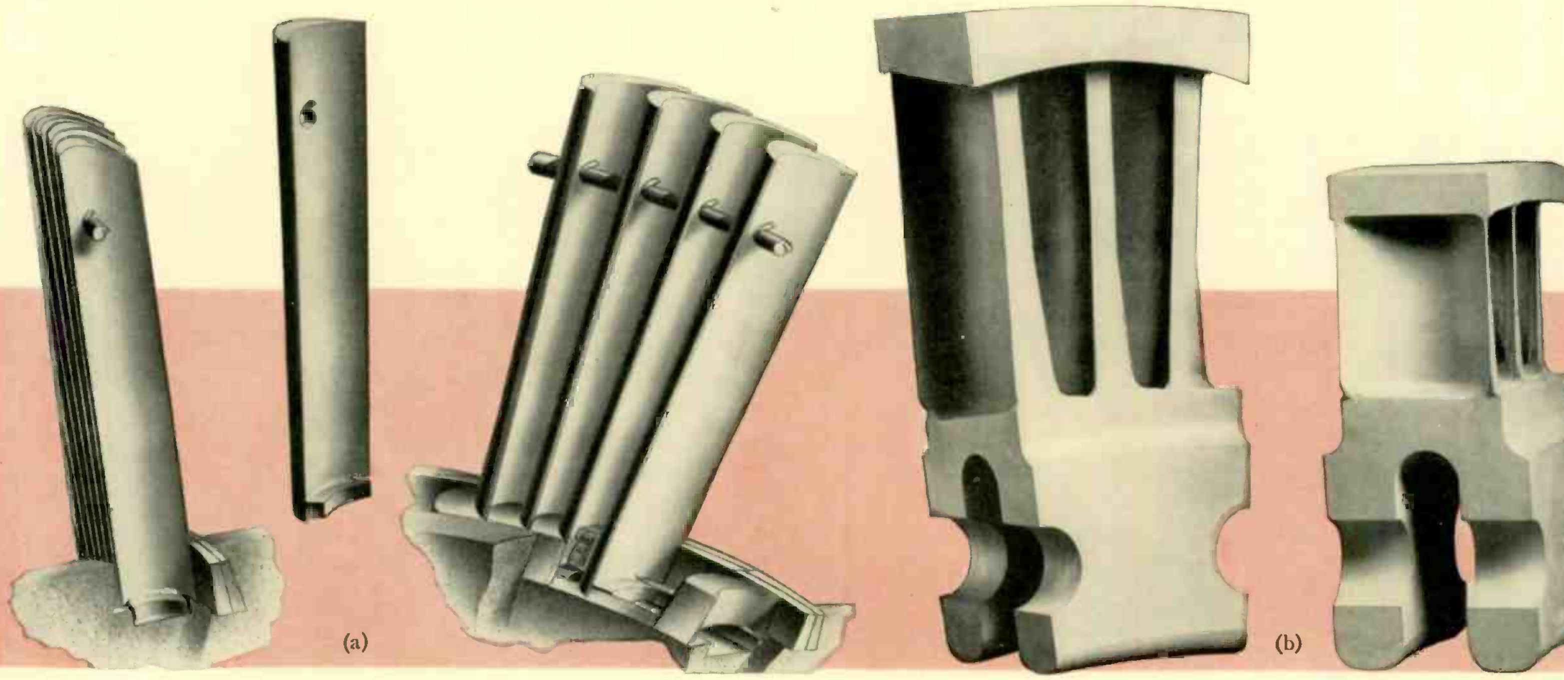
The Course of Governor Development

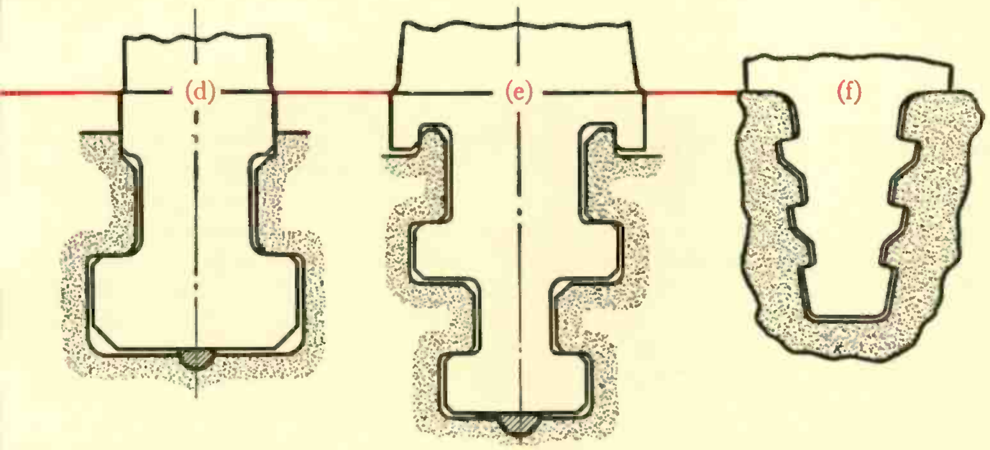
The Parsons' turbine brought to this country in 1896 had an electric governor that was responsive to voltage output. Speed varied with load. Delicate impulses of a solenoid were transmitted to the steam-inlet control valve through a steam relay that was made to oscillate and admit steam in puffs of long or short duration, according to load.

To enable machines to have the constant-speed characteristics required for operation in parallel, the first Westinghouse unit retained the Parsons' steam relay and puff admission system, but substituted for the solenoid a flyball governor responsive to speed change.

To an all-reaction turbine it matters little to efficiency whether steam be admitted steadily or in puffs. But, when turbines with an initial impulse stage were introduced the puff system was found to be quite detrimental to efficiency. This led to the substitution of oil relays for those steam operated, retaining means for oscillating the valve gear slightly to eliminate friction of rest.

Although this control system was greatly improved in detail over a period of years it possessed certain fundamental mechanical handicaps. Westinghouse replaced it in 1922 with a fully hydraulic control system. Applied first to small turbines, it was, during the ensuing years, vastly improved in design and has become standard for all turbines except small ones used for mechanical drive. One of the more important features of the hydraulic system was the replacement of the gear-driven main oil pump by a centrifugal oil pump mounted directly on the main turbine rotor, served by an oil ejector located in the oil reservoir. This system is free of the mechanical-drive problems that beset large gear-driven pumps and has also introduced greater flexibility in selection





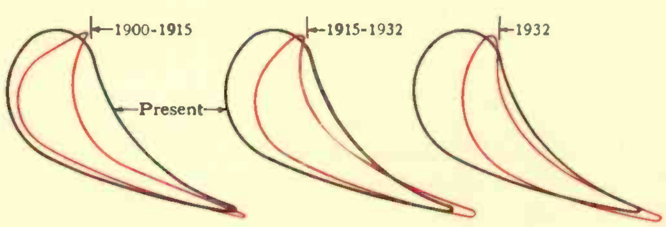
of most advantageous oil-reservoir location. Years of service have proved the soundness of the hydraulic principle.

In this hydraulic governor, speed change is sensed as a change in the oil pressure from a centrifugal impeller. In the early hydraulic governors a single pump provided this pressure as well as the needs of the lubrication system and the servomotor that moves the steam valves. Since 1933 a separate small impeller provides this pressure, impulses resulting from speed change being transformed by powerful hydraulic, and essentially motionless amplifiers. The sensitivity, speed of response, and reliability are excellent.

The Steam Chest and Valve Mechanism

The steam chest to contain today's high-temperature, high-pressure steam, and the mechanism for admitting it as desired to the turbine, is of prime importance. Early machines had double-seated valves, which theoretically are balanced. The complexity of the castings made three admission points the practical maximum. In spite of the theory of double-seated valves, in some valve positions dynamic unbalance was large. Double-seated valves were difficult to keep tight under all service conditions.

Great improvement came in 1930 with the "bar-lift" valve chest. The servomotor opens the valves by lifting two stems supporting a heavy bar from which the several valves are suspended. As the bar rises the valves on rods of different and adjustable length are opened in desired sequence. The only points of friction are the two stems. The force necessary



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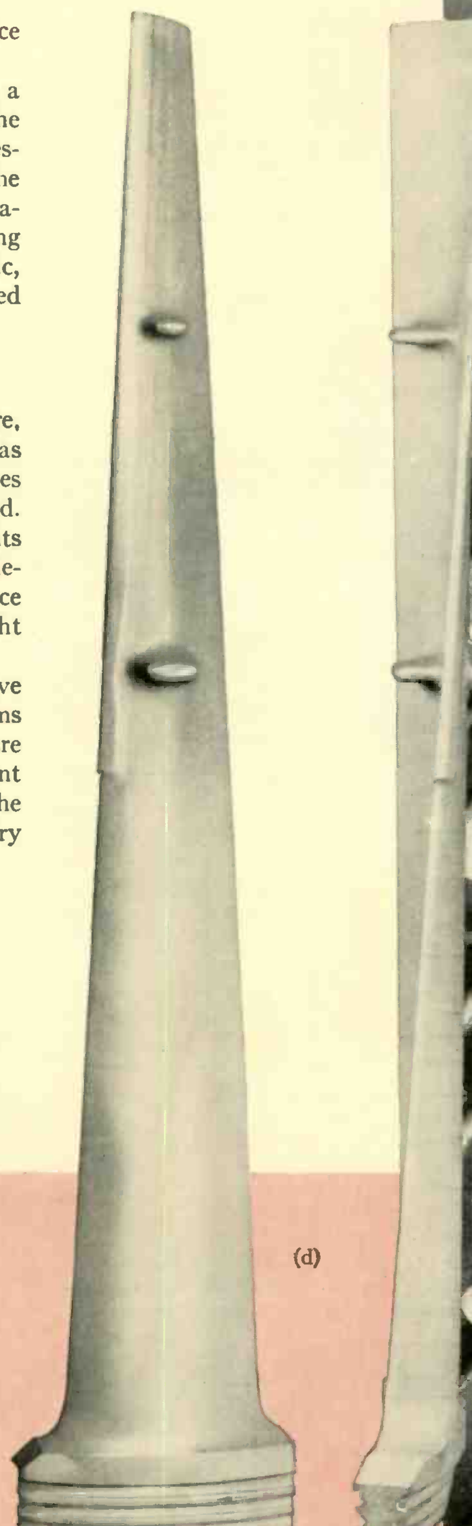

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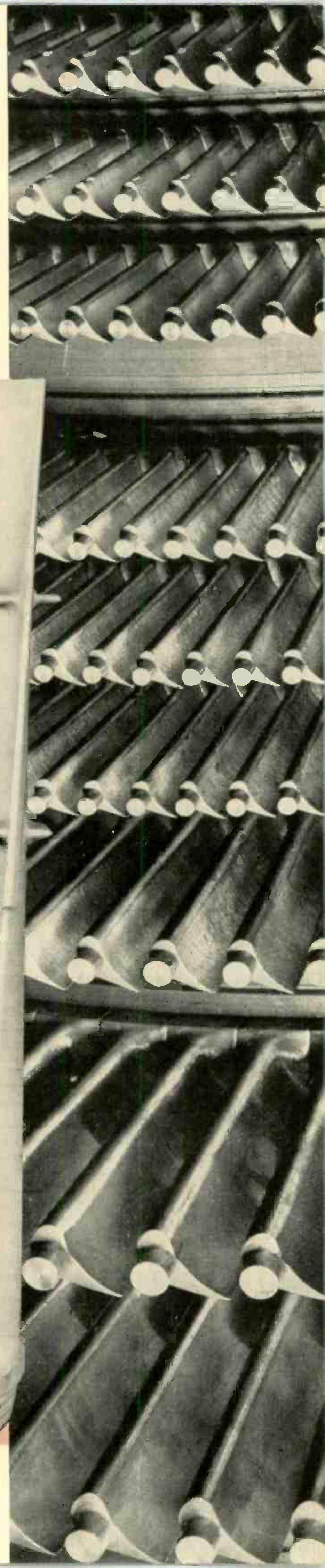
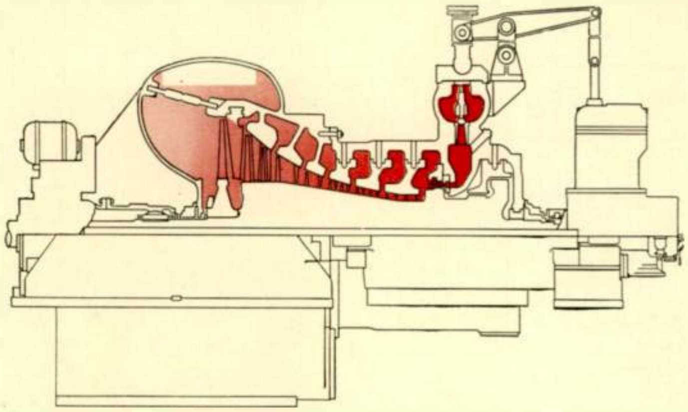
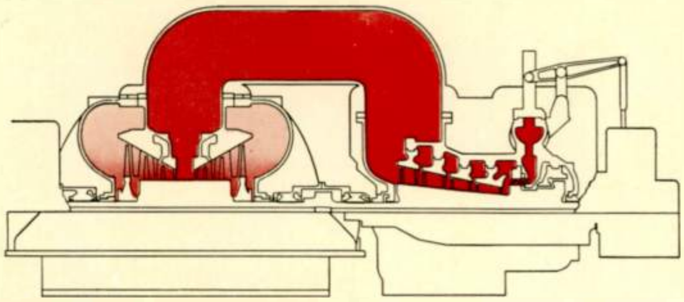


(e)

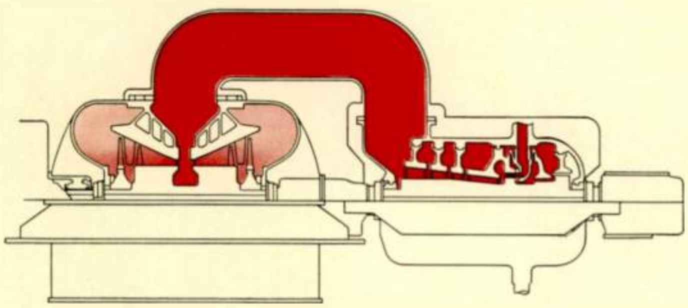
In 1912 the manner of fastening blades to the rotor, shown in (a), was introduced. Spacers were provided with dovetail sides and the blades were upset to form a hook that locked under the spacer. The impulse blades (b) are used for severe, inlet stage duty. They are formed in groups, with inverted U roots, and are fastened to the rotor with pins. The present blade section, (c) blunt by comparison with those of earlier blades, has superior strength. The longest 3600-rpm blade now used is the 23-inch reaction blade (d), which has a tapered serrated root and forged lashing abutments. The end view of reaction blades (e) shows the tenons for riveting to the shroud rings.



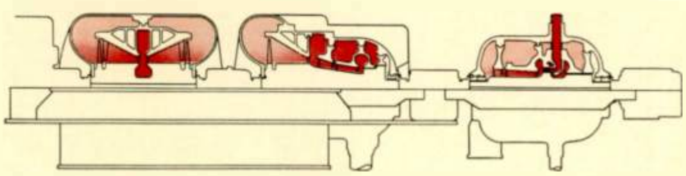
Simplified standard single-cylinder turbine, 30 000 kw, 3600 rpm.



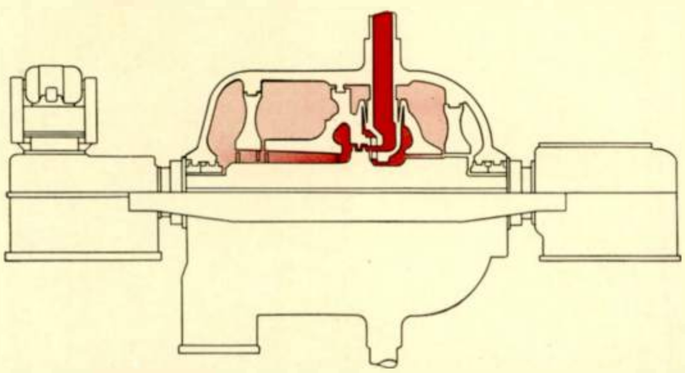
Tandem-compound, double-flow turbine, 80 000 kw, 3600 rpm.



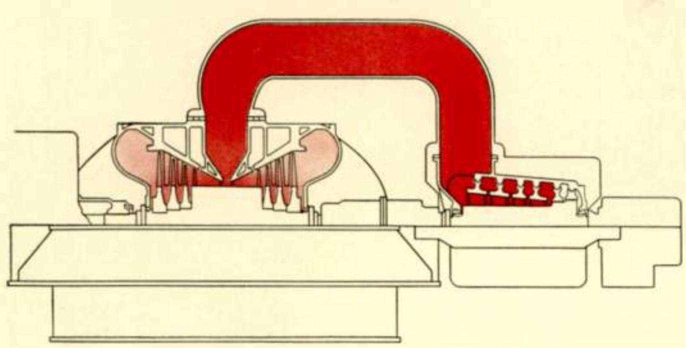
80 000-kw, 3600-rpm tandem turbine, separate steam chest.



125 000-kw, 3600-rpm tandem-compound, triple-flow reheat turbine.



High-pressure 3600-rpm element (above) of 150 000-kw cross-compound turbine and low-pressure, tandem-compound 1800-rpm element. Use of this arrangement depends on steam conditions.



to lift a single-seated valve is large, but, in contrast to the larger double-seated valve construction previously used, this loading is readily predictable and not reversible at any point in its lift. Further, the possibility of seizure or binding resulting from distortion of any of the parts has been virtually eliminated. All forms of packing have been removed from the bar-lift rods, leakage being sharply limited by the small working clearance between rods of high-carbon, chromium steel and nitralloy guide bushings, and nitriding both rod and bushing of heat-resisting materials in the case of the 1050-degree turbine.

Essential Turbine Adjunct—The Condenser

The turbine, as it played its dramatic role in a half century of power-generation evolution, has had a silent, little-observed but essential companion—the condenser. One of the distinct advantages of the turbine over the displacement engine is its ability to convert more of the heat energy of the steam to mechanical energy because it can continue to extract energy by expanding the steam far below atmospheric pressure. A 950-degree, 1250-pound condensing turbine obtains almost as much energy in the expansion of steam from atmospheric to 29 inches vacuum as it does from 1250 pounds down to atmospheric.

Early turbine progress in this country was hampered by lack of equipment capable of producing high vacuum. Seeing that success with the turbine hinged on a good vacuum system, Westinghouse, shortly before the turn of the century, developed a barometric jet condenser in time to so equip the Westinghouse Air-Brake installation in 1899, giving it a vacuum of about 26 inches, probably establishing a record for that day.

The lack of adequate means for removing accumulated air in the vacuum system, however, limited the vacuum available for several years to 26 or 27 inches of mercury. To overcome this, Westinghouse acquired in 1907 the American rights for the rotary hydraulic air pump from LeBlanc of France. This made possible vacuums of 29 inches or more.

In 1912 Westinghouse produced the surface-type condenser in which the cooling water is circulated through tubes. Steam flows around this nest of cold tubes, giving up heat and condensing en route. The surface condenser greatly improved plant operation in that it provided distilled condensate for boiler feed water with all its enormous implications in power-plant operation. An important feature of these condensers in the larger sizes is that the steam flows radially to the center of the tube nest instead of downward to the bottom, giving several performance advantages.

The rotary air pump remained as the preferred method of extracting entrapped air, which acts as a parasite. Then in 1913 Westinghouse introduced the steam-jet air pump, also from LeBlanc. This was used first for marine service, and about 1919 came into use for land installations. Although the basic features of vacuum apparatus have since not changed, some improvements have been introduced. For example, a condensing-type air ejector, in 1922, reduced the steam consumption of air-removal systems.

Vertical single-stage propeller pumps were introduced in 1929 for pumping circulating water. Being of high capacity and high speed, they were smaller and simpler than centrifugal-type pumps in general use. Multi-stage pumps, in 1946, raised the head applicable for propeller pumps to 75 feet from about 25 feet, which stood as a limitation of the single-stage pumps. Surface condenser construction was improved in 1931 when welded steel replaced cast-iron shell construction, with substantial reduction in weight and in air leakage. By combining the intermediate condensers and after-condenser of the air-ejector system into a common shell, in 1938, relief valves were eliminated and piping simplified. All in all, the condensing equipment has had a profound and often overlooked influence on steam-plant development.

Today!

Many developments, of which some major ones have been touched on, have led to the steam turbine of 1950. Nearly all central-station turbines operate condensing, that is, exhaust at a pressure far below atmospheric into condensers, from which feed water of good quality is returned to the boiler plant. Most modern units operate at 3600 rpm, driving two-pole, 60-cycle generators, which have increased sixfold in maximum rating in two decades.

Now under construction is a single-shaft, 3600-rpm turbine for 125 000-kw maximum output with triple-flow, low-pressure section. A triple-exhaust turbine of this general type can be made to deliver 150 000 kw economically at 28.5-inch vacuum. The relatively few units built for ratings above the economical limit of the single-shaft 3600-rpm are either tandem-compound 1800-rpm machines, or cross compound.

Single-case, high-speed units are available up to 30 000 kw inclusive, and will eventually be extended further. The tandem-compound construction extends upward to include 125 000 kw. The more common steam conditions encountered for units of 20 000-kw rating and upward are 850 pounds pressure, 900 degrees, but 1250 pounds, 950 degrees and 1450 pounds at 1000 degrees are growing in favor.

The problems associated with these top steam conditions are both metallurgical and mechanical. When temperature reaches 1000 degrees the steam chest is separated from the turbine case. This gives a simpler, more symmetrical casing. By suitable selection of materials this construction has proved satisfactory in service at 1050 degrees F.

Ahead!

The pattern in the next several years for the large turbine is rather well established. The step to 1050-degree steam has only recently been taken. It will be well to "digest" this before moving upward. Caution will be exercised as a prolonged outage of costly revenue-producing machinery would rapidly devour the savings otherwise effected. Laws of diminishing returns prevail. It is, therefore, reasonable to expect that, while operating experience is being gathered with the pioneering 1050-degree plants, new installations generally will be built for temperatures closely approaching such level. Thus the average of the nation's power plants will rise closer to this present top limit.

After some pause at the 1050-degree level, the economics of rising fuel and labor costs will bring to being a large 1100-degree turbine. This should be possible with modification in construction and materials of the general type now in use. Perhaps the next step to 1150 degrees will soon follow, but this would require better materials than are now at hand.

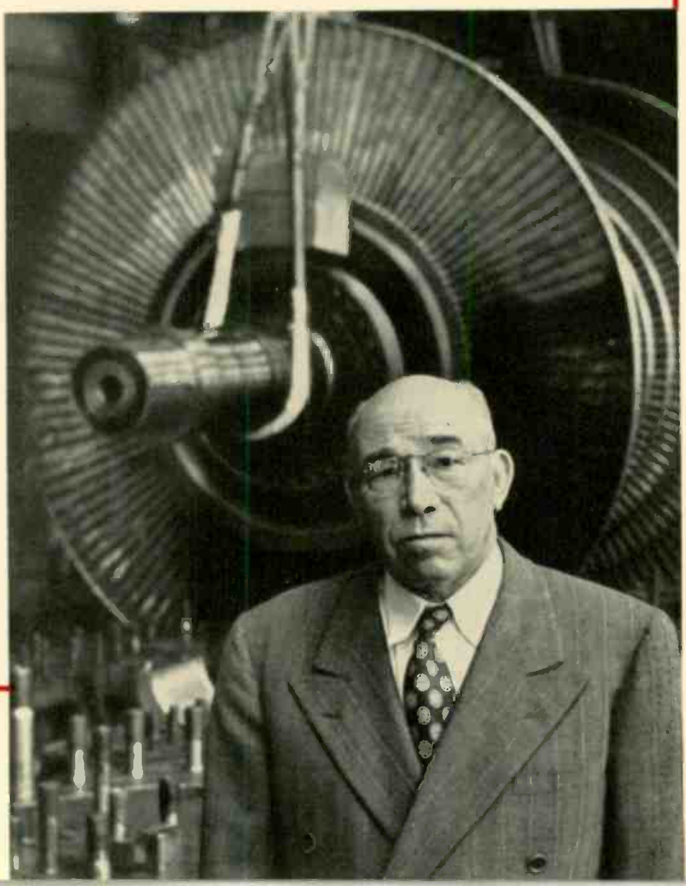
Machines of larger maximum capacity are clearly in the short-range picture. These do not appear illogical or im-

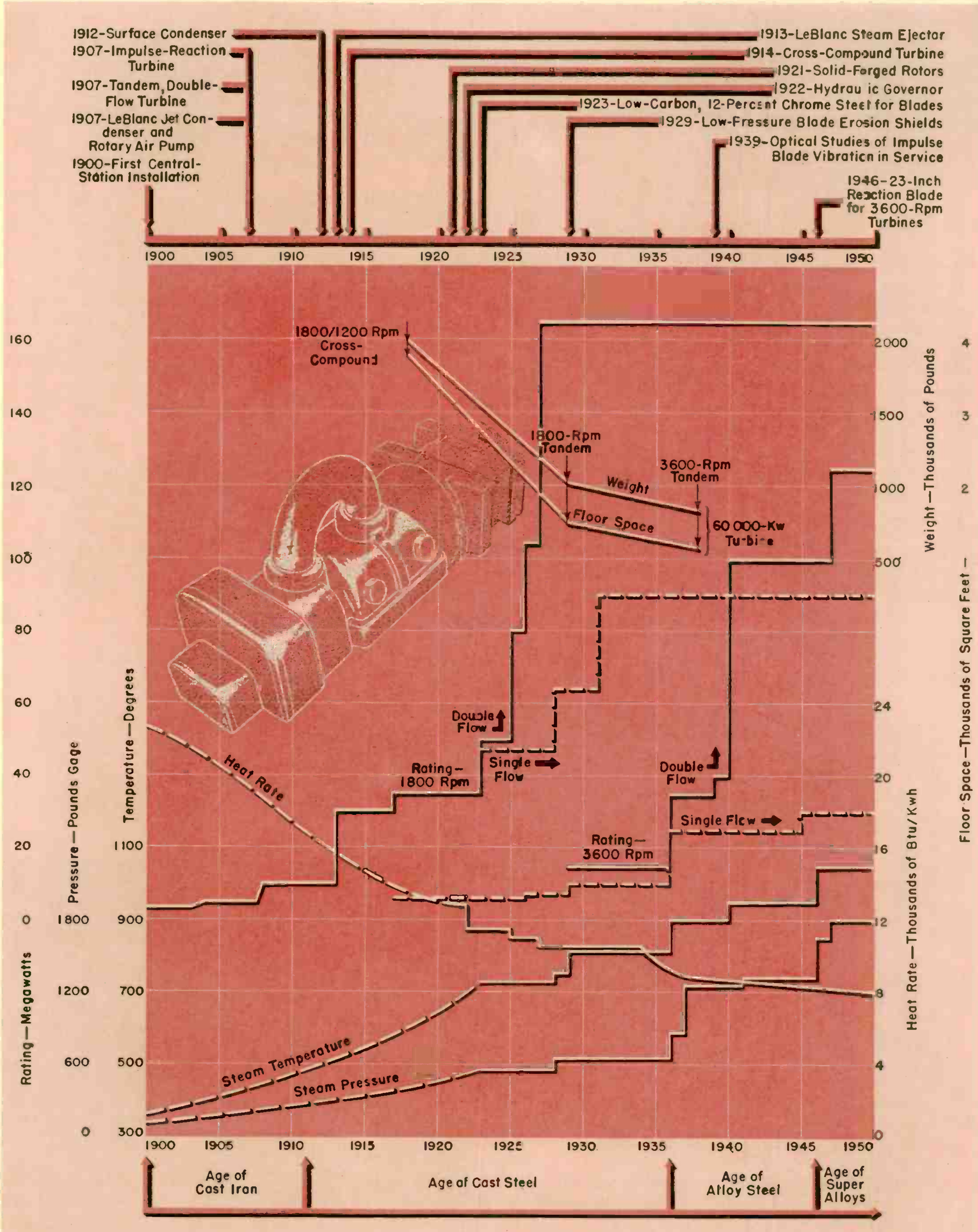
D.W.R. MORGAN

The engineering profession generally, and Westinghouse in particular, almost got cheated of an illustrious engineer back in the spring of 1913. When David W. R. Morgan entered Ohio Northern University four years before, his father, a very determined man, had insisted that "Dave" study engineering. Dave had wanted to study law and was not without determination himself, as his career has since proved. So he compromised. He studied both, meanwhile neglecting to mention the law courses. Came spring 1913, Morgan complied with the wishes of his father and took his degree in mechanical engineering.

With an eye for experience, Morgan took a technical apprentice job at the Westinghouse Machine Company in Pittsburgh. Shortly thereafter he was assigned to help test one of the first geared marine turbines ever built, which a year later was installed in the historic collier *U.S.S. Neptune*. In 1914 Morgan was transferred to the drafting department, and soon to the engineering department. The year 1917 found him manager of condenser engineering. From 1926 to 1931 he was in charge of oil-engine development, returning to the condenser activity when that development ceased. It was during these years, working with condensers and pumps, that he did most of his creative engineering work, having some 30 patents credited to his name.

Since 1940 advancements have come with regularity. In that year he was made assistant manager of engineering of the entire Steam Division at the South Philadelphia plant. Eighteen months later he took full charge of the manufacturing activity, and next year he became works manager. In 1944 he was appointed assistant manager for the Company's Steam Division activities, which includes all steam turbines, condensers, and stokers. In 1945 he was made general manager of the Steam Division. The next year, the booming young Aviation Gas Turbine Division was also placed under his jurisdiction. In 1948 he was elected vice president in charge of the Steam and Aviation Gas Turbine Division. Looks like the legal profession lost a good man.





A summation of a half century of steam-turbine progress.

possible if the economic need for larger machines arises.

At any one time the largest turbine built does not necessarily represent the limit of manufacturing ability. There is a rough relationship between system size and the maximum rating of generating units appropriate for it. Many utility managements feel that the largest turbine generator should not exceed about ten percent of the total system capacity. Otherwise the problem of providing spare capacity should that machine be out of service becomes troublesome.

Some systems are now approaching two million kw in capacity and could justify the largest turbine generators now available. Therefore in the not-too-distant future, turbine generators of 150 000 to 200 000 are likely to be in demand. Already under construction are single-shaft, 3600-rpm turbines having maximum capabilities of 125 000 kw. Application studies are being made for larger machines, which should result in a few years in a single-shaft turbine capable of delivering 150 000 kw. Because an 1800-rpm turbine can be built about four times larger in output than 3600-rpm units, single-shaft low-speed machines of 600 000 kw would be technically possible. However, using known designs, materials, and near-future steam conditions, turbines larger than 150 000 kw would be cross compounded to obtain the advantages for the high steam conditions of 3600 rpm and the ability of the 1800-rpm construction to accommodate the accompanying tremendous exhaust-steam volume.

The *reheat* principle has reappeared and gives every evidence that it will prove satisfactory. A single stage of reheat to the initial throttle temperature decreases heat consumption by about 4½ percent. To obtain similar gain by advancing the steam temperature from 1050 degrees would call for 1200 or 1250 degrees—far more difficult and costly to achieve. Thus, reheat offers attractive gains. Operating experience will show how to simplify reheat equipment, increase flexibility, and decrease cost. Reheat seems likely to be an adjunct of future high-economy, large-capacity units of further advanced steam conditions.

Turbine standardization has been both successful and popular. It has released design engineers for more development work, thus disproving the argument that standardization restricts progress. In the four years this program has been in effect, about 60 percent of the units built by Westinghouse within the range of standardization were of such class.

The top limit of standards—60 000 kw—is small for the larger systems. In the light of recent developments standardization of a 90 000-kw machine is indicated and preliminary consideration might be given to one of 135 000 kw.

Atomic power stands, obviously, as a potential means of furnishing heat for large production of electric energy by steam-driven turbines. It should be reduced to practicality at the earliest time. However, so little is yet known about its problems, and the development work that lies before it is so prodigious that the only logical conclusion at the moment is that central-station use of atomic energy is some years away. Because of the numerous unknowns, any attempt now to visualize how atomic power will fit into the central-station picture is idle. No account can be taken of it at present.

Further Ahead!

United States population and kilowatt consumption are both growing steadily and show every indication of continuing to do so. Within the next ten or twelve years installed generating capacity will be doubled; within the remainder of the century at least tripled or quadrupled. We can hardly expect that the resulting gigantic power systems will be served simply by large numbers of big generating units of the kind already visible on the horizon. What they will be cannot be predicted with finality, because of enormous intervening obstacles. But suppose that intensive research provides suitable materials and that the economic situation becomes such as to justify ultimate thermal efficiency regardless of machine cost. What form might the turbine colossus take and what would it achieve by today's standards? A turbine built for steam conditions of 1200 degrees and 3206 pounds pressure (which is the pressure at which water and steam have the same density) should produce about 8 percent more kilowatthours per ton of coal than a 1050-degree, 2000-pound turbine, both employing reheat. This would give a turbine with about 40 percent thermal efficiency compared with today's anticipated best of about 37 percent.

In building such a super-turbine the front end would be the critical one. Steam might be brought to the first stage wheels through a series of small inlet pipes feeding nozzle chambers separately cast of some metal unknown at present, capable of withstanding such high pressure at high temperature. Forged parts would be out of the question because operating temperatures are already on the heels of forging temperatures. The rotating element would pose severe problems because of the high centrifugal forces also at high temperatures. Approaches to this matter might take different directions. Instead of one large rotating first stage there might be several small wheels operating in parallel at speeds two or three times 3600 rpm and geared to the main high-pressure element. These small wheels, using alloys developed for gas turbines or some improved austenitic material, could expand the steam from the 3200-pound level down to 1800 or even lower where it could be handled more conventionally.

An alternate method would be to build high-pressure turbine stages in a separate, compact turbine element directly coupled in tandem to the main unit shaft.

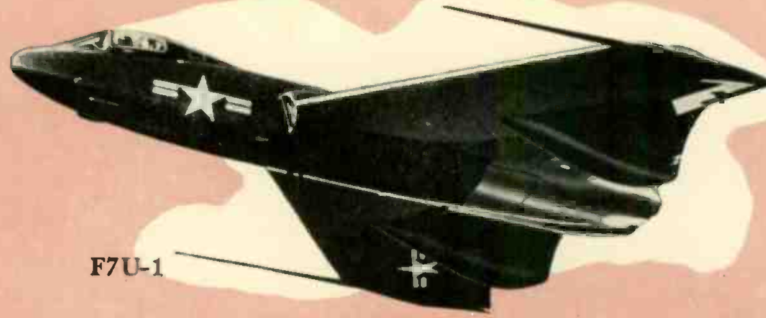
For the 3200-pound turbine to retain the mass-flow relations of the high-pressure stages, the rating should be at least 240 000 kw, possibly more. This is desirable from the standpoint of leakage control and good experience.

The exhaust end would not likely interfere with building a 240 000-kw unit even at 3600 rpm for these extremes of 1200 degrees, 3200 pounds. Existing exhaust blades arranged for quadruple flow would handle the steam for a 240 000-kw turbine at the supposed inlet conditions. Furthermore, we can ultimately look for exhaust blades even longer than the present 23-inch. Assuming that such a longer blade provides a 25-percent increase in exhaust annulus, a high-speed turbine with quadruple exhaust flow could then be built for a maximum output of 300 000 kw.

If turbines larger than 300 000 kw become economically justifiable, the most obvious way of obtaining both sufficient exhaust annulus and generator capacity is to go to cross compounding with an 1800-rpm, low-pressure element, whereupon a turbine delivering a half-million kw would become possible. Conceivably then such a gigantic unit for 1200 degrees, 3200 pounds might be a cross-compound machine with multiple-flow, low-pressure section and a high-pressure element of the multi-cylinder type, with the first stage in tandem or geared to this 3600-rpm element.

Mid-way in the 20th century the turbine designer reviews with considerable satisfaction five decades of very considerable progress. At the same time he views ahead—with pleasant anticipation—a mountain of development work to be done before the ultimate in power conversion with the rotating heat engine is achieved.

F2H



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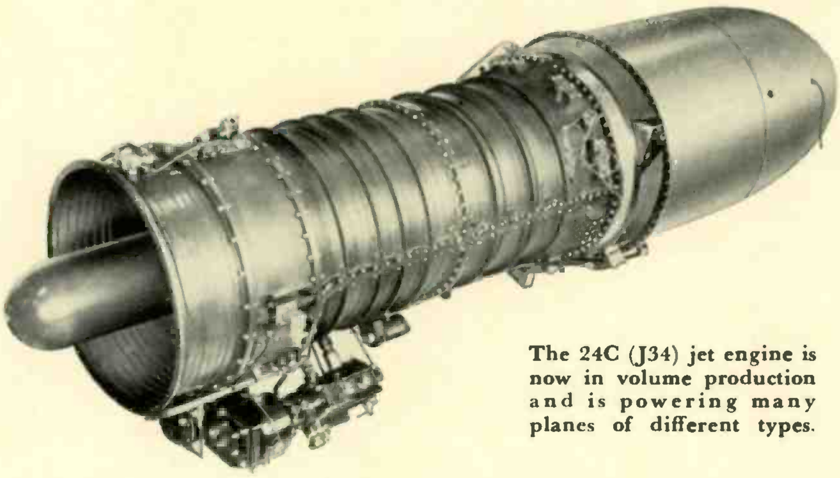
THE NEWCOMER

The Gas Turbine



The 24C (J34) jet engine is now in volume production and is powering many planes of different types.

THE RECENT war brought to relatively sudden fruition an idea that had been developing slowly for many years—the gas turbine. The idea of developing mechanical power by expanding hot gases of combustion directly through a turbine—eliminating the intermediate step of converting water to steam—had long been attractive to power engineers. Westinghouse had in the early 30's studied a closed-cycle gas-turbine system for a 25 000-shp ship drive. But, except for special cases where hot gases were available under pressure anyway, at little or no cost, the gas turbine had not in the United States become a practical device. Two things were necessary for the system to deliver an adequate amount of power—a compressor of high efficiency and materials capable of handling higher temperatures than are experienced in steam turbines. The war, with its disregard for economic considerations, and its acceptance of short life, accelerated the development of both.

The jet engine. With the war raging in Europe, the military services saw the need for speedier aircraft than was possible with reciprocating engines, and early in 1941 Westinghouse was asked by the National Advisory Committee on Aeronautics to participate in a study of a new form of engine. Within the next few months Dr. Stewart Way at the Research Laboratories conceived—what since has been learned to be independent inventions—the ram jet as well as the axial-flow turbo-jet engine. The events on December 7 of that year spurred the program and resulted instantly in an assignment under the auspices of the U.S. Navy to develop a new jet-propulsion engine independently and without reference to the work then known to be proceeding in Europe. This logically became a task for the Steam Division, wherein was embodied a vast amount of experience with high-temperature materials, high-speed apparatus, and blowers.

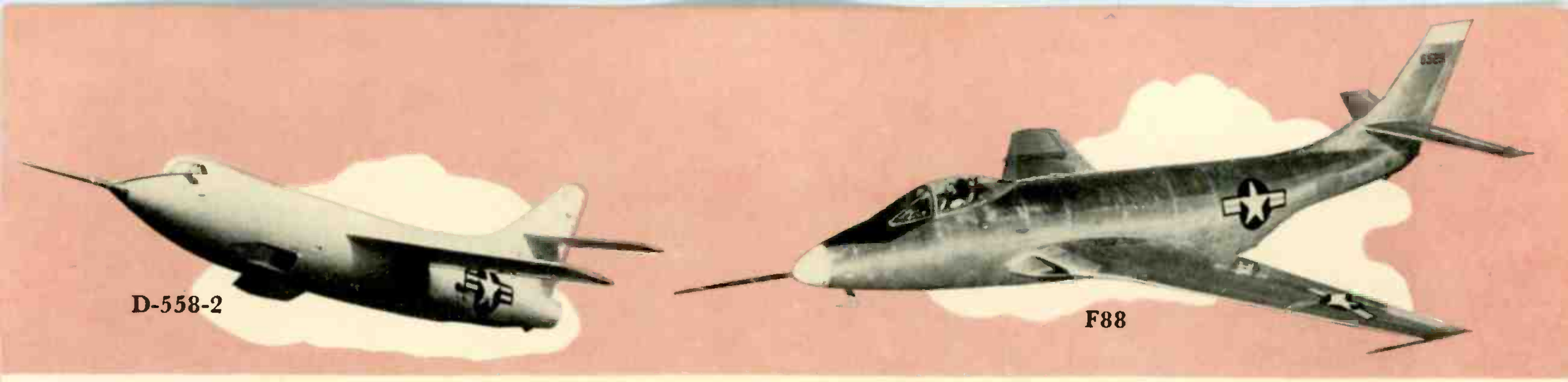
The result was the first jet engine of American design. The historic 19-A was brought to test (March, 1943) in the astonishingly brief time of 15 months after a start was authorized, considering it was a radically different type of power plant and involved temperatures several hundred degrees beyond those accustomed for steam apparatus. Unlike most jet-propulsion engines developed by the Allies at this time, this one comprised a compressor of axial-flow form (in distinction to the radial or centrifugal-flow type), a combustion chamber, and a turbine in a straight line, resulting in a compact, streamlined arrangement.

Although many improvements of detail and in performance have since been made, this construction has remained and in fact has become the pattern for jet units the world over. Interesting features of the 19-A engine included an adjustable exhaust nozzle, a combined oil cooler and reservoir, and a combustion chamber made up of 24 separate burner cells.

From the outset, progress in jet-engine development has been rapid, with new engine models appearing at short intervals. The 19-A was soon followed by the 19-B of the same dimensions, but with thrust increased from 1200 to 1365 pounds and a decline in specific weight from 0.65 pound per pound thrust to 0.58 pound and fuel consumption from 1.4 pounds of fuel per hour per pound of thrust to 1.3. The 19-B engine was followed in a few months by the 19-XB, still of the same size but with 1600 pounds thrust and 30 percent less weight and 15 percent better fuel performance. The rapidly rising demand of the services for greater speed soon brought about a larger engine physically, (the 24-C) 24 inches in diameter instead of about 19, and with a basic thrust of 3000 pounds. Both the 19-XB and the various editions of the 24-C have been produced in quantity. Greatly improved versions of the 24-C with undisclosed performance are currently in extensive production. Other engines of greatly increased rating and much lower specific weight and fuel consumption are in various stages of development.

Two other types of jet engines were also developed. One was a small engine (type 9-A and 9-B)—9½ inches in diameter—produced in limited numbers. The first of these weighed only 150 pounds and developed 275 pounds thrust. A gas turbine (25-D) was designed and a gear built for propeller drive.

Various numbers of this jet-engine family have powered many illustrious military planes such as the McDonnell FH-1 "Phantom" and F2H "Banshee," the Chance-Vought F6U "Pirate," and its F7U "Cutlass," and the Douglas XF-3-D "Sky Knight" all-weather fighter. Newer applications are the Lockheed XF-90, the McDonnell XF-88 Air Force Fighter, and the XJ-85 McDonnell Parasite Fighter. Experimental



planes to explore transonic flight include the Douglas D-558-II "Skyrocket" and the Northrup XS-4. Altogether these engines are scheduled to serve more types of production and experimental aircraft than any other family of jet engines.

Eight years have brought improvements at a fast pace in jet-engine construction—without altering the basic principle. Research on materials, involving creep to rupture as well as fatigue testing, has produced no less than four turbine-blade materials, each better than its predecessor, and each finding its way into production engines. Precision-casting techniques have been developed and applied to production of turbine blades. New research-developed, high-temperature alloys such as K-42-B, Refractaloy, and Discaloy found application in the hot parts of the engines. The cell-type combustor of the 19A gave way to the annular or basket type of burner chamber, which, further perfected, remains the accepted type. By virtue of these developments the altitude of reliable combustor operation has been increased fourfold. Burner life has been improved by nearly 20 times, and is now comparable to that of other basic engine parts. Roller bearings, superior in cold weather, have replaced sleeve bearings.

Present-day jet engines can perform under operating conditions that were not visualized when the first designs were achieved. Increased emphasis is given to operation in very cold and in very hot weather. The icing problem of the engine itself is recognized and anti-icing means are being developed. Flight speeds are increasing. The jet engine is the means by which supersonic speeds are being attained.

The present state of jet-engine development can be compared with the Model-T era in automobiles. Increasing requirements, primarily for improved performance, will tend to make the jet engine more complex. Further refinements and increased compression ratios may well bring down the fuel consumption to 0.7 pound of fuel per pound thrust within the next decade, an improvement of 50 percent since 1941. Very likely jet engines will divide into two classes. One, for long-range and transport, to be highly efficient, with long life, relatively heavy and complex. The other, for extremely high speed, moderately efficient, and designed for the intake pressures and temperatures suitable for supersonic speeds. The latter engine will be used frequently with after burning, i.e., burning of fuel in the turbine exhaust, for takeoff or burst of power in combat.

Technically, jet engines can now be justified in commercial aircraft in spite of different methods of handling airplanes that will be required. As airplane speeds go up—and they always do—and as time between overhauls on jet engines increases—as it does—the use of the jet engine will be more and more attractive.

The Industrial Gas Turbine. The rapid progress with jet units for aircraft as a natural consequence spurred development of gas turbines for land use. At Westinghouse this led, in 1946, to the completion and testing of a 2000-hp, 1350-degree gas-turbine power plant created with an eye to its possible use either as a locomotive unit or for industrial service. This unit, like its older cousin in aircraft duty, consisted of an in-line arrangement of air intake, axial-flow compressor, tubular-type combustor, and turbine. With it on the same bedplate are a gear and two d-c generators. The whole occupies a space but 20 feet long, $4\frac{1}{2}$ feet high, and 5 feet wide, and weighs 26 000 pounds—only about one tenth as much as a comparable, well-perfected diesel-electric power plant.

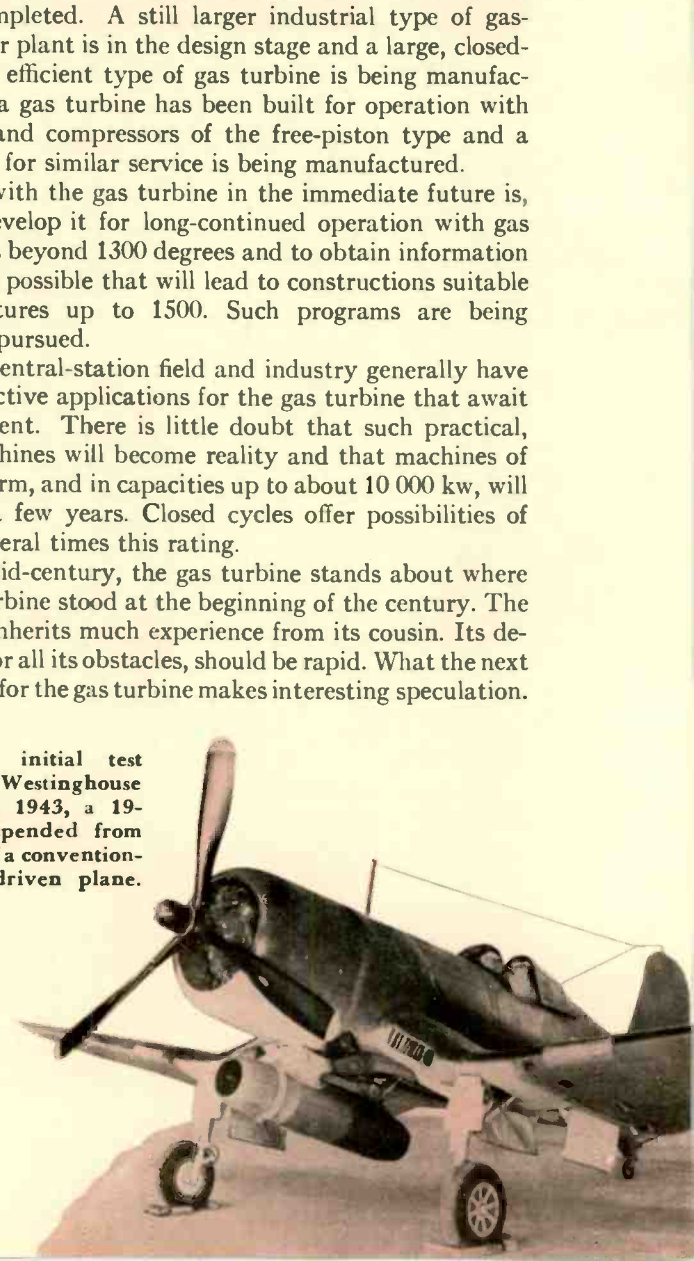
After many months of successful shop testing, much of it in service simulating the frequent starting, stopping, idling, and loading experienced by locomotives, the unit was placed in experimental service in mid-1949 in Arkansas, driving a centrifugal compressor in a natural-gas pipe line. These tests, intended to be an exhaustive examination of the effects of high temperature upon the life of blades and other components, are scheduled for completion early this year.

The gratifying results of the shop-test on the 2000-hp experimental unit resulted in the decision to construct two additional similar units for installation in a locomotive now virtually completed. A still larger industrial type of gas-turbine power plant is in the design stage and a large, closed-cycle, highly efficient type of gas turbine is being manufactured. Also, a gas turbine has been built for operation with combustors and compressors of the free-piston type and a 3000-hp unit for similar service is being manufactured.

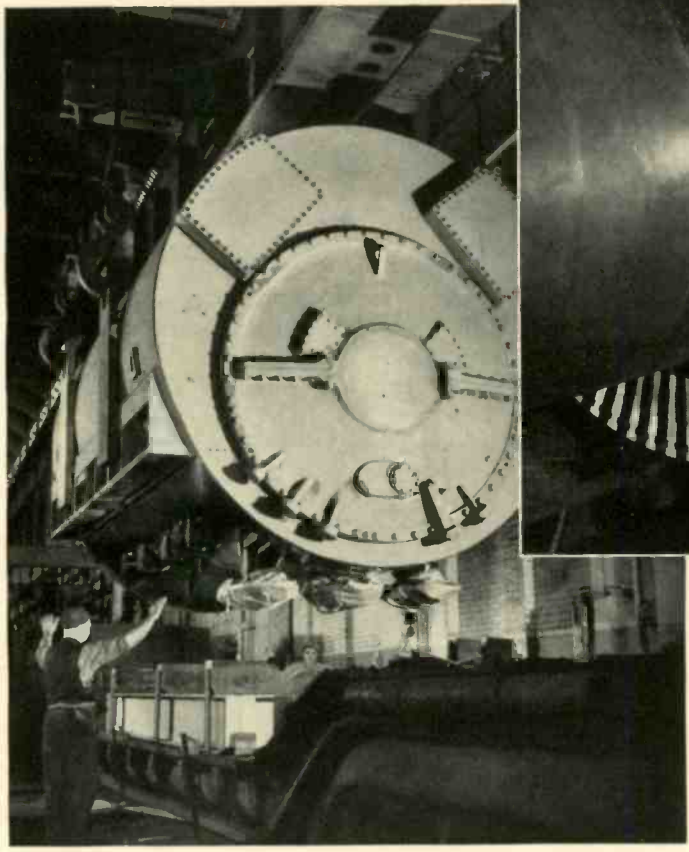
The task with the gas turbine in the immediate future is, clearly, to develop it for long-continued operation with gas temperatures beyond 1300 degrees and to obtain information as quickly as possible that will lead to constructions suitable for temperatures up to 1500. Such programs are being aggressively pursued.

Both the central-station field and industry generally have several attractive applications for the gas turbine that await its development. There is little doubt that such practical, long-life machines will become reality and that machines of open-cycle form, and in capacities up to about 10 000 kw, will be built in a few years. Closed cycles offer possibilities of machines several times this rating.

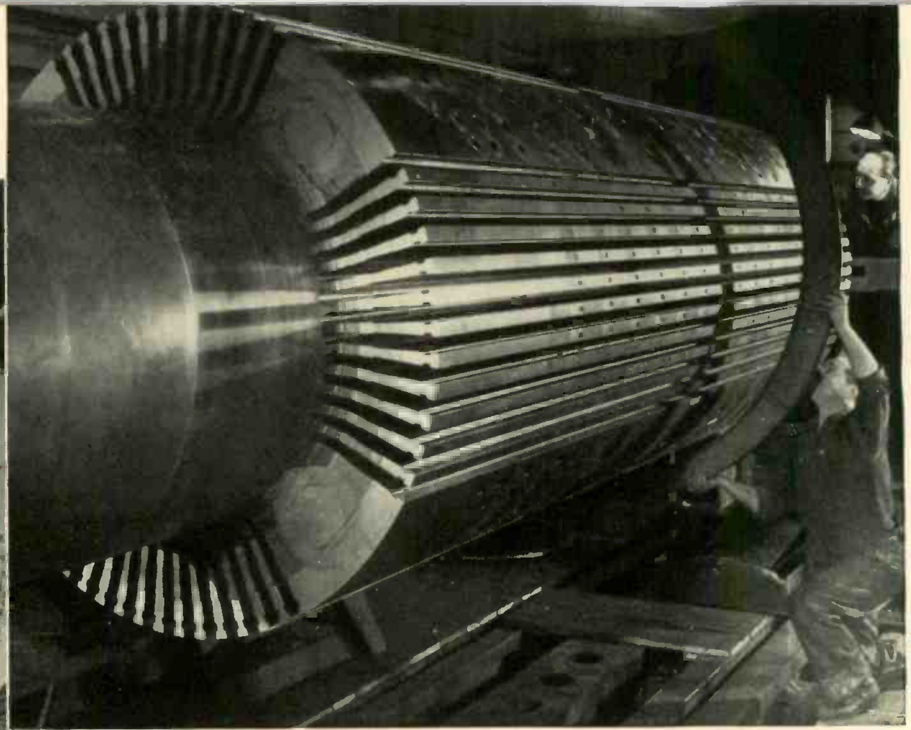
Now, at mid-century, the gas turbine stands about where the steam turbine stood at the beginning of the century. The gas turbine inherits much experience from its cousin. Its development, for all its obstacles, should be rapid. What the next 50 years hold for the gas turbine makes interesting speculation.



The historic initial test flight of the Westinghouse jet engine in 1943, a 19-inch unit suspended from the fuselage of a conventional propeller-driven plane.



A high-speed, central-station generator starts on its way.



Construction of modern four-pole generator rotor.

EVOLUTION AND EVENTUALITIES

THE GENERATION of electric power as we know it today was born of titanic struggles. There was first the question of whether it was to be alternating current or direct current, with d-c the winner of the early rounds. In fact the electric industry was established as a going business on the basis of direct current. The industry foundations appeared to be laid. Not until the arrival of the transformer and the dramatic experience at the Chicago World's Fair in 1893 was there any evidence that the entrenched d-c system was to be threatened. But when the turn came, the rise of the a-c system was rapid.

Then there was the matter of frequencies—many frequencies between 16⅔ and 133⅓ having ardent and vocal proponents. Not until about 1894, when Westinghouse engineers determinedly promoted 60 cycles, was that matter settled.

Too, what kind of engine was to drive the a-c generators? Again, a late-comer appeared—the steam turbine—to sweep past the well-developed reciprocating engines.

The physical forms of the a-c generator were long in debate, but the appearance of the high-speed prime mover and the brilliant design techniques developed by B. G. Lamme gave rise to the turbo-generator pretty much in the form it is known today.

These struggles had about run their course by 1900. Even waterwheel-driven generators, with the epoch-making installation at Niagara Falls in 1895 providing basic experience in this field, were fairly well established although the Niagara construction did not endure.

One might be tempted to say that the a-c generator of 1950 is but a grown-up version of the one of 1900. But improvements have been so numerous in iron, insulation, windings, ventilation, and attachment of poles, etc. that any suggested resemblance is but in name only. The astonishing fact is how, without change in basic form or principle, so much betterment has been possible—particularly considering that in five decades generators have grown in rating about 60 times.

This story of generator development can best be told by tracing the evolution of the basic components that are common to all generators, regardless of how driven.

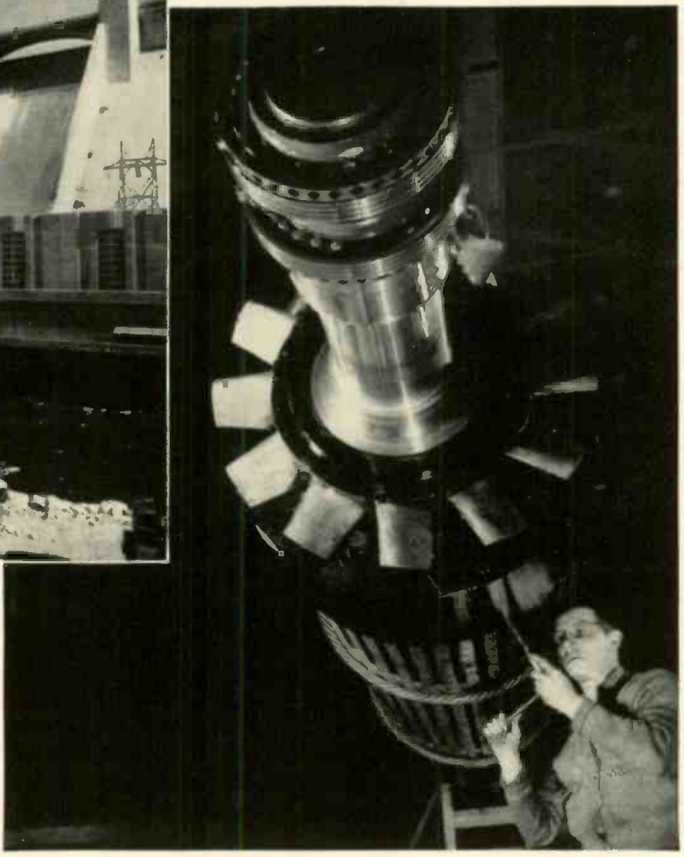
Insulation

In the beginnings of electric machinery, operating voltages for the a-c and excitation windings were so low that insulation was more or less taken for granted. Any insulation was enough. The wires and coils were wrapped in untreated cloth and paper. Operating voltages did not remain low for long, the higher voltages necessitating an increase in insulation thickness, which was accomplished by cut and try methods. Cloths and papers were treated with natural oils and resinous products to improve their insulating properties.

Economic pressure to increase machine capacities and efficiency, and to reduce costs, led to still higher operating voltages, which in turn created new insulation problems. The scientific approach to insulation design and application began in 1891 when Messrs. Scott and Skinner of Westinghouse made the first high-potential dielectric tests with equipment of their own design.

Experience with early machines, using varnished-cloth and varnished-paper wrappers, indicated a need for insulation improvements. This was accomplished by combining mica with cellulose materials such as paper or cotton to supplement their dielectric strength. Mica increased in use as its efficacy was proved by service experience. Finally mica became the

Grand Coulee is the largest concentration of water power.



The rotor of a high-speed generator, showing air-foil blower.

by **C. M. LAFFOON**

# of A-C Generation

major insulation, and paper or tape served only to provide mechanical support. In 1894 Westinghouse insulated the Niagara Falls generators with mica. These machines gave an excellent operating record, although operated at excessively high temperatures for long periods. Mica is now considered the essential part of modern generator insulation, especially for high-voltage windings.

In 1911 a major insulation development occurred. The mica on paper or tape, i.e., the folium or wrapper type of insulation, which had been introduced in this country by Westinghouse, was simply wound around the coils. While it provided a highly consolidated mica wall around the conductors in the slot, the insulation was not as dense as could be desired. Haefely, of Switzerland, developed a process by which relatively thin mica sheets, consisting of paper, bond, and mica flakes, were applied to the slot portions of armature coils in a wrapping machine that heated and rolled the folium onto the coil. This took out slack in the wrapping and consolidated the wall into a dense dielectric barrier. Mica-folium slot insulation applied with heat was a great improvement. It had relatively high dielectric strength and was quite satisfactory in many respects. It continued in use with shellac bond in its original form for about 15 years following 1911.

One disadvantage was its brittleness. Also it was not applicable to the end-turn insulation, and these coil portions were insulated with varnish-treated cambric tape. This necessitated a complex seal with multiple tapers between the mica-folium slot insulation and the cambric-tape end-turn insulation.

In 1926 mica folium was modified by replacing the shellac with a plastic asphalt bond, and the asphalt-bonded mica tape was substituted for varnished-cambric tape as end-turn insulation. These changes improved the flexibility of the insulation and provided mica insulation for the entire coil. However, it did not eliminate the joint existing between the folium on the slot part and the tape in the end turns.

Still larger machines were needed. Designers found themselves limited by the length of coil to which mica-folium insulation could be applied. This limitation was circumvented and other problems existing with the folium insulation were solved in the late 20's by continuous mica-tape insulation. It consists essentially of multiple layers of mica tape, continuously applied over the coil ends and slot. Bonding between layers is accomplished with brushing bonds and by impregnation or pressing or both, followed by vacuum drying. The common forms of continuous mica tape employ thermo plastic asphaltum bonds and impregnants. The result is a flexible coil that can be handled and assembled in the machine with less risk of damage than coils insulated with mica-folium.

When fiber glass became available, designers quickly saw in it an improvement over existing insulation for high-voltage coils. Fiber glass has excellent corona resistance, good mechanical strength, and high thermal endurance. In 1928 fiberglass insulation was adopted as a surface binder for coils, replacing cotton and partially replacing asbestos finishing tapes. Likewise, glass twine was quickly adopted for lashing the end windings. Conventional organic twines had been subject to corona attack that hastened deterioration. In addition, the finishes applied to glass tapes have since been improved in resistance to oil and corona. Modern Westinghouse high-voltage generators use an alkyd-resin, pigmented-enamel finish that has had an excellent operating record.

Corona, long a bugaboo to generators, has been allayed. Before 1928, slot corona had been tolerated on high-voltage machines as a necessary evil. Where mica was used, corona did no serious harm although the paper backing for the mica and organic bonds and surfaces was frequently eaten away. This resulted in looseness of the coils in the slots, opportunity for slight movement that could lead to premature failure. In 1928 Dr. C. F. Hill of Westinghouse developed a treatment for suppressing slot corona. It consists of applying a compound of low electrical resistance to the surface of that portion of coils that lie in the slots and for a short distance beyond the end of the core. This semi-conducting surface satisfactorily distributes the voltage stresses within the solid insulation so that none of the little gas spaces can ionize.

This effectively eliminates corona in the slot portions of the machine as long as the semi-conducting sheath is grounded. However, the treatment, because of its low resistance, could not be safely applied to the exposed or end windings, leaving them still subject to corona. About 1938 this problem was solved by Dr. Hill, Messrs. McCulloch and Berberich of the Research Laboratories by the introduction of Coronox. This also is a semi-conducting compound but of much higher resistance. It is applied over the exposed portions of the coils not given the low-resistance treatment. It distributes the voltage stress along the coil surface just outside of the iron so as to hold stress concentrations below the critical. Both forms of corona suppression treatment are now in general use throughout the industry on high-voltage windings. Properly applied these treatments completely prevent corona within generator windings at operating voltages.

Stator Conductors

In many of the larger pre-1900 generators, stator conductors were rectangular copper bars. The copper temperatures actually experienced were much higher than expected from calculations based on d-c resistance coefficients of the copper and with known ventilation. It was soon discovered that the distribution of alternating current over the conductor cross section was not uniform as with direct current. The first complete mathematical analysis of the effect of eddy currents in conductors of rectangular-shaped slots was made in 1916 by A. B. Field, formerly a Westinghouse engineer. This original, fundamental work was later expanded by Mr. R. E. Gilman of Westinghouse to cover laminated conductors and multi-turn coils for various winding arrangements. Out of this came a method of calculating with reasonable accuracy the current distribution and consequent losses in any construction of stator winding. This led to the modern practice of stranding and transposition of conductors.

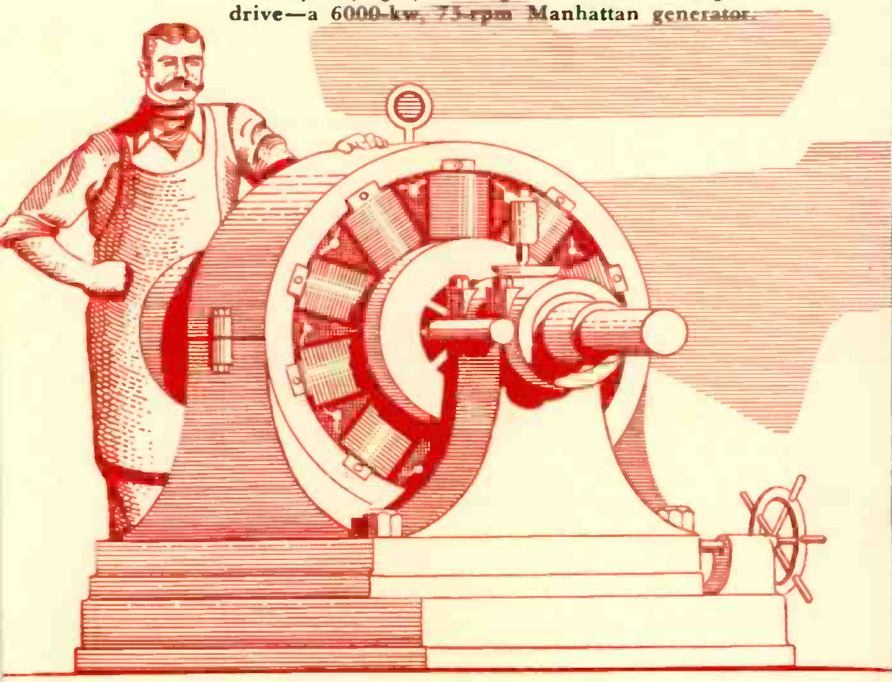
This can be accomplished at the end coils outside the slots, or within the active portion of the coil in a slot. Originally Westinghouse employed external stranding exclusively, but with the development by Roebel in Europe of internal transposition, both methods are used. The internal system, when applicable, avoids the multiplicity of bulky connectors at the end turns.

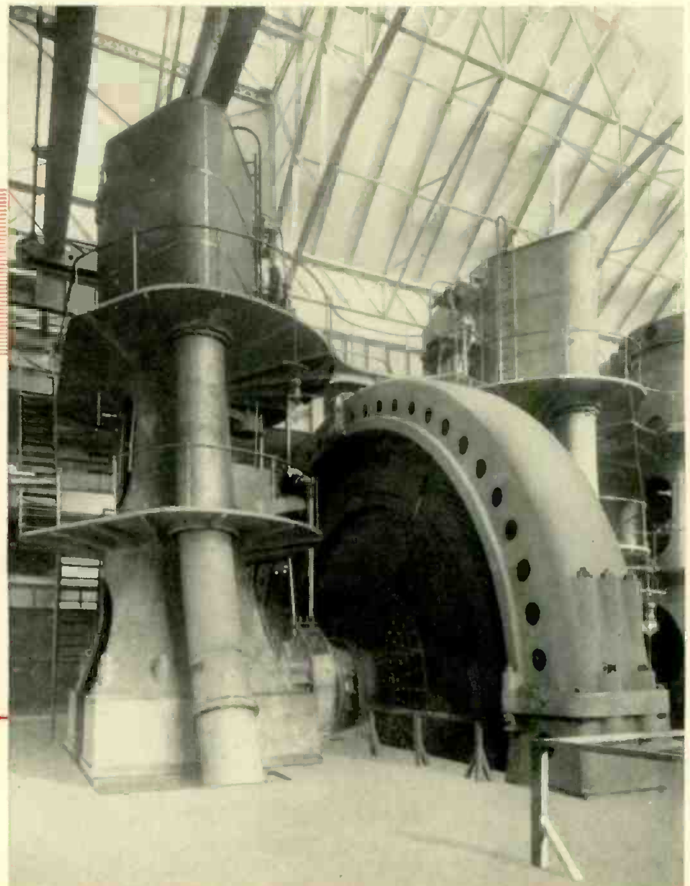
Stator Iron

Until about the middle of the first decade, stator cores were built up of thin iron laminations, punched from soft sheet steel. This grade of iron with its relatively low permeability and high ductility, which facilitated punching, was suitable. However, its electrical resistivity was relatively low, permitting the magnetizing flux to cause high secondary currents and consequent comparatively high losses in the stator core. When silicon iron became available (see page 51) a major improvement in stator cores became possible. Not only did silicon iron have higher permeability, but also resistivity was increased. Consequently, hysteresis and eddy-current losses were greatly reduced.

Little further improvement in core material occurred until about 1922. At that time a very significant betterment in core loss was achieved, resulting in part from better control of carbon content by improved melting practices. Also, changes in

(Below) A rotating-armature a-c generator, pre-1890 style. (Right) The high-water mark in engine drive—a 6000-kw, 75-rpm Manhattan generator.





annealing processes improved the properties. To some extent the wide variation then existing in four-percent silicon iron was narrowed. This superior material resulted in a two-way improvement in generator efficiencies; not only were iron losses reduced directly but also because less ventilating air was needed, ventilation losses were lowered.

Hot-rolled silicon iron remains the accepted stator core material. The two low-loss electric sheet steels, Hipersil and Hipernik, are not economically justified for a-c generators, because of their relatively high costs. The advantages of Hipersil's lower permeability in the direction of grain cannot be utilized in a-c generators where the voltage is produced by a rotating magnetic field in which the flux in the stator teeth is at right angles to that in core behind the teeth. Hipersil, arranged to favor low core losses, would have the most unfavorable direction for the stator teeth. With the most favorable position of the grain in the punchings and taking full advantage of the directional characteristics to reduce the amount of material, Hipersil still cannot be justified economically.

Hipernik is not directional in its characteristics, but its permeability is somewhat reduced at high inductions. Its high nickel content makes it too costly for generating equipment.

Cold-rolled sheet steel for generator cores offers the greatest possibilities for economical production and processing when starting from the billet and ending with the finished punching. A new cooperative development with a producer of steel sheet offers promise that a cold-rolled generator-core material will soon be available in continuous strip form. However, until then, present silicon sheet produced by hot rolling will be used. It can be butt-welded to form continuous strip and then economically processed with new and improved manufacturing equipment and processes, giving a flatter sheet and the advantages of continuous-sheet manufacture.

Ventilation

The steady improvement in cooling has been enormously important in enabling designers to meet continually rising demand for kilowatts output with available materials. As early as 1891 engineers recognized that heat had to be actively helped to escape. Unaided radiation and convection from the external surfaces was not enough. Air, being universally available, logically was used as the coolant. Two stator-core constructions were developed to bring it into intimate contact with those parts in which heat originates. One provided axial ducts in the stator core through which the air passes from one end to the other, or from both ends to the middle for discharge outward through radial passages.

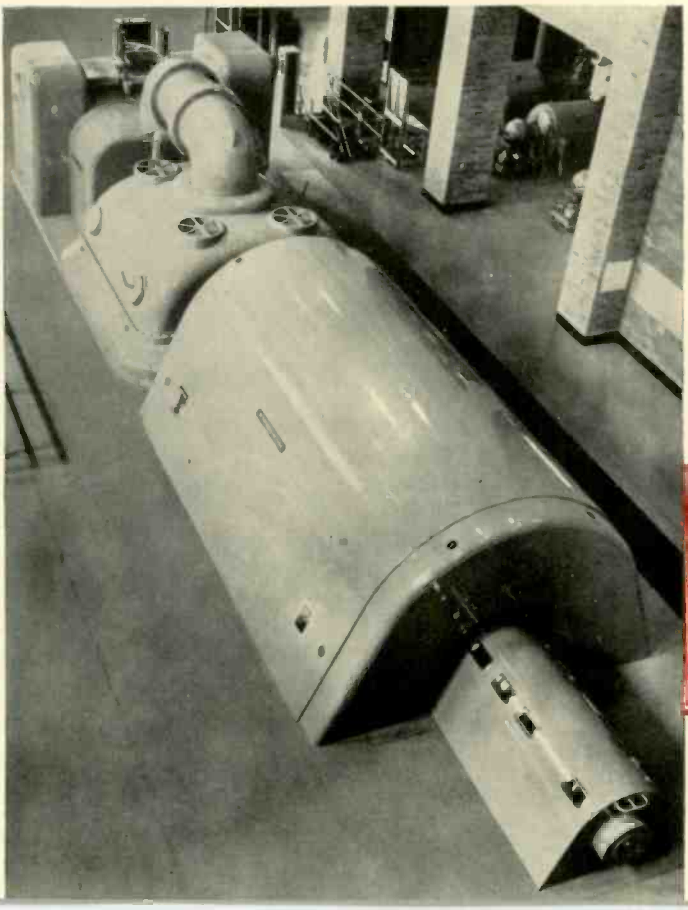
This construction reduced the core length and increased its diameter. While it can be satisfactory from a mechanical standpoint, it has two inherent ventilation limitations: (1) only a small portion of the air passes through tooth zones where much of the heat is generated; and (2) the temperature of the air increases appreciably as it passes axially through the machine. The total result is reduced cooling efficiency, and thus higher average and maximum temperature rises for the stator winding and teeth. For these reasons Westinghouse abandoned the axial system of ventilation for larger rotating machines about 1918.

In the other construction, stator and rotor cores of salient-pole generators were provided with radial ventilating ducts. The air was brought in through axial passages formed by the air gap, space between field poles, and openings in the rotor spider, and then discharged radially through the core ducts. This construction had an opposite effect on machine proportions; it reduced core diameters and increased length, and introduced some additional mechanical and magnetic problems. With the radial system of ventilation, all cooling air passes through the high-loss zones and results in efficient and uniform cooling in both radial and axial planes.

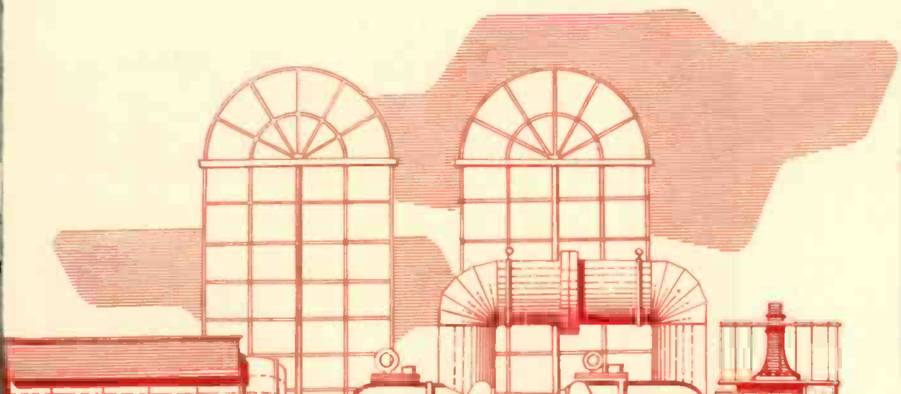
The radial ventilation system continues, after 60 years, to be the most effective means of cooling. During recent years, much effort has been devoted to improving the ventilating circuit through the machine and the blowers, so that maximum cooling can be obtained with the least pressure drops.

Hydrogen Cooling

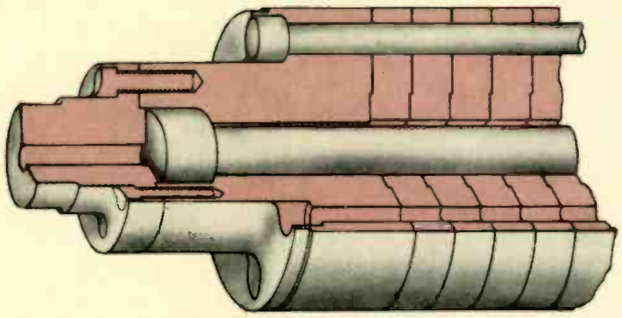
As early as 1920, Field, Gilman, and Newbury at Westinghouse were giving consideration to coolants other than air



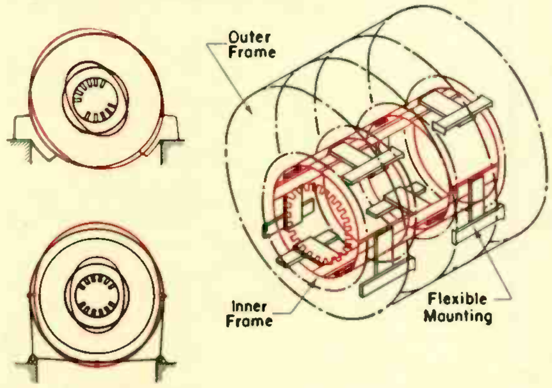
(Left) A modern 90 000-kw, 3600-rpm generating unit, and (below) a 62 500-kva, 1200-rpm unit of 1925.



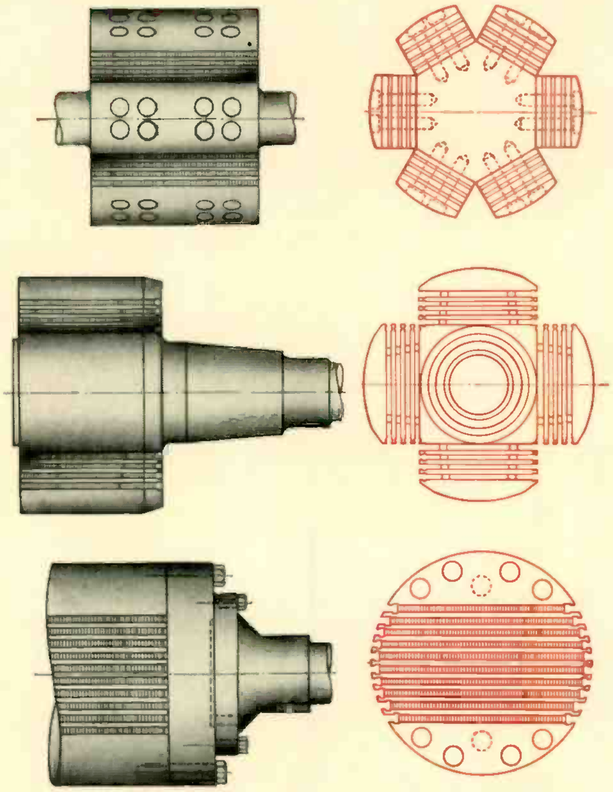
Evolution of Turbine-generator Elements



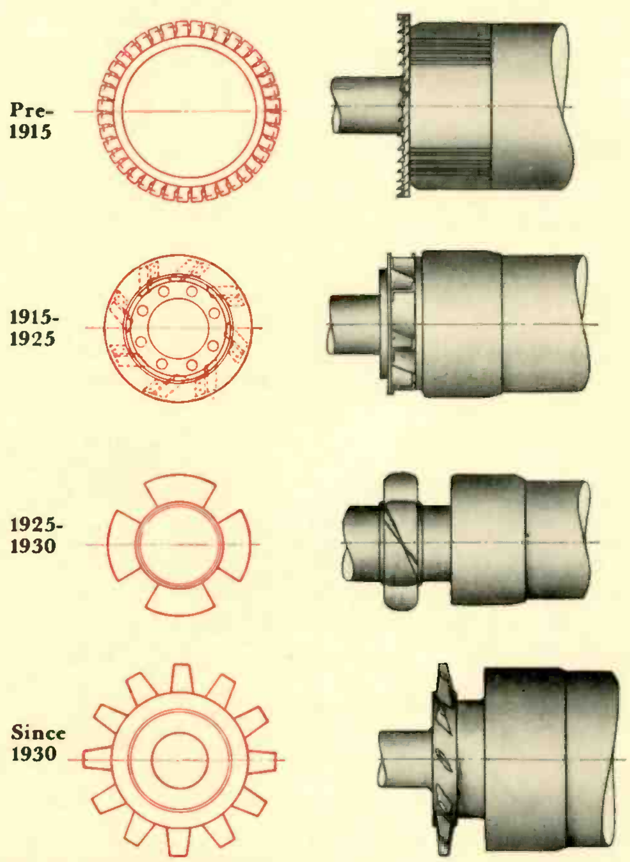
Before the day of dependable large forgings, rotors were built up of discs clamped between heavy end heads.



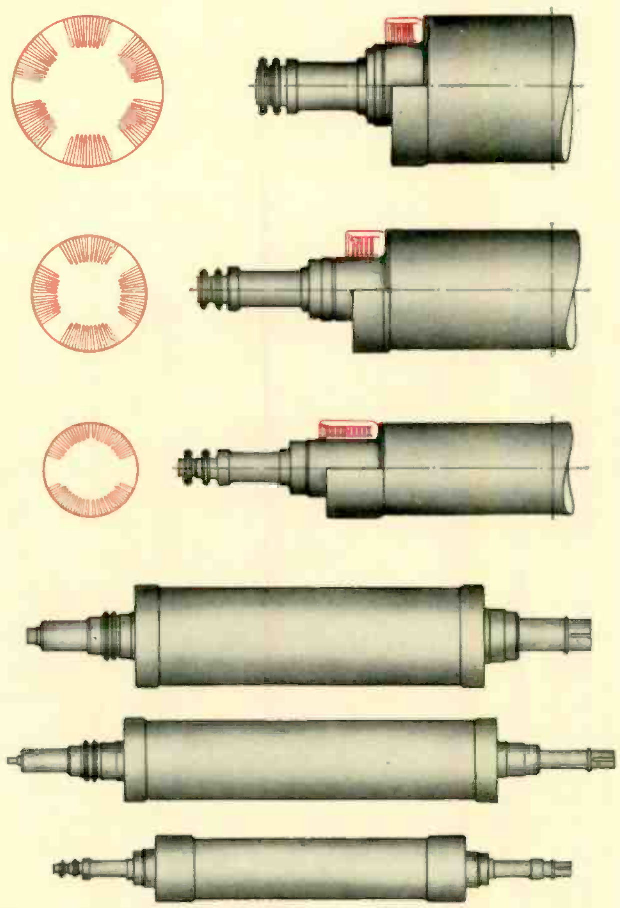
Under the action of the two-pole field, the stator distorts slightly into a rotating ellipse, causing a double-frequency vibration, absorbed by flexibly mounting the stator.



Early (above) and modern (below) constructions for six-, four-, and two-pole generators.



Evolution of turbine-generator blowers:
- Pre-1915, guide-vane type
- 1915–1925, centrifugal type
- 1925–1930, screw-propeller type
- Since 1930, air-foil propeller type



Modern turbo-type rotors for 80 000-kw generators: 6-pole, 166 tons (never built); 4-pole, 77 tons; and 2-pole, 49 tons.

and liquids. Goals were: improved cooling efficiency, lower losses, and reduced fire hazards. Hydrogen and helium were both attractive candidates, but hydrogen is readily available and cheap. Power-generating equipment designers, both in this country and abroad, readily saw the possibilites of hydrogen cooling for high-speed machines such as synchronous condensers, frequency changers, and turbine generators. A Swiss engineer, Max Shuler, had obtained a patent on cooling with hydrogen. In 1924 Westinghouse and another manufacturer obtained the rights to manufacture hydrogen-cooled dynamo-type machines under his patent.

Two experimental turbine generators were built and operated on a special test setup for several months to determine design limitation and construction requirements. The first unit, built in 1926, was rated 7500 kva, 2300 volts, 3 phase, 60 cycles, 3600 rpm. It was similar to air-cooled machines with respect to mechanical construction and gas-cooler location. In 1930 a similar but slightly larger unit, rated at 9375 kva, was designed to meet the problems introduced by the new requirements without regard to the design tradition of air-cooled units. These two units paved the way for the larger capacity, 3600-rpm hydrogen-cooled turbine generators that began to be used in numbers about 1935.

The first hydrogen-cooled, totally closed machine built by the Westinghouse Company for commercial use was a 15 000-kva, 900-rpm synchronous condenser, which was designed and constructed in 1928. Since then hydrogen cooling has been quite generally used on synchronous condensers, frequency changers, and turbine generators.

The oil-pressure, floating-ring type of shaft seal as initially developed proved effective on model tests for a wide range of gas pressures, and has, with some modification, been used with a high degree of success. Hydrogen-control equipment automatically indicates gas pressure and purity. Service has proved hydrogen apparatus to be safe, reliable, and simple.

Increased Gas Pressures

The normal ratings of generators have been based on a hydrogen pressure of 0.5 psi, just enough to insure that any leakage will be outward. It was known, however, that a denser gas would be more effective as a coolant. In fact, over the range from 0.5 to 15 psi, generator output can be increased one percent for each additional pound of gas pressure without exceeding the temperature rise guaranteed at atmospheric pressure. Accordingly, for several years prior to 1948, Westinghouse machines had been designed for operation at gas pressure up to 15 psi.

With larger generator outputs sought, the possibility of raising the gas pressures still further has had appeal. Between 15 and 30 psi, the increase in rating per pound increase in gas pressure is about two-thirds percent. Hence, with hydrogen at 30 psi, a generator can deliver about one fourth more output than at 0.5 psi. Several large machines are now in operation at this pressure and their success suggests the desirability of rating machines on the basis of still higher gas pressures.

Turbine Generators

Turbine-generator development can be arranged in three periods. Between 1900 and about 1920, the larger ratings were built for 1200 rpm. Maximum ratings of 62 500 kva were reached. In the intermediate period, from 1920 to 1935, 1800 rpm was the predominant speed, and machines up to 200 000 kva were built. In the present period, starting in 1935, 1800 rpm gave way to 3600 rpm and hydrogen replaced air as the cooling medium. Maximum ratings of 165 000 kva are now being built for this speed with 30 psi gas pressure.

The *rotor* normally sets the limit on turbine-generator rating. Early rotors were designed to operate below the first critical or resonant speed. This restricted the rotor to a relatively small ratio of body length to diameter, and this in turn fixed the maximum rating possible for a given speed with existing rotor materials and construction practices.

As more design and operating experience was obtained, the designer rather reluctantly agreed to consider operation of rotors above the first critical speed. As rotors were better proportioned and balance improved, operation above the first critical became possible. For many years rotors have been operated well above the first critical speed, but below the second critical without any sacrifice in performance at normal speed and with no undue vibration when passing through the first critical speed. This has allowed rotors to become relatively longer, which provides larger outputs.

In early Westinghouse turbine generators the parallel-slot type of rotor construction was used, a practice originating in Europe. The rotor proper consisted of a body forging or casting with end heads bolted on. Rotor-winding slots, as shown on p. 24 were provided parallel to the axial length and transversely at each end. The rotor winding was thus completely encased in iron or other metallic materials.

During the period from 1912 to 1915, the radial-slot rotor was undergoing development at Westinghouse under the general guidance of Messrs. B. H. Behrend and R. E. Gilman. With the rotor winding located in slots that lie in radial planes, bending stresses in the tooth and pole sections of the rotor body are completely eliminated. This development immediately opened the way to larger rotor diameters for which the mechanical stress loadings can be more accurately determined by calculation.

Before steel companies could provide large forgings of assured uniform quality Westinghouse used rotors built up of multiple plates for large 1200- and 1800-rpm units. A series of rolled plates or forged discs were stacked together between heavy shaft-end heads and the assembly clamped by heavy through bolts. This construction is shown by the sketches and posed many problems, such as total clamping pressure, area of contact of mating surfaces and unit contact pressure, contact-surface finish, machining and assembly techniques, and inspection procedures, which required years of study to solve. For rotors of large physical dimensions and weight, this multiple-element construction has the possibility of complete inspection of each section before assembly. This offers the maximum assurance of reliability.

The shift from 1800 to 3600 rpm for turbine generators relieved the generator-rotor-forging situation by reducing the diameter and weight of the rotor. This greatly simplified the problem of producing reliable rotor forgings and has stimulated the production of higher strength forgings. The yield strength for rotor forgings has steadily increased during the past 50 years. With the development of nickel chrome, molybdenum, and vanadium alloy steels having vastly increased strength, it has become feasible to obtain rotor forgings of sufficient size for the largest generators required.

Rotor Windings—Until 1928, soft, commercially pure copper was almost universally used for rotor windings. At about this time distortion of the rotor coils was observed in units that had operated at total temperatures of 135 to 150 degrees C and under widely changing load conditions. This was a serious situation—one that demanded a solution if future trouble was to be averted. Extensive research disclosed that the shortening of the rotor conductors was due to plastic yielding of the copper when anchored in the slots and subjected to large compression forces during successive heating and cooling. A partial solution was provided by cold working the copper sufficiently that only elastic deformation can result from the expansion and contraction forces. Further analysis indicated that the "creep" characteristics of the cold-worked conductor material was an important factor of this conductor-distortion problem. The creep rate of cold-worked silver-alloy copper is much lower than for cold-worked commercially pure copper or cold-worked aluminum alloy.

The use of cold-worked alloy-copper for the rotor winding practically eliminates permanent deformation of the rotor conductors due to starting up and shutting down, load changes, and material creep under sustained operating conditions. The permanent deformation that can be expected on rotor conductors after ten years of operation is negligible. The use of cold-worked alloy-copper for rotor windings is considered the most important advancement ever made in turbine-generator rotors.

Ventilation assumes great significance in machines that rotate at high speed. The cumulative progress made during the past 30 years in building generators of larger and larger capacity with improved efficiency has been dependent on and commensurate with progress in developing high-capacity, high-efficiency blowers and streamlined, efficient ventilating circuits. There are many steps in progress (see p. 24) from the multi-bladed, axial-flow, vane-type air-gap blowers used on early turbine generators to the high-pressure, high-volume axial-flow blower with blade sections brought into use by the modern airplane. This simple, rugged, high-efficiency blower has become the standard for most manufacturers in this country and Europe.

Double-Frequency Vibrations in Two-Pole Generators—A two-pole rotor has, inherently, a problem of vibration not possessed by rotors of four, six, or more poles. Because the slots for the field windings are on opposite sides of the rotor body, and not uniformly placed around the rotor, it is not only unbalanced but also more flexible in one direction than in one 90 degrees to it. When rotating at 3600 rpm, this causes a deflection at a frequency equal to twice the rotating frequency. It results in a double-frequency vibration—i.e., 120 cycles per second for a 60-cycle machine. These double-frequency rotor vibrations have been eliminated by machining relatively narrow cross-wise slots in the pole body at definite intervals along the body length, thus equalizing the rigidity of the rotor body on the two major axes.

Double-frequency vibratory forces are also inherent in the stator core because the magnetizing field is at a maximum value on one major axis and zero on the other. The effect of the strong two-pole field is to force the stator slightly into an ellipse that rotates with the speed of the rotating field, or 3600 rpm. This tendency is felt by the stator supports as a 120-cycle vibration. Although it is physically impossible to eliminate these vibration forces, they can be mitigated. By an ingenious flexible support the core is allowed to vibrate without the forces being transmitted to the foundation and associated apparatus.

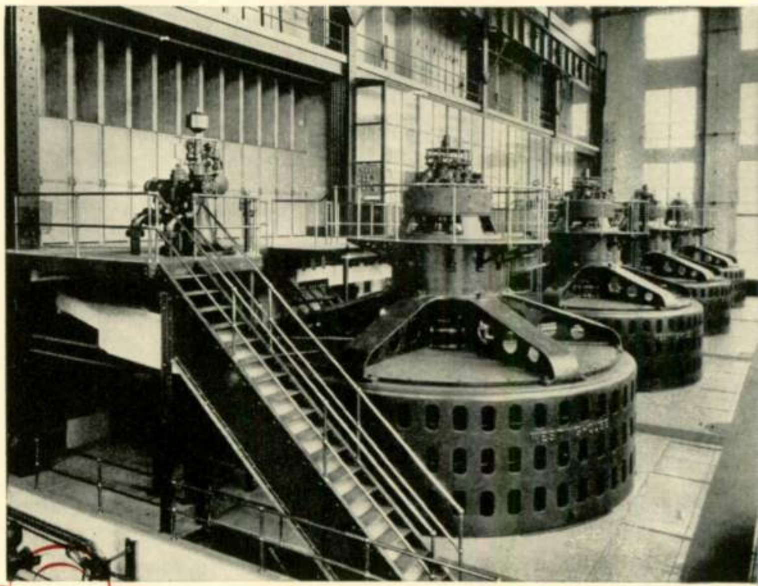
These construction features have made a remarkable reduction in the magnitude of the vibration and noise in the area around high-speed generators. It is frequently possible to balance a coin on the bearing housing of a generator turning at 3600 rpm.

Exciters—Before 1910 generator excitation was obtained from a separately driven motor-generator set or from a battery. Even then the unreliability of this supply of power and intervening equipment and the nuisance of the control leads and switches were recognized. This began a trend to exciters driven by the generator itself, which became pronounced for both steam-turbine and waterwheel generators after World War I when electric utilities were rapidly increasing their generating capacity. In the ten years following 1920, there came the direct-driven pilot exciter to furnish excitation to the main exciter and to reduce the power required for the voltage-regulating control circuits. Direct-driven main and pilot exciters were quite generally used on large turbine generators, predominately of 1800 rpm, and waterwheel generators between about 1925 and 1935.

When 3600-rpm turbine generators began to be a major factor in central-station generation about 15 years ago, Westinghouse experience with the direct-connected exciter had been so satisfactory that it was retained even for the higher capacities at this higher speed. High-speed, direct-driven exciters up to 280 kw have been built and have performed so admirably that the trend in the industry is generally toward direct drive as against gear drive. The success of Westinghouse 3600-rpm direct-connected exciters is due primarily to the type of commutator used, in which a floating-shrink-ring type of construction permits thermal expansion in both radial and axial directions, while still keeping the commutator perfectly smooth and centered on the shaft.

Present Westinghouse exciters are designed with greatest regard for insuring that the exciter is not responsible for generator shutdown. The entire exciter housing or cover is on wheels so that it can be rolled away, exposing the entire machine without affecting its operation. Likewise all brushes with standard shunts can be removed, without the hazard introduced by tools, with the machine running.

The latest development in Westinghouse turbine-generator excitation consists of the application of the Rototrol principle to these shaft-driven exciters. This is done in two ways. In one the main exciter is of standard construction but provided with a self-excited shunt field, a stability shunt field, and a field controlled by a Rototrol. The pilot exciter is eliminated



In 1927 this was a modern waterwheel generator installation. Each of the four units, installed in a West Virginia station, was rated at 16 000 kva, 133.3 rpm.

and replaced by a Rototrol. This main generator exciter, together with a Rototrol and static network, provides main generator excitation stability and voltage regulation without a contact-making regulator and with only two moving elements, the armatures of the main generator exciter and of the overhung Rototrol. This system provides excitation, automatically, without disturbance of load, even in case of a short circuit or open circuit in the Rototrol itself. If such difficulty occurs, the unit can then be operated stably under hand control, until shutdown becomes convenient.

Another type of Rototrol excitation for turbine generators consists of the main generator exciter built in the form of a two-stage Rototrol, in which case the pilot exciter and contact-making type of regulator are omitted. This main-generator, two-stage Rototrol exciter, together with the static network, provides excitation, stability and voltage regulation with only one moving element, the armature of the main-generator Rototrol exciter. This system provides more rapid response than the first scheme. Cross compensation can also be provided in either of these Rototrol schemes, giving all the advantages of the conventional-type machine and eliminating contacts and contactors in the regulating system. In addition, these Rototrol systems give "continuous" regulation instead of "step" regulation, since a contact-making regulator requires a definite small interval of voltage change before a correction can occur.

A recent development in turbine-generator excitation is the use of higher excitation voltages. By increasing it from 250 to 375 volts or even higher values, direct-connected exciters up to 450 kw at 3600 rpm can be built, providing excitation for 3600-rpm turbine generators up to a now-contemplated capacity of 150 000 kw. Use of 375 volts reduces the excitation current to two thirds and imposes easier duty on the exciter commutator and on the generator collector rings, as well as reducing brush expense by one third. The first Westinghouse unit employing 375-volt excitation was placed in service during the latter part of 1948, and several additional units are now in process of construction.

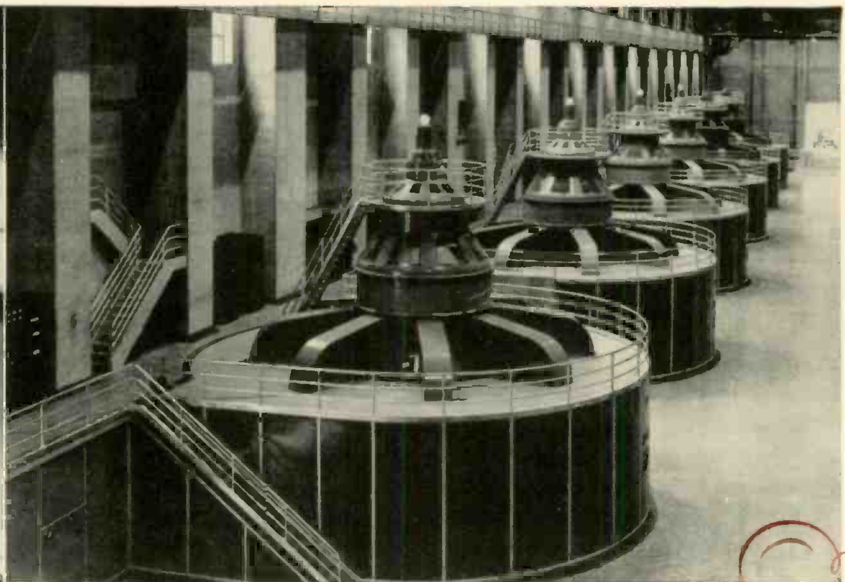
In the relatively small number of cases where the direct-driven exciter is not desired, excitation can be supplied by motor-generator sets or the ignitron type of electronic conversion equipment. Both have high inherent reliability but are subject to voltage fluctuations and power interruptions of the supply system. These limitations can be and in some instances are overcome by (a) providing special characteristics in the design and construction of the excitation equipment, (b) obtaining the electric power supply from either a separate station auxiliary supply system or an auxiliary a-c generator driven from the main-generator shaft.

Waterwheel Generators

The spectacular success of the original Niagara Falls hydroelectric development sparked hydroelectric development in this country. Installed capacity now totals 17 million kw.

In 1938, just 43 years after the Niagara Falls generators were installed, Westinghouse built the first 108 000-kva, 120-rpm vertical waterwheel generator for the United States Bureau of Reclamation, Grand Coulee power plant. This generator has a total weight, excluding coolers, housing, and exciters, of about 1 415 000 pounds. It was designed and built, using slightly over 13 pounds of material per kva of generator capacity. Compared to the original Niagara Falls units, the weight per kva for this type and rating has been reduced 36 pounds, which is 0.7 pound per year reduction in weight per kva. Compared to the Manhattan engine-powered units, the weight per kva of the 108 000-kva unit has been reduced 183 pounds. When completed Grand Coulee will be the largest concentration of power in one location in the world. The eighteen 108 000-kva and three 12 500-kva machines will represent a total installed capacity of almost two million kva.

In the original Niagara Falls generators, the rotating-field member was placed external to the stationary "armature." Due to its resemblance to a rotating umbrella, it was referred to as the umbrella type of construction. In 1928 the Westinghouse Company introduced the modern "umbrella" construc-



Installation of the 82 500-kva units (above) at Hoover Dam began in 1933. In each wing at Grand Coulee (left) will be nine, 108 000-kva, 120-rpm units all installed or under construction.

tion in which the combined guide and thrust bearing is located below the generator rotor. This is the simplest construction from the standpoint of number of guide bearings, lubrication, and oil cooling. Since the rotor can be removed without disturbing the bearings and alignment of the shaft, it adapts itself to the lowest station heights and simplest maintenance operation.

Most hydroelectric power projects in this country have relatively low heads, for which the vertical hydroelectric generating units make maximum utilization of the water. Consequently, the vertical units installed far outnumber those of horizontal form.

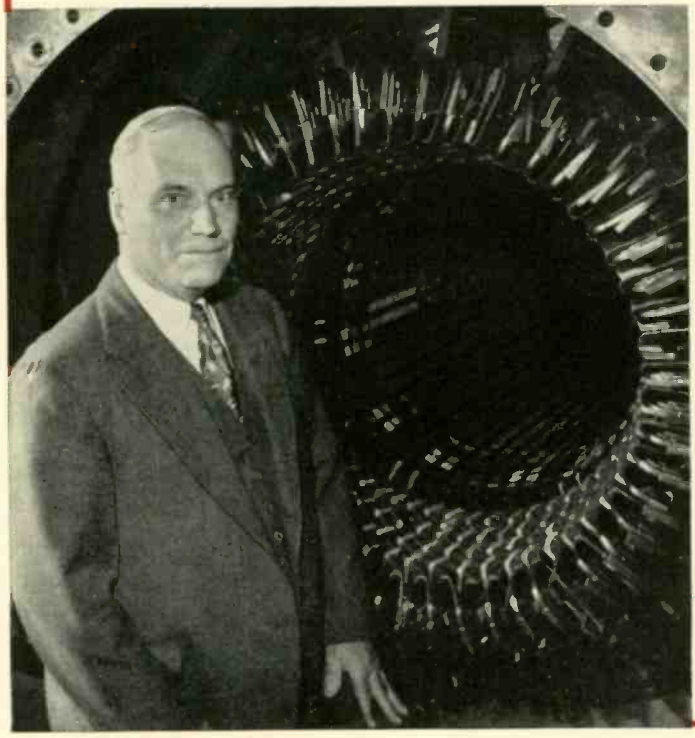
With the low heads available, large volumes of water must pass through the turbine. The turbine must be large in diameter and, to keep stresses within bounds, rotate at low speed. High inertia is required to limit the rate of rise of speed with sudden loss of load. This introduces difficult mechanical problems in the construction of thrust bearings and rotor. Bearings originally were lubricated by oil or water under pressure. The total load capacity of such bearings was increased by a stepped shoulder. This construction was reasonably reliable but required high-pressure pumps to maintain the oil film and an ample flow for cooling. Loss of power to, or failure of the pump supplying the lubricant left the thrust bearing with insufficient lubrication, and prompt failure of the bearing or shaft parts resulted. Roller thrust bearings were tried but proved inadequate, largely because of mechanical difficulties encountered with the heavily loaded rollers turning at high speed.

In 1911 a radically different thrust bearing was announced by Dr. Albert Kingsbury, a Westinghouse consulting engineer. In his bearing, the rotating parts are supported on shoes or pads, in turn pivotally supported on jackscrews at the center-of-loading point of each pad. The success of this bearing lies in the fact that the pads inherently take the most favorable position with respect to the thrust-bearing runners to develop and maintain a wedge-shaped oil film required for the particular speed of rotation and the type of oil used.

C. M. LAFFOON

Some men are drawn from childhood toward the work for which they are outstandingly fitted with a mysterious force and fortune. It is akin to that force impelling a homing pigeon to reach its far-distant objective through adversities of wind and weather. The rise of C. M. Laffoon to his present position is a sterling example of that. He was raised on a farm south of Kansas City, remote from industry or city life. With "store bought" toys out of the question, he had to make his own. This necessity sharpened a latent mechanical skill, illustrated at one point, curiously enough, by the invention of a multi-bladed windmill he erected on a 12-foot tower and connected to an available water spray pump. Two decades later he was to lead the development work on blowers for the country's large turbine generators.

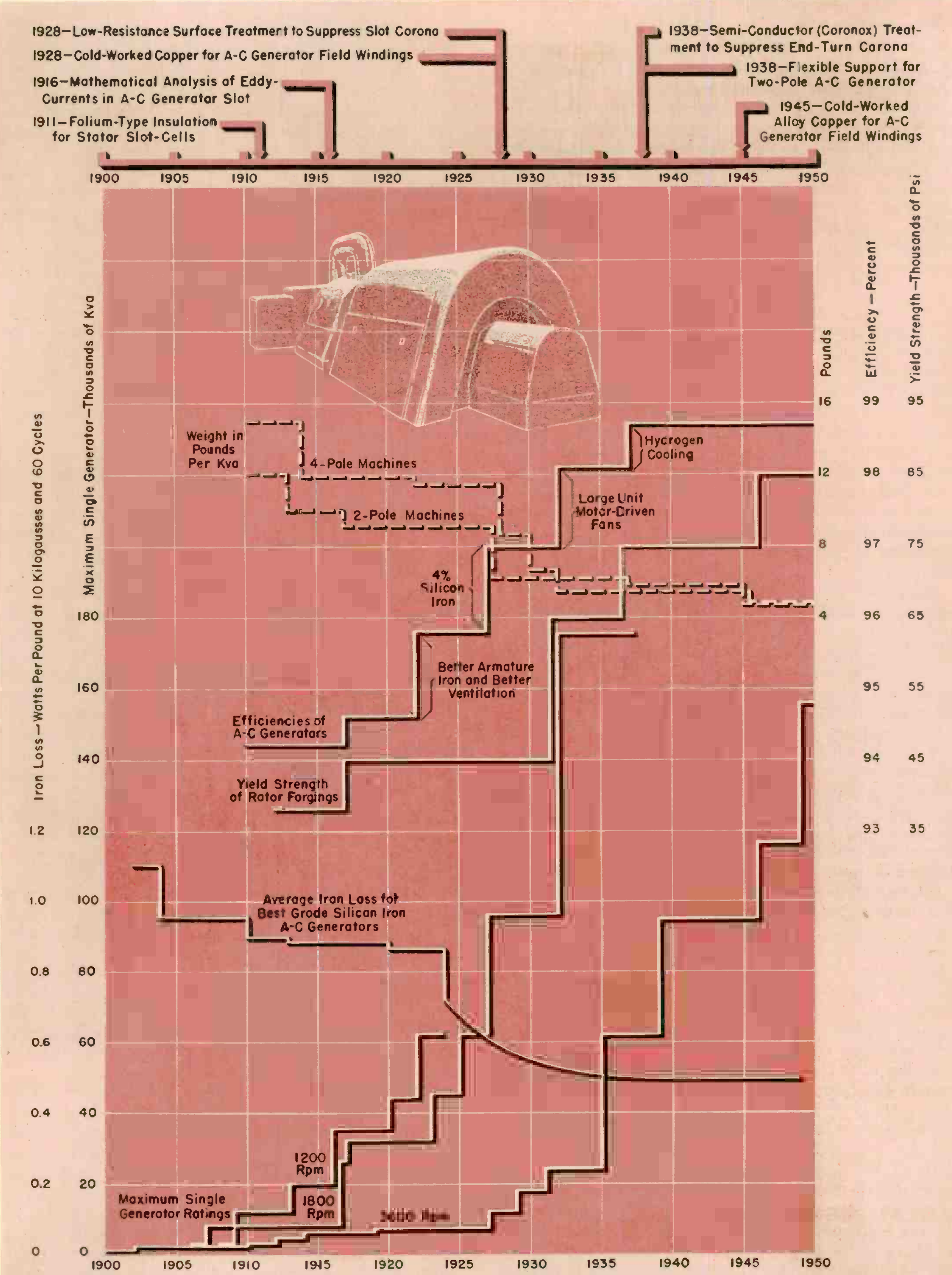
Without ever having seen a motor or generator, he decided that electricity was the field for him and he set his course steadfastly in that direction. This led, after the one-room country school—where he won spelling-contest prizes—through three years of study at Warrensburg (Missouri) State Teacher's College interleaved with three years of earning the funds for same. During this period he distinguished himself in two fields, debate and public speaking—attributes not too common in embryonic engineers. Then came electrical engineering at the University of Missouri, and to the B. S. earned in 1914 was added an M. S. in engineering in 1915. One of Laffoon's classmates, who preceded him to Westinghouse, wrote glowing accounts of the Westinghouse design school and in particular of the illustrious B. G. Lamme, then chief engineer for the Company and guiding force in the student-training program. That was precisely what Laffoon was looking for, so he came to Pittsburgh.



During the latter part of Lamme's career, each year he selected one or two promising young men to work in his own office. In 1917 Laffoon was one of the two favored young men sitting on the other side of Mr. Lamme's big oak desk. After a year of personal tutelage by Mr. Lamme and exposure at close range to the whole of the Company's engineering, plus the stream of distinguished personages who visited that office, he was ready to begin his creative career in a-c generator engineering, of which he has been manager since 1936. In that time he has participated or been a leader in almost every phase of development of the modern turbogenerator, in particular high-voltage insulation, ventilation, and rotor construction. His work has not all been with 60-cycle generators. He laid the design groundwork for high-frequency generators in the 5000-cycle class.

For all his engineering ability and interest, Laffoon has never quite gotten the farm life out of his blood. He maintains a country home in the Allegheny foothills. He finds that on the back of a saddle horse is an excellent environment in which to think through tough engineering problems. Soon after we had interviewed Laffoon for the above information, we saw him leaving the plant, taking the long strides a man of his stature can take. "Playing hookey?" we chided. "I am going to the farm to get ready for an old-fashioned apple-butter making. Don't tell anyone."

Nor is that all. Laffoon has a five-acre ranch stashed away in San Diego County, California, pending retirement. "Going to raise avocados," he says.



A summary of a half-century of a-c turbogenerator progress.

The first installation of the Kingsbury-type pivoted-shoe thrust bearing was made in 1911 to replace a roller bearing on an 18 000-kva Westinghouse-built waterwheel generator at the Holtwood Power Station of the Safe Harbor Water Power Corporation. This type of bearing, with either the adjustable screw or equalized support, has been used on all Westinghouse waterwheel generators since. The bearing has demonstrated its adaptability for use over a wide range of loads, speeds, and abnormal operating conditions. During recent years the design and research engineers have obtained much fundamental knowledge of its construction requirements and performance characteristics under a much wider range of waterwheel-generator operating conditions.

Look Ahead

Progress in 60 years of a-c generation has been outstanding, but the ultimate goals have not been reached. Under present economic conditions, with high labor and material costs, a wider field is opening for generating units of larger capacity. There is a need to reduce capital costs of buildings, auxiliary equipment, and the man-hours operating labor required per day per kw produced. The rapid increase in capacity of individual generating systems and the heavy power interchange connections between adjacent systems already justify generators of 200 000 to 225 000 maximum ratings. These can be met with single-unit, 3600-rpm hydrogen-cooled generators of present-day construction operating at 30 psi gas pressure.

With reasonable improvement in the physical characteristics of alloy forgings, and somewhat better rotor ventilation and insulating materials, it is anticipated that 3600-rpm, 250 000-kva single-shaft generator units can be built as soon as the need for them arises. On the basis of the same design condition, single-unit, 1800-rpm generators can now be built for ratings of 350 000 kva and perhaps more.

On the basis of forward-looking programs now under way and contemplated, the greatest possibilities for still larger increases in ratings can be expected from new insulation materials, improved methods of ventilation, and the use of new cooling media. The numerous new or improved materials already available greatly widen the designer's horizon and offer almost unlimited opportunities for advancement in the design and construction of a-c generating equipment.

Generator insulation of the future will be very different from that we use today. We have only to look at the insulating materials used fifty years ago and compare them with those used today to realize the tremendous advances made in a half century. These improvements are largely the result of evolution and step-by-step changes rather than sudden changes. In all probability the contributions of chemical research to the insulations of the future will predominate. Many new, promising synthetic insulating materials are already available, as yet untried in windings, offering prospect for considerable improvement. Insulations eventually will be almost wholly man-made or synthetic. Only synthetic resins will be used for bonds and impregnants. Mica, if not made obsolete by something better, will probably be produced in the crucible in a few hours, rather than by nature during many millenniums in the earth's crust. It may no longer be necessary to depend only on mica flakes as dielectric barriers of high thermal endurance. Synthetic resins can be expected to have suitable physical as well as electrical properties to be used as reliable dielectric barriers without including embedded films, such as the manner in which mica is now employed.

Physical properties of future insulations will likely be vastly different from the present composite mica-asphalt or mica-varnish insulations. Physical problems resulting from thermal cycling and consequent insulation migration will have completely disappeared, as the insulations will have great physical strength and resilience. Higher intrinsic dielectric strength and reduced variability will result in working insulations at much higher voltage stress. This will permit building machines of even higher operating voltages and will allow more room for copper on lower voltage machines, and have the further advantage of reducing thermal gradients through the insulation wall. Its greatly improved thermal conductivity will further reduce the temperature gradient through the insulation. Copper can then be loaded at a higher current density without increasing its temperature rise. It is to be remembered that the advantages of even a small change in insulation thickness in a high-voltage generator is compounded manyfold in total station economies. Thinner insulation means the heat can be removed easier, calling for reduced ventilation. This sets off a chain of economies: smaller machines, lighter foundations, smaller buildings, and reduced overall investment.

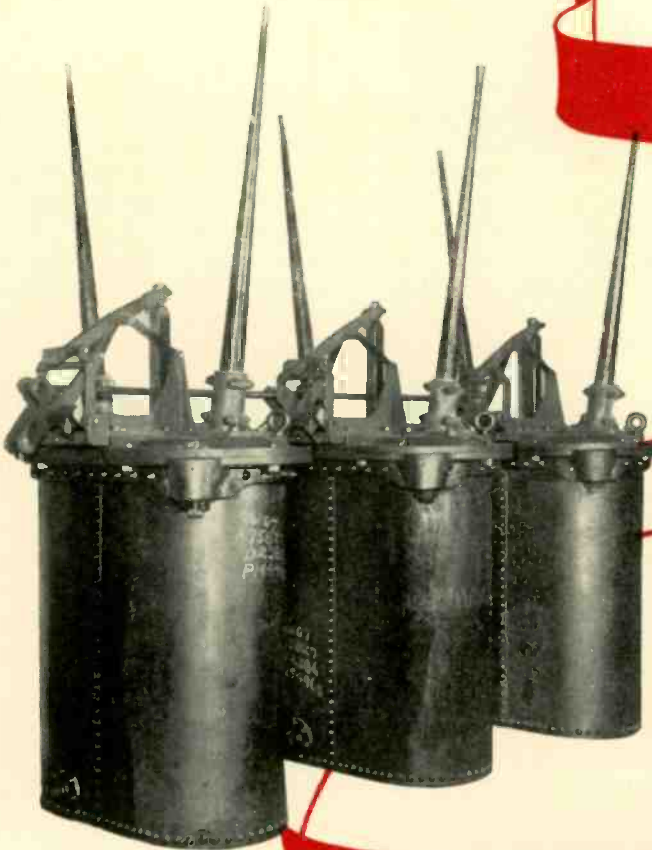
The thermal and voltage endurance of insulations will be greatly improved to the extent that thermal aging will no longer be a factor, and dielectric breakdowns in service will practically disappear, except from physical damage from some outside source. The design engineer will then be able to design electrical machines without reference to insulation aging, and can obtain the best design balance based on other factors.

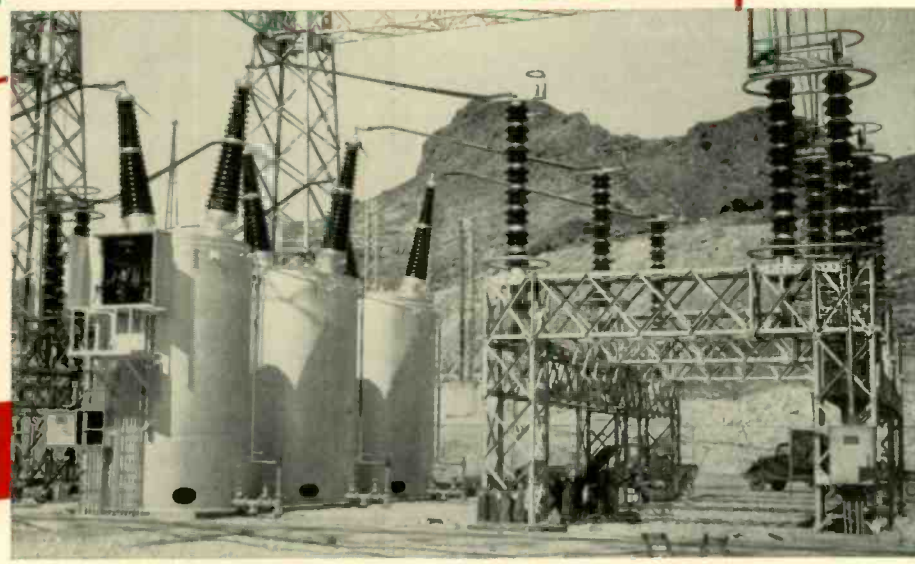
The greatest gain will result from the development of far superior methods of using either the present or new cooling media to dissipate the losses with the lowest thermal drops from the seat of the loss to the cooling medium. In the future the primary design problem of a-c generators will be to obtain a much greater output per unit of materials used. It is believed that generator outputs per pound of active material will be increased from 33⅓ to 50 percent. This would make possible the use of less costly materials and would result in lower power generation costs and an increased consumption of electrical energy per capita.

Waterwheel-generator construction reached a high degree of stability a number of years ago. Basic designs have not changed appreciably. Their smaller numbers have not justified the extensive development devoted to the turbo-generator. It now appears, however, that the hydraulic generator of the future may be the beneficiary of many improvements created for its cousin in steam stations. Some of the improved ventilation systems, perhaps using gases other than air, much better insulations, and other new materials—while devised primarily for the high-speed generator—can be beneficially applied to the more massive, slower speed machine. It is not unreasonable to expect that the waterwheel generator can be made to deliver from one fourth to one half more kilowatts without any increase in size or weight.

The next 50 years cannot be expected to bring an increase in a-c generator ratings anything like that of the past 50. Also little further gain in reliability can be expected. There is, however, a great deal that can be hoped for in the way of making better use of a given amount of materials. In this respect the rate of improvement in the decades ahead will be fully equal to those behind us. This will be true not just for the machines of largest rating but the smaller ones as well. Certainly the art of generator design has reached no ultimate peak. The money and effort for further development is greater now than ever—and the possible rewards fully as great.

SWITCHGEAR DEVELOPMENT AND TRENDS





by J. B. MacNEILL

Last year a circuit breaker was built that raised the interrupting capacity from 3½ million to 10 million kva—all in one jump. Only two years ago lightning arresters were produced for a 500 000-volt experimental transmission line—287 000 volts being the previous maximum. Fuses have increased significantly in capacity. In less than a decade the rating has risen from one fourth million at 69 kv to one million at 138 kv. Indoor station switchgear capable of interrupting two and one half million kva is now fairly common.

All this but illustrates the norm in the field of switchgear. The development of devices to protect electric circuits and systems has always been a race with geometrically increasing problems resulting from compounding of several factors. Among these are increasing generator size, increasing short-circuit ratios, more machines operated in parallel with other stations and other systems, the need for higher reclosing speeds, and the growing necessity for ability to withstand rapidly repeated operations under major faults. It is the unusual conditions—not the usual ones—that determine the maximum duty requirements for switchgear. During short circuits, currents may be up to 60 times the normal power flow through the switchgear.

In the beginning of electric-power systems, switchgear engineers were hard pressed to provide equipments adequate even for that period. P. M. Lincoln wrote* in 1920, speaking of the closing years of the last century, "lightning arresters were totally inadequate; the oil switch was not yet known; the insulator was woefully defective, and such a thing as reversed power protection was not even dreamed of.

"An arrester that would operate with perfect success on a system of a few hundred kilowatts failed utterly to quench the arc when the Niagara generators were back of that arc. It was necessary to introduce a resistance into the discharge circuit to limit the amount of current that could flow. This in turn limited the effectiveness of the arrester.

"In 1896 protecting devices for transmission lines were conspicuous by their complete absence. The oil switch was not yet conceived and there was no method known by which a short circuit on an operating transmission line of the capacity we had at Niagara could be opened without shutting down the entire system. The only overload protection we had at the beginning of operations was fuses. It soon developed that the fuse under these conditions was a menace and not a protection. The amount of power to interrupt was so large that the fuses of that day could not begin to interrupt a short circuit successfully. After this fact had been demonstrated by several sad experiences, all fuses were removed. The only alternative was to arrange that the entire plant would be shut down in case of a short circuit.

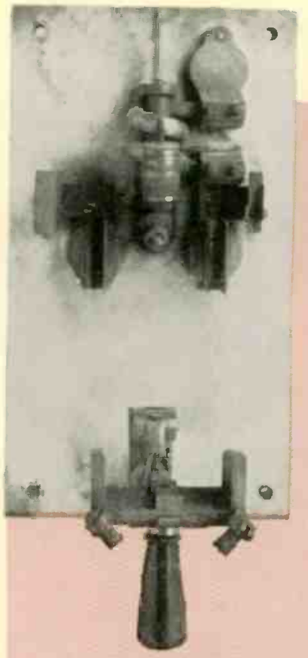
"When the air-break air-operated switches were designed and built in 1894–1895, they were the best that the art afforded. It was confidently expected that they would be able to interrupt any load that might be thrown upon them. However, it required but a very brief experience after the first generators had been put into operation to realize that these switches would be totally useless to interrupt short circuits."

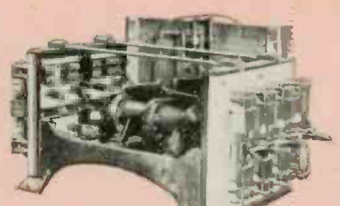
In spite of this gloomy picture of the state of switchgear, by the turn of the century much had been done that was sound and that endures in modified form today.**

In 1900 fused air circuit breakers were in service. They were

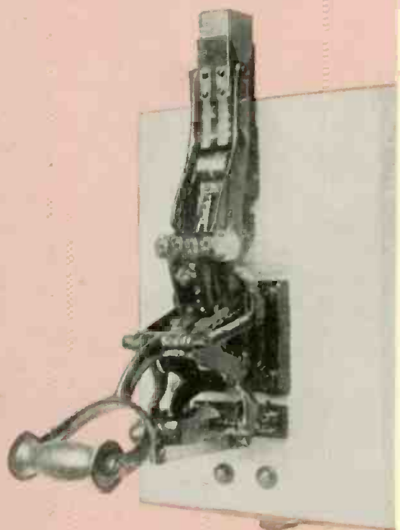
Left above is a high-voltage circuit breaker of the 1905–1910 era, and beside it are modern 287-kv, 3-cycle breakers at Hoover Dam.

*"Niagara Power," by Adams, Volume II, p. 278–284.
**An interesting history of early switchboard and switchgear development has been given by B. P. Rowe in *The Electric Journal*, for 1915–1916.



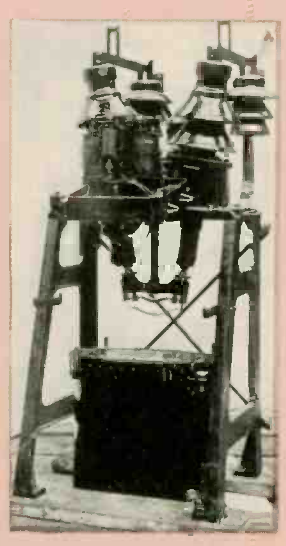


Left, one of the earliest circuit breakers on a marble base. Below, breaker built for original Niagara Falls system.



(Right) A carbon circuit breaker of about 1900.

(Below) A modern heavy-duty air circuit breaker.



(Right) An early outdoor oil circuit breaker (bridge type), 1906. →

(Left) Modern air circuit breaker.

single-pole assemblies with the circuit closed by the insertion of the individual units into clips similar to the insertion of a fuse. They were opened by the fusing of a wire or by a pull on a light cord that released the fuse wire. A catalog description of these breakers now seems optimistic as it stated: "These circuit breakers are light, simple, easily removed or replaced, quickly fused, reliable, and can be operated with the utmost safety." An added attraction doubtless was the low list price —$43.50 for a 40 000-volt single-pole unit.

Switchgear engineers had already made use of compressed air. Switches for the Niagara Falls plant were operated by compressed-air cylinders from iron control stands. These stands with the instruments were located above the busbar and the switch compartments. The plant was a pioneer in the field of remotely controlled switchboards as well as one of the first to be operated by compressed air. The switch breaks were provided with resistance shunts that greatly reduced the current before the final break. Several of these features of remote power control, the use of compressed air, and resistance shunts are typical of modern high-power practices.

An outstanding advance in the low-voltage field was the development in 1898–1899 by Westinghouse of the carbon circuit breaker. This form possesses certain inherent advantages that continue to make it useful in modified form. The breaker is so arranged on the face of the switchboard that it can be mounted above the heads of operators, though still accessible for closure. The main brush contacts and carbon break contacts are arranged in a line so that an arc, if incorrectly formed on the main contacts, moves upward to the carbons. The inherent magnetic blowout loop formed by the stationary and movable contact parts exerts a positive motive action on the arc, sweeping it safely above the circuit breaker and the operator to dissipate in the air overhead. The carbons gave long life with minimum burning and offered some resistance and therefore current-limiting effect.

The close relationship of this early device to the modern air circuit breaker is easily recognizable. We still rely on the inherent magnetic blowout effect of the contact members, and by so doing can handle a-c circuits up to 600 volts and involving up to 100 000 amperes or more on short circuits, without blowout magnets. Heavy direct currents for 750- and 1500-volt railway service are also handled by this type.

Early lightning-protection devices were relatively crude and ineffective. Westinghouse had brought out the Wurts arrester of the so-called "non-arcing metal" type in which a row of brass cylinders spaced a small distance apart permitted discharge of excess line voltage and for a time gave protection against power-follow current on light circuits. These arresters, equipped with resistors to limit current flow, were made in ratings up to 66 kv and gave spectacular effects during summer storms. For important service two sets of arrester gaps were put in series, one of them shunted by a resistor of suitable value. If needed to limit the power current, another resistor was put in series with both sets of gaps.

1900

At the turn of the century, switching equipment consisted of switchboards, on the exposed front of which were mounted air circuit breakers, both automatic and non-automatic, knife switches, fuses, and instruments. Such an arrangement presented many live parts subject to casual contact by an operator. Fuses were used to a great extent as interrupting devices because of their cheapness, considerable ability to open short circuits and the inherent time lag in their operation, which carried service through instantaneous current surges. Switching equipment, with few exceptions, was installed indoors.

In addition to the increased voltages introduced by the a-c system, there occurred at the turn of the century another major development in generation—the introduction of the steam turbine, which rapidly grew to large sizes. This made necessary an immediate large advance in switchgear to provide greater capacity under faults and more safety to both service and personnel.

The *oil circuit breaker* arrived on the scene just in time to meet this increased switching requirement; in fact, for a time it seemed that the circuit breaker had out-distanced its rival, the generator. Westinghouse, in bringing out a complete line, was able to speak, in 1901, of a type-C circuit breaker of "unlimited" interrupting capacity.

That this was an overstatement became apparent. However, many of its features are still retained in modern circuit-breaker construction, such as vertical gravity break with the open position being maintained by gravity, a separate oil tank for each phase, all contacts completely immersed in oil and safely enclosed in the tank structure, each phase built into a separate masonry cell, and operation by solenoids.

The immediate success of the oil circuit breaker encouraged its use at higher voltages, and designs soon became available for indoor service at 44 000 and 66 000 volts. An early device of this type, designed in 1905 and known as type L, was of multi-pole arrangement, each phase being housed in a wooden tank with a soapstone top, and provided with porcelain terminals surrounding leads wound with insulating material. This design had the sound fundamentals of gravity-break with all contacts under oil and enclosed upward leads.

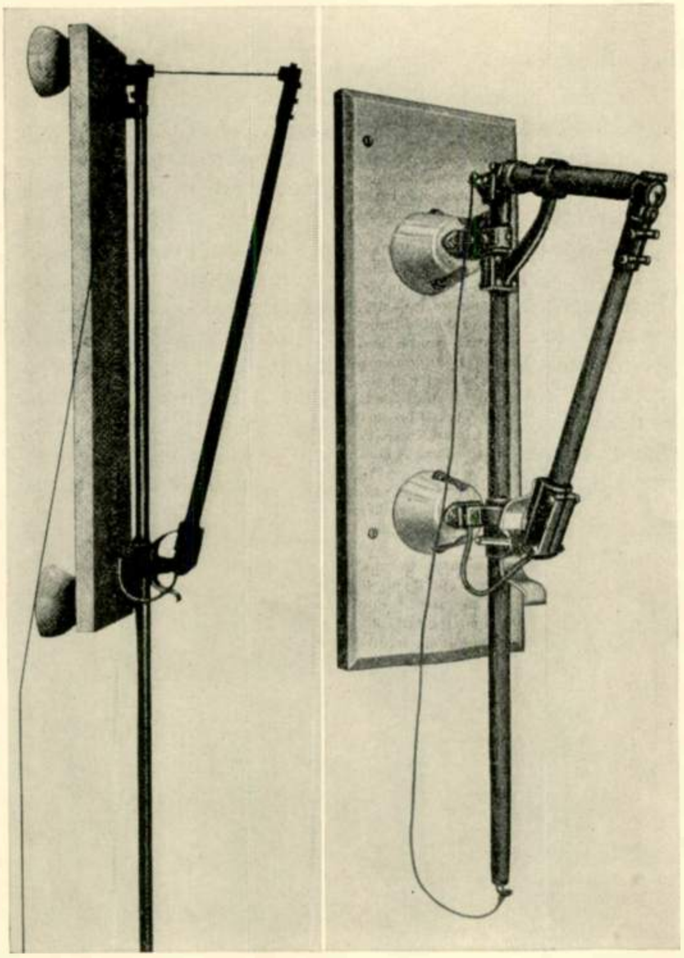
The need for a more powerful high-voltage circuit breaker resulted in the type GA, in which each phase was provided with a cast top and an individual steel tank. This type included, in addition to the best points of the earlier type, the first condenser bushings, which have been an outstanding feature of all Westinghouse high-voltage equipment. With the introduction of voltages of 66 000 volts and above, the limitations of the existing porcelain and cloth insulation became increasingly apparent. In the fall of 1905 James C. Dow, and later A. B. Reynders, working at East Pittsburgh, arrived at methods of subdividing or grading the voltage through the wall of a bushing. This resulted in the condenser-type bushing, which was widely acclaimed at the time and is today broadly used both in Europe and America on high-voltage transformer and switchgear equipment.

Outdoor Stations—One of the major decisions of the first decade was whether substation apparatus was to continue to be housed or emerge to brave the elements unsheltered.

In 1907 S. Q. Hayes, while discussing station layouts of the indoor type up to 120 000 volts, stated: "It is quite possible that in the not distant future where the climate is not too severe, high-tension transformer houses with their breakers, busbars, etc., will no longer be used; the transformers, oil circuit breakers, disconnecting switches, busbars, wiring and connections, will probably be in the open air. The top-connected circuit breakers and the open arrangement of busbars and wiring are particularly suited for an outdoor transforming station, and it may not be long before such a station is designed and installed."

The subject of indoor versus outdoor stations was given extensive airing before the AIEE in 1909. K. C. Randall of Westinghouse in an exhaustive paper on this subject concluded: "The advantage of outdoor apparatus lies in cheapening the installation due to a saving in building; there is also less life and property hazard. The disadvantages are: absence of protection from weather when inspecting, overhauling or making repairs, and exposure to molesters."

The reaction to this presentation, though mixed, was generally in favor of outdoor stations, where practical; one commentator stating—"The indoor substation, with apparatus operated at 40 000 volts or higher, is an absurdity." On the other hand, the comment was made—"Unless financial considerations make it necessary, there seems to be no reason for their use. There certainly is not apparent any engineering advantage in using them." And again in the same vein—"Considering storms, accumulation of moisture, general climatic conditions, and the trouble of making repairs, it seems as though the outdoor station could never be a serious competitor of the protected station."



Fused air circuit breakers of this type were in service in 1900.

In 1906, Westinghouse developed an outdoor single-pole oil circuit breaker for sectionalizing purposes on the 11 000-volt single-phase system of the New York, New Haven & Hartford Railroad. The breaker gave a great impetus to outdoor station use. Many early outdoor breakers of this type are still in service, having been modified to take advantage of later advances in interrupters.

Circuit breakers of the G type referred to above were well suited to outdoor service. The bushings coming through the roof of the circuit breaker were naturally adapted to carry overhead leads to an outdoor structure. The condenser bushings were readily fitted with a weather casing or porcelain shell to protect the fibrous insulation from rain, snow, and sleet. The cast tank tops could easily be designed to enclose the linkages for operating the gravity-break contacts and prevent water leaking into the oil. The contact structure, being free of horizontal insulating members, could withstand the effects of carbonization of the oil by arcing as well as the introduction of moisture by the breathing action of the air chamber above the oil. A number of such breakers for 44 000 and 88 000 volts, some hand operated and some electrically operated, were installed during 1909 and 1910 on the Southern Power Company system. These were the first high-voltage outdoor circuit breakers. By the end of 1910, therefore, Westinghouse was supplying oil circuit breakers for both indoor and outdoor use, from 44 000 to 110 000 volts, both hand and electrically operated, and incorporating the fundamental features described above, which are still recognized as basically correct for high-voltage circuit breakers.

Lightning Arresters

A marked advancement in lightning arresters occurred in the period 1906–1910 with the introduction of the electrolytic or aluminum-cell arrester, which was applicable to alternating and direct currents and to both indoor and outdoor service.

This arrester, which employed the unusual insulating properties of exceedingly thin films of aluminum oxide, took the form of stacks or columns of aluminum cones or trays mounted in stoneware jars, and later placed in sheet-metal housings. The rating of the arrester was the cutoff voltage. Power-follow current was a function of how recently the film had been reformed by "charging" and of how much film was damaged by the discharge. The more the damage, the greater the current while reforming the film. Although it was a moderately effective protective device when kept in good condition, it had drawbacks of size, presence of liquids, cost, and maintenance.

By 1910, then, transmission voltages were up to 110 kv, the outdoor oil circuit breaker had proved itself practical for most climates, and the electrolytic lightning arrester had reduced line outages. The increasing size of turbo-generators and waterwheels was adding to the short-circuit current obtainable on faults; breakers were being offered for circuits with connected capacity up to 12 000 kva at generator voltage and to 120 000 kilowatts on high voltage. Switchgear was still being rated on the basis of connected kva of generating capacity with no definite relation between the ability of the switchgear and the actual conditions of current, voltage, and power factor obtained on short circuit. Rating did not take into account the fact that machines had different reactances and stored energy and of the wide differences existing between waterwheel generators and turbo-generators.

However, the relatively large interrupting capacity of simple oil breakers had generally been more than adequate for the circuits on which they had been applied. Extrapolations of designs for higher voltages and higher interrupting capacity had been successful, but this period was being brought to an end by the increasing power concentrations.

1910

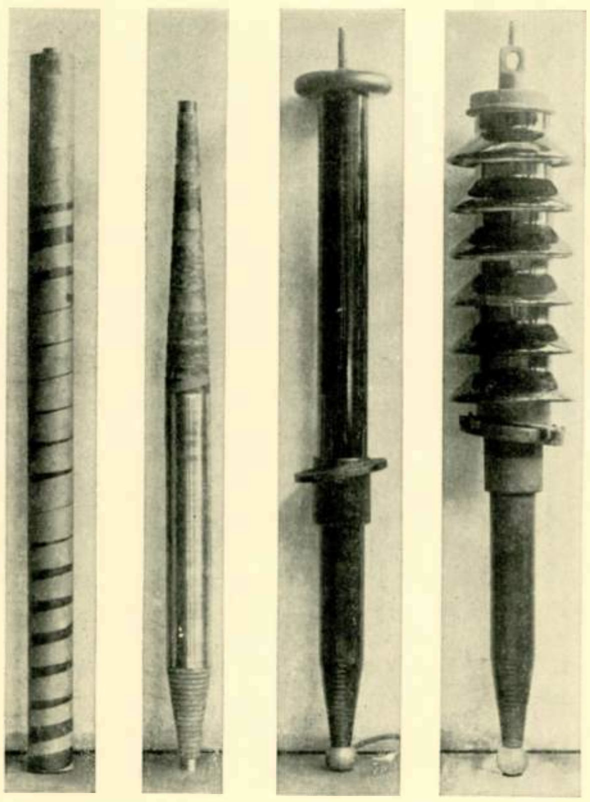
The rapid increase in generating capacity early in the second decade of the century required that a more rational basis for applying circuit breakers must be found than simply the capacity of the connected systems. In 1918 the three large electrical manufacturers proposed a method of rating circuit breakers in terms of the system voltage and the current to be interrupted during short circuit. They outlined a method of determining the kva to be expected on faults through consideration of machine characteristics. This general method of rating circuit breakers is still in use.

Also in this period generators again caught up with oil circuit breakers in their continuous see-saw race. It became apparent that oil circuit breakers would have to be improved to increase their interrupting ability. This led several operating companies to make field tests to secure data for design improvement. In 1915 Westinghouse demonstrated, on the 25-kv lines of the Detroit Edison Company, a multi-pole circuit breaker for indoor powerhouse use, called the type O, which had cylindrical steel tanks and condenser bushings. This sturdy type offered advantages over previous more fragile constructions. It opened approximately 500 000 kva on the Conners Creek bus, which at the time was an unusual amount of testing power, and gave this type of circuit breaker an immediate popularity.

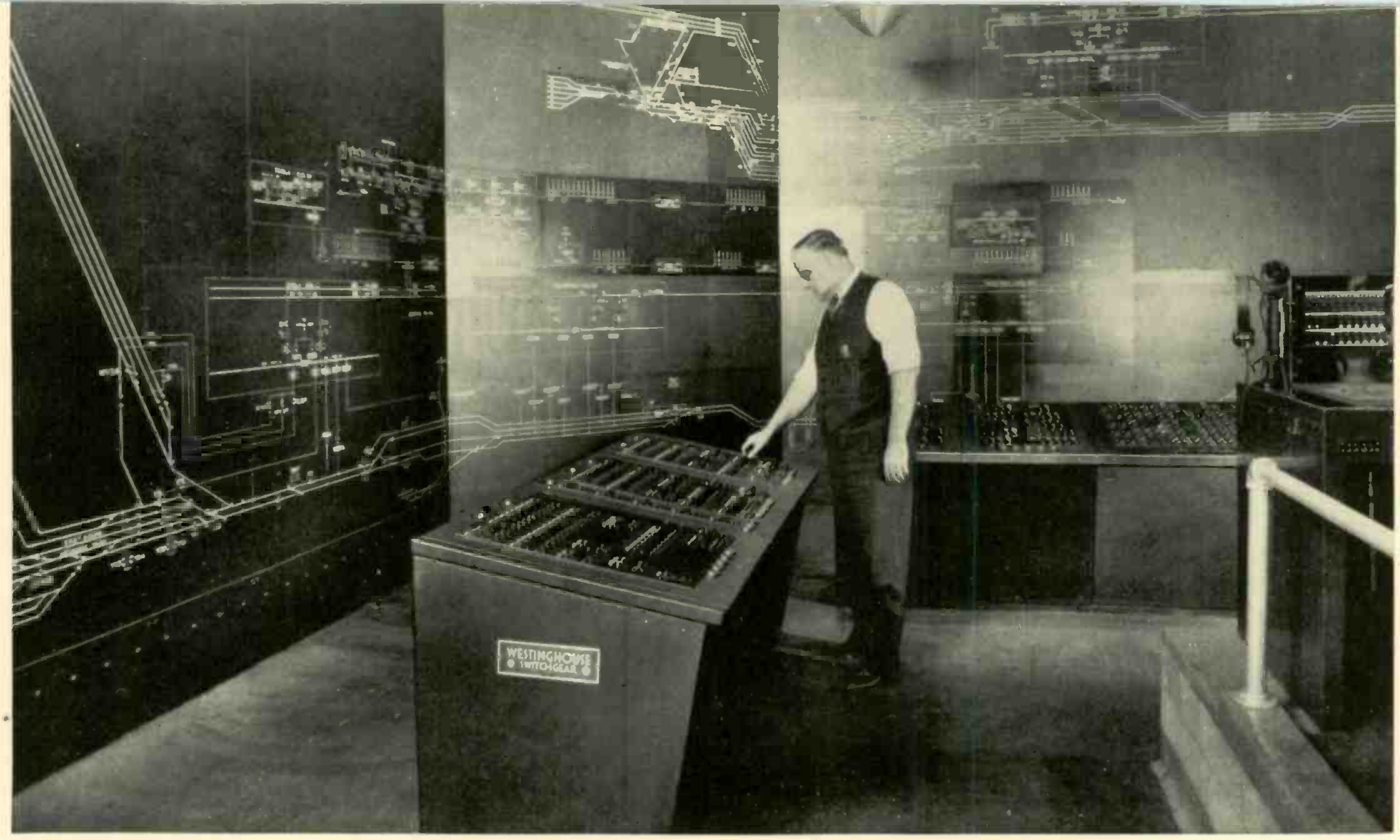
In 1917 Westinghouse produced a powerful outdoor circuit breaker for 135 000 volts in which each phase was mounted in a cylindrical heavy steel tank with domed top and bottom, and equipped with gravity breaks and condenser bushings. These breakers are the prototype of most of the high-voltage, high-power circuit breakers of today. They had an ingenious feature known as a quick-break device whereby the main moving parts separated at a reasonable speed with the circuit maintained through a set of arcing tips, which were later snapped apart at a much higher speed.

Automatic Switching Equipment

By 1914 the improvement of electrical equipment for generation and transmission, and the development of reliable protective relays (see p. 66) made timely the introduction of fully automatic and unattended stations. The flexibility of electric control had for a long time held out hope for such



A modern 115-kv condenser bushing at left; (above) construction of an early condenser high-voltage bushing.



Dispatcher's control desk, supervisory control for Pennsylvania Railroad electrification, built in 1938.

use, and as early as 1906 Westinghouse had offered an automatic synchronizer for connecting a-c generators to the system when phase relationships were correct. At the same time, with the increase of small outdoor and indoor stations, the burden of station service had decreased to a point where mere "attendance" was called for on the part of the operator.

In 1916 Westinghouse pioneered a form of automatic station known as the relay type. In this the functions of starting, running, and stopping are controlled by relays, and thus each function is responsive to the existing electrical conditions. The first of these stations for 500 kw for street railway was placed in operation in 1917. The relay-type station is the one now generally used.

Important milestones in the development of equipment for unattended, automatic stations include: the first multi-unit station control in 1919; in 1922, the first successful speed matcher and automatic synchronizer for a-c machines, followed by an electronic synchronizer in 1927; a system of motor-generators and synchronous converters for re-energizing an Edison d-c network in 1924; a completely automatic power supply in 1940 for the 40 000-hp wind-tunnel motor at Wright Field; and, in 1935, a completely automatized 60 000-kva frequency changer.

Supervisory Control

Soon after the success of unattended stations was established, it became apparent that overall system efficiency could be increased if a central dispatcher could not only be kept continuously informed of load and operating conditions of remote stations, but also be able to operate all equipment in them. As a result Westinghouse installed the first complete system giving visual indication and control of apparatus position for the street-railway substations in Cleveland in 1922. A central dispatcher in a downtown office building is not only able to see quickly the relative loadings of the various stations, but also can start and stop machines, open and close feeder breakers, transfer load from one station to another, and be informed of any unusual operations or trouble. Telephone wires in cable are used as the connecting channel.

The original equipment incorporated four features still recognized as essential to reliable supervisory control. These are: First, the transmission of a code of pulses to the remote station. Second, the station returns a check code to insure the operator that contact has been established with the proper unit. Third, the operator sends a code to cause the desired operation. Lastly, the remote equipment, having made the desired action, returns a code indicating that fact to the operator, assuring him that his desires have been carried out.

Subsequent developments have included, in addition to many detailed improvements in circuity, apparatus, and operating features, major enlargements of scope. In 1923 several stations were first controlled over a single channel. Services other than supervision have been added, such as the reading by telemetering of any remote load or apparatus position, the synchronizing of a-c sources, voice communication, and the movement of a given device such as a valve or rheostat to a new preselected position.

Long distances are now covered by supervisory control. The longest by cable is the 126-mile system of the Pennsylvania Railroad in 1938 and the longest carrier-current channel is the 270 miles between Hoover Dam and Los Angeles.

Supervisory control now employs a variety of channels—with reliability the most essential quality. A pair of telephone wires in a shielded cable is the most reliable. Where great distances are involved the power lines themselves are used. Space radio has not proved dependable but microwave beamed channels are being developed and show promise of extensive use. Westinghouse experimented with a microwave channel as early as 1943 to control a railway substation.

1920

Power Circuit Breakers

During the first quarter of the century switchgear designers labored under the distinct handicap of seldom know-ing the exact capabilities of their apparatus. Except for an occasional test made on some operating system, usually with great inconvenience and some hazards to service, there was no way to measure what switching devices could do. Such was the situation by 1920. The interrupting requirements of stations and systems were known to be beyond the capacity of existing designs. But how much was uncertain.

Something had to be done about this. As a result, during the early twenties, considerable elaborate field testing was performed with the invaluable cooperation of power companies. The Consolidated Gas, Electric Light and Power Company of Baltimore in 1920 and 1921 made possible the testing on its 13.2-kv system, short circuits of 600 000 kva being obtained. In several hundred tests, invaluable information was obtained on many details of breakers in this class and led to a much improved dead-tank breaker for powerhouse service. This breaker relied for interruption on the inherent blowout of the magnetic loop formed by the contacts, and led to a staunch physical construction and means for exhausting the gases through mufflers and headers to prevent secondary explosions. Breakers of this type, sufficiently rugged to withstand repeated short circuits without throwing oil, while safely venting the arc-produced gases, led to the later compact design of three phases in one tank. This gave a sound basis to an installation of a breaker of this type, rated 1½ million kva in Hell Gate Station, which is still operating with little change. Similar breakers of 2½ million kva have been added since.

Currents were becoming so large that they were giving trouble from thermal and magnetic effects. To explore this problem the New York Edison Company offered the services of its concentrated system. In the resulting tests record-breaking currents of 130 000 amperes were obtained.

Out of such field tests came data that led to a new breaker (B-20) in which capacities up to 500 000 kva were provided with all three phases in a single cylindrical tank. The whole structure was designed to resist heavy internal pressure. The air chamber was adequately vented through oil-separating mufflers. In this way a non-oil-throwing construction was secured in small space, and gas resulting from circuit rupture led safely out of the switchgear. This type of breaker made possible the Westinghouse metalclad switchgear for industrial plants and substations, without the complication of gum-filled or oil-filled buses.

To further the development of high-voltage breakers, the Alabama Power Company in 1922, and later, staged a large number of interruption tests on 44 000- and 115 000-volt circuits with Westinghouse participation. This resulted in improvement of the round-tank circuit breakers, type G-2, and the general use of high-speed contacts, which reduced arcing time and arc energy. These investigations marked a new high in interrupting tests on high-voltage circuit breakers.

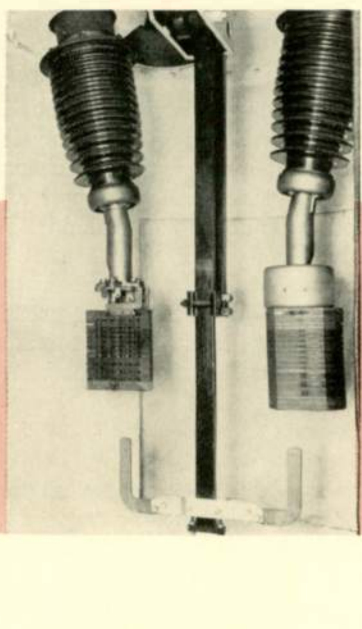
System capacities and voltages continued to rise. In 1923 line voltages rose to the milestone figure of 220 in California. The outdoor cylindrical-tank (G-2) oil circuit breaker, the design of which was based on cooperative field tests, proved very successful and is still in service. It has recently been modified for higher capacity and speed.

High-Power Laboratory

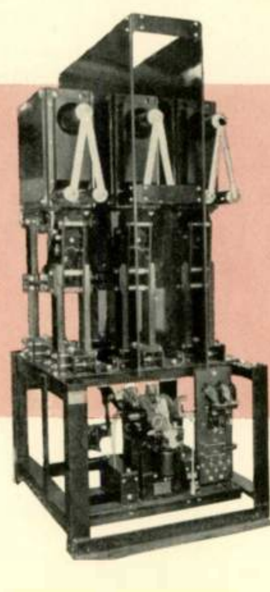
By 1925 it was becoming increasingly evident that the growing needs of American switchgear could not be met without a more direct attack on the fundamentals of arc rupture. Field testing, while invaluable, was becoming more difficult and more inadequate. The result was a new design tool—the high-power laboratory, where tests can be made in great variety under controlled conditions day after day. Westinghouse equipped its first high-power laboratory with two 13.2-kv, 60-cycle generators, making possible 400 000 short-circuit kva (symmetrical). The addition of a 100 000-kva bank of power transformers in 1928 made available three-phase voltages up to 230 kv. Short-circuit capacity was increased in two steps—1930 and 1940—so that now the short-circuit capacity is 2½ million kva with voltages up to 345 kv, 3 phase. Currents up to 345 000 amperes can be obtained. Special laboratory facilities have been added, such as a cold room for testing at temperatures below zero. More than 200 000 tests have been made in this laboratory, giving fundamental data on every phase of switching equipment.

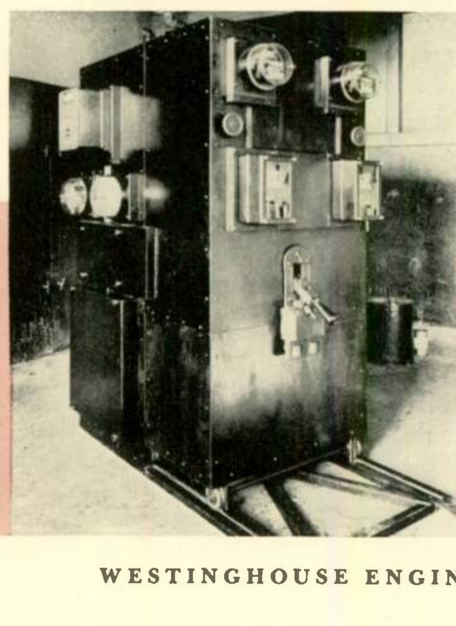
De-ion Circuit Breakers

Dr. Slepian's discovery of the cold-cathode arc marked a great advance in the understanding of arc phenomena and resulted in the De-ion air circuit breaker. In this, arcs in circuits up to 25 kv were broken into a series of short arcs and rotated at high speed in an annular space between copper plates. Circuit interruption occurred at the next current zero. This gave an efficient arc interruption not previously possible on high-voltage circuits and provided an interrupting time of less than three cycles. The first of these breakers was placed



(Left) Mechanism of a De-ion grid oil breaker. (Below) De-ion air circuit breaker, and (right) an early truck-type circuit breaker.





in operation in 1927. Many subsequent steel-mill circuits, heavy furnaces, and important utility lines have proved this method of arc interruption particularly desirable for high-speed operation and heavy duty between service periods.

De-ion Grid Circuit Breakers

Another comparable development by Westinghouse in this period was the De-ion grid for high-voltage oil circuit breakers in which the arc drawn between the contacts during the opening stroke was forced, by magnetic action, into a series of slots and oil pools and thus brought into intimate contact with de-ionizing forces. The first of these devices was introduced in 1929. Numerous tests showed the feasibility of eight-cycle or, in most cases, even five-cycle interrupting time. This outstanding development in high-voltage circuit breakers has been the basis of many modern interrupters by several manufacturers, and is widely used both in this country and Europe. It marked the beginning of modern, controlled circuit interruption with minimum contact wear, low oil depreciation, low gas pressures in the structure, and low maintenance.

Metalclad Switchgear

The truck-type circuit breaker was developed early in this period. Westinghouse supplied, in 1922, electrically operated breakers mounted on removable trucks arranged to be plug-connected to a complete stationary metalclad housing. This construction enabled the rapid replacement of a unit in trouble by a duplicate. It led in 1929 to the so-called metalclad switchgear in which all conductors are completely covered by solid insulation.

This type of gear, now the general standard in America, provides interchangeability of removable units, eliminates in most cases the necessity of double circuit breakers. By taking advantage of the greater reliability of modern circuit interrupters, it provides a relatively simple and accessible metal-enclosed structure, which, with proper interlocks, assures safety to personnel and service. It also provides a measure of portability so that the complete switchgear units can be moved from one location to another.

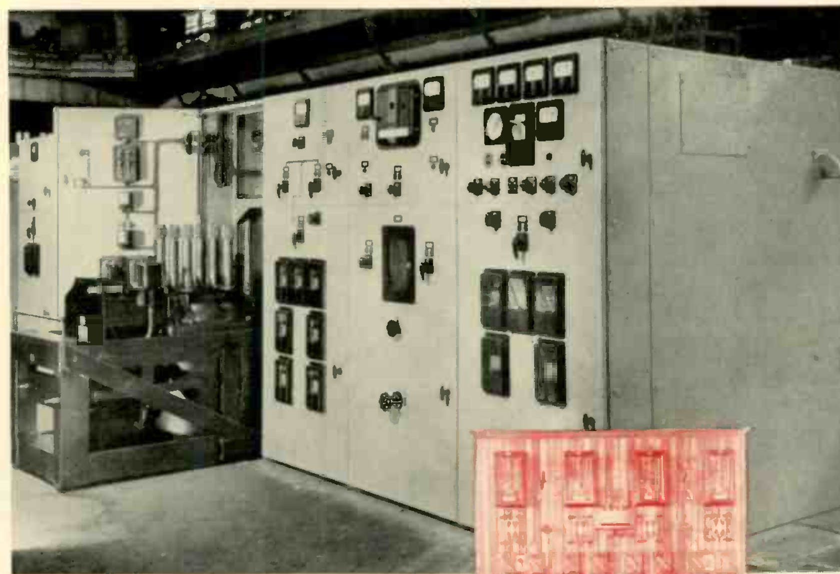
Cooperation within the Industry

A forum for the study of mutual problems was provided by the AEIC in the establishment in 1927 of the Committee on Electric Switching and Switchgear. Later this was supplemented by the joint AEIC-EEI-NEMA Committee, which has for many years served as a valuable stimulus to development work and overall industry economy through standardization and simplification of the methods by which circuit breakers are rated.

Circuit-Breaker Details

It had long been desired to have a source of low-voltage energy of proper power factor for indicating or metering of main-circuit conditions without the expense of a high-voltage metering transformer. In 1925 J. F. Peters invented the network potential device, which drew voltage from a high-voltage circuit breaker or transformer bushing through a bushing tap and then modified the power factor of the low-voltage circuit to be in phase with the main circuit. The use of this device on modern switchgear, fed either from the apparatus bushings or from separate coupling capacitors, has become common. Frequently all six bushings of a three-pole circuit breaker are so equipped.

Much distress on high-voltage electrical apparatus has been caused by the admission of moisture through packing



A modern installation of metalclad switchgear, and a switchboard (about 1885), when it really was a board of wood, with switches, lamps, and instruments mounted on its front surfaces.

glands or gaskets. Joints consisting in part of porcelain have been a special source of trouble. Westinghouse developed in 1928 the Solder Seal by which porcelains are coated with a fired metallic ring that makes a perfect bond with the porcelain body, and to which metal parts can be soldered. This process is now used for weather casings of lightning arresters and bushings or circuit breakers, transformers, and capacitors.

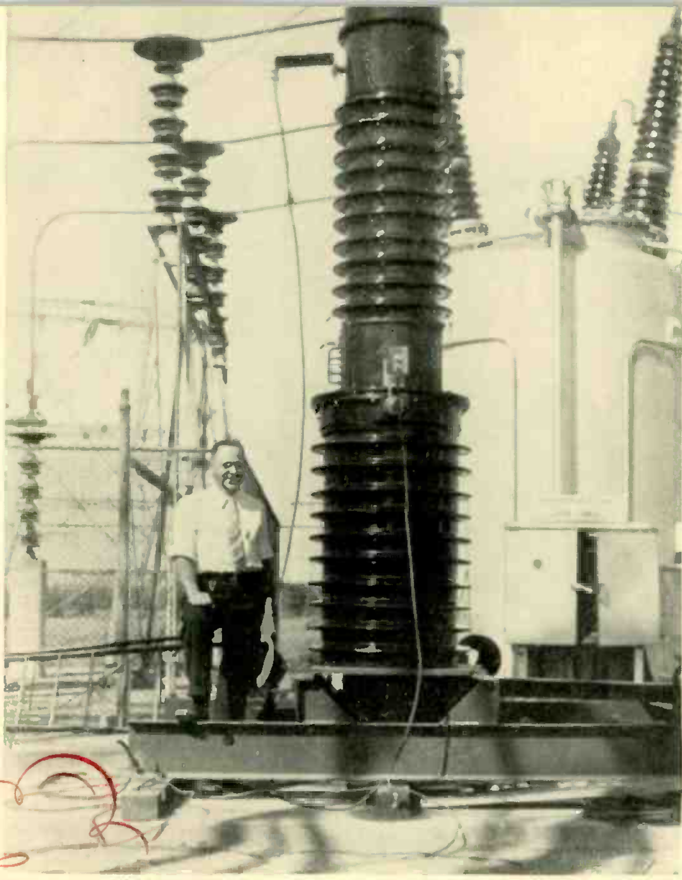
Insulating parts of power switching equipment are in many cases required to withstand or transmit large mechanical forces. Natural woods prove unreliable and porcelain is too fragile. In 1920 a resin-impregnated laminated wood compressed to smaller volume, known as Wood Micarta, was developed. It possesses three times the strength per unit area of ordinary wood and has contributed greatly to mechanical and electrical reliability of switchgear.

Lightning Protection

The electrolytic lightning arrester in use during the early twenties, although a moderately effective protective device when in good condition, was bulky and expensive. Also, the presence of liquids complicated maintenance.

The Autovalve principle, an ingenious new method, was disclosed by Dr. Slepian in 1921. It led to an arrester comprised of a suitable number of spark gaps between flat, parallel electrodes made from material of appreciable resistivity. The current density on discharge was low and the glow voltage high, facilitating the interruption of power-follow current. A new era in distribution-circuit reliability resulted through application of this small, compact, effective arrester to distribution transformers and later to small substations.

High-voltage arrester construction until 1927 had been handicapped by lack of an adequate insulating material. By that time, however, electrical-porcelain manufacture had advanced to a state where it became possible to market a porcelain-clad, high-voltage arrester. Wooden braces and insulating pillars essential in the early units were no longer



This single-pole, high-voltage oil-poor breaker was tested up to 2 500 000-kva, 3-phase equivalent. Interrupting time, 4 cycles.

needed. A reduction in size and weight was accompanied by increased reliability.

The search for a small and better lightning arrester continued. In 1927 Slepian devised a new one that operated on the principle of restricting the discharges to small pores. Its characteristics permitted closer coordination between the arrester operating point and the insulation level of the system, making protection more nearly complete. This advantage was gained with considerable further reduction in size. The present-day Autovalve arrester is an outgrowth of this.

The economical protection of transmission lines against outages due to lightning was greatly advanced about 1929 by Torok and others. Their invention of the expulsion-type, fiber-tube lightning arrester provided a means of discharging surges harmlessly from transmission lines and interrupting the power-follow current. Its application increased the reliability of existing exposed lines to a degree that, in some instances, made a second parallel line unnecessary.

Automatic Reclosing

Experience demonstrated that most faults on transmission systems are temporary and that re-energizing the section restores service. Special relays were developed for the automatic reclosing of circuit breakers and improvements in circuit interruption made the increased duty feasible. Periodic-reclosing equipment, built by Westinghouse under the patents of F. E. Ricketts, was installed in 1916. The prototype of the periodic-reclosing relay (type GR) was first installed in 1919.

From 1920 to 1930 applications of automatic reclosing using reclosing times down to 15 seconds became common. Furthermore, it became evident that service continuity could be greatly enhanced and considerably larger powers could be transmitted over a given line before approaching the stable load limit if high-speed reclosing with little or no intentional time delay was used. The success obtained in a study of immediate reclosure on four utility systems in 1931 showed that it reduced "outages" to a fraction, since for most customers momentary interruptions passed practically unnoticed and caused no inconvenience or loss.

1930

Improved Performance of Circuit Breakers

The early depression years was a period of quiet in expansion of generating facilities. But it was one of marked improvement in switchgear performance. The high-power laboratory as a tool for switchgear designers was beginning to pay off handsomely in improved interrupters over a wide range of current and voltage ratings. Interrupting time, which had been 16 to 20 cycles on 230-kv breakers, was reduced by De-ion grids to about eight cycles, and to about five cycles on lower voltages. The maintenance problem was greatly simplified. Instead of being necessary after every two operations, it could be arranged on a periodic basis at convenient times.

These improved interrupters were applicable to old circuit breakers as well as new. Many have been applied to breakers built as long ago as 1915, resulting frequently in increasing the capacity from a half million kva to several times that figure and permitting the switching equipment to keep abreast of system growth. The consequent saving in switchyard construction has been great. This method has had considerable bearing on the continuation of the grounded-tank oil circuit breaker as the American standard for outdoor service.

Breakers with Three-Cycle Interrupting Time at 287 Kv

A high point in switchgear practice was the decision of the Bureau of Power and Light of the City of Los Angeles in 1934 to build 287-kv transmission from Hoover Dam to Los Angeles. Due to the stability requirements and the importance of the service, this customer asked for three-cycle breakers—an outstanding requirement at that time for high-voltage work. A three-cycle interval on a 60-cycle circuit is the time required for a freely falling body to move three-eighths of an inch and in a three-cycle circuit breaker this time must cover the whole period of operation including tripping action, movement of mechanical parts, and arc interruption. To secure the necessary amplification of interrupting ability and break distance, a group of ten modified De-ion grids using rotary-arc features was developed, together with capacitor shields to secure voltage distribution among the interrupters. The possibility of such sub-division of interrupting duty in grounded tanks had been seriously debated, but was shown by this development to be practical both for faults-to-ground and fault-between-phases.

Breakers of the GO type having 2 500 000 kva rupturing capacity at 287 kv, to interrupt short circuits above 25 percent of capacity in three cycles or less, were supplied for Hoover Dam. These breakers have since been changed by improved interrupters to 3 500 000-kva interrupting rating to accommodate system growth. The multiple interrupter idea with proper voltage subdivision is now the basis for the majority of American extra-high-voltage designs.

Rapid Closing

Rapid reclosing of circuit breakers, because of its advantages, grew in acceptance. Experience showed that shorter de-energized times could be used. "Instantaneous" reclosure, with no time delay before the closing was started, restored voltage in 35 to 60 cycles. Shorter closing times were obtained by using pneumatic operating mechanisms with their energy stored in the compressed-air reservoirs. The length of time the lines were de-energized dropped to 15 to 20 cycles.

Reduction of Oil in Switchgear

Just previous to 1930, European switchgear engineers gave attention to development of oil-poor and compressed-air circuit breakers as a means of reducing fire hazards and conserving oil and metals. While the need to do this in this country was not so great because the materials problem was not so severe, and we did have the De-ion air breaker, designers began to explore these possibilities. In 1934 and 1935 Westinghouse developed an oil-poor breaker for high-voltage service, in which the interrupting element, isolating break, and current transformer were all built in a single porcelain column. It interrupted on single phase the three-phase equivalent of 2 250 000 kva, in a total interrupting time of four cycles.

This general design has since been used by several Westinghouse affiliates in Europe. Many of these porcelain-clad breakers are in service there. For American high-voltage practice, however, where numerous current transformers are required for relay operation, where grounded systems require more frequent breaker operations, and where high-speed reclosing is becoming more common, the improved dead-tank breaker is most widely used.

Metalclad Gear

It was natural that industry should take advantage of the growing reliability of circuit interrupters to simplify station construction. Massive and costly individual masonry cells were no longer employed. In 1929 Westinghouse produced metalclad switchgear of relatively light construction, using these improved circuit breakers with sheet-metal barriers between circuits, and with proper shutters and interlocking to safeguard personnel. The round-tank breaker was a most logical device for this type of gear, which became almost universally used in the period 1930–1940. This gear relied on individual circuit breakers that were readily removable from the structure for maintenance, service being continued through a spare unit interchangeable in all breaker locations. The De-ion air circuit breaker (type U) was also well suited to this class of work and many installations are in use in steel mills and other heavy industrial service. Early in this period a similar, convenient metal-enclosed arrangement for 440-volt equipment using drawout-type, interchangeable breakers (CL) became available and enjoyed considerable popularity.

Low-Voltage De-ion Breakers

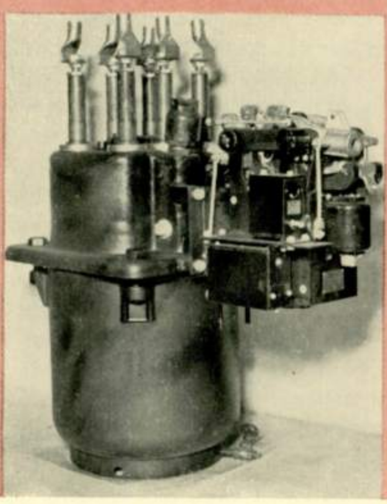
An important development at this time was the thermal De-ion breaker (type AB). It was the culmination of a scheme dating back to 1924 when O. S. Jennings of Westinghouse conceived the idea of protecting devices and circuits by a small circuit breaker tripped through a bimetal strip responding to the heating action of circuit current. Such a device could be promptly reclosed after opening on faults, and possessed the necessary time lag to cause tripping only when necessary to protect connected apparatus. Following its initial development to protect small household appliances, it appeared in 1928 in larger units for the protection of house circuits. These have been valuable in reducing fuse replacements by power companies. Several manufacturers now produce a complete line of this apparatus with carrying capacities up to 600 amperes at 600 volts alternating current.

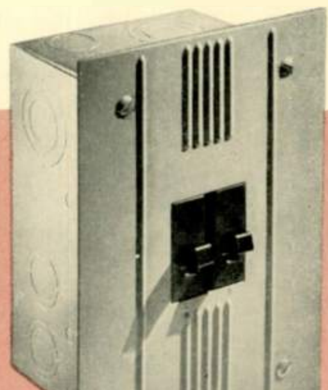
For low-voltage industrial work, the DA line of breakers, brought out in the latter part of this period (1939), provided superior operating features to the earlier carbon-type breakers. They utilized modern arc interrupters with arc splitters and enclosures, resulting in low arc energy and great reduction in the visible flame characteristic of older forms.

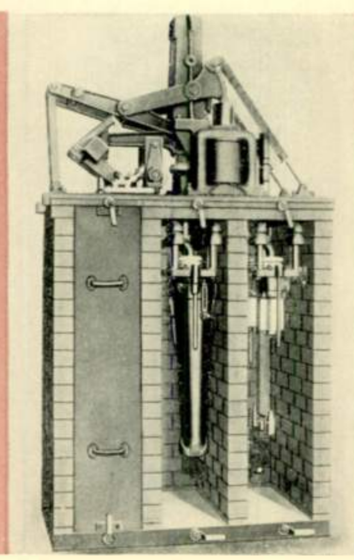
Compressed-Air Circuit Breakers

The desire to eliminate oil continued to grow, as indicated by the several approaches to the problem both in Europe and the United States. Westinghouse engineers made an extensive investigation of water and compressed-air breakers used in Europe and experimented with other types such as vacuum, boric-acid, and other self-generated gas interrupters. This study, plus consultation with utility engineers, led to the conclusion that compressed air had the best chance of covering the generating-station interrupting requirements up to 2 500 000 kva in this country.

Accordingly, development was begun on a simple form of compressed-air breaker using the cross-blast principle, in which the breaker structure is divided into three integral parts for safety and improved operation. A lower compartment contains the control wiring, alarms, etc., and a storage tank with sufficient compressed-air capacity for interrupting two short circuits and reclosing without air from the main station storage. The middle compartment houses the







(Left) A round-tank breaker developed in the late 20's. (Above) A small air breaker for home service, and (right) a type C oil circuit breaker, in 1901.

high-tension leads, arc chutes, and contacts designed to withdraw to a safe position outside the chute for isolation. The top compartment is an expansion space for the gas after it has passed the arc-chute structures. It is interesting to see the return of compressed air as an interrupting means after almost 50 years since the early air switches were operated by compressed air at the Niagara Falls development.

1940

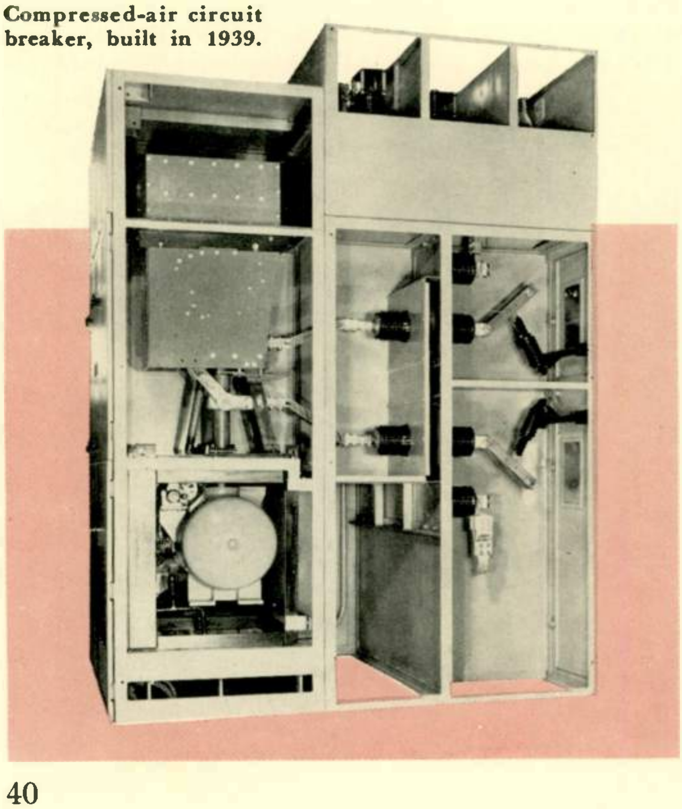
In the past decade switchgear developments varied in accordance with the suddenly changing needs of the period.

The Prewar Period

The two years ahead of the actual participation of the United States in the war were marked by extensive activities of power companies to increase their facilities as the war-engendered load climbed. The ability of manufacturers to provide standard switchgear for this need was strained.

Two significant new switchgear activities did come about in this period. One was the development of compressed-air mechanisms for operating high-voltage circuit breakers. The need for these arose because outdoor stations were covering such a large area that it was becoming difficult to carry control power from the central point to the outlying equipment. These compressed-air mechanisms, in addition to the necessary pistons, valves, and trip devices for actuating the circuit breakers, have individual air compressors and storage tanks sufficiently large to give several breaker operations without compressor action. These mechanisms provide fast synchronizing action of large breakers, give high acceleration during the opening stroke, and require only small power from a control line to run the compressor. At present probably two thirds of the large circuit breakers built in this country for outdoor service use compressed-air operating mechanisms, although the older solenoid type is preferred by some users.

A second important development occurred in the field of large-capacity gear for 2.5- to 5-kv service. This was a new type of air breaker (DH) in a metal enclosure. This breaker interrupts the circuit by drawing an arc in a chute having a series of transverse zirconium baffles with tapered arc slots. The arc inserts a coil in the main circuit to produce a magnetic field for blowing the arc into the narrow ends of the slots, which are staggered so that the length of the arc and the cooling are increased. Being less expensive to manufacture than its predecessor De-ion breaker (U), it has made possible metal-clad air breakers at no greater cost than previous oil breaker gear. Subsequently this type has been extended to 15-kv service for mounting in both indoor and outdoor metal enclosures, and provides the safety features, interchangeability, and easy removal, characteristic of metal-clad.



Compressed-air circuit breaker, built in 1939.

As early as 1937 low-voltage equipments had been built of the drawout construction for large capacities. With the development of the DA breaker, drawout metal-enclosed equipment became almost universal for low-voltage service.

The War Period

The onset of the war swung the productive efforts of manufacturers largely to supplying the needs of the armed forces. The greatest switchgear requirement at the time was for the vast numbers of cargo and fighting ships for the Navy. Ability to withstand shock has always been a major problem in Navy designs, and these requirements were greatly increased as progress of the war showed the effect of heavier concussions. The need to conserve space and weight called for careful arrangement of circuit breakers with a view to improved selectivity in tripping. There was also some use of low-voltage breakers arranged in cascade, with provision for protection by tripping sequences to permit the use of what otherwise would have been inadequate interrupters.

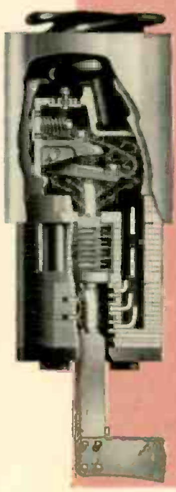
Large use was made by the Navy of the molded-case breaker (AB), originally developed for low-voltage industrial service. The safety of total enclosure, together with its quick make and break action and its efficient arc rupture, encouraged its modification and broad use for shockproof service.

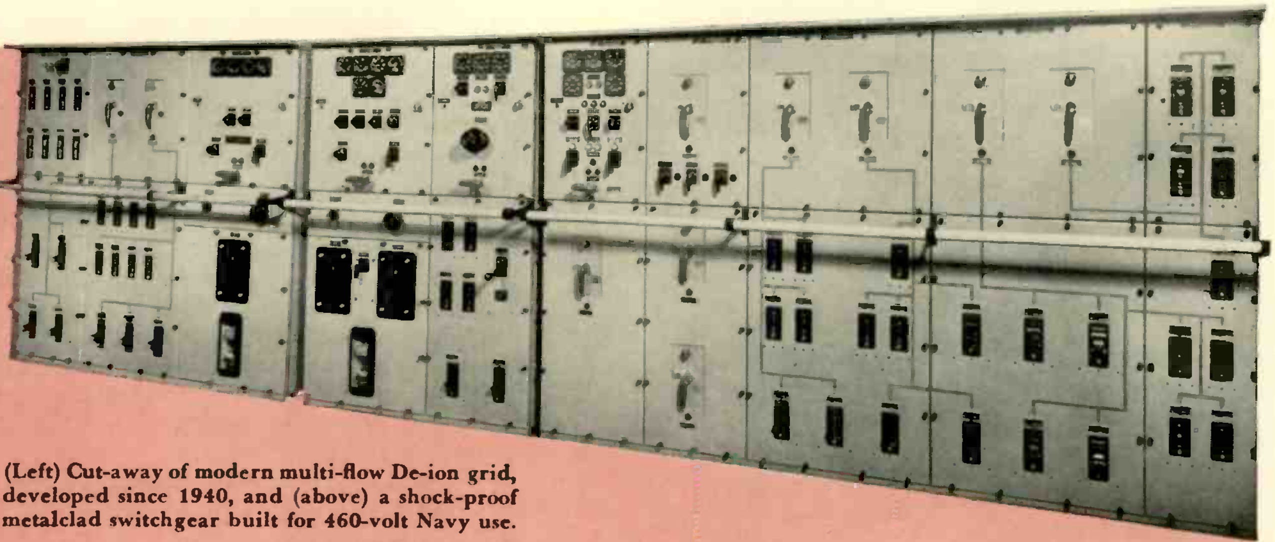
Since the war, further study of this problem has resulted in low-voltage circuit-breaker designs having three bands of time values depending on circuit current. A long-time tripping band at low overload currents is provided to protect service, including motor starting. A short-time tripping band is used for higher current values where the breaker represents back-up protection. Each breaker has, in addition, an instantaneous trip where it is used to clear heavy short circuits.

The Postwar Period—Factory-Assembled Gears

The third period of the 1940–1950 decade began promptly with the end of the war and—contrary to general expectation—found both the utilities and the large industrial users short of electric power and equipment to meet the postwar expansion. During the depression years many utilities had disbanded or reduced their construction groups and associated engineering personnel. As a result the postwar period made extensive use of factory-assembled and factory-tested switchgear, which, with a minimum of skilled work, could be set down on the floor of a station and quickly connected for service. The De-ion air breaker (DH) by this time was available to 500 000 kva at 15 kv and the compressed air breaker for larger capacities had been developed to 2 500 000 kva. These types, with the De-ion low-voltage breakers (DA) previously described, were entirely suitable for these broad oil-less metalclad requirements.

The oil circuit breaker in moderate capacities is still preferred by some customers for indoor use for reasons of insulating values, or for use in explosive atmospheres. Other-





(Left) Cut-away of modern multi-flow De-ion grid, developed since 1940, and (above) a shock-proof metalclad switchgear built for 460-volt Navy use.

wise the air types of switchgear are preferable. Since the war few oil breakers have been installed in main stations.

The Rise in Interrupting Capacities

A distinguishing feature of switchgear practice in the past few years has been the growth of power concentrations on high-voltage circuits and systems. As early as 1926 switchgear for generating stations was built with 2 500 000-kva interrupting capacity. This still marks the maximum switchgear requirement at generator voltages because this represents the logical limit to a concentration of power that can safely be placed on an indoor bus system. However, for outdoor service, system studies have continued to demonstrate the advantages to operation of increased circuit-breaker capacity. To illustrate, Hoover Dam required 3 500 000 kva at 287 kv in 1941; American Gas and Electric required 3 500 000 kva at 138 kv in 1945; several others have since reached this value of 138 kv; American Gas and Electric further required 6 000 000 kva at 138 kv in 1949; Aluminum Company of America required 5 000 000 kva at 161 kv in 1949; and Grand Coulee, needing 10 000 000 kva at 230 kv in 1947, now indicates they will probably need 12 000 000 kva or more in the near future.

These requirements have been filled by the use of the multi-flow grid, designed since 1940, and arranged to give breaker times of 8, 5, or 3 cycles as desired. In this type of interrupter a gas-generating arc drives oil jets under pressure into the arc stream where they are deflected into vertical components to break up the arc effectively, and then discharged through ports from the interrupting structure.

These grids have been intensively developed both by high-power laboratory and field tests, and have been applied broadly in the manufacture of high-voltage apparatus and the rebuilding to higher capacities of earlier equipment. Their use has been accompanied by a considerable reduction in oil volume in new designs, up to 40 percent in the largest sizes.

A factor in recent high-voltage switching is the stress placed on proper interruption of line-charging currents. With increase in line length and charging currents, it has been increasingly necessary to provide auxiliary means of interrupting the charging current in times consistent with load current for voltages above 100 kv. Numerous practical tests including many on operating systems have shown that the combination of conditions that can be assumed and which give the highest voltages rarely, if ever, occur in service. The method of interrupting charging currents recommended by Westinghouse is to use the oil piston contained in the multi-flow grid, as this completely removes voltage from the fault within the breaker time, and readies the line for high-speed reclosure.

The oil circuit breaker continues to handle the bulk of outdoor switchgear requirements in this country. Some low-oil-content breakers for high-voltage service are in use, but their need of multiple single-pole operating mechanisms and the American use of numerous current transformers are unfavorable to their broad acceptance.

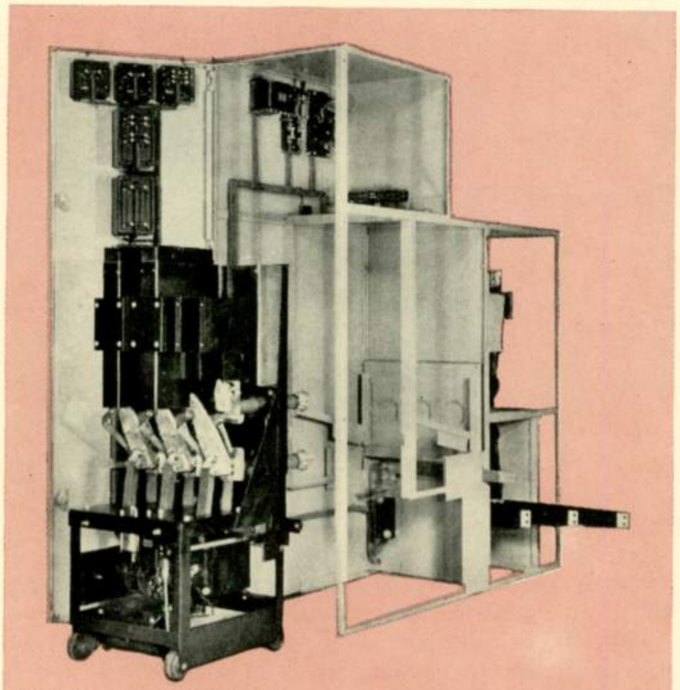
In 1941 a 138-kv, compressed-air breaker for outdoor service was installed for field trials. This breaker is still in use and other breakers of the same type have been built for 66 and 33 kv. The numerous modifications of compressed-air breakers for outdoor service tried in Europe have not become attractive to either the American buyers or manufacturers. A satisfactory outdoor type of compressed-air breaker may be developed, but there still remain hazards due to the porcelain construction, the high pressures necessary for interruption of great power, and the problem of removing sustained electrical stresses from the short-gap interrupters.

An indoor compressed-air breaker to interrupt 3 500 000 kva in 3 cycles, for location in densely populated districts where 66 000-volt cables are used for bulk transmission, was started in 1947. (Type 3500-CA-69). It is built with fibrous insulation to eliminate possibility of porcelain fracture, and mounted in a sheet-metal house equipped with outlet boxes, current transformers and necessary interlocks. This breaker differs markedly in construction from the cross-blast breakers used on low voltages, and has two interrupters of the longitudinal-flow nozzle type in series, one of which introduces a resistance. If necessary, this design, which avoids the hazards of outdoor compressed-air constructions, can be expanded to other high voltages for indoor service, although in this country nearly all switchgear above 33 kv is of the outdoor type.

An interesting application of switching principles using compressed-air is the recent development by Westinghouse of the protective features by which high-tension series capacitors in transmission lines can be shunted out during line faults and restored one half cycle later to normal service, thus increasing the permissible limits of line load. An important installation of a size to affect 15-kv regulation at full load on 230 kv is now being made on the Bonneville Power Administration System.

Microwave Channels

The use of radio channels for remote control, telemetering, relaying, and voice communication for power dispatching pur-



The air circuit breaker for metalclad switchgear up to 15 kv.

poses has been limited in usefulness due to high interference levels originating from power circuit lines (such as leaking insulators, corona, and lightning). When equipment for producing higher frequencies in the microwave region above 300 megacycles became available, the possibility was recognized of using them for control purposes since the signal-to-noise ratio can be very high. Furthermore, these frequencies can be "beamed" like light. Thus it is possible to use small transmitting power and to increase greatly the efficiency of channels within a given geographical area. An experimental installation of a microwave channel for supervisory control in a location where power arcs were prevalent was made in 1943. Using a frequency of 530 megacycles, reliable operation was maintained over an eight-mile, line-of-sight path through dark clouds and heavy rains. As soon as F.C.C. provided microwave frequency bands for point-to-point use, transmitter-receivers and multiplexing equipment were developed for commercial use by power and industrial companies.

Cost

The great demand for electrical equipment since the close of the war has made possible the repetitive manufacture of many lines of switchgear, and the distribution of development and overhead expenses over a wider area than previously available. As a result of this, and improvements in design and cost, Westinghouse is now selling switchgear as a whole at approximately 18 percent above 1939 prices. This is in marked contrast to the price of electrical equipment in general at 40 percent above 1939 prices; labor rates at 110 percent above 1939; material costs at 80 percent above 1939; and manufactured goods in general at 100 percent above 1939. A continuation of the present high volume is obviously necessary for the continued use of these low prices.

The Future of Switchgear

For the future it seems fair to assume that a-c generation and transmission will continue to supply the bulk of our power. The problem of circuit interruption can be adequately covered by conventional oil circuit breakers, compressed-air breakers or oil-poor breakers, in the portions of the field for which each is most practical.

Assuming that voltages will go to 400 kv or even 500 kv, the a-c circuit with its reoccurring zero points affords twice in each cycle the opportunity for interruption by a suitable number of arcs in series, with voltage distribution assured through resistance or capacitance dividers. There is considerable leeway in the number of series arcs necessary. While conventional apparatus uses two arcs in series for 15 kv or lower, recent experimental work has shown that a single arc with proper control can be made for 230 kv. At present, however, for a wide range of current, two arcs in series for 230 kv are a desirable minimum.

A considerable problem in modern interruption at high power is to limit and control the production of gases during arcing. Studies of interruptions over wide current ranges indicate that proper design will handle the currents on high-voltage circuits without undue distress up to the limits now foreseen for power-system service.

If the generation of gases during arcing periods should present a future problem, means are available for synchronizing the interruption with the current wave to secure adequate interrupting conditions on the decreasing portion of the current loop, thereby avoiding long waits for a current zero. This seems unnecessary at 60 cycles but at 25 cycles even a half-cycle of arc power presents disruptive effects on contact and interrupter constructions. For 16-cycle railway service this problem has had considerable attention, particularly in Europe. Synchronization can reduce the total energy released within the breaker to a small fraction of that released by unfavorable timing.

Increased efficiency of modern arresters, with ability to discharge at a voltage 2.5 times the crest of the rated arrester voltage and to seal off after heavy surge currents, has led American utilities to consider reducing insulation values on high-voltage circuits. It is almost universal practice to use 196-kv insulation for 230-kv service, and industry committees are now studying the situation more generally. Such economy in insulation is obviously to most advantage on systems of very high voltages.

High-frequency actuation of impedance-type relays through carrier-current control will in many cases be supplemented by microwave systems for dependability. Where necessary, through high-speed relays and circuit breakers, circuit interruption will be accomplished in three cycles or less with beneficial effect on stable load limits and conductor and insulator damage. High-speed reclosing in nine cycles, or even less on three-phase circuit breakers at the highest voltages is now obtainable. This can be further reduced, particularly if separate mechanisms are used on each pole. The de-ionization of faults need be the only limitation on high-speed reclosing. While this is affected to some extent by the fault-interruption time, it seems clear that reclosure will not be generally successful under 11 to 13 cycles on voltages up to 66 kv and 12 to 20 cycles on the higher voltages.

While high-speed reclosure on very heavy power concentrations is receiving a good deal of attention, its actual use is restricted at present. Through apparatus improvement and successful operation, it is apparent that this practice will grow and considerably affect system design through elimination of parallel circuits. More dependence will be placed on the ability of a minimum number of lines to carry adequate loads through momentary fault conditions.

High-voltage direct current remains a possibility for future power transmission. Should it come about, the transformation from alternating current at the generators to direct current at the line, and back to alternating current at the load presents formidable problems for the electrical manufacturer and especially for the switchgear designer. Interruption of direct current is more difficult than the interruption of an alternating current at equal voltages, because the current must be forced to zero by an interrupter. One possibility is to force the current to zero by the discharge of a capacitor and to prevent it building up again by means of a gas-discharge tube similar to those used for rectifiers. Another method is to insert resistors until the current is reduced to an easily interrupted value. A third and more speculative suggestion has been to use superconductivity of a resistor cooled by liquid helium and to reduce the current by the increase in resistance as the conductor is heated. A fourth would awaken memories of the last century, as it is to remove faults by momentarily removing power from the portions of the system affected.

For the future, manufacturers equipped with large testing laboratories can, through analysis of the arc phenomena of their interrupting devices, determine the operating characteristics for the large capacities that will be required. Through special laboratory arrangements, connections, and the use of small scale models or portions of complete interrupters, the final operation of large devices can be adequately proved. The generally lower values of recovery voltage experienced under field conditions give this procedure a factor of safety that would not otherwise be available. While the average customer no longer feels called on to demonstrate circuit interrupters on his own system, there will arise in the future, unusual cases where cooperative testing between manufacturers and users will be valuable to the industry.

System engineers, of course, keep power concentrations under fault conditions within the limitations of the available apparatus; however, it is repeatedly found that increased ability to handle faults and to reclose rapidly is an economical method of assuring high-grade service on important transmission systems.

The Grand Coulee bus, with 10 000 000 short-circuit kva under fault conditions, is an illustration of the large power concentrations made practical by modern high-speed switchgear, which removes faults in three cycles or less. It can be reclosed as soon as the fault is de-ionized, and thus assures satisfactory operation through fault periods with a minimum number of lines that in the past would have been wholly impractical. It cannot be assumed that this interrupting capacity will be adequate for even the near future since short-circuit kva figures of 12 000 000 and 15 000 000 kva have been considered. The American switchgear industry can produce apparatus to handle these concentrations when required.

J. B. MacNEILL

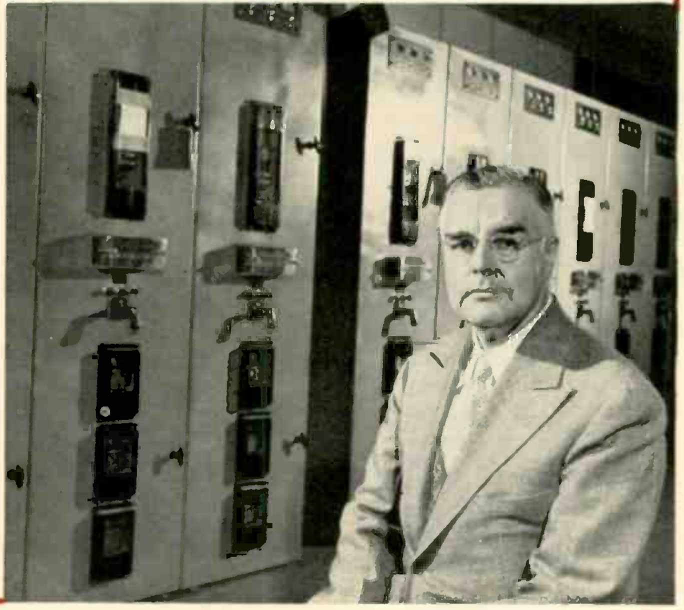
J. B. MacNeill, noting the passing of men associated with early developments, had often thought it would be worthwhile to have a complete history of Westinghouse switchgear. The request to prepare such a paper for this Mid-Century issue gave him the excuse to tackle the job. The result was an exhaustive, carefully documented treatise on switchgear of which, unfortunately, we were able to use only a portion.

Mr. MacNeill, after graduating from the Lowell Institute, and later from M.I.T. in 1913, came directly to the Switchgear Division of Westinghouse. It was an interesting period for two reasons: first, the engineers who had made the early developments were still active in the work, and, second, the growth of rotating machines and particularly the general use of the steam turbine, were rapidly pushing into obsolescence the earlier forms of switchgear. Mr. MacNeill has been associated with the development work that has raised switchgear from an inadequate and frequently awkward auxiliary of the power machines, to the modern apparatus that aids immeasurably in the stable and relatively fault-free operation of our today's generating and transmission systems.

Mr. MacNeill was a circuit-breaker designer from 1913 to 1917, at which time he became Manager of the Circuit Breaker Section of the Switchgear Engineering Department. In 1928 he was made Manager of the newly formed Circuit Breaker Engineering Department, and in 1933 became Manager of both the Circuit Breaker and Switchgear Engineering Departments. In 1943 he was made Manager of the Switchgear Division at East Pittsburgh.

The switchgear developments and installations in which he has had a personal engineering part read like a list of milestones in the art. Among these were the first superpower station switchgear using the 1 500 000-kva breakers for the Hell Gate Station in 1921; the single round-tank circuit breakers, which made possible our modern American metalclad switchgear; the De-ion grids for high-voltage breakers; multiple-interrupter circuit breakers, of which the three-cycle breakers for Boulder Dam are typical; and the high-speed switching equipment for the Pennsylvania Railroad electrification.

In 1938 Mr. MacNeill received the Westinghouse Order of Merit award and citation "for his creative ability in the advancement of the art of circuit interruption; for ingenuity in design and development, which has enhanced the Company's reputation both at home and abroad; and for his executive ability in supervising the engineering work on the widely diversified lines of products in the Switchgear Division." In 1946 Mr. MacNeill was recipient of the coveted Lamme Medal of the AIEE.



RESEARCH

by **J. A. HUTCHESON**

LORD KELVIN, a renowned scientist, and good friend of George Westinghouse, once said, "No great law in Natural Philosophy has ever been discovered for its practical applications, but the instances are innumerable of investigations apparently useless in this narrow sense of the word which have led to the most valuable results." Certainly the truth of this statement was evident at the start of the twentieth century. Even then it was possible to point to the practical application of the laws of Natural Philosophy determined by such men as Oersted, Ampere, and Faraday. Early in the 1820's Oersted had discovered that an electric current in a wire produces a magnetic field. Also he showed that a force is exerted on a current-carrying wire placed in a field of a permanent magnet. Ampere, following Oersted, discovered the force existing between parallel current-carrying wires. In 1831 Faraday discovered electromagnetic induction, observing that a changing current in one conductor produces a current in a second circuit placed in a magnetic field of the first conductor. The mathematical expressions of Oersted, Ampere, and Faraday developed to state the relations between current, magnetic field, force, and distance are the laws that with others, similar in that when first stated they were of academic interest only and apparently otherwise useless, are the foundation upon which the electrical industry is based.

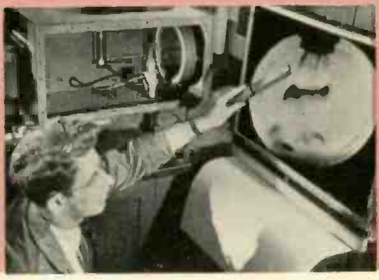
Some 60 years elapsed before the application of Faraday's, Ampere's, and Oersted's laws to the motor, the generator, and the transformer became a practical reality. During that period many inventors had been experimenting with methods of applying these laws to the construction of apparatus. However, it was about 1880 when the development of apparatus based on these laws had progressed to the point that practical use could be demonstrated.

Following the first practical demonstration of the application of the laws discovered through the fundamental researches of earlier investigators, the development of the apparatus began to move with increasing speed. Many false moves were made in the course of the development. These were caused in the main by a lack of appreciation of these basic laws by the men who were doing the development and also by the complete lack of knowledge of other fundamentals that also played a part in the operation of the apparatus. That this situation was quickly realized is evident by the writings of B. G. Lamme, Chief Engineer for Westinghouse. In an article published in the *Electric Journal*, he states, "One of the characteristic features in the early direct-current design was the radical differences in construction of the machines built by different designers or manufacturers. In fact, every designer appeared desirous of getting out a new type which could bear his name. In consequence, freak designs, from the present viewpoint, were much more common than those built upon sensible principles as understood to a limited extent in those days.

"Aside from the desire of each particular designer to have his name connected with some new or special type of machine, many of the freakish characters of these early machines were due primarily to an incomplete or wrong conception of the magnetic circuit. . . . In direct-current machines, as in other types of electrical apparatus, the real development and eventually the standardization of general types was a result of the development of the calculating engineer as distinguished from the experimental and the 'cut and try' designer."

Early in 1897 Lamme presented his classic paper on the polyphase motor, which gives adequate backing to Lamme's claim that the real advances were made by the "calculating engineer." This paper gives a thorough analysis of the problems encountered in the design of alternating-current motors, based upon Lamme's knowledge of the fundamental laws.

The development of the electrical industry was so rapid that the design engineers soon were utilizing all of the pertinent fundamental principles known. In spite of this it was apparent that further progress was possible although waiting the availability of new knowledge. The knowledge being applied was the summation of bits of knowledge accumulated over many years as the result of the efforts of individuals or of small groups of scientists. As the need for additional knowledge became apparent, it was seen that the best way to get this was to organize a group of competent scientists and direct their efforts to the acquisition of knowledge pertinent to the problems of the moment. Such a group was organized in Westinghouse in 1904 under Mr. C. E. Skinner. Thus was



established one of the earliest industrial research laboratories.

The staff of the first research laboratory was very small indeed. Only a half dozen men were employed. When it became apparent that the metallurgy of turbine-blade materials was an important consideration, one man was hired to be the "chemical and metallurgical research staff." This man's laboratory was an abandoned blacksmith shop. The personnel has steadily grown until today 550 people work at the main laboratory in all the fields of physical sciences.

The broad scope of the activity contained just in the main laboratory is suggested by the eight departments in which the work is done. The Chemistry Department has, for example, been engaged in studying organic compounds used for molded and laminated plastics. It was in the Electronics and Nuclear Physics Department that the x-ray fluoroscope image amplifier was produced and the work done on absorption of microwaves (radar) by clouds and rain. The automatic pilot, a new device providing a high degree of maneuverability of a high-speed airplane, is typical of the handiwork of the Electromechanics Department. The Insulation Department, obviously, concerns itself with such important matters as enamel coatings for copper wire. From the Magnetics Department has come an illustrious family of electric and magnetic materials including Hipernik, Hiperco, Conpernik. A vast body of problems generally having to do with the properties of materials comprise the province of the Mechanics Department. These include studies of shock, vibration, fatigue, photoelastic strain analysis, the phenomena of combustion, and the behavior of bearings. The study of erosion of turbine-blade metals by moisture and the development of high-temperature alloys are representative of Metallurgy Department activities. The Physics Department has, for example, developed various commercial forms of semi-conductors and is continuing the study of their underlying phenomenon.

It was not until 1916 that the main research laboratory was separated physically from the East Pittsburgh manufacturing plant. This was to a new building, now well known, prominently located on a bluff a mile distant. Additions have been made to this building itself and numerous other special-purpose laboratories have since been erected around it. These include the nuclear-physics laboratory (atom smasher), the electronics laboratory, and the combustion laboratory.

Physically this is but the main Westinghouse Research Laboratory. There are numerous others—the number depending on what boundaries are placed on the word research. Lamp research has, since 1917, been conducted in a laboratory at the main Lamp Division plant at Bloomfield, New Jersey. There are three separate high-power and high-voltage laboratories where much fundamental work on arc phenomenon and interruption has been and is being conducted. In numerous other laboratories—at least two score—investigations are conducted on materials, processes, products the nature of which falls somewhere between a strict definition of research and product development.

And that brings us to an important point. What constitutes research? The "ivory tower" concept popularly held is correct in part, but only in part. It is less than half of modern research work. The research work done today is so varied in character with some kinds shading into others—that it is difficult to draw hard and fast classifications. At first, probably, the research staff was concerned simply with acquisition of knowledge necessary for the solution of problems of the moment or for making possible improvements in the product. Much of it was the "get-out-of-trouble" type, which, I may say, will always be with us. A fine example of it is given by Dr. C. E. Skinner, first Manager of Westinghouse Research, who wrote as follows in 1908:

"When transformer units of larger size were needed, cooling by radiation from the case became impractical, and water-cooling coils were introduced into the case. Trouble resulted, due to deposits from the oil settling on the cooling tubes, and, as these deposits were heat insulators, the efficiency of the cooling system became impaired. An investigation was required to determine the cause and prevention of these deposits. On account of the very complicated chemical structure of mineral oil, the investigation proved to be difficult both as to determining the cause and finding a cure for the trouble. After making hundreds of tests on many kinds of oil, it was possible to eliminate the effect of the electrostatic field, the effect of the combination of the oil with other insulating materials and metals used, and many other features which it was thought might be responsible, and to resolve the problem into one of the simple effect of temperature. Oil chemists and others consulted did not think it possible that deposits of this class in sufficient quantity to cause difficulty could result at a temperature not exceeding 80 degrees C, but such has proved to be a fact. When this was proved, it became necessary to make further investigation to determine what oils, if any, would be free from this effect, and, after another series of tests, a material was found which met all practical conditions of service."

The research engineer will always be required to back stop the designer or process engineer, helping solve unanticipated difficulties. A given design may for years be completely successful. Then, with no warning, field troubles with new editions of that design may crop up. Why? Perhaps the size or rating may have crept up until—unsuspectedly—a point is reached when some principle involved no longer holds. Or because of a seemingly unimportant load change a material normally adequate is no longer satisfactory. Or a minute and unrealized change by the supplier of a material may have introduced a new characteristic or weakness in the material. Or some new factor may have crept into the process that possessed a detrimental effect all out of proportion to its apparent importance.

An example of this type of research is given by an experience of some years ago with gears in an electric locomotive. The gears, which were supplied with the locomotive, were designed in accordance with the best information available at that time. However, in service these gears failed rapidly. A research project was started immediately which, in a short time, disclosed the reasons why the gears were failing, and also produced the new knowledge about gears from which satisfactory units were designed.

Then a second great body of research effort has to do with improving materials or processes. It is desired to enable a given material to do more. It is not a trouble-removal problem but the natural consequence of design competition forever calling for pushing back present limits.

The research and development work on the dielectric material in a capacitor is an excellent example of this kind of effort. The characteristics of the dielectric material with respect to power factor, voltage breakdown and so forth, determine the performance of a capacitor for power-factor correction. The program of research and development on this material has resulted in a gradual, steady improvement in the characteristics of the dielectric. These have been incorporated from time to time with resulting improvements in the performance of capacitors of the power-factor correction type. As a result of the work, today's capacitors, for a given kilovolt ampere rating, have one-third of the power loss, one-tenth of the volume, and one-seventh the cost of a unit of the same rating built twenty-five years ago.

High-temperature metals are born of this class of research. The program has been aimed at developing metals that endure higher and higher temperatures without serious loss of strength and without displaying undue tendency to creep, i.e., slowly distort with time, load, and temperature. This work, originally prompted by the need for superior steam-turbine materials, has been heightened enormously by the jet-propulsion and gas-turbine activity of the last decade. It has resulted in numerous new high-temperature metals, of which K-42-B, Refractaloy, and Discaloy are examples.

The third job of industrial research is to develop new knowledge and to discover new principles. To do, in other words, the sort of thing that Oersted, Ampere, and Faraday did from which the whole industry came. All of the great new industries which contribute so much to our present standard of living have been based on research work that preceded the development of the industry. What new industries will come in the future, no one can promise, but one can say that whatever they are, they will result from research work being done today. This work is being done in many places under many different agencies; in industry, in the universities and colleges, and in government laboratories.

Research programs of the future will undoubtedly be governed by the course of present events. What new principles will be discovered, what new materials will be developed, what new processes will be devised obviously no one can name. If they could there would be no need for research. Ours is still a new industry but its rate of growth is such that it is rapidly reaching maturity. Certain phases of our industry show this maturity already. For example, present-day transformers leave little to be desired in many aspects of their performance. Their efficiency is nearing the ultimate, their reliability is excellent and their maintenance requirements are small. Thus one may expect the improvements in this type of apparatus to come in relatively small increments. On the other hand, other phases of our industry are still lusty infants with consequent need for attention. They still are characterized by relatively rapid growth in a short span of years. Electronics, as we know it, is scarcely 30 years old and is still developing at a rapid rate. The last decade has been extremely fruitful, witnessing as it has the advent of radar and television on large scales. Clearly, in this field one may yet expect great improvements and dramatic new products, even new industries, as a result of research programs.

An illustration or two will show the kind of thing currently in progress. Work in the atom-smasher continues. Originally —ten years ago when the Van de Graaff generator was first erected at the Research Laboratories—the task was to shoot high-speed particles at other particles and observe what happened. The study was purely exploratory. The work was in an unknown field. No one knew just what the character of the findings would be or what use could be made of them. As it turned out valuable new knowledge did accrue. Here was measured the ability of a uranium atom to capture or absorb a moving neutron (technically known as cross-section) resulting in fission. This was one of the basic facts employed in designing the first atomic reactor, the famous one at Chicago that established history in December, 1942.

The work of the atom smasher today is gradually changing in character. While work of an exploratory nature continues to occupy the major part of the program, there is now becoming evident the need for refinement in some of the data collected earlier by the use of this and other machines. Therefore, a small but growing portion of the use of the atom smasher is devoted to obtaining more accurate information on previously observed nuclear constants, i.e., improving the figures to the right of the decimal point. There is much of this not-so-glamorous but absolutely essential work to be done before the atom can be harnessed for power production.

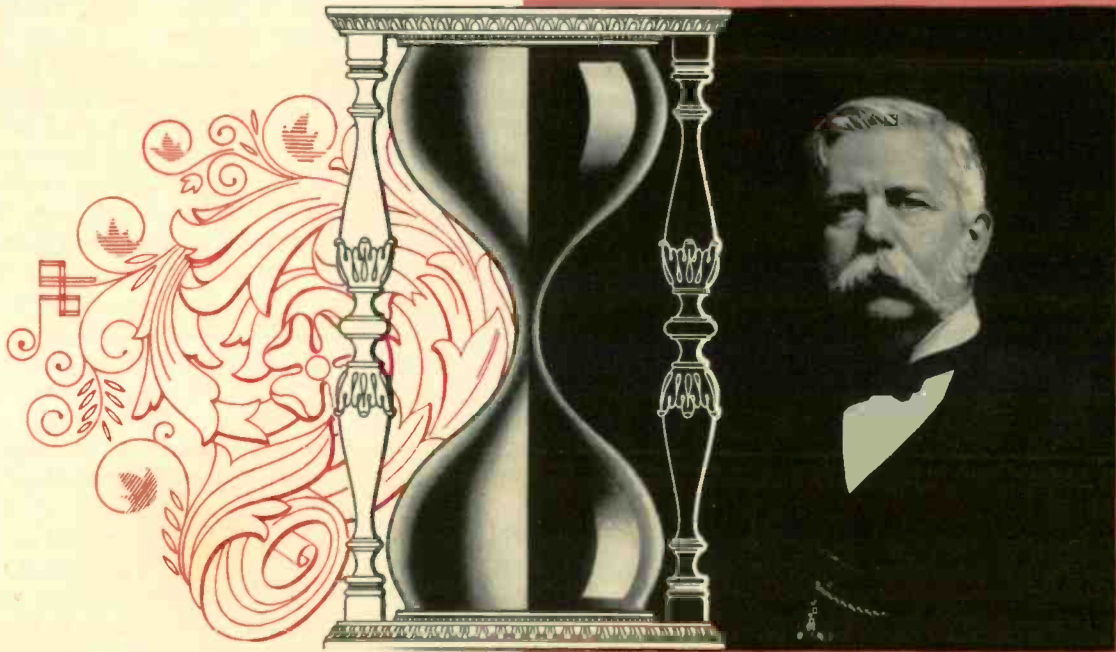
Another fundamental research, not so far along, is the study of the behavior of solids at low temperatures, called cryogenics. That electrical resistance virtually disappears as absolute zero is reached has long been known. Just why or how much or the factors affecting it are not known. What the studies will show or what practical use can be made of them no one can say. But this matter of electrical resistance of materials is too important not to do everything possible to cut

Westinghouse Men of Science and Engineering

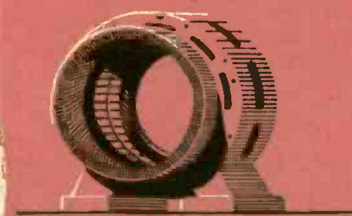
Editor's Note: This is a selection of a few Westinghouse men who have played an outstanding part in the development of the electrical industry. It is purposely confined to those whose contributions have been technical rather than managerial. Also it is limited to those active between 1900 and 1950, and whose work is concluded within that period. True evaluation of men's efforts in any field requires the perspective of time. When the account of Westinghouse in the second half of the 20th century is written, the names of many men now active will properly find places in any enumeration of the greats.

The dates and the white panels apply to the periods of active service at Westinghouse.

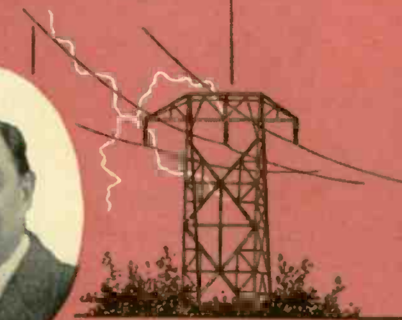
1880 1890 1900 1910 1920 1930 1940 1950



GEORGE WESTINGHOUSE
1869-1914

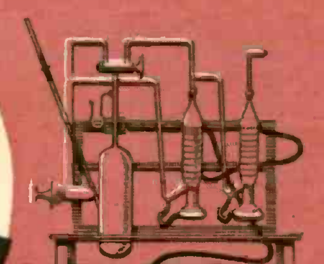



B. G. LAMME
1889-1924
Calculation and rational design of DC and AC motors and generators—Rotary converters—Training of young engineers.

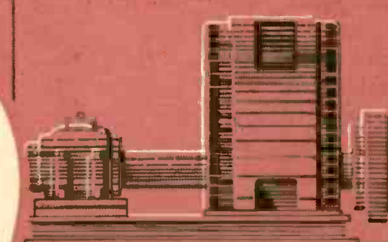



C. L. FORTESCUE
1898-1936
Insulation theory—Condenser bushing—Symmetrical components—Theory of lightning behavior and protection.

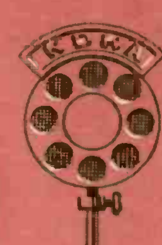

FRANCIS HODGKINSON
1896-1936
Steam turbines.

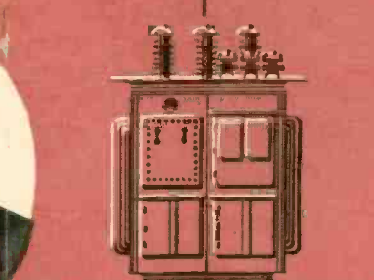
H. C. RENTSCHLER
1917-1948
Rare and common metals for lamps and electronic tubes—Gaseous discharge phenomena—Ultraviolet radiation phenomena and measurement.

C. F. SCOTT
1888-1914
Induction motors—Transformers—AC system

FRANK CONRAD
1890-1941
Meters and instruments—Motor control—Long and short-wave radio.

H. V. PUTMAN
1925-1946
Synchronous motors—Transformers—Electric torpedo.

C. E. SKINNER *Transformers—Insulation—Pioneer of electrical research.*

H. P. DAVIS *Measuring instruments—Circuit breakers—Arc lamps—Motor controls—Railway apparatus—Radio broadcasting.*

N. W. STORER *Railroad electrification apparatus and systems.*

WILLIAM BRADSHAW *Watthour meters and measuring instruments.*

R. E. GILMAN *Design of high-voltage conductors for turbogenerator—Eddy-current calculation.*

F. C. HANKER *Generation, transmission, and distribution of power for railways—Central-station application engineering.*

A. M. DUDLEY *Induction motors—Engineer training.*

R. E. HELLMUND *DC and AC motor theory and design—Motor control.*

L. W. CHUBB *Radio—Research in electricity, light, physics, and chemistry.*

C. W. DRAKE *Electrification of paper, textile, and similar industries.*

J. F. PETERS *Klydonograph—Bushing potential devices—Transformers and reactors—Control for ordnance.*

H. A. TRAVERS *Relays—Switchboards—Calculating boards—Protection devices.*

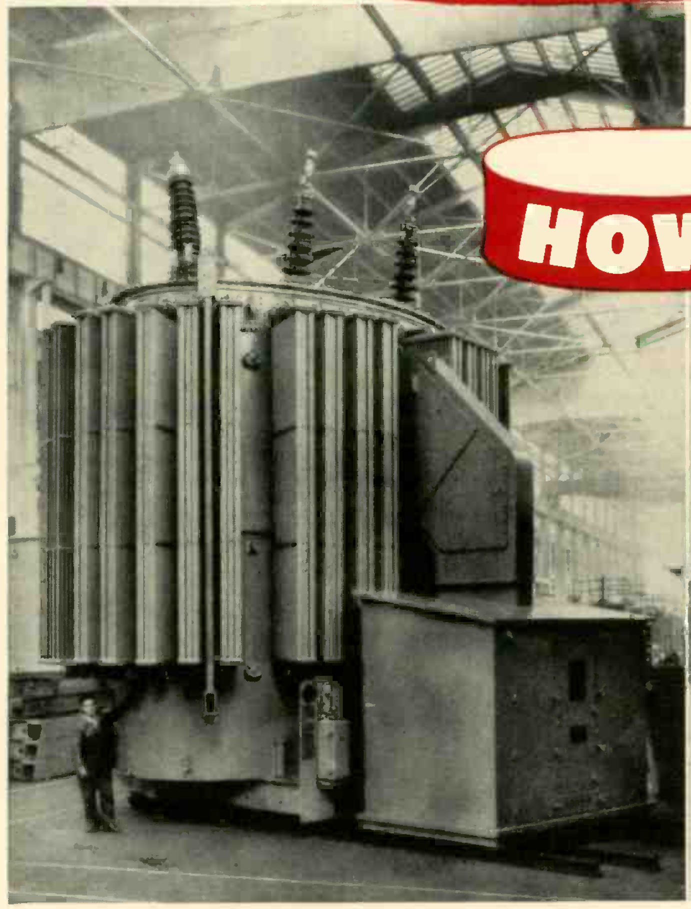
H. F. SCHMIDT *Steam-turbine governors—Pumps and blowers.*

R. D. HALL *Tungsten filament—Molybdenum processing.*

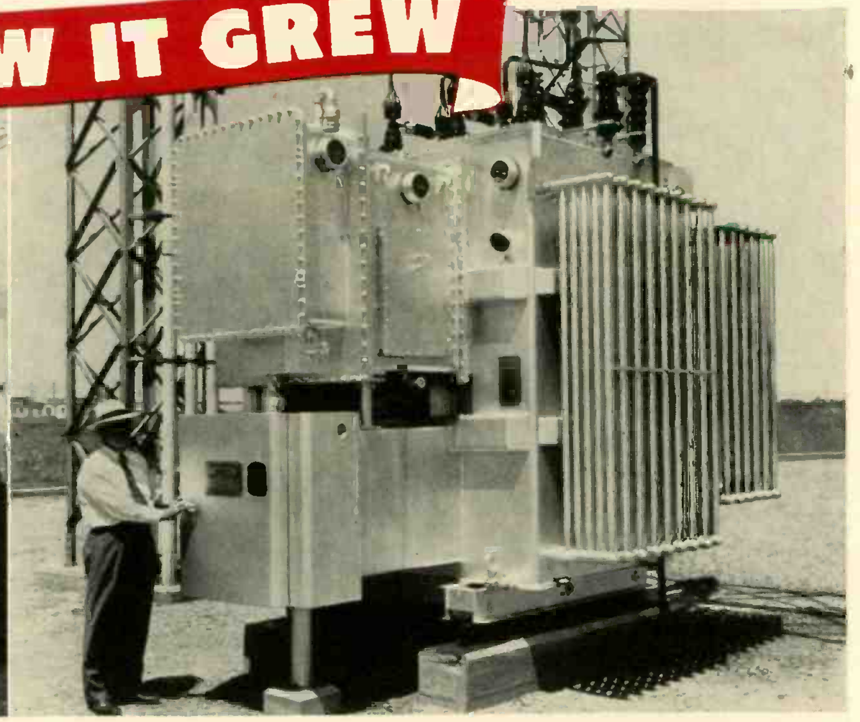
W. SYKES *Steel mill, mine and marine electrification.*

R. D. EVANS *Interference coordination—High-voltage transmission—System stability—Application and development of symmetrical components to AC transmission.*

THE TRANSFORMER AND HOW IT GREW



A 1928 transformer equipped for changing taps under load.



A modern, three-phase, 10 000-kva load-regulating transformer.

As we crossed into the twentieth century an observer of the infant electrical industry might well have concluded that the transformer had already reached such an advanced state of development that only relatively minor, detail improvements lay before it.

The transformer had developed with great swiftness. Only 15 years had passed since George Westinghouse had brought the idea of the alternating-current transformer from Europe. Arrangements had been made with Gaulard and Gibbs of England for the American rights for their "inductorium," although it was known that Zipenowski, Deri, and Blathy of Hungary had also worked on such a device. But in the decade and a half since 1886, William Stanley, a Westinghouse engineer had made of the "secondary generator" a practical device, employing the all-essential parallel connection instead of series. Stanley's experimental installation at Great Barrington, Massachusetts, which had proved the practicality of the a-c distribution system, was history. It had been followed in November, 1886, by the first commercial plant at Buffalo and within a month, one at Greensburg, Pa. By 1890 Westinghouse had equipped 300 a-c central stations.

By 1900 a transformer was no longer rated in terms of the number of 16-candlepower lamps it could supply; it was now identified in kilowatts. Transformers had reached sizable capacities; 2000 kw had been surpassed. The milestone voltage of 50 000 had been passed. Why want much higher voltages? Efficiency was already high, hovering about 98 percent, which, by comparison with efficiencies accustomed for other apparatus, seemed to offer small hope for significant betterment. Transformer theory and methods of design involving use of iron-loss curves, and formulas for reactance and regulation had been quite well understood since about 1893. The transformer had no moving parts; it required little attention; it promised to have long life. In brief, the transformer had grown up. How could one expect much more of it?

That same hypothetical observer, standing at today's vantage point—50 years later—finds that much has happened. Maximum operating voltages have been increased about sevenfold; maximum capacities by 70 times, weights per kva have been reduced to one seventh. Reliability has been immeasurably improved. Even efficiencies have been bettered; a new transformer has less than half the power loss of its ancestor of 1900.

All this has come about without fundamental change in transformer principle but in numerous betterments in iron, insulation, tank construction, cooling, protective systems, and the many other things that go to make up a transformer. Each has had an interesting evolution—in fact the transition from yesteryear to today can best be observed by tracing the more important of those separate but interrelated evolutions.

The Heart of the Transformer: Core Material

Nothing displays the remarkably steady progress in transformer development better than the material for the magnetic circuit. Also none is more important, for each improvement in transformer iron is compounded. Ability to operate at higher inductions for a given loss means a reduction in core section. This directly means a saving in steel. Because the core section is smaller the turns of copper to surround it are shorter—hence less copper, which likewise means less weight of insulation, and less copper loss. The total assembly becomes smaller so that less oil is required to insulate it, and the tank to

down the toll of energy our electrical highways make for passage of current.

Minute quantities of impurities in a material such as copper, for example, ordinarily produce no observable change on the electrical resistance of the copper when measured at normal room temperatures. However, when the measurement is made at very low temperatures, impurities may have a profound effect on the electrical resistance. Consequently, through studies performed at low temperatures the presence of impurities may be detected. In turn, it is believed that impurities in copper determine to a large extent the performance of a semiconductor made from the copper. Thus, through studies at very low temperatures it may be possible to learn more about the phenomenon of semi-conduction.

But this is not all. There are many relationships at the basic science level that are not always apparent even to the trained engineer. The principle on which the igniter in the ignitron rectifier operates is that of semi-conduction. While the ignitron has been a highly successful device, it is probable that it stands to be significantly bettered if the mechanism of semi-conduction is determined. And the same holds true in a seemingly quite different field—the fluorescent lamp. The principle of semi-conduction is involved in the behavior of the phosphor that converts energy from the wavelengths developed in the mercury spectrum to those in the visible regions. Thus the work of those probing the basic nature of semi-conductors, when it comes to fruit, will benefit many diverse fields of practical engineering.

A somewhat similar situation exists in the field of conduction in gases. Many highly successful devices depend for their functioning on the effects of current in a gas. The mercury-arc rectifier, circuit breaker, fluorescent and mercury-vapor lamp, many electronic tubes, even commutation are dependent on this phenomenon. Yet it is imperfectly known. This in spite of the fact that much research has been done in that direction. Efforts to resolve the remaining mysteries in this field are being redoubled and can be counted on to be highly fruitful.

While the Research Laboratories have already provided much information that has been basic to the present success of the gas turbine and jet propulsion much more can be expected. This is true not only in the way of high-temperature materials but also in knowledge about combustion.

The work of research is like a cone resting on its apex. Each new discovery opens up other things that cry for investigation. And as each is developed to commercial form it in turns poses its new problems for study. Thus, while research emphasis changes with time and in accordance with industry changes, we can count that research now in progress and to be done tomorrow will be productive of new technology, new industries, and a better control by man over his environment.

J. A. HUTCHESON

The particular star to which John A. Hutcheson fastened his aspirations as a minister's son in North Dakota was none of the usual occupations such as locomotive engineer or policeman, but a maker of wireless sets. He proceeded to do something about it too. His dad had given him a one-volume encyclopedia on practical mechanics, which contained pictures showing how to make a wireless set. That was for him. It must have been a good book because he followed the pictures, and the contraption worked. That was in 1913 and wireless sets were pretty crude. Hutcheson was then eight years old.

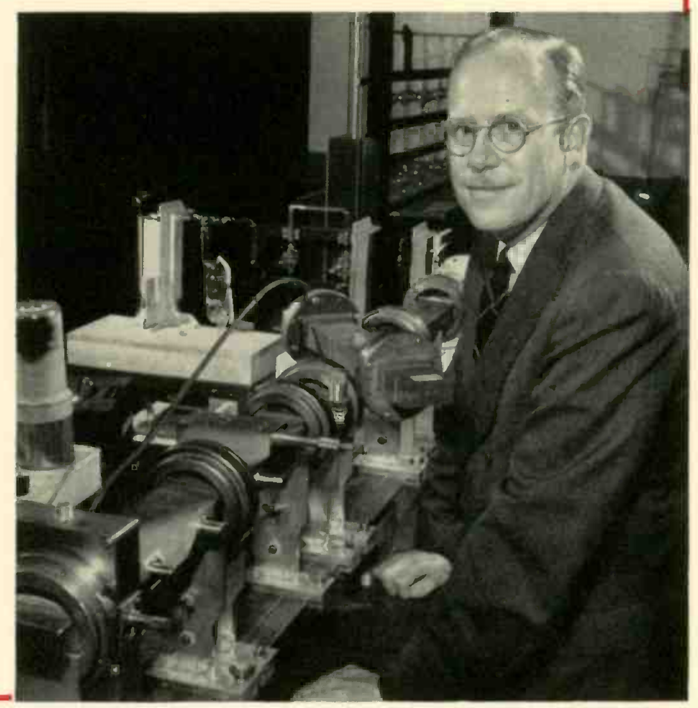
By the time he was 16, he was in the radio business for himself, as repairman and manufacturer. Sometimes he made as much as $200 a month. Good thing, too—because that was what paid most of his way through electrical engineering at the University of North Dakota. He finished there in 1926 and came directly to Westinghouse on the student course. His first position was given him by Dr. Chubb, then Manager of Radio Engineering, who, curiously enough, was the same gentleman from whom Hutcheson 23 years later took over the reins of the main Westinghouse Research Laboratory, although their paths had separated widely in the meantime.

It was at this point that Hutcheson finally got his chance to build radio sets in a big way. He followed the radio department in its moves from East Pittsburgh to Springfield, Massachusetts, to nearby Chicopee Falls, and finally in 1938 to Baltimore. He was involved in design of radio telephone and broadcast transmitters for the Navy and for commercial stations. One of his biggest jobs was designing the modulation system for the 500-kv transmitter for WLW in Cincinnati.

In 1940 he was picked to be manager of the Radio Engineering Department, which, under advance effect of the approaching war, was swelling to some five times prewar size. Because of outstanding work in building his staff and turning out radio and radar equipments for military services, he was chosen in 1943 to understudy Dr. Chubb, Director of the Research Laboratory, in anticipation of his retirement last year. This work has involved not only helping re-establish the Research Laboratory to a peacetime basis, but a great amount of personal activity in the atomic-energy field before the days of Hiroshima and since.

While these later years have led Hutcheson away from his first love, radio, his enthusiasm for it has not dimmed. When we asked about this he replied:

"My spare time? . . . Well, I've got some ideas of my own about television. Someday I am going to collect enough spare time to build my own set."



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J. A. HUTCHESON

The particular star to which John A. Hutcheson fastened his aspirations as a minister's son in North Dakota was none of the usual occupations such as locomotive engineer or policeman, but a maker of wireless sets. He proceeded to do something about it too. His dad had given him a one-volume encyclopedia on practical mechanics, which contained pictures showing how to make a wireless set. That was for him. It must have been a good book because he followed the pictures, and the contraption worked. That was in 1913 and wireless sets were pretty crude. Hutcheson was then eight years old.

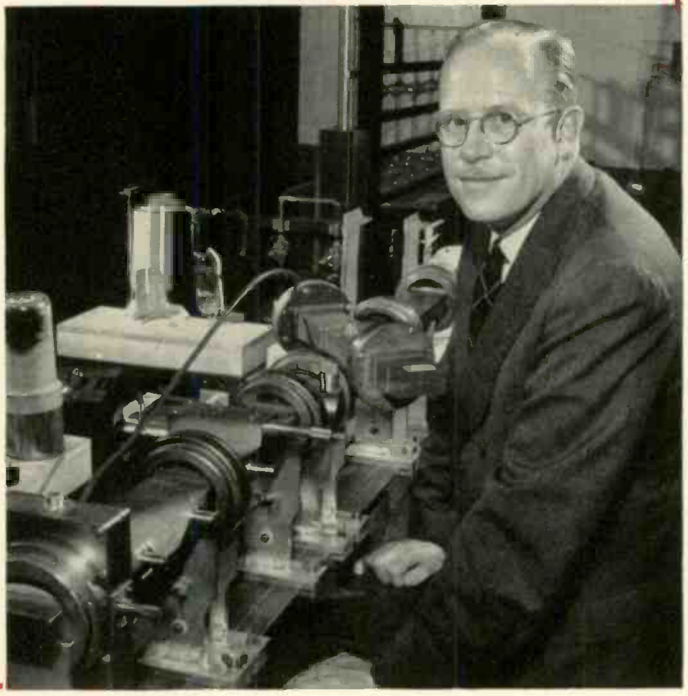
By the time he was 16, he was in the radio business for himself, as repairman and manufacturer. Sometimes he made as much as $200 a month. Good thing, too—because that was what paid most of his way through electrical engineering at the University of North Dakota. He finished there in 1926 and came directly to Westinghouse on the student course. His first position was given him by Dr. Chubb, then Manager of Radio Engineering, who, curiously enough, was the same gentleman from whom Hutcheson 23 years later took over the reins of the main Westinghouse Research Laboratory, although their paths had separated widely in the meantime.

It was at this point that Hutcheson finally got his chance to build radio sets in a big way. He followed the radio department in its moves from East Pittsburgh to Springfield, Massachusetts, to nearby Chicopee Falls, and finally in 1938 to Baltimore. He was involved in design of radio telephone and broadcast transmitters for the Navy and for commercial stations. One of his biggest jobs was designing the modulation system for the 500-kv transmitter for WLW in Cincinnati.

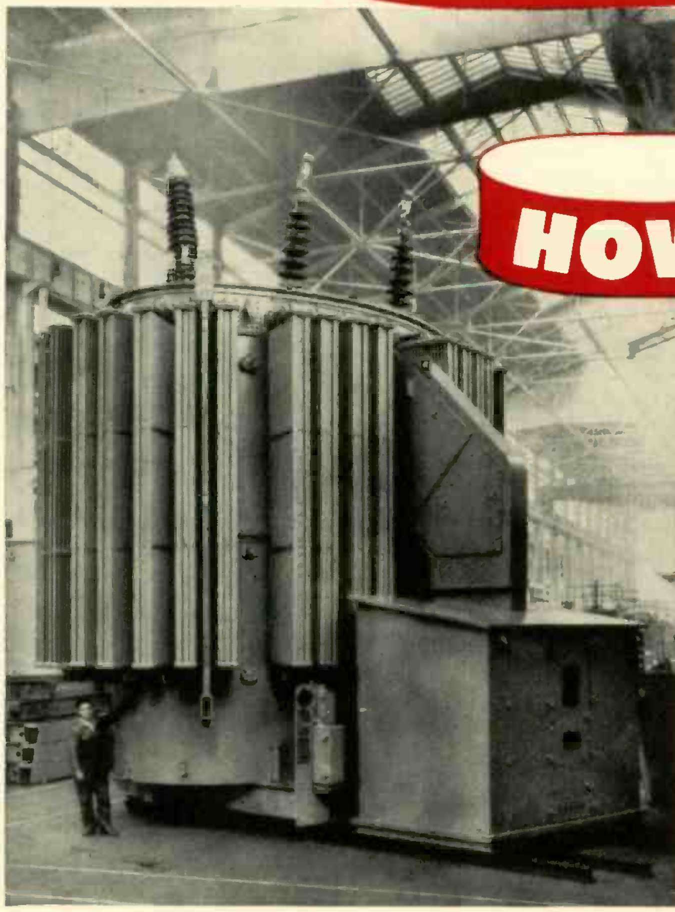
In 1940 he was picked to be manager of the Radio Engineering Department, which, under advance effect of the approaching war, was swelling to some five times prewar size. Because of outstanding work in building his staff and turning out radio and radar equipments for military services, he was chosen in 1943 to understudy Dr. Chubb, Director of the Research Laboratory, in anticipation of his retirement last year. This work has involved not only helping re-establish the Research Laboratory to a peacetime basis, but a great amount of personal activity in the atomic-energy field before the days of Hiroshima and since.

While these later years have led Hutcheson away from his first love, radio, his enthusiasm for it has not dimmed. When we asked about this he replied:

"My spare time? . . . Well, I've got some ideas of my own about television. Someday I am going to collect enough spare time to build my own set."



THE TRANSFORMER AND HOW IT GREW



A 1928 transformer equipped for changing taps under load.

A modern, three-phase, 10 000-kva load-regulating transformer.

As we crossed into the twentieth century an observer of the infant electrical industry might well have concluded that the transformer had already reached such an advanced state of development that only relatively minor, detail improvements lay before it.

The transformer had developed with great swiftness. Only 15 years had passed since George Westinghouse had brought the idea of the alternating-current transformer from Europe. Arrangements had been made with Gaulard and Gibbs of England for the American rights for their "inductorium," although it was known that Zipenowski, Deri, and Blathy of Hungary had also worked on such a device. But in the decade and a half since 1886, William Stanley, a Westinghouse engineer had made of the "secondary generator" a practical device, employing the all-essential parallel connection instead of series. Stanley's experimental installation at Great Barrington, Massachusetts, which had proved the practicality of the a-c distribution system, was history. It had been followed in November, 1886, by the first commercial plant at Buffalo and within a month, one at Greensburg, Pa. By 1890 Westinghouse had equipped 300 a-c central stations.

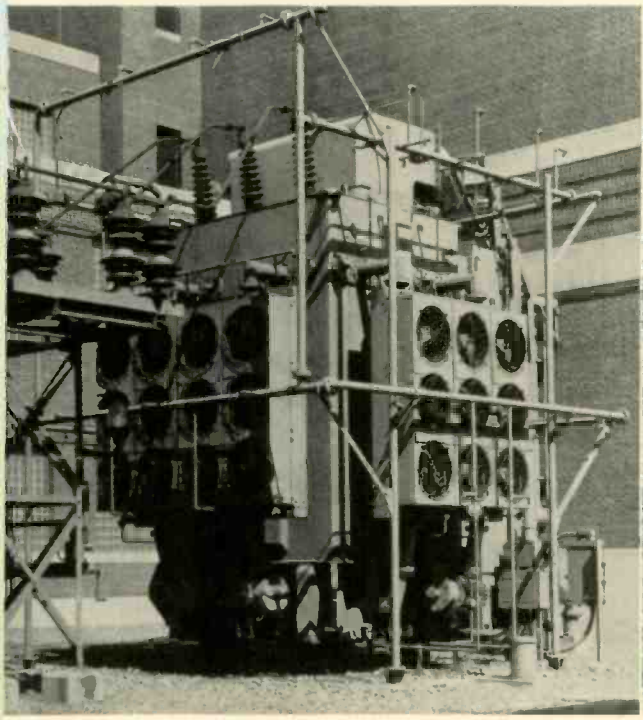
By 1900 a transformer was no longer rated in terms of the number of 16-candlepower lamps it could supply; it was now identified in kilowatts. Transformers had reached sizable capacities; 2000 kw had been surpassed. The milestone voltage of 50 000 had been passed. Why want much higher voltages? Efficiency was already high, hovering about 98 percent, which, by comparison with efficiencies accustomed for other apparatus, seemed to offer small hope for significant betterment. Transformer theory and methods of design involving use of iron-loss curves, and formulas for reactance and regulation had been quite well understood since about 1893. The transformer had no moving parts; it required little attention; it promised to have long life. In brief, the transformer had grown up. How could one expect much more of it?

That same hypothetical observer, standing at today's vantage point—50 years later—finds that much has happened. Maximum operating voltages have been increased about sevenfold; maximum capacities by 70 times, weights per kva have been reduced to one seventh. Reliability has been immeasurably improved. Even efficiencies have been bettered; a new transformer has less than half the power loss of its ancestor of 1900.

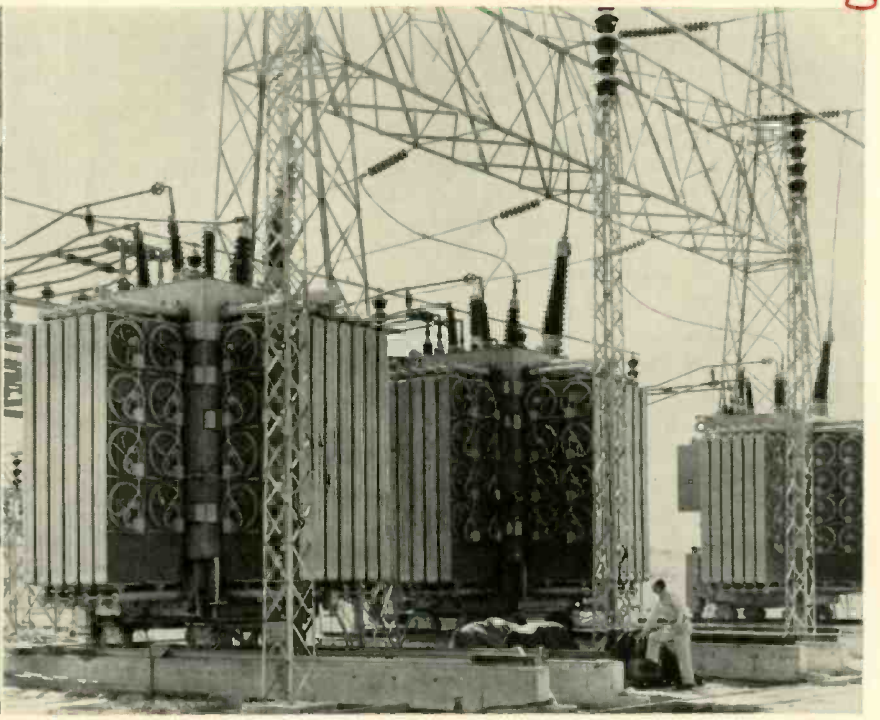
All this has come about without fundamental change in transformer principle but in numerous betterments in iron, insulation, tank construction, cooling, protective systems, and the many other things that go to make up a transformer. Each has had an interesting evolution—in fact the transition from yesteryear to today can best be observed by tracing the more important of those separate but interrelated evolutions.

The Heart of the Transformer: Core Material

Nothing displays the remarkably steady progress in transformer development better than the material for the magnetic circuit. Also none is more important, for each improvement in transformer iron is compounded. Ability to operate at higher inductions for a given loss means a reduction in core section. This directly means a saving in steel. Because the core section is smaller the turns of copper to surround it are shorter—hence less copper, which likewise means less weight of insulation, and less copper loss. The total assembly becomes smaller so that less oil is required to insulate it, and the tank to *by* **F. L. SNYDER**



A 105 000-kva, three-phase transformer installed in 1948.



Single-phase transformers rated 50 000, 62 500, and 83 333 kva.

contain the core and coil assembly and oil is also smaller.

The first transformer engineers used the only iron available, ordinary hot-rolled iron—"stove-pipe" iron. At one time even the thin steel plates used for photographic "tin types" were used, raising the price and creating a shortage that made the budding electrical industry unpopular with photographers. As the 19th century turned to the 20th, it became increasingly evident that a better magnetic material was needed. An alarming aging effect was occurring in which the losses rose considerably after transformers had been in service awhile, causing them to run excessively hot. Aging was serious; it cast a threatening shadow on the rapidly expanding a-c system.

The cause of "iron-aging" was a mystery, heightened by the fact that it was so much more pronounced with some batches of seemingly identical steel than others. One shipment of steel might display almost no tendency to age while the next aged if left in a warm furnace. The finger of suspicion was pointed at the rapid reversal of magnetization in service. This was thoroughly investigated as were different rates and combinations of heating and cooling. About 1895, aging of a given electrical steel was definitely proved to be solely a matter of operating temperature.

Not until 1904 did the steel companies provide an electrical steel based on an idea proposed by Hadfield of England in 1889, namely, that steel alloyed with silicon does not age. The addition of silicon completely licked the aging problem. Today silicon is an essential alloying ingredient of all power and distribution transformer cores.

Hot-rolled silicon-steel sheet was in other ways a great improvement to previous iron. Transformer core losses were reduced by half in two years after its introduction. For the next three decades hot-rolled silicon iron remained the core material used by all manufacturers. In this interval it was much improved as steel companies strengthened their quality-control methods, devised better rolling techniques, and learned more about heat treatments. The hot-rolled silicon iron of 1931 had only about one fourth of the loss of that same alloy produced in 1904.

But by 1930, improvement in transformer iron was coming at a declining rate. The possibilities of betterment in silicon-iron obviously were being exhausted. Some fundamental change was called for if progress in magnetic material was to continue upward. Westinghouse and Armco Steel Corporation undertook development of a new type of silicon steel in which permeability and core loss were simultaneously improved, so that the steel could be worked at still higher densities without increasing the exciting current.

The result of that long research was Hipersil. This is a silicon-iron alloy and as such possesses permanent non-aging characteristics. It differs from ordinary silicon steel not so much in what is in it but how it is made. One resulting difference, however, is of great significance. Its structure is such that the individual magnetic crystals are "oriented," that is, lined up with their cube edges parallel to each other and to the direction of rolling, like bricks in a wall. This is in contrast to the pattern incidental to ordinary silicon steel. Research long ago disclosed that silicon steel is more easily magnetized if the crystal cubes are oriented in the direction of magnetization, and that more flux can be carried by the steel with the same magnetizing force than if these crystals are haphazardly placed. This means simply that the knee of the magnetization curve is lifted to a higher flux density. Thus induction was given an immediate lift of about 30 percent at magnetizations normally used in a transformer.

Upon its appearance, Hipersil, like its predecessor, began its career of improvement. Again, by better rolling practices, by closer control of the alloying agents and "impurities," and by more effective heat treatments, present-day Hipersil permits an aggregate of almost 40-percent increase in working inductions for transformers.

Many improvements in the production of Hipersil have been aimed at obtaining a more perfect orientation of the grain structure. Periodically Armco and Westinghouse research engineers provide an improved Hipersil that can be operated at higher induction for the same loss. Designs can then be based on that new level until further improvement accumulates to an amount that makes redesign feasible.

Availability of the new material, Hipersil, was in itself a great achievement. Nevertheless it was only half the solution to the problem. Designers had to find how best to use it. Some new form of core was required if full advantage was to be taken of its favorable magnetic properties. The several years that followed the original availability illustrates the long period of design and manufacturing development that ordinarily lies between an original invention and commercial, quantity use.

In 1934 two small distribution transformers were built using a core made up of I-shape punchings arranged so the magnetic flux flows with the grain. These were successful but it was not until late 1938 that quantity production was undertaken (on a 100-kva rating) to gain manufacturing experience.

During this period attempts were made to develop cores using Hipersil and conventional hot-rolled silicon steel in combination because of the high cost of Hipersil. This proved impractical because of the difficulty of manufacturing the two materials to identical thicknesses. It was decided in 1939 that the only way to break the barrier of high cost was to employ Hipersil exclusively, which would permit the steel maker sufficient production to reduce the cost. This decision, coupled with the simultaneous development of ribbon-wound cores (type C) led, in 1940, to large quantity production of all ratings of distribution transformers, thus climaxing a ten-year period of development.

Form-fit construction, in which the case hugs core-and-coil assembly, saves space, weight, oil, and metal, and allows better cooling.

In parallel with improvement in the core material itself, progress has been made in methods of insulating the punchings from each other. Paper was used at one time—and still is by some European manufacturers. Engineers at Westinghouse early turned to synthetic enamels of the Bakelite type. Since the introduction of Hipersil a new coating was developed. It consists of a chemical change in the surface of the sheet applied during manufacture. This altered surface is able to withstand annealing temperatures and punching. It has the further merit of being thinner than enamel coatings. The space factor of a core with the new surface insulation is 97 percent, for enamel-insulated punchings it was 92 percent.

Insulation Development

Standing close to core material in importance is insulation. This importance was not always recognized, however. Attention of early designers was directed to the copper, iron, and other more substantial parts of the transformer. The choice of what kind and how much insulation to use and where to place it was left to the shop foreman. Not until 1895 did designers begin to specify the insulation, which shop people frankly considered usurpation of their duties.

For the most part, cotton-covered conductors were used in the early transformers. Strips of "fullerboard" (now called pressboard) were used between turns of rectangular conductors to reinforce the insulation. Other insulations were developed, including varnished-cambric tape, oil-soaked paper, and superior varnishes.

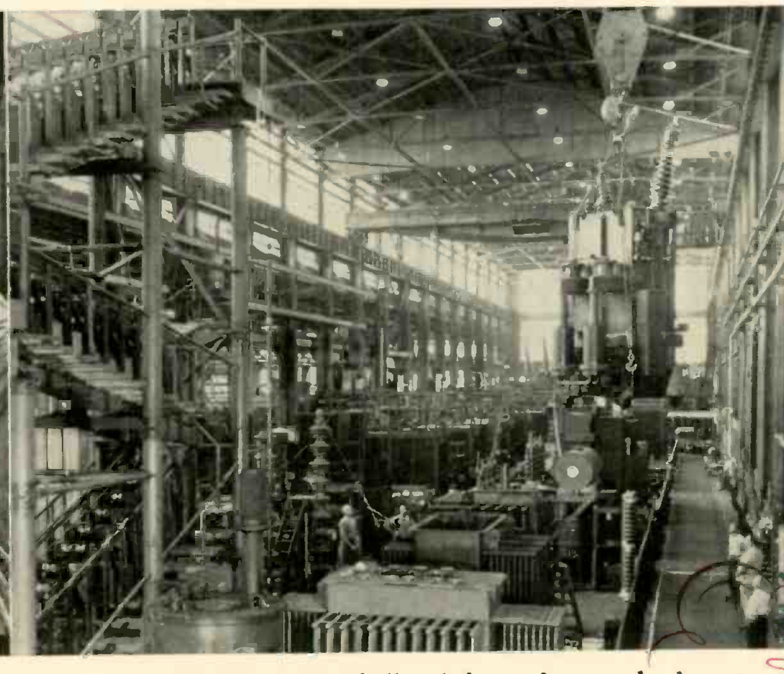
The improvement in transformer insulation generally kept pace with increasing voltages. To be sure, there were occasional failures resulting from lightning, but lightning was looked upon as an "act of God" phenomenon of such magnitude that any hope to insulate a transformer against it was idle. Experience taught that a transformer with the outer turns additionally insulated fared better than one that wasn't. A complete explanation of the greater vulnerability of end windings was given for the first time in 1902 in an association paper by P. H. Thomas, one of the transformer pioneers at Westinghouse.

Until the 20's, engineers could be forgiven for not attempting to build transformers to withstand lightning surges. They didn't know what to design for. The true nature of lightning was unknown. The magnitude and shapes of lightning-produced surge waves had not been recorded. The improvement in insulation strength made prior to 1920 consisted largely of strengthening the turn-to-turn insulation through the development of better paper-insulated conductors. Insulation was designed and proportioned chiefly with the aid of 60-cycle test data, much of which bore little relation to impulse strength.

This mystery as to what transformers had to deal with was not to be forever tolerated. With the data collected first by the klydonograph and later cathode-ray oscillographs, and other lightning traps (see p. 65), it became possible to analyze impulse-voltage stresses existing in transformer windings and to determine the proportions of insulation to meet them. Methods of accurately calculating voltage stresses in transformer windings were then evolved.

Simultaneously with the cathode-ray oscillograph came high-voltage surge generators, capable of testing complete transformers. With these two tools more fundamental data was obtained on the behavior of transformer windings and

An assembly-line surge test assures that the completely self protecting distribution transformer lives up to its name. Surge-voltage impulse testing began in 1934 and direct-stroke testing in 1939.



A 145 000-kva, forced-oil-cooled transformer—the largest ever built—hangs from a crane, while at the left is a portion of the surge generator for quality control testing of power transformers.

insulation in the laboratory in a few hours than was possible by field experience in as many years.

Startling facts of far-reaching importance were learned about the behavior of insulation in the presence of lightning. For example, insulating barriers were seen to be weak in creepage to impulse voltages by comparison with 60-cycle voltages. On the other hand, their puncture strength to impulses was high. This showed why insulating structures proportioned according to 60-cycle data proved inadequate for impulse voltages. Knowledge of the strengths and weaknesses of insulation enabled designers to marshall their forces better. Designs were redrafted to compel surges to go through insulating barriers, not around them. This permitted the total quantity of insulation to be decreased, yet attaining greatly increased impulse strength.

Corona was another problem. Even in the early days it was suspected that corona meant deterioration of insulation and incipient failure, but transformers were tested at three to four times their operating voltages. Corona might occur at test voltages but, as long as none could be detected under normal operation, the transformer was considered satisfactory. Not until impulse testing was developed was it realized fully that lightning voltages must be considered operating voltages and that there must be no corona, even during test. So doing avoids progressive deterioration of insulation even under surge conditions. The old suspicion, that insulation so designed would wear out with time, was definitely dispelled.

Another source of weakness was discovered—gas entrapped in the oil or absorbed by the insulation. Gas reduces the impulse strength of transformers, especially to steep-front voltages such as are encountered in direct strokes to lines adjacent to transformer substations and as are duplicated by front-of-wave testing in the laboratory.

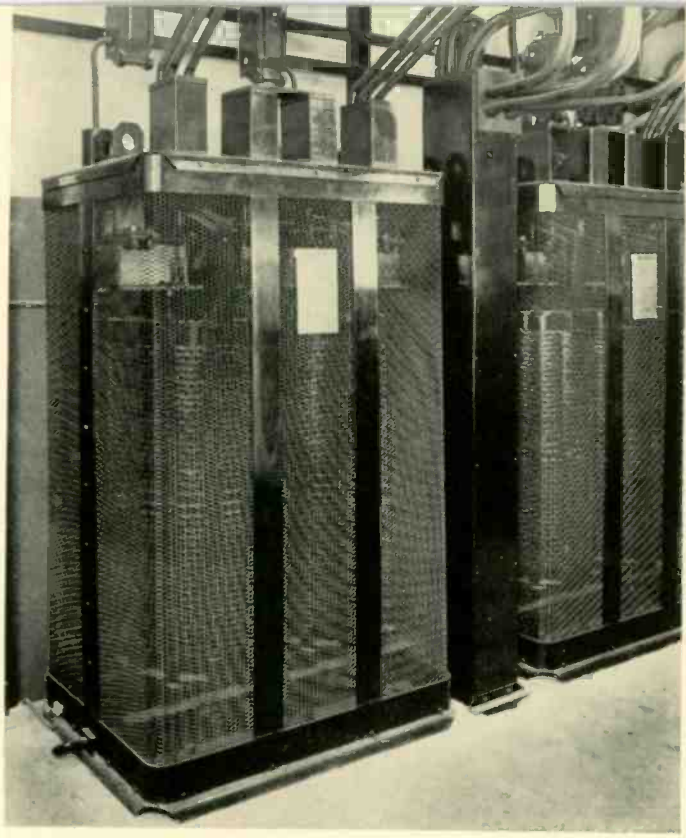
The weakness known, the remedy became clear. In 1932 Westinghouse introduced the practice of applying a high vacuum to assembled power and distribution transformers, first to remove the gas and then to keep it out during impregnation and filling with oil.

These are but some of the lessons taught by experiments with natural and artificial lightning. Because of them the impulse strength of transformer insulation has been doubled in the past two decades.

With knowledge came confidence. As the nature of lightning surges became clear, engineers no longer accepted failures caused by lightning as an inevitable effect of nature. They believed transformers could be made surge-proof. In fact they began deliberately to subject their equipments to simulated lightning strokes.

Initially, the surge generator was a tool used solely by the research and development engineer to devise a transformer design that was lightning-proof. It was not considered practical to surge test transformers produced commercially. However, as soon as transformer engineers developed new and better surge generators and new and better techniques for using these generators, a setup was made where transformers were surge tested when requested by the customer. At a still later date, surge testing was adopted as one of the very best methods of quality control, since no other test is as searching in uncovering insulation faults with both design and manufacture. Both ASA and NEMA have now established standards for surge testing transformers.

Inasmuch as distribution transformers have in general greater exposure to lightning than do power transformers, it was only natural that this new tool, that is, the surge generator, should be first used to develop a surge-proof distribution transformer. In accomplishing this objective the first step was to develop a reliable De-ion lightning arrester for use on distribution transformers and to make this arrester an integral part of the transformer. This development took care of protecting the high-voltage winding against lightning. There still remained the problem of protecting the low-voltage winding, and the insulation between the high- and low-voltage winding. The problem of protecting the low-voltage winding was solved by the use of coordinated low-voltage bushings, i.e., bushings that have lower insulation strength than the windings. The combination of the coordinated low-voltage bushings for the low-voltage winding, and the De-ion lightning arrester for the high-voltage winding, gave perfect



Early dry-type transformers were enclosed in steel mesh. These 500-kva units were installed in a retail store basement in 1939.

protection for the insulation between the high- and low-voltage winding. This combination was named three-point protection and, thus, came into existence the surge-proof distribution transformer.

Thermal Protection

The lightning problem solved, distribution-transformer engineers turned their attention to solving the next most serious problem related to distribution transformers, and that was protection against short circuits and overloads. The practice at the time was to fuse the transformer using elements with low enough rating that they would blow with a short circuit on the transformer secondary, and also to select a fuse rating high enough so that it would not blow when the transformer was carrying its normal load, but would blow with the transformer seriously overloaded. This was asking just too much of a fuse, and the problem could not be adequately solved in this fashion. Distribution transformer engineers solved the problem by replacing the fuse with a low-voltage thermal breaker and immersing the thermal breaker in the transformer oil. The heart of this breaker was a bimetal actuated tripping mechanism. The bimetal was so connected in the circuit that the secondary current flowed through the bimetal, which was designed to have a gradient approximately the same as that of the transformer winding. Since the bimetal was immersed in the transformer oil, the time-temperature characteristics of the breaker were the same as that for the transformer itself, resulting in almost perfect overload and short-circuit protection. The combination of the lightning protection principles and the short-circuit and overload protection built into a single transformer gave the transformer industry the famous CSP distribution transformer.

The first breaker used for this purpose was one developed for industrial circuits (AB). Soon, however, breakers were created especially for this duty—smaller, with larger capacity and with better thermal characteristics. Other refinements have also been added, such as a signal light to give visual warning of overload before the breaker opens the circuit.

The CSP transformer has been eminently successful, the outages being reduced in the ratio of ten to one by comparison with fused transformers. Approximately two fifths of all distribution transformers in the United States are built under these patents. The principle has been extended to cover the full range of sizes used in distribution systems.

The first thermal protection for power transformers consisted of a hot-spot indicator applied about 1923. By 1941 a special thermal relay (TRC) was developed that gave to power transformers the same operation by copper temperature the breakers had given pole-mounted distribution units. Such a thermal protective system, with improvements, continues to be a feature of all Westinghouse transformers.

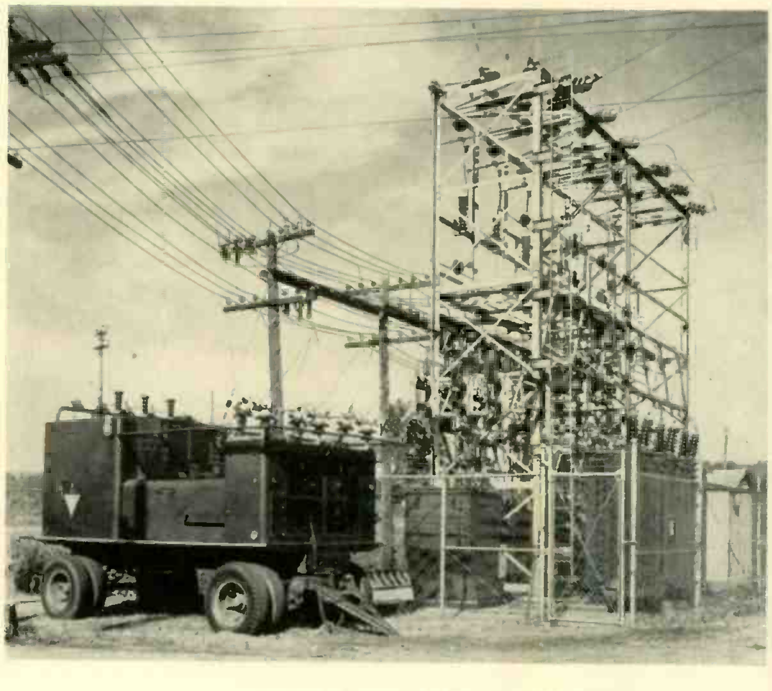
The Surrounding Medium

Those who superintended the beginnings of the transformer were fortunate in one respect. They had available a medium in which to immerse their units, which admirably served two essential functions—cooling and insulating. This was oil. A mineral oil, similar to kerosene, was first used because it was cheap. To be sure, sludging developed but oil companies soon produced for the infant electrical industry an oil less likely to sludge and with a higher flashpoint. The excellence of oil is indicated by its continuing extensive development and use—after 65 years—for this purpose.

Oil has survived many attempts to find a superior substitute liquid for electrical apparatus—the objective all the while being to avoid oil's outstanding weakness—inflammability. The closest approach to success are the members of the Askarel family, such as Inerteen, introduced in 1932. Numerous units so filled have been applied where the fire hazard is particularly objectionable, as in buildings and beneath streets.

While these fluids doubtless will continue to have use, in two decades they have not assumed a large portion of the business and are not likely to. This is largely because the Askarels themselves have some disadvantages, the principal ones being higher cost, toxicity, lower dielectric strength, and tendency to form acid in the presence of water.

In recent years mobile transformers have become an invaluable tool in emergencies, temporary loads, and substation servicing. This one is equivalent to all the equipment of the substation beside it.



Oil's only real competitor as an environment for the transformer mechanism has been air. And in this regard, air has been increasingly successful, particularly within the past dozen years.

Air-insulated transformers are not of recent origin. The Great Barrington "inductoriums" in 1886 were air insulated. In fact they did not even have tanks. Between 1908 and 1925 large numbers of air-insulated transformers were built. They were called New Yorkers because they were brought into existence by a New York City ordnance banning electrical apparatus containing oil. An interesting sidelight on this transformer is shown by a design change notice in the Sharon archives dated April 29, 1912, which reads, in part, as follows: "Arrange to have the holes in the upper casting screened so that rats will not be able to get inside of transformer."

Although many thousands of dry-type transformers with class-A insulation had been built, the real impetus did not come until 1936 when the present thriving family of dry-type transformers was introduced by Westinghouse with the construction of a 500-kva, 13-kv unit with essentially fireproof insulation. The demand for the air-cooled transformer came principally from the growth of the network system of distribution and the desire to place these transformers in buildings. The war, with many new plants and their general adoption of the network idea, and the savings in materials offered by dry-type units, hastened their acceptance. Also, concurrent with the need came new materials—principally glass insulations—that made the dry-type transformer fireproof.

Ratings of dry-type transformers have steadily increased. From the original 500 kva, they have grown to 3750 kva, 3 phase, and 2500 kva, 1 phase, self-cooled. Recently a 6000-kva self-cooled transformer (10 000-kva, forced-air-cooled) was built, which was comprised of three single-phase units. Dry-type transformers are built for voltages of 15 kv and less. The voltage rating is likely to increase when a gas with better dielectric strength is found or developments and economics make feasible the use of present available gases.

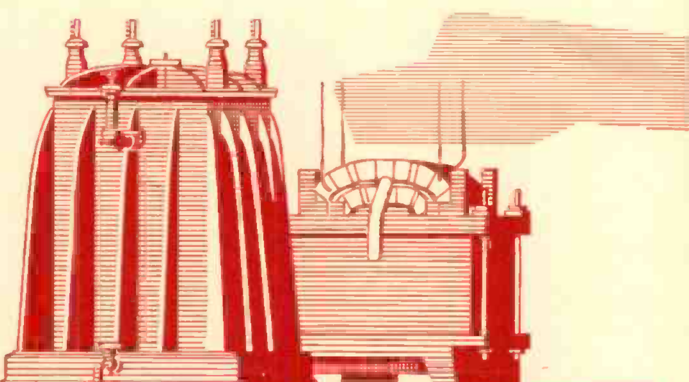
Oil Preservation

Although the tendency of the oils early used in transformers to sludge when hot was greatly reduced by the refiners, preservation of oil has always been a problem. The principal enemies are oxygen and water. Many ways have been devised to protect oil against both.

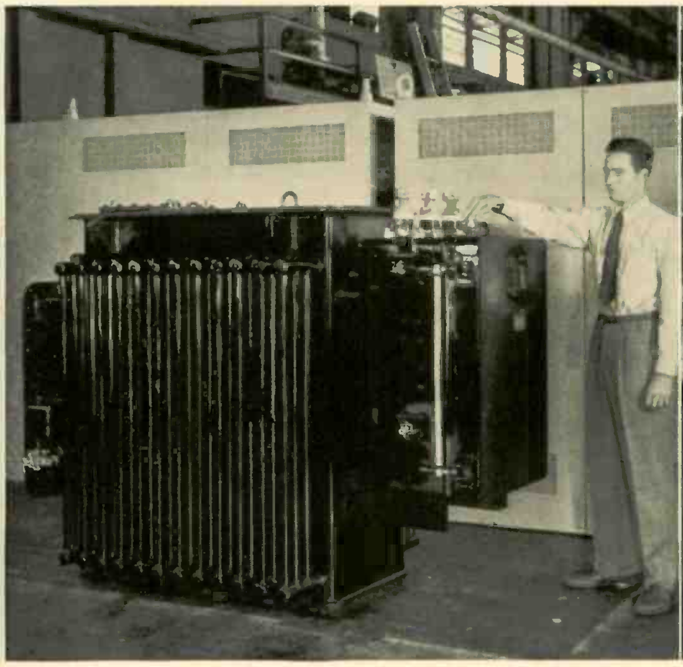
A bold and highly successful scheme was brought forward for power transformers in 1922 largely through the efforts of W. M. Dann. It was a direct approach to the problem. It was based on the premise that the best way to prevent deterioration of oil by oxygen and water is to keep them completely apart. In this system, the transformer is tightly sealed and made to do all its inbreathing through filters that absorb all oxygen and moisture. Thus oil as it heats and cools is exposed only to the inert components of the atmosphere, giving the system its name, Inertaire. This system has become a basic feature on Westinghouse power transformers, it being regularly employed on units larger than 2500 kva or above the 46 000-volt class.

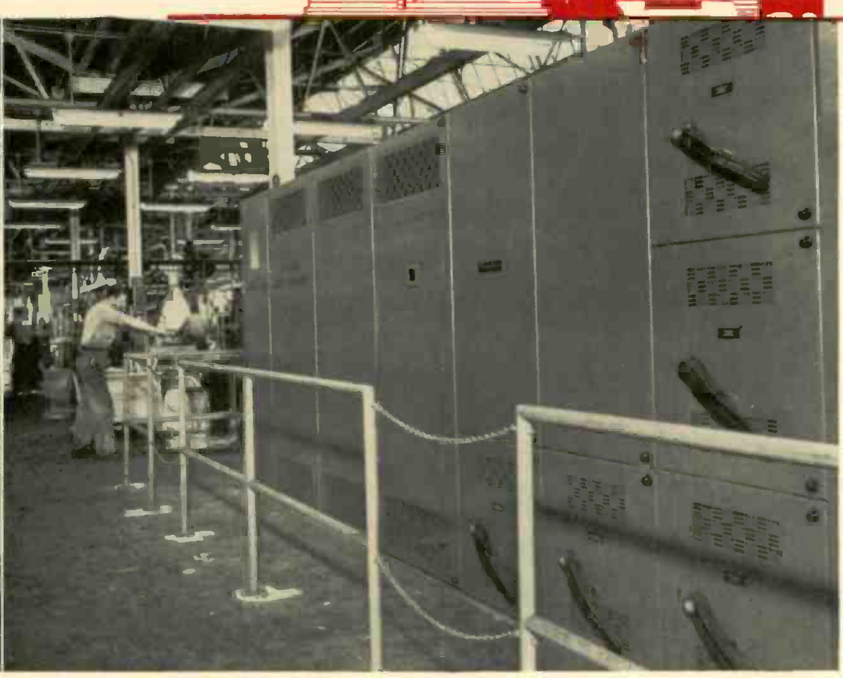
Another important measure to prevent oxygen and water contamination came in the middle 20's, when Westinghouse began shipping power transformers to distant points filled with dry nitrogen under slight pressure and sealed, the oil to be added at the site. Also, in 1932, those transformers oil-filled at Sharon were first subjected to vacuum to pull out entrapped and absorbed gases. This gave better impregnation of insulation by the oil, increasing the dielectric strength, and reducing the oxygen left to join with the oil when the unit

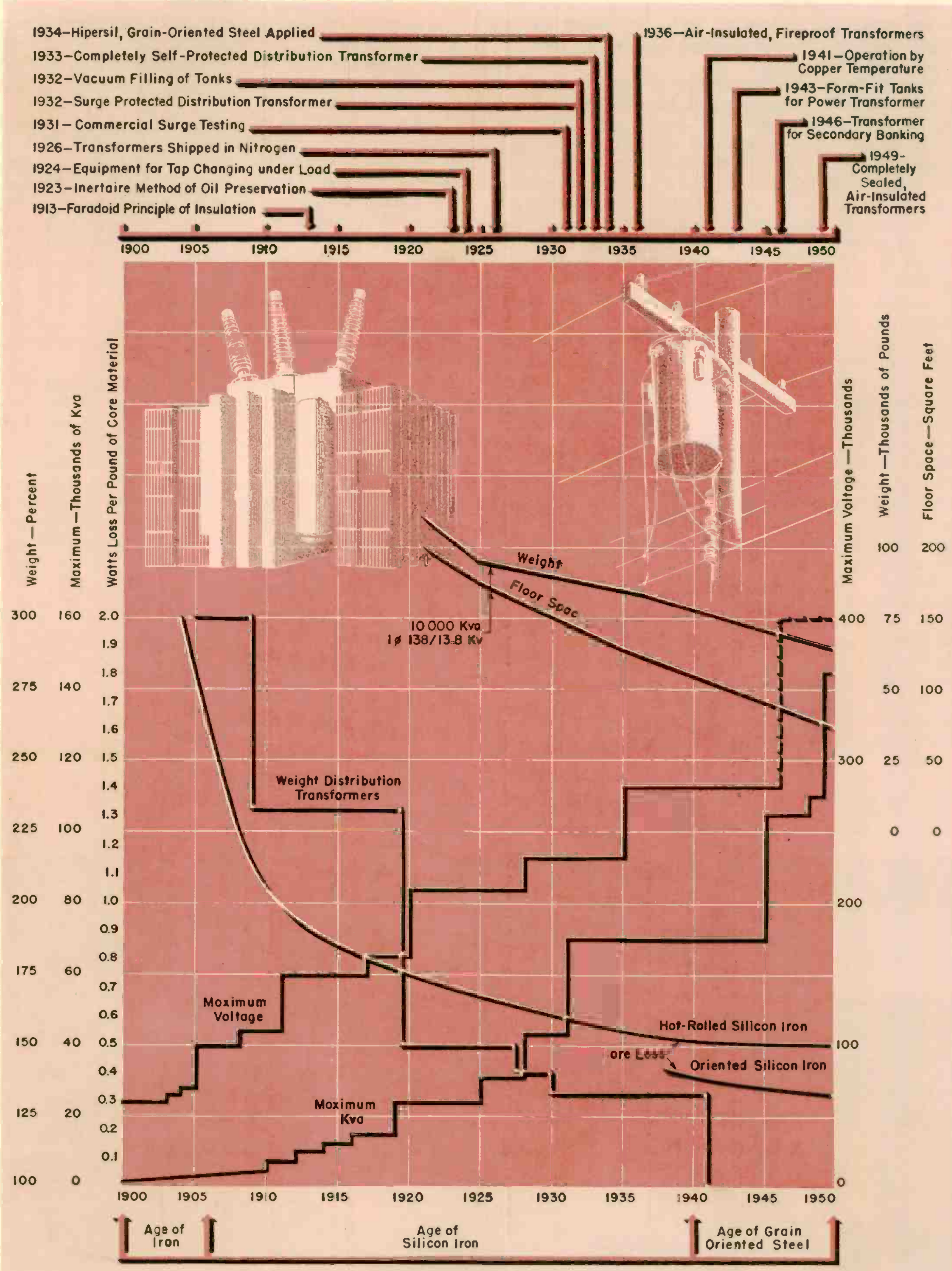
A 6-kva, 1150/517-volt cast-iron tank transformer of about 1892.



Below is a 500-kva, subway-type network transformer. At lower right a 750-kva dry-type transformer and switching equipment constitutes a modern power center close to the load in the factory.







A summary of a half century of transformer progress.

undergoes the normal heating and cooling cycle in service.

A further means of enabling oil to retain its original properties is to seal the tank by welding the joints, thus preventing breathing altogether. The Sealedaire-type transformer appeared in 1929 and has since grown to cover a range of ratings through 10 000 kva and 69 kv. A recent innovation for power transformers that cannot be hermetically sealed is to mount on the tank exterior a set of oil filters containing an active material that removes the products of oxidation.

Cooling Systems

The ways devised to enable transformers to rid themselves of heat are legion. They logically divide into two types: self-cooling and forced-cooling. The first transformer tanks had smooth walls, but the need to find some means of more rapid dissipation of the heat soon became apparent. One of the first expedients was to place vertical flues within the transformer, open to the air at both ends so that air might rise by chimney effect. This idea was a dud.

At the turn of the century engineers considered the self-cooled transformer would never compete in size with the water-cooled. Water-cooled ratings grew from 2000 to 10 000 kva from 1900 to 1912, while the self-cooled were increased from 250 to 2000. Just before the first World War several important developments gave an impetus to self-cooled designs. Improved electric arc welding made it possible to build all welded tanks without rivets. It was found practical to weld steel tubes to the sides of the transformer tank and obtain much greater cooling surfaces. Detachable radiators, fashioned after the design of steam radiators for house heating, made especially for transformers, proved very successful. By 1914, 5000-kva, self-cooled units were built. Ten years later, 25 000 kva was maximum, but it was still smaller in capacity than the largest water-cooled unit. Five years passed and two 40 000-kva transformers were built; one was self-cooled, the other water-cooled. Since then the two types of cooling have kept pace with each other, with the self-cooled in the lead a year ago at 110 000 kva, and the water cooled now ahead with a recent unit at 145 000.

In 1930 Westinghouse developed a novel and still highly successful radiator for self-cooled transformers. This was the expanded-metal radiator, consisting of two strips of sheet metal welded together at the edges and down the middle and then "blown up" with air. This forms a radiator large in cooling surface, light in weight, and strong. Frequently these are mounted in banks vertically, between header pipes, which are connected to the transformer tank. Radiator assemblies are often larger than the transformer itself; sometimes they are mounted on separate foundations and the oil piped to the top and bottom of the assembly by large horizontal pipes. The demountable radiator, which enables the cooling surface to be shipped separate from the transformer, was one of the principal developments that have made possible the larger self-cooled transformer ratings.

Self-cooled, oil-immersed transformers run cooler when the wind blows on them. This fact was utilized almost 50 years ago, when a transformer was placed over a pit and a blower forced air up around it. Many different methods have been used since to obtain higher ratings out of self-cooled units. Unit-type blowers with elaborate duct systems to feed the air to the radiators were popular in the 1920's. Blower and motor were mounted in a "dog house" beside the transformer, ready to start and blow when the thermostat in the oil called for air. This scheme was good, but expensive. No one thought seriously of using ordinary fans until a few years later it was found that more reliable and effective forced air cooling could be obtained by mounting small fans on the radiator. Today, three fourths of the self-cooling power transformers are equipped with fans to obtain higher ratings.

Forced-oil cooling, used in Europe, began to attract attention here about two decades ago. The idea of taking the hot oil out of the top of the transformer, pumping it through a heat exchanger, and returning it to the bottom of the tank had been tried in many places.

One of the first forced-oil installations was on the transformers shoehorned into locomotives. These units are compact, with transformer, pump, motor and oil-to-air heat exchanger all in one frame. The first units were oil insulated; now fireproof Inerteen is used for railway application.

Today forced-oil cooling is more than just cooling the oil in a heat exchanger, and returning it to the transformer. The pumping system developed by Westinghouse in 1930 and now used on large transformers actually directs the oil at a high velocity through the components where the heat develops. Large transformers have three or four centrifugal pumps, circulating thousands of gallons per minute.

Self-cooling, forced-air cooling, forced-oil cooling were developing pretty much in their independent ways. Then in 1943 they were happily combined to give the modern "triple-rated" transformer. The unit can be operated self-cooled. As load increases, fans blow air across the radiators, increasing the rating by 25 percent. Should this still be insufficient, pumps built into the return ducts between radiators and tanks raise the capacity an additional third. Thus, for example, a transformer may have ratings of 50 000, 62 500, and 83 333 kva, depending on the cooling employed.

Tank Construction

The enclosing structure plays a larger part in transformer design than it does with most electrical apparatus. Also it has undergone many and more radical changes than are experienced by most apparatus components. This is in part because the tank is more than just a "bucket" to house the "works." It plays an important role with a transformer as a heat exchanger. Also, because of the limitations imposed by shipping, the transformer tank requires special attention.

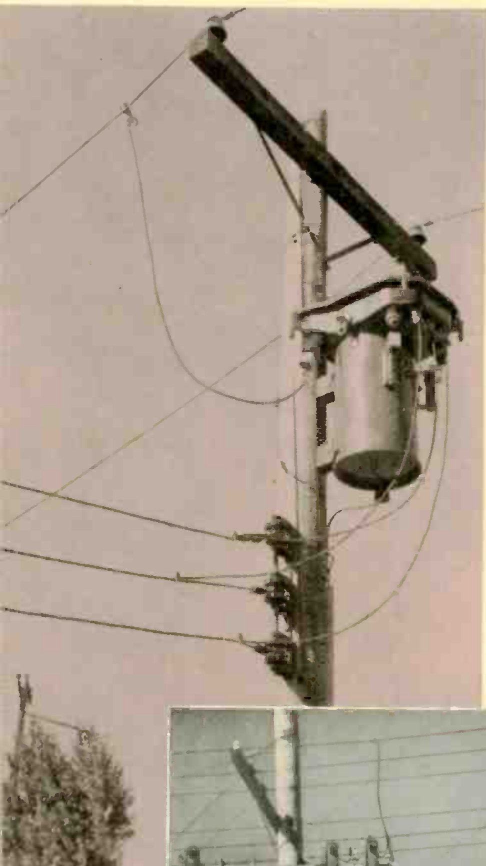
The first transformer designers were absorbed in the problems incident to the transforming function. Tanks received secondary consideration. So, needing an enclosure to contain oil and the transforming assembly, the pioneers logically borrowed from a neighboring established field—i.e., boiler practice. Round steel walls were riveted to steel bases. The difficulties one might expect with leakage were soon realized. By 1900 tanks were made by casting the base around the walls, which were of terneplate, smooth or corrugated, round or square. Another construction was to solder sheets of terneplate together and support them in an angle-iron cage. A variety of constructions involving different combinations of riveting and casting, with lead-gasket seals, were tried without gaining much on the ever-annoying problem of oil leakage. When arc welding reached the point that tight joints could be made, a development hastened by World War I, transformer designers turned hopefully to it. This was about 1915. It brought about the first fabricated steel tanks. An incident at that time illustrates the resistance encountered to the full acceptance of a new development. Tests amply indicated that welded lifting lugs provided a wide margin of safety. In spite of this orders were given that the lifting lugs had to be riveted in place as before, in addition to the welding. Rivets, however, were soon discarded.

While this approach was right, welding was not without its difficulties. The coated welding rod had not yet appeared. As a result the early welding introduced stresses relieved only by normalizing, which was not feasible for big tanks. The tanks, therefore, gave trouble with cracks in welds. Successive improvements in arc welding—many of which were brought about because of the transformer (and circuit breaker) tank problem—have brought us to today's manufacturing practice in which all power and distribution transformer tanks are of welded steel. Leakage is now a rarity.

Tank shape for power units has undergone an interesting evolution. Circular ones came first because of their simplicity. But that entailed a lot of waste space that had to be filled with oil. The square tank better fitted the core-and-coil assembly, but presented manufacturing problems. These two forms continued to dominate the field until the three-phase transformer began to become important about 1920. This meant that a tank must be devised to fit a definitely rectangular shape. Several solutions appeared. The first ones were oval, made of round ends butted and welded to flat sides followed by ones approximating an ellipse.

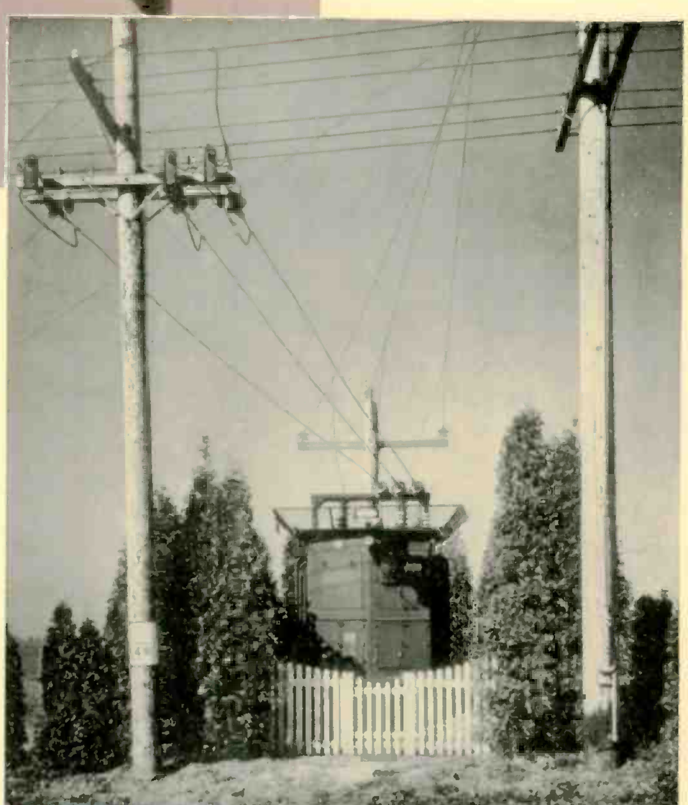
About this time other factors appeared to complicate the matter of tanks. The Inertaire system and the practice of vacuum impregnation and filling required that tanks withstand internal vacuum as well as pressure. This doomed the elliptical tank, which has good bursting strength but is weak to collapsing forces present when internal pressure is low. As transformers had grown in physical dimensions, shipping clearances were exceeded, requiring the tanks to be sectionalized for reassembly on location. Thus the need for a vessel of least size, least weight, and greatest strength became acute. Designers again went a-borrowing, to unfired pressure-vessel practice. A successful answer to this came in 1932 when Westinghouse developed the octagonal tank that has high collapsing and bursting strength.

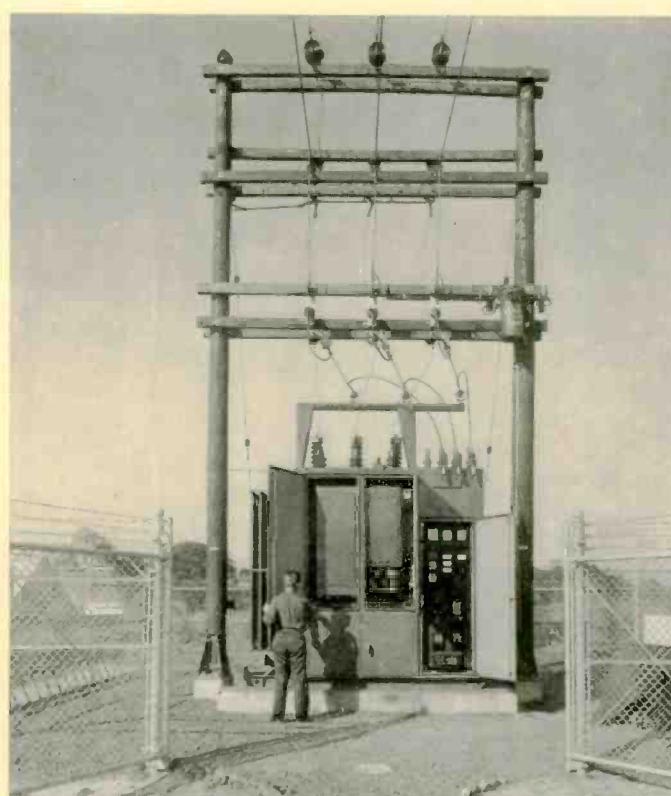
All this evolution was leading in one direction—to a tank that fit the assembly shape closely, not just approximately. The recent war brought this evolution to a climax. Transformer engineers were given the problem of building a 37 500-kva transformer with the smallest possible dimensions so that it could be lowered through the hatch of a ship. Weight also was an important consideration. So they took the final, logical step in tank evolution—a tank gloved to fit what had to go in it. This was the beginning of the form-fit tank. A base was made to fit the narrow, lower part of the transformer below the iron, and the transformer was set into it. After drying and treating the core and coils, a hood, broad at the bottom to cover the wide part of the assembly where the iron is



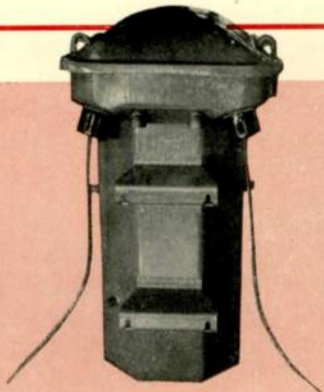
Many thousand completely self protected distribution transformers, such as this 10-kva unit, are in service. Failures due to lightning surges have been almost negligible.

Below, the early and the modern in CSP Power (single feeder) Transformers. The one at the left is a 1000-kva unit installed in 1937. Complete installation was made between dawn and dusk. The one at the right is a recent 1250-kva unit.

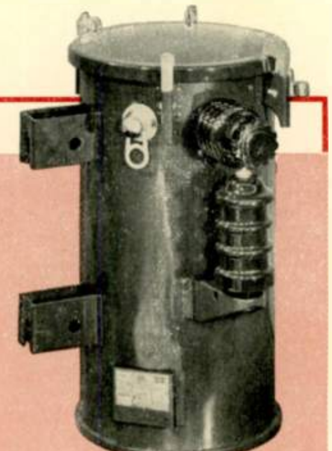




Distribution Transformers



At left is the original 10-kw, 2400-volt surge-proof transformer of 1932. (Center) one of the 6900-volt completely self-protected transformers of 1935 showing the circuit breaker and De-ion arrester. At far right is latest CSP unit for voltages below 4160.



stacked and narrow at the top like the base, was set down over the transformer onto the base. Then the two sections were welded together, making a hermetically sealed unit and the whole thing filled with oil.

The resulting transformer weighed about one fifth less than a standard forced-oil-cooled unit, which resulted from a 10-percent saving in tank metal and one third of the oil (about 3300 gallons in the case of the 37 500-kva unit.) The floor space occupied is 35 percent less, being about 7 by 16 feet, instead of 10 by 17½ feet.

If this 37 500-kva transformer had been cooled with radiators with the conventional form of tanks, the floor space would have been 16 by 23½ feet. The total weight would have been 50 percent greater. It would have required 42 000 pounds more steel and 4600 gallons more oil.

The form-fit tank has proved to be one of the all-time outstanding developments in transformers. Born of a wartime need to conserve materials it figures prominently in other major betterments. The economy in amount of oil to be purchased, shipped, handled, and preserved is sizable.

The form-fit tank also pairs with the shell-form core construction to do several other extremely important things. The relatively tight fit makes additional mechanical bracing unnecessary. Transformers can be and have been shipped and operated lying flat instead of standing vertical or moved from one position to the other during erection. This combination has a large cooling advantage because, with the narrow spaces between tank and core, the cooling oil cannot by-pass the parts to be cooled but must flow up through them. This means much more effective use of the oil.

Also the form-fit, shell-form team have no troublesome ceiling as to operating voltage or ability to withstand surges. In this arrangement no conducting parts are close to the tank wall, making special electrical insulation between core and tank unnecessary. Thus it was that engineers found no real obstacle to the construction of the half-million-volt transformers for the high-voltage transmission experiment on the American Gas & Electric Company system and anticipate no difficulty in building transformers for the highest operating voltages likely to become practical.

Distribution transformers, like their larger brothers, have undergone an important evolution in tank construction. For many years, cast-iron tanks were used for the smaller sizes, and for larger ones corrugated sheet walls cast into top and bottom castings and with cast covers. The first major break in this arrangement came in 1919 with the departure from casting to pressed-steel with plain, corrugated walls or with radiating tubes as rating demanded. This gave a weight saving of 30 percent, an economy of great importance for pole-mounted apparatus.

Functional Transformers

For the first 35 years of its history a transformer was simply a transformer. That is, its job almost exclusively was to step voltage up or down. Then, in the early 20's it began to assume other duties—a process still continuing.

When large utilities first began to tie their systems together, it was necessary to find some means of controlling the flow of wattless current between the two systems at the tie point where it was not desirable to have true power flow in either direction. Under these conditions it is necessary that the voltages of the two sides of the tie-in transformer have the same transformation ratio as the voltage levels of the two systems at the tie-in points. Since the voltage levels change under different system loading conditions, it became necessary to have some means of adjusting the voltage ratios of the tie-in transformer without disconnecting the transformer from the line. The load tap changer was the answer.

While this apparatus was designed originally to solve this particular problem, engineers quickly saw that here was a tool that could be used for controlling the voltage level of transmission lines and heavy distribution circuits within a system, without interrupting service to the customers.

In the early days of the load tap changer only a small percentage of large power transformers was supplied with it. Later smaller and less expensive apparatus was developed so that today load tap changers are applicable to all sizes of transformers down to the smallest power transformer built. The number of power transformers now equipped with this apparatus has become such a large percentage of the total that load tap changers are now considered essentially standard equipment.

The second class of functional apparatus to be developed was the network transformer. This transformer, which is a combination of a small three-phase automatic breaker and a small three-phase disconnecting switch with a small three-phase power transformer, was used to service an a-c network for city areas having high load density. During the last 28 years it has gradually forced the d-c system out of existence in large cities.

During the last 15 years transformers have begun to assume more and more of the duties of complete substations. A transformer into which was built all the apparatus for a single-circuit substation—tap changing, switching, protective devices—was introduced by Westinghouse in 1936 (the CSP Power Transformer). This was in addition to the adoption of power transformer for multi-circuit Unit Substations, which occurred a few years earlier.

The idea of unitized substations for power systems has recently been extended to substations for distributing power in factories. The power-center transformer is in reality an

The following extract from a recent letter from Dr. C. E. Skinner gives an interesting sidelight on the early development in electrical steel. Dr. Skinner, now retired, was associated with transformer development from 1890 until he became the first Westinghouse Director of Research.

"In the early days I followed the development of magnetic steel in detail, being present at the pouring of nearly every heat. As there were rumors of spies in the plant to find out how we did it, our supplier arranged all heats to be poured at midnight or after. The so-called "XXX dope" was carried at the last minute from the laboratory by a metallurgist, well wrapped in paper and this thrown into the ladle as the pour was complete. This "dope" resulted in a very spectacular burst of yellow flame and smoke as the five pounds of salt flame flared from the molten steel. The salt of course had no effect whatever on the steel but was supposed to fool completely any spy."

industrial substation engineered, coordinated, shipped, and installed as a single piece of apparatus. These are usually installed in factories, and, therefore, use the dry-type transformer, air breakers, and air-insulated disconnecting switches, so they can be installed in open areas of industrial plants.

The newest line of functional or unitized apparatus to be developed is the CSPB distribution transformer. It had been known for some time that if the secondaries of distribution transformers could be properly interconnected by suitable secondary breakers, the previous drawbacks to secondary banking could be eliminated and better service could be rendered by utilities to their customers at less overall cost. To serve this need the CSPB distribution transformer was created in 1946. It consists of a CSP distribution transformer unit equipped with an additional low-voltage breaker. The two breakers were so interconnected within the tank as to sectionalize the low-voltage circuits in case of secondary faults or overloads. Use of these transformers in a bank assures continuity of service, reduction in voltage flicker, lower regulation and less money invested in apparatus.

Transformers of the Future

In the reasonably near future the maximum commercial operating voltage can be expected to increase from its present level of 287 000 volts, possibly to the neighborhood of 400 000. The work being done by the American Gas and Electric Service Corporation on the Tidd test lines at Brilliant, Ohio, is laying the necessary background to determine the maximum actual operating voltage levels that are economical for a given block of power to be transmitted a given distance.

Whether operating voltages higher than 500 000 will ever be required in this country is doubtful. Factors that would make this economically desirable are not now in evidence. Should such be the case, however, transformers for super-voltages are expected to offer no insurmountable problems.

Most certainly there will be an increase in the maximum kva that can be built into a single unit and shipped completely assembled from the factory. A top level of 145 000 kva has been reached this year. Two hundred thousand kva can be provided when needed. Taking advantage of some of the new engineering principles outlined early in this discussion, the weight that can be handled by a single railway car, and not the dimensions, will determine the upper limit in kva rating that can be shipped.

It also seems certain that the three-phase transformer will be dominant. Our transmission, subtransmission, and much of our distribution systems are three phase, and as load density increases three-phase transformers should, therefore, be more economical than single-phase transformers. Large high-voltage power transformers will probably be forced-oil-cooled instead of self-cooled since the increased cost of the straight self-cooled transformers for these very large ratings can hardly be justified. The present trend will continue until gas-filled units supplant them. The complete factory-built, fully coordinated unitized substation will largely supplant the conventional substation built piece by piece in the field. The network and banked secondary distribution systems will make inroads on the straight radial systems for both central-station and industrial use.

With the increase in high-voltage underground transmission, more transformers with cable entrances will probably be used. In this manner high-voltage lines can be completely enclosed, with power plants located in congested areas and no overhead transmission needed to carry the power to the outskirts of cities. Electrical circuits from the generator to the overhead transmission line will not be exposed, but will be enclosed in metal throughout. The liquid-filled transformer will largely disappear from factories, office buildings, subways, and industrial plants, and be replaced by air or gas-insulated transformers.

Looking to some more distant tomorrow, engineers like to contemplate what forms transformers would take if research and materials engineers make available greatly improved core, conducting, and insulating materials.

The transformer designer, for example, would welcome a new core material capable of carrying twice as much flux with the same or lower loss as now. What is the prospect? Obviously, the possibilities of grain orientation will be pushed to the limit, advancing closer and closer—but more and more slowly—toward the ultimate induction attained with a single crystal, i.e., perfect alignment of all the grain elements, which is some 15 percent better than the present commercially available grade of grain-oriented steel. After that some other new fundamental must be found. There is, for example, a possibility of a new alloying agent, other than silicon. Cobalt offers possibilities of a one fifth improvement but some way must be found to reduce its losses and embrittlement. The most hopeful direction for another major gain in core material appears to be in a rearrangement of the electrons in the outer orbits of the iron atoms. If some practical way of achieving this could be found the stage would be set for a 50 to 100 percent further improvement in transformer steel—approached no doubt, as in the past, by a gradual evolution.

Also, the designer includes among his dream materials—as does indeed every electrical designer—a conductor of lower resistivity than copper. At present there seems little prospect of this in any known alloy or metal, the search having gone on since the industry's beginning. The possibility of using low temperature to obtain this result should not be ruled out.

A third much desired improvement would be a solid insulation with dielectric strength much higher than anything now known and with exceptional thermal conductivity and stability. Much work has been done to this end. Some synthetics of promise have been created, even some experimental "cast-insulation" transformers have been built. But as yet no new solid insulation qualifying electrically, thermally, and economically has been found.

If the designer of tomorrow should be so favored as to be provided with all three dream materials—core, conductor, insulator—or a reasonable facsimile of them the transformer of tomorrow might well be enormously reduced in dimensions, with the core and windings cast into a solid mass of the solid insulation. The steel exterior would become unnecessary. The whole solid unit could, if desired, be buried in the ground, with power entering and leaving by underground cable.

Or perhaps, instead of the solid dielectric, some new synthetic fluid—liquid or gas—will be produced that is a better insulating medium than oil. Such a medium may be used under several atmospheres pressure, thereby obtaining the advantage of greatly increased insulation strength. Thus we might sometime see the high-pressure transformer, perhaps buried underground, with cable systems entering the transformers and distributing energy much like oil and gas are done by pipe lines.

Some engineers suggest that the trend in electrical insulation for high-voltage apparatus may lead in the opposite direction—to no liquids or gases and no high pressures. Instead, a high vacuum. In a vacuum, there being nothing to ionize and cause breakdown, the problem of high-voltage insulation is greatly simplified. This enlarges the problem of disposing of the heat, but with the assumed low-loss core and conducting material the heat to move is greatly reduced so that the scheme might not be as impractical as it now seems.

Engineers have long begrudged the energy necessary to drive fans and pumps to bring out the heat developed within the transformer interior. If an efficient heat engine could be developed capable of operating on low-temperature differences it would be possible to use the heat developed within the transformer to effect its conduction to the atmosphere, improving the efficiency thereby.

One can hardly imagine that the day will come when the transmission of electrical energy between generation and utilization will not require transformers. Let us assume, for example, that for some reason, which we do not now comprehend, it becomes desirable and economically practical to use high-voltage, d-c transmission. Transformers will still be required between the generator and the rectifiers at the sending end of the line and again between the inverter and the subtransmission and distribution stations at the receiving end of the line. In any case, such a prospect is distant. Meanwhile, there are clearly many interesting avenues and developments —more now, in fact, than at any time in transformer history. It is certain that research will be aggressively pursued and can be expected to be as fruitful in the half century ahead as in the one just closed.

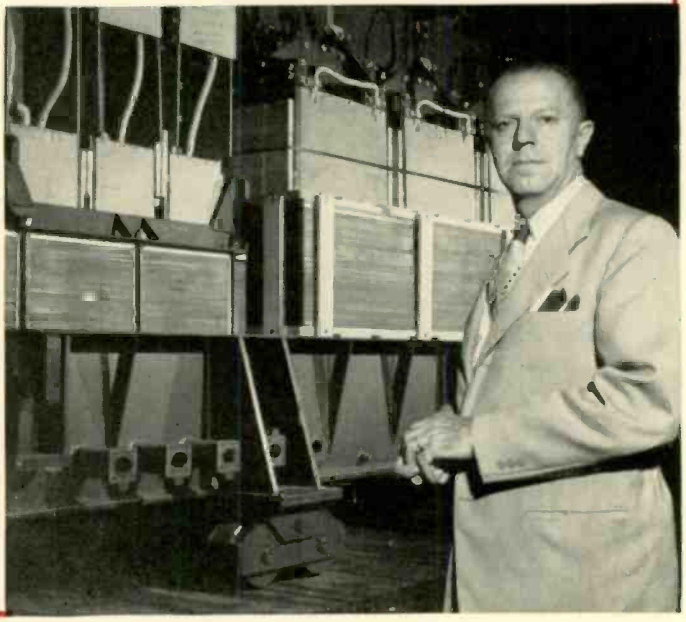
F. L. SNYDER

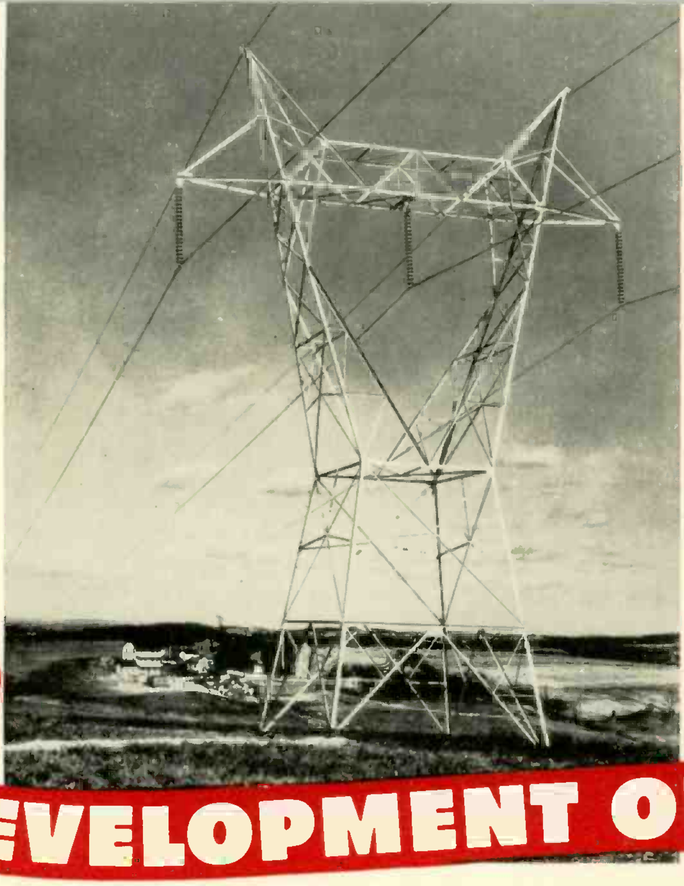
The career of Frank L. Snyder has by no means been as static as the transformers with which he is usually associated. It has had variety both within the transformer field and outside it. This is suggested by the variety of committees on which he is active. He is, for example, chairman of the Transformer Standards Committee of the American Standards Association, which establishes the standards for all transformers built in this country. This, of course, is not surprising, and is both an honor and a mark of technical skill. Snyder is chairman and civilian member of the Underwater Ordnance Panel, which guides the technical aspects of that phase of the Nation's defense. In addition Snyder is a consultant on the committee that guides all Westinghouse activities in the atomic energy field. This is in addition to his primary responsibility as manager of the Westinghouse Transformer Division.

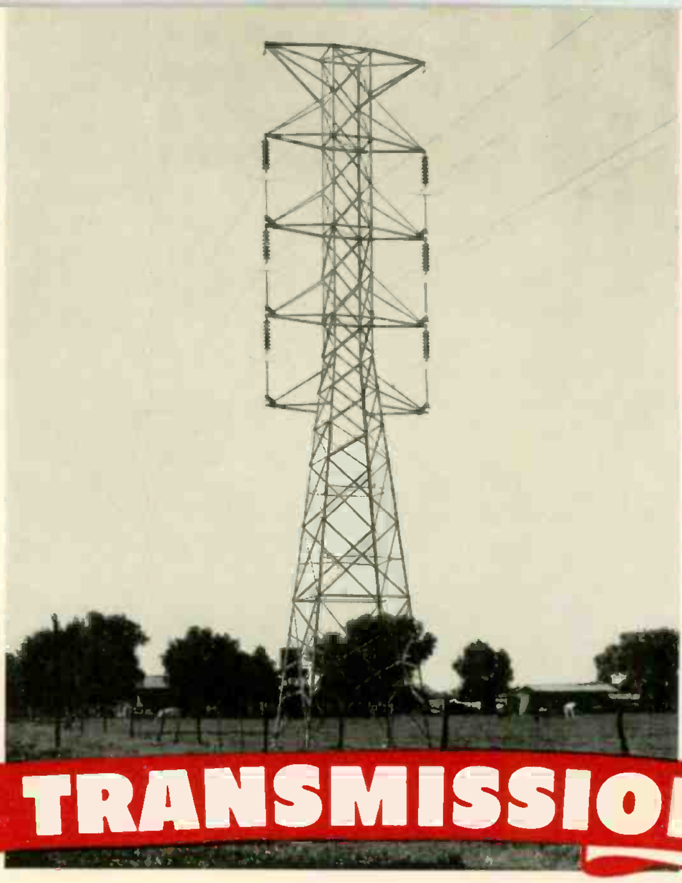
Neither did Snyder arrive at his present position by the most direct route. Brought up on a farm in Bedford County, his high-school record won him a scholarship to Gettysburg College, where he studied electrical engineering, and graduated in 1923. Snyder then went from Gettysburg to Sharon, Pennsylvania, by way of two years as a high-school principal in New York state, and a year of graduate engineering study at Columbia. He arrived, in 1925, in time to be assigned to developing a complete set of Westinghouse standards for power transformers. The largest standard unit at that time was 10 000 kva. "I recall," he says, "that we were particularly proud at the time of being able to build a 10 000-kva self-cooled unit."

The tap-changer engineering section then asked for the loan of Snyder for six months. However, like some other lend-lease, he never returned to the power-transformer group. This was at the time when transformers were beginning to assume voltage-regulating functions as well as plain transformation. Snyder, probably more than any other individual, can be credited with the Westinghouse no-load and under-load tap-changer schemes and mechanisms now used extensively. In 1940, Snyder was made engineering head of the recently formed Instrument and Regulator Division. Altogether he has worked on power transformers, regulating transformers, instrument transformers, tap changers, reactors, power CSP transformers, mobile transformers, control, and protective devices.

Then came the war. The Navy asked Westinghouse to design and build the electric torpedo. Transformers and torpedoes both begin with the letter *t*, beyond that the similarity ends. Nevertheless, Snyder was placed in full charge of that activity early in 1942, which resulted in a new underwater weapon that made one of the most spectacular records in all military history. In the next three years, there were but three days, except for hurried trips to Washington, in which he was not in the plant, sometimes almost around the clock. The affair in the Pacific settled, Snyder returned to transformers as assistant engineering manager. In less than a year, he assumed full charge of transformer engineering, and six months ago he was given command of all Transformer Division activities.







DEVELOPMENT OF TRANSMISSION

ELECTRIC power is more than perishable; it can be generated only while it is being used. This absence of time between generation and use establishes the basic task of transmission and distribution engineering: of building a system of circuits to convey electric power from generator to user that provides the ultimate in continuity of service. The delivery system must be reliable to a degree commensurate with the service required, recognizing possible hazards. This was the task of transmission and distribution systems 50 years ago; it remains so today; it will continue to be in the foreseeable future. The success the engineer has had in the face of increasing complexity of systems, larger power concentrations, higher voltages, more stringent demands, is a tribute to his skill and a promise that in the year 2000, when the industrial and domestic consumption of electric energy will be many times what it is today, he will still be master of the phrase "continuity of service." The task will be no easier or less important.

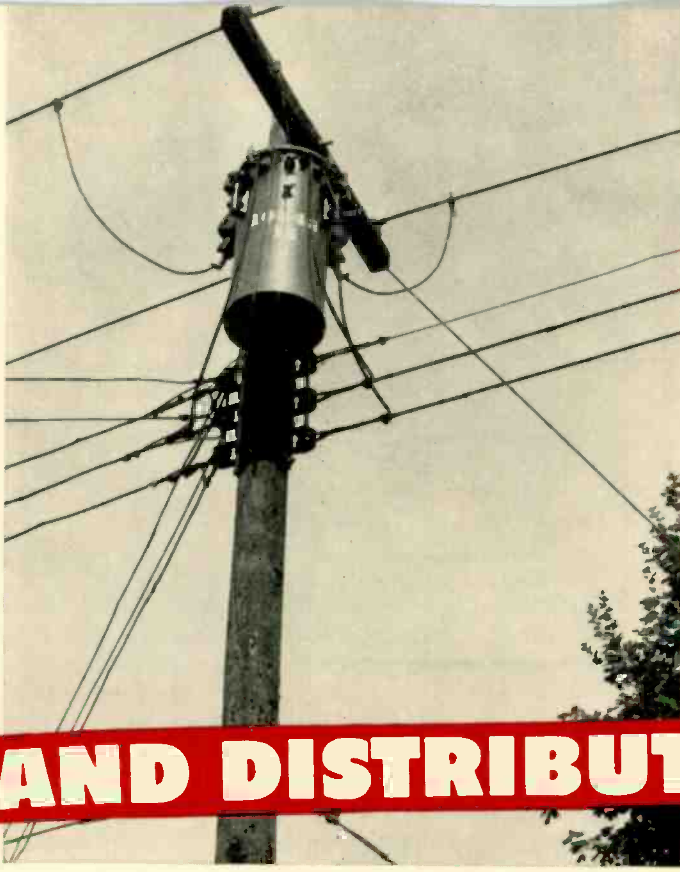
Transmission Systems

The reliability of early systems left much to be desired, as failures were frequent and often of long duration. Lightning was not understood and apparatus failures from it were numerous. Faults on the transmission lines caused many long outages, particularly if the line burned off and physically broke the circuit. Some faults would burn clear, but if they did not, there was no alternative but to shut down the whole system. This was done by lowering or removing the field excitation on the generators. Circuit breakers were little more than disconnect switches, and could not interrupt the circuit under power conditions. Power transformers, too, were weak links in the system because of their inability to withstand repeated short circuits and surge voltages from switching or from lightning. As breakers and transformers were improved, the voltage and power levels of systems were raised gradually with greatly improved reliability. Greater reliability of transmission lines came with lightning-proof construction of lines based on the direct-stroke theory (as against induced surges), introduced in 1930 by Fortescue.

Line Insulation—Initially, transmission-line construction followed the telegraph practice of using wood poles, with pin-type insulators supported on wood cross-arms. By 1904 voltages had slowly climbed from an initial of 10 000 volts in 1890 to 40 000 volts. Insulators were a definite limitation; for the most part they were made of dry-process porcelain, which was porous and shortly after being put in use became semi-conducting. The industry had to contend with this, however, as it was the only material available. Even though glazing of dry-process porcelain insulators was studied extensively in the early 1900's, it was not until wet-process porcelain insulators were introduced, about 1903, that significant insulator progress was made.

From 1900 to 1910 extensive studies were made of line and insulator losses. Coupled with technical advances in the art, these set the stage for the rapid increase in line voltages. The development of the Hewlett-Bush suspension insulator removed many voltage limitations, but not until the development of the cap-and-pin suspension insulator in 1908 was line insulation on a firm foundation. High-voltage lines progressed rapidly from the supported conductor, using pin insulators, to the suspended conductor type using strings of suspension insulators. The rise in voltage and power levels of transmission lines necessitated development of high-strength suspension insulators. Over a period of 30 years the tensile strength was increased from about 2000 to 30 000 pounds. Westinghouse developed the first high-strength suspension insulators in 1928. Stronger insulators made possible a much longer transmission span and enabled power lines to span wide rivers.

The need for better insulation in the low-voltage field remained acute and the development of pin-type insulators was active from 1910 to 1920. The first designs were of glass or solid dry-process porcelain bodies, which usually caused line faults if they failed for any reason. As voltages rose, the large and complicated porcelains required became extremely difficult and costly to manufacture and gradually two-, three-, and four-part insulators, cemented together, replaced solid porcelains for higher voltages. Designs to attain maximum flashover voltages were pretty much cut and try, resulting in numerous designs. While it was recognized that a relationship



AND DISTRIBUTION SYSTEMS

by **F. R. BENEDICT**

between the mass and shape of the porcelain and the flashover voltage existed, it was not until the "Faradoid" principle was developed by Fortescue in 1918 that insulator designs were rationalized and this effectively removed the limitations set by line insulation.

With the rapid development of radio in the 20's, great importance was thrown upon the elimination of radio interference produced by lines and apparatus. In 1930 Westinghouse offered the first radio-interference-proof, pin-type insulator. Careful analysis of interference produced by all types of line materials and apparatus and appropriate design changes have assured that power lines do not unduly influence radio and television transmission.

Why line insulators should be an attractive target to men with guns has always been a mystery. Many outages have resulted from breakage of insulators by gunfire. Westinghouse was the first to build pin and suspension insulators that can withstand the shock of high-power bullets.

Types of Transmission Systems—The first commercial a-c power-generation station based on William Stanley's Great Barrington, Vermont, development in 1885–6 was single phase, with the initial installation in Buffalo, New York, in 1886. Single-phase a-c systems were followed closely by two-phase a-c systems with the development of the polyphase generator in 1889. Until this time a-c systems were designed to handle lighting loads and small single-phase motors up to about three hp, but the announcement of the polyphase a-c system, closely followed by the polyphase motor, rapidly changed the system picture. Voltages were low, the systems being what we call distribution systems today.

As the high-voltage polyphase system developed for bulk transmissions of power, both the "delta" ungrounded connection and the "wye" grounded connection were employed. Engineers at first favored the delta-connected system, since it was less subject to outages due to a ground fault. It could continue to operate with one phase inadvertently in contact with ground. However, as systems grew and consequently the capacitance to ground increased, particularly on cable systems, the delta ungrounded system ran into serious difficulties on arcing grounds. Many of the apparatus failures in the early days were probably caused by transient overvoltages due to arcing grounds on ungrounded systems. Ground detectors were developed, but those were of little use in locating the point of fault. If simultaneous grounds occurred on different phases, a system outage developed and the outage could be cleared only by visual observation of the line. Recognizing the limitations of the ungrounded system, George Westinghouse, with B. G. Lamme and others, held that the grounded-neutral wye system was the most satisfactory for three-phase high-voltage systems. The advantages of the grounded system became so apparent that it was rapidly adopted and is now almost universally used for the higher voltage lines in the U. S.

System Interconnection—By 1917 individual power companies had extended gradually the areas covered until the country was supplied by many isolated systems. It is interesting to observe that the number of generating stations in 1900 was 3400, which is only 600 less than today. In 1917 it was 6542. The crisis of the first World War disclosed that the lack of large blocks of power—larger than individual systems could provide—were limiting the war effort. This brought about a new technique in system engineering, which we now call "interconnection." Until then individual systems operated as unrelated units, maintaining their own frequency and voltage. But to effect interconnection, it became necessary for all member systems to operate at the same frequency and to give careful consideration to the flow of real and reactive power.

Electrical engineers have now solved most of the problems encountered with interconnections. For example, spread of troubles from one system to another is prevented by proper relaying and circuit-breaker operation. The holding of proper

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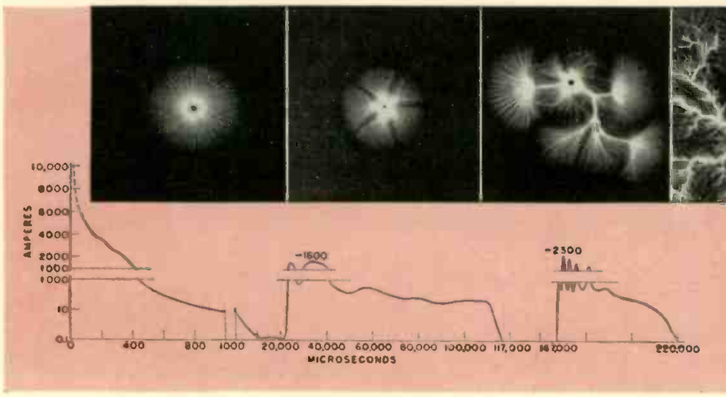
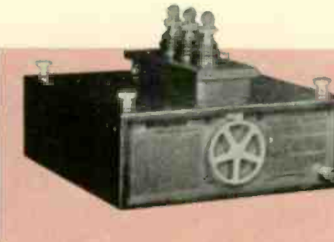
The principles of lightning-produced surges enunciated by Fortescue were applied in the 220-kv Safe Harbor line of the Pennsylvania Water & Power Company about 1931, upper left. It employed rational design of ground wires, low tower-footing resistance, and wires buried in the earth below the line (a counterpoise) making it one of the first lightning-proof high-voltage lines. At left, center, is an early high-voltage line protected by De-ion tubes. Above is a completely self-protected transformer designed for banked-secondary operation. The sketch suggests the distribution system of the future, with semi-buried transformers.





Above is a Peters' klydonograph, one of the earliest lightning-study tools. Beside it are five records obtained with it showing, left to right: a surge with abrupt wave front, one with a 5-microsecond front, two that are beyond the calibration range, and an oscillatory surge. The record of lightning, left, was obtained with modern equipment.

voltage and the flow of wattless current over interconnections are controlled by adjusting automatically, if necessary, the ratio of transformation. Load regulators of various types automatically control the flow of power in the system and over interconnections. The electric clock and its dependence on system frequency demanded close control of frequency.

Lightning—Lightning has been one of the most formidable enemies of power lines and equipment. At first it was considered a natural hazard that would have to be tolerated, but its ravage took such a heavy toll of generators, transformers, line conductors, wood structures and line insulation that it could not be ignored.

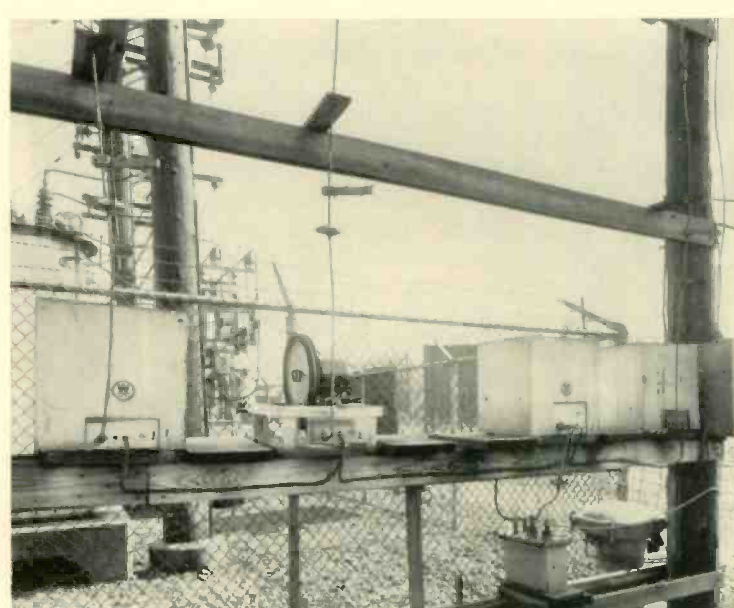
The first approach followed house-protection practices of the day; installation of lightning rods on each pole. This was helpful but it was not recognized that the cone of protection provided by a rod five or six feet high was small and gave little or no protection in the middle of the span. Failing to obtain protection with rods, engineers reasoned that grounded wires, stretched above the conductors, should give better protection. Ordinary barbed wire was used first. This was nearly disastrous as the wires were poorly installed and were mechanically weak. Breakage from wind and ice often caused them to fall across the lines, producing short circuits. Ground wires were abandoned completely for a considerable period, but when it was recognized that mechanical difficulties and not lightning were causing the wire failures, they again came into general use, particularly after the direct-stroke theory of lightning was proved. Excellent protection is secured by ground wires of adequate strength.

As a second attempt at protecting transmission lines against lightning, Wurts of Westinghouse developed what was called the "non-arcing metal arrester," about 1892 (see p. 32). This type of arrester never gained wide favor, but it was better than nothing. It did not give adequate protection, as the resistance element did not have the inverse current-voltage relationship so necessary to this type of device.

The aluminum-oxide electrolytic arrester was the first really satisfactory arrester to be used commercially. It was introduced about 1908 and was the standard of the industry until 1918 when the oxide-film arrester was developed. The Autovalve arrester, developed in 1921, was the first to abandon the chemical principle. Early Autovalve arresters worked on the basis of a glow discharge between small carbon discs, separated by mica spacers, with these discs arranged in stacks and connected to the line through an isolating gap. A large amount of development was expended on this arrester, but it was recognized that it had definite limitations in surge-current carrying capacity and the search went on for an improved arrester. In 1928 an arrester was introduced in which a block of specially processed carborundum powder acted as a glow-discharge element and eliminated the need for the many discs and spacers in the old type of arrester. The block-type arrester had high surge-current carrying ability. Improvements in 1939 further increased its current-carrying ability and this type of arrester is a standard of the industry today.

The De-ion protector tube was introduced in 1931 and was a Westinghouse development stemming from De-ion breaker work in the late 20's. This device is simply a hollow fibre tube containing spaced metallic electrodes. One electrode is grounded and the other is connected to the circuit or apparatus to be protected through an isolating gap. If a surge voltage of sufficient magnitude is impressed across the isolating gap and the enclosed gap, both break down and the lightning current passes to ground. This places a direct short circuit on the system and power current immediately starts to flow to ground. The lightning current and the power-follow current vaporize a small amount of the fibre wall, producing a gas blast out of the open end of the tube and a power de-ionizing action on the arc takes place. At the first current zero the power-follow arc is extinguished, both gaps regain their insulating properites and the device is again ready to operate. Special types of tubes, called "De-ion arresters," are used on distribution systems and in distribution transformers (see p. 62, right-hand illustration).

Between 1910 and 1920, lightning was extensively studied in both the laboratory and in the field, but no really satisfactory method was available for actually measuring current



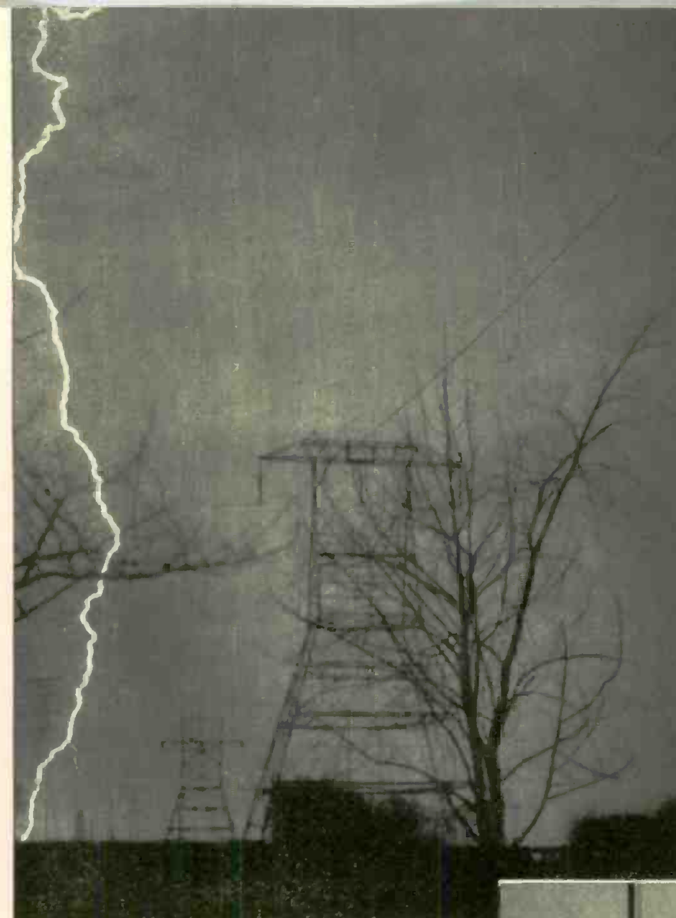
and voltage in lightning strokes. In 1924 the study of natural lightning received an impetus with the development by Peters of the klydonograph. This was the first satisfactory field instrument for the study of lightning voltages and currents.

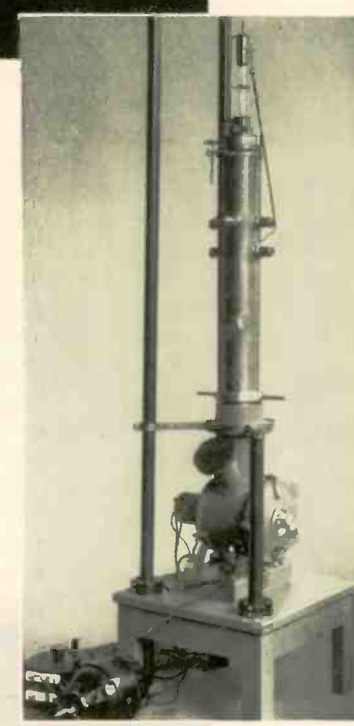
Lightning studies were given a further impetus in 1928, when Westinghouse introduced the Norinder-type continuous-beam cathode-ray oscillograph in this country. Extensive studies were made through 1930 and 1931 and a tremendous amount of lightning information was obtained. As a result of these studies, Fortescue, in 1930, was the first to promulgate the direct stroke as the chief cause of lightning outages on high-voltage lines. Previously it was believed that induced voltages from nearby strokes caused outages. This work by Fortescue and his colleagues made possible the design of practical lightning-proof transmission lines through the scientific application of ground wires, counterpoises, and coordinated insulation.

In the 30's the principal electrical manufacturers cooperated to establish impulse levels for apparatus and developed the principles of insulation coordination, whereby each element of the transmission line is coordinated to obtain maximum impulse strength of the line. The introduction of arresters of low impulse ratio during this period made it possible to take maximum advantage of insulation economies. Marked reductions in transmission-line costs were effected.

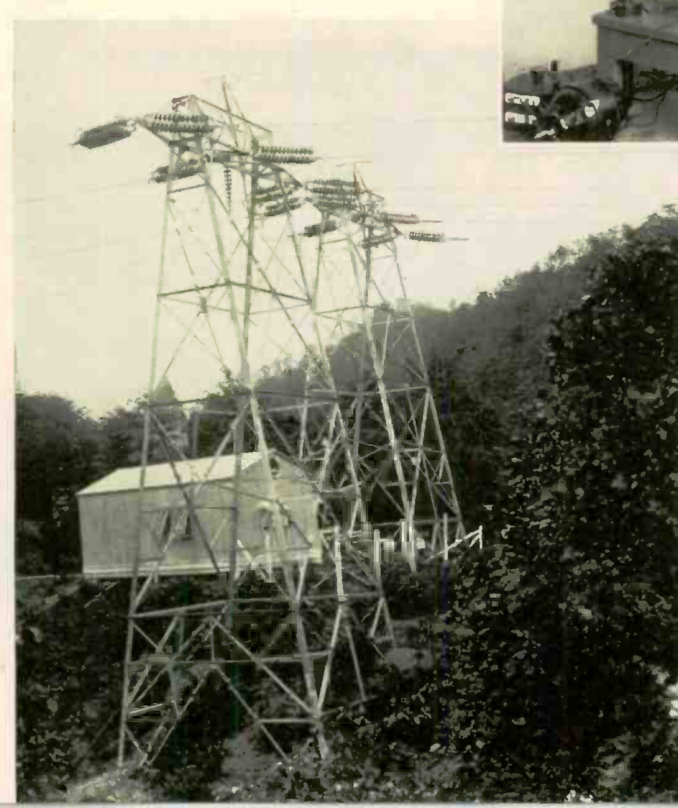
Transmission-Line Theory—Until 1918 only the balanced symmetrical conditions, such as normal load flow for three-phase short circuits, could be readily studied. There was no good way of solving for the currents and voltages under the unbalanced conditions, such as line-to-ground or line-to-line short circuits, whereas it is essential that these quantities be known for the application of all types of equipment to power systems. In 1918 Fortescue conceived the method of symmetrical components, an accurate method of calculating polyphase current and voltages in unsymmetrical conditions. This method was developed and brought to fruition through the work of Wagner and Evans, described in a series of articles starting in 1928 and later published in book form in 1933. Universal acceptance of this method followed rapidly.

Theory and calculation must be checked by tests and, therefore, various instruments were introduced as the art progressed. The Duddell or galvanometer oscillograph was used





On the track of lightning. At far left is a battery of fulchronographs, while below are two views of one of the earliest expeditions into the field. A crew with mobile equipment set up to observe lightning in Tennessee in 1928. At right is one of the early cathode-ray oscillographs. Above is a historic picture taken fortuitously soon after Fortescue announced the direct-stroke theory. This picture proved his point.



widely in measuring wave shapes and in actual measurement of transient voltages and currents. In 1914 Westinghouse developed the Chubb harmonic wave analyzer, a device for resolving any complex wave shape into its harmonic components, and its use resulted in a much better understanding of complex phenomena in a-c systems.

After the extensive interconnections, which developed during the period 1917–18, system stability became of paramount importance and a great deal of theoretical work was done in establishing stability limits for transmission systems. Methods of stability calculation and means for improving stability have resulted largely from Westinghouse contributions coupled with investigational ventures with the utilities, who frequently loaned their systems and facilities for testing purposes, as Mr. MacNeill describes.

During the twenties, with the growth of power-system interconnection and increasing extent of systems, computations of their performance became more and more arduous. The d-c calculating board became quite inadequate to deal with phase relations between machines, and this culminated in the development of the a-c calculating board in 1929. Coupled with the transient analyzer, developed later, this a-c calculating board has made possible complete system studies of the most complex systems in a tiny fraction of the time required for calculation, if, indeed, calculations could be made at all. Extensive theoretical work was done on practically every phase of a-c transmission and many new devices have resulted from such calculations.

Relays—Short circuits on electrical systems are not only destructive to the equipment involved, but they also impair or interrupt service to other parts of the system. It was recognized from the beginning that automatic means must be provided to detect and isolate defective lines or equipment much quicker than an operator can locate the trouble and open the proper switches. This led to the development of protective relays and of the protective relay art. This development has always been concerned principally with the abnormal, or fault conditions, in contrast to the normal, or load conditions. As power systems grew, the problem of adequate protection against short circuits became more complicated, but the scope, variety, and functional capabilities of protective relays have kept pace.

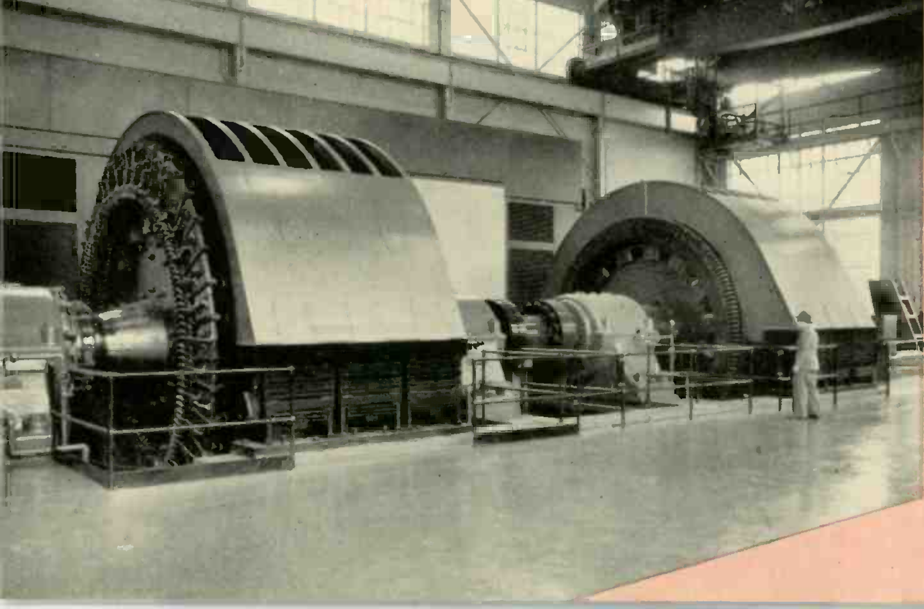
As might be expected, the first relays applied to power systems were overcurrent relays, followed later by voltage relays. These early relays were usually of the plunger type, and when timing was added by dashpots or bellows, they were not too accurate. Timing was found necessary, in addition to current or voltage indications, in order to obtain selectivity between the several relays and attendant circuit breakers affected by a fault. In 1901, Westinghouse introduced the induction-type relay, which greatly improved relay accuracy and reliability. Relays operating on the induction principle have reached a highly perfected state today. Relay settings only by "tap and time lever" soon became inadequate to cover all situations, so that in 1910 Westinghouse developed the watt-type directional element. The inclusion of an element to determine the direction of power flow in conjunction with the settings for current and time greatly facilitated the solution to problems of selectivity.

As power systems grew in extent, particularly with transmission lines being closed into loops, it became more and more difficult to obtain proper selectivity with directional overcurrent timing relays. This led Westinghouse to develop the impedance-type time-distance relay in 1922. This induction-type relay, through using current to drive it and voltage to restrain it, adjusted its own time setting inversely proportional to the distance to the fault, and thus broke the bottleneck of fixed time settings on many extensive systems.

This was a great step forward, but the continuing growth of power systems and the attendant stability problems put increasing emphasis on the need for faster clearing of faults by higher speed breakers and faster relays. Until 1926, fast clearing of faults was not practical, as the relaying was slow and circuit breakers could not be opened quickly mechanically. Most faults on transmission and distribution lines involve an arc path and, if not quickly removed, damage line insulation or conductors. Slow-speed clearing of faults also was a prime factor in system instability. In 1926 Westinghouse first conceived and obtained patents on a breaker and relay scheme that would make it possible to clear all faults on the system rapidly. Ultra-high-speed relays were developed for railways in 1927 and were used in conjunction with 25-cycle, high-speed breakers that operated in less than one cycle. The high-speed distance-measuring relay for power systems was introduced in 1929. This new breaker and relay scheme was so successful that it completely revolutionized the breaker industry.

As the result of system-stability studies, Westinghouse engineers first presented the advantages of high-speed reclosing of circuit breakers on transmission lines. Extensive investigations of de-ionization of arc paths were carried on during 1933 and indicated the practical reclosing times.

With the successful development of carrier-pilot relays,



Some of the tools by which power systems and power apparatus are approved. At left are two generators providing energy for high-power testing of switching apparatus. Below is the rotating synchronous switch of the analog computer and, right, a general view of the alternating-current calculating board.

through which the two ends of the line could be tripped simultaneously at the time of a fault, the fast-reclosing scheme was developed. By the new scheme all three phases were opened to clear the fault. It appeared desirable, in some cases, however, to clear and reclose only the phase in trouble. Later Westinghouse developments made this practical and here resulted in successful applications of single-pole reclosing on several power systems.

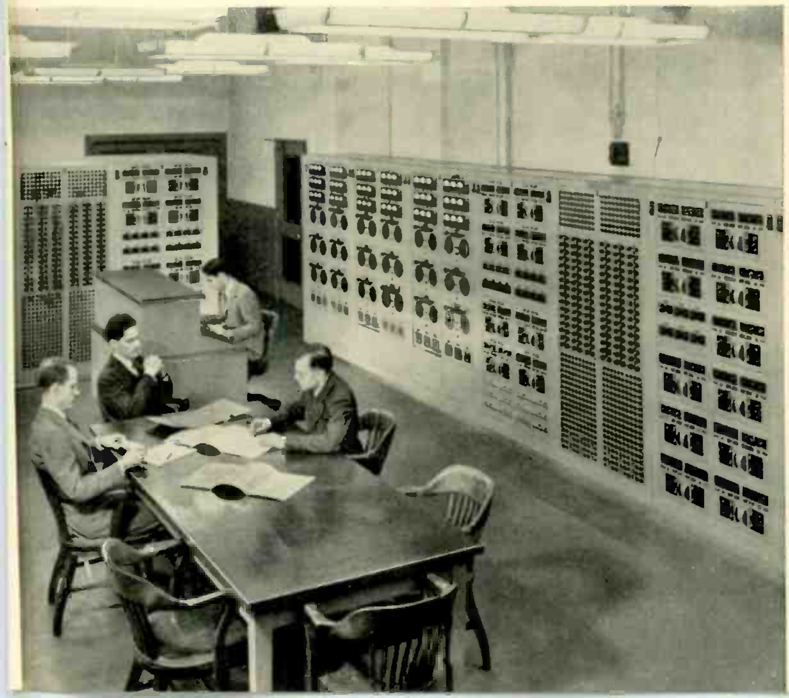
In 1936 carrier current, in connection with high-speed impedance relays, made possible one- to three-cycle operation of the relaying system for faults at any point on a transmission line, thus eliminating the "end zones." Shortly thereafter, in 1938, Westinghouse introduced a new form of high-speed, pilot-wire protection for transmission lines wherein only two wires are needed between stations to obtain high-speed relay protection for both phase and ground faults.

The method of symmetrical components began to exert larger and noteworthy influence in relay design and application problems in the 30's. With symmetrical components, the problems were analyzed with greater facility, and understood better. Also, the concepts of symmetrical components pointed the way to invention, and many relays have been designed using these concepts. Most prominent examples are the pilot-wire relay previously referred to, followed by an adaptation of this relay to carrier current in 1944, a relay for detecting single-phase-to-ground faults for bus-protection problems in 1942, and in 1941, a relay for selecting the phase in trouble when phase-to-ground faults occur. The same principles have been applied in impedance and reactance relays for ground fault protection, both in 1936 and in 1948.

With the advent of World War II, the stability of power systems became even more of a problem in view of the heavy loads being carried. It was difficult in some cases for impedance relays to recognize the difference between a "swing" condition from which the system could recover and a genuine fault. This led to modified impedance relays introduced in 1944 to take proper account of the phase angle between current and voltage. Thus it became possible to discriminate between heavy synchronizing power and short-circuit current.

Distribution Systems

At the turn of the century the commercial areas of the big cities were in general served by the Edison d-c network system. This was then the most reliable system of distribution. However, it was quite costly because the power had to be distributed at utilization voltage. The smaller cities and towns and also many outlying sections of large cities that were made remote from the generating plant or plants had their power distributed by means of a simple a-c radial distribution system. Generating stations were relatively small and electric power was distributed from them at generated voltage—usually 2400 or less—over radial feeders, which supplied the distribution transformers for stepping down to utilization voltage. The earlier systems were largely single-phase for supplying lighting. However, power loads requiring three-phase systems came more and more into vogue. In general, as time went on, power and lighting loads were supplied over the same primary feeders by separate transformers and separate secondary lines were used for distribution to the two types of load.



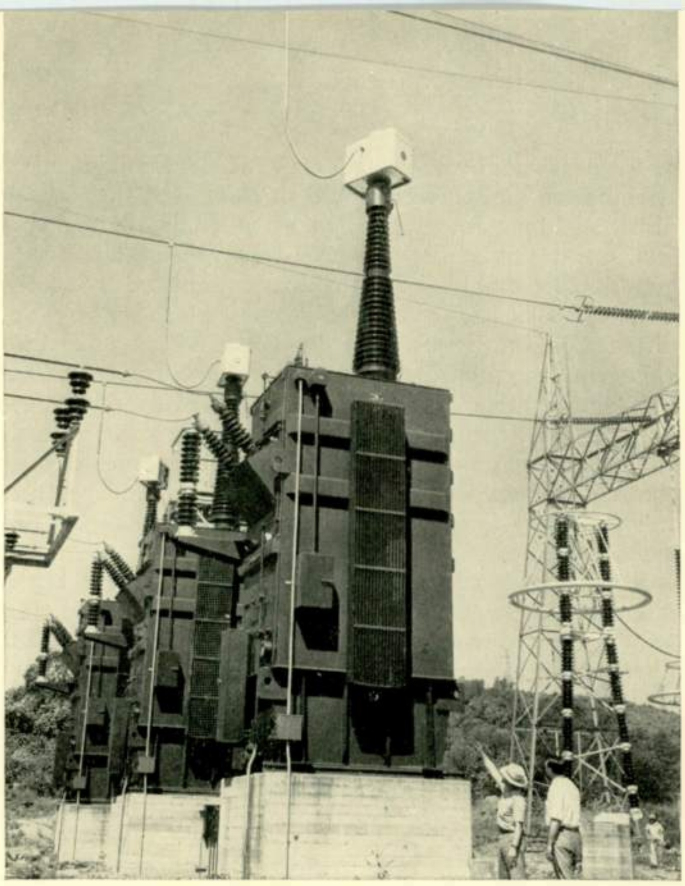
As use of electric energy expanded, both the areas that the distribution systems must cover and the density of load grew to the point where it was not practical to serve all loads directly from the generating station. This led to the establishment of additional feed points in the form of substations from which power could be distributed. To supply these substations the power was often stepped up to a transmission voltage carried to the substation location and there stepped down to distribution levels.

As systems grew, maintenance of constant voltage at the load points, which was originally taken care of by the generator regulators, became a serious problem. This led to the development of induction regulators to regulate the individual primary feeders. Another way in which regulation problems were met was by raising the voltage of the distribution feeders. For example, 2400-volt delta systems were often changed to 4-wire, 4160-volt wye systems.

Distribution substations grew. In many cases their size was limited only by the space available for substation equipment and the ability to take primary feeders away from the substations. These substations were often tied together by a network or grid of high-voltage circuits that served both to supply power to them and as interconnections between the generating stations. These substations had both high-voltage and low-voltage buses, together with the necessary switching equipment. Double buses or transfer buses for better service reliability, and to permit maintenance of the substation equipment, were often used. Control of voltage on individual feeders in these large stations was necessary.

By the early 1920's load densities in the larger cities had reached the point where the d-c network system was excessively costly when compared to the less reliable radial a-c systems; and furthermore it was becoming increasingly difficult to find space for the necessary equipment and circuits. This led to the development by Westinghouse in cooperation with the Consolidated Edison Company of New York, Inc., of the a-c secondary-network system. This is now the standard method of distributing power in the commercial areas of cities and in other heavy-load density sections.

A natural outgrowth of the secondary-network system idea was the primary-network system, first placed in service in 1930. In this the primary feeders, rather than the secondary or utilization voltage circuits, are connected to form a network or grid. Since the networking is not done immediately adjacent to the consumers' services, the primary network does not provide the same high quality of service as does the secondary network. However, it does result in comparatively small and simple distribution substations. This system offered considerable advantage from an economic standpoint when compared with most radial systems of that day with their large and costly individual-feeder-regulated substations.



Here data is being obtained for construction of lines above the 287-kv limit. Shown are the 500-kv transformers and lightning arrester on the experimental lines at Tidd station.

Use of the primary network system in medium- and light-density areas stimulated re-examination of the entire problem of distributing electric energy. This led to a further use in radial a-c distribution systems of smaller, simpler, unattended distribution substations supplied over simple radial and looped subtransmission circuits. These substations are often factory assembled. Much of this overall system simplification has been brought about by greater coordination of the design of the subtransmission circuits, distribution substations, primary feeders, distribution transformers, and secondaries. This has resulted in more economical, more flexible, and simpler radial distribution systems for serving medium- and light-density areas.

Simple radial and looped subtransmission circuits have decreased the need for high-voltage switching at the distribution substations and eased the problems of relaying and power flow. By keeping substations small, bus regulation can be provided by load-tap-changing equipment in the substation transformers instead of the more expensive method of regulating individual feeders.

Great strides have been made in bringing electric power to rural communities. Because of the great distances between rural loads, it became necessary to adopt higher distribution voltages—usually in the 15-kv class—than are normally used in urban areas. There is now a trend to using these higher distribution-system voltages in urban areas rather than the usual voltages in the 5-kv class. This trend in general appears to be sound economically only where the higher voltage eliminates a voltage transformation, and thus the necessity for building many distribution substations.

As motor-driven appliances have become more numerous and the size of these motors has increased, light flicker has become a problem in the design of distribution systems. For this reason as well as better average loading, banking of distribution transformers is becoming more common.

To meet the increased need for flexibility and service continuity in many of the medium-density overhead areas, network protectors and transformers are now available, which make the secondary-network system practical in these areas.

There is an ever-increasing demand to improve the appearance of residential areas by eliminating overhead distribution systems. This problem is largely an economic one and considerable work is being done at present to develop a relatively low-cost underground distribution system for these areas.

Many distribution systems in this country have by no means taken full advantage of the improvements and simplifications enumerated. The future will bring further system changes, all directed toward decreasing overall system cost while providing better service and improved appearance.

Transmission Voltages

The problem of voltage selection has always been one of cost. Early systems, about 1904, operated with maximum voltages of about 40 000. Voltages increased in numerous steps, reaching 100 000 kv in 1907. From then on the steps were much larger, climbing to 140 kv in 1912; 150 kv in 1913; 220 kv in 1923; 244 kv in 1926; and 287 kv in 1934. Today there appears to be justification for going to voltages somewhat above 287 kv, as the next logical step.

A Look to the Future

In 50 years the amount of power generated in the United States will be many times greater than today. The invention of devices now unknown, the creation of needs that do not now exist, the incentive and enterprise of private industry for growth and advancement will provide new and enlarged outlets for power.

In the tomorrow we will see extensive standardization of the basic units following that already started in turbines, generators, and transformers. The direct results will be cheaper installation, faster delivery. Engineering progress will provide more efficient equipments.

Hydroelectric power must of necessity occupy a diminishing role percentagewise as about one-sixth of the water power potential of this country has already been developed. Steam power from coal, oil or gas, will play an increasingly important part, as our chief source of power supply must be from the fossil fuels. Atomic power will certainly be a factor if an adequate supply of atomic fuel is developed. Atomic power plants will probably not be small but they have a potential of delivering tremendous amounts of power for their size.

With increased power density more generation will be located near the load. With high power densities, power stations will be large. Single stations may contain as much as two million kilowatts installed capacity. With these power concentrations transmission will be a problem. For such areas high-voltage transmission lines will be short and underground. If suitable cable dielectric is developed, all high-voltage lines may eventually run underground, thus eliminating lightning and weather hazards completely. With the aid of television and other high-frequency equipment, it may be possible to operate these power stations without attendants, with all control from a major dispatching office.

Out of the research on superconductivity, we may be able to unlock some of the secrets of conduction. Much of our apparatus is of great size to provide space for insulation, conductors, and magnetic material. If resistance of conductors—perhaps copper, perhaps something else—could be significantly reduced, say to one fifth, tremendous savings could be made in all types of apparatus. Transmission conductors would be lighter, towers less bulky and generators and transformers much smaller. Improved magnetic steels are already at hand but more can be expected.

Insulation too has tremendous possibilities. We consider air as nearly perfect dielectric, but it gets better if we compress it. It gets still better if we add certain gases to it and then compress it. Solid insulations too are not completely developed. Combinations of solids and gases, such as has already been done in high-voltage, gas-filled cables, holds great promise for improving apparatus.

Possibly all electric services including telephone should be piped through one duct, all underground, arranged so that easy repairs could be made to all services. With the increasing load used in individual homes, possibly every home should have its own transformer built into it and fed from an underground cable. With electric heating coming into the picture, such installations could provide economical and highly satisfactory service.

The home of tomorrow is certainly not going to be like the home of today. It will employ high-speed, automatic cooking; new types of high-efficiency light sources; private elevators and moving stairways; automatic laundries; automatic indoor climatic control; built-in color television; and other devices for saving labor, improving comfort and providing new kinds of entertainment. We now have a yearly absorption of 1400 kilowatthours in the average home, but this can increase many times if the uses are properly developed.

With systems expanding rapidly, control of the entire system is assuming great importance. The adaptation of relays to "compare notes" over long distances at high speed to determine fault locations has reached a high degree of perfection in pilot-wire and power-line carrier installations. However, the load on the allotted frequency spectrum has about reached the saturation point in many cases, considering the number of lines involved and the requirements of carrier for other uses, such as communication, telemetering, and supervisory control. The next logical step seems to be to take the carrier signals off transmission lines and send them through space by means of microwave channels. Trial installations have been made.

Looking to the future, the constant increase in speed of circuit-breaker operation puts the pressure on the relay system to operate faster. The minimum operating time of high-speed relays may or may not have reached a "brick wall" for mechanically operated relays. The further application of electronics may, in the future, shorten the time to a fraction of a cycle, if attendant problems can be solved. The ideal goal is, of course, relay operation just before the fault occurs, so that operation of the protective gear prevents the fault rather than removing it from the system after it happens. Perhaps television methods may be set to watch over the system to detect approaching trouble.

As the consumption of electric energy doubles, triples, and quadruples, we can be sure that that energy will not be transmitted and distributed simply by an extension or enlargement of present methods. Some new ideas are already in sight. Technical ingenuity can be counted on to produce more.

F. R. BENEDICT

Seldom does one find so many phases of electrical-engineering experience packed into two decades as shown in the record of Frank R. Benedict. The space here can contain only the barest outline of it.

This record in part has been possible because Benedict got a running start on engineering. Although not a "radio ham" himself, while Benedict was still in high school in southwestern New York he built and sold radio receivers. This was in 1923 and 1924, during the infancy of tube-type receivers. Ahead of college, he spent a year in instrument-transformer testing for General Electric at Schenectady, New York, and Pittsfield, Mass. Then came a college engineering education. But quick. Between August, 1926 and August, 1928—long before World War II made accelerated engineering courses popular—Benedict took all the courses for an electrical-engineering degree at Tri-State College, Angola, Indiana. This was made possible by round-the-calendar classwork, plus his experience at GE and some extra courses in mathematics in high school. To this he added the graduate-student course at Westinghouse.

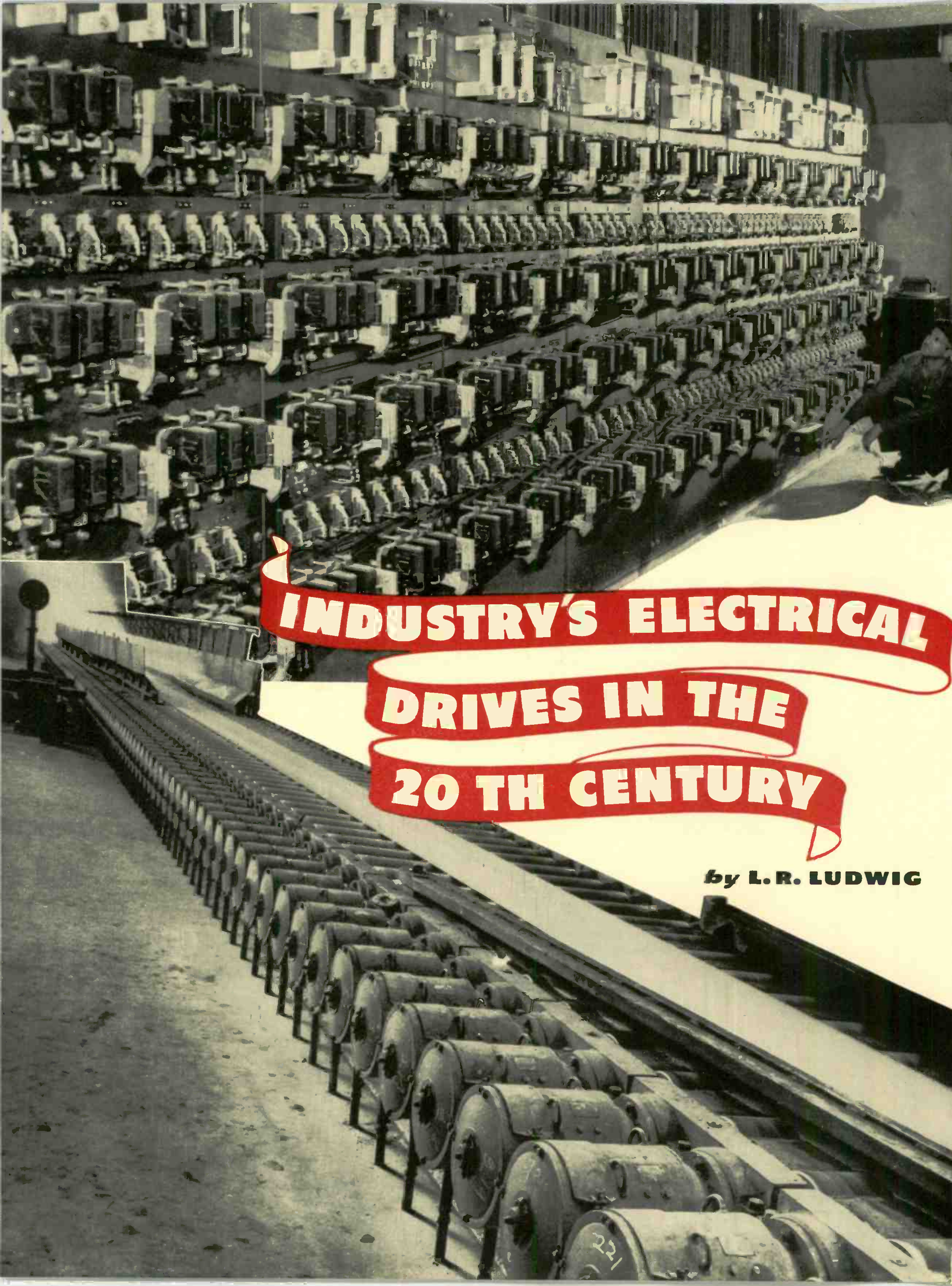
In the next nine years Benedict took a zigzag path that led him through almost every laboratory in the Westinghouse Company except the main Research Laboratories. This included the studies of natural and artificial lightning, the development of oscilloscopes and other surge-measuring devices, the application of precision bridges to determine insulation losses, and the development of all manner of protective devices. A year and a half was then spent as liaison engineer working on coordination and correlation of interplant developments, dealing particularly with materials, processes, and quality controls.

In early 1940 came an abrupt change: a turn of experience in direct contact with electrical problems in the field. This included customer application work in Philadelphia, and the managership of this same activity in New England.

Back to headquarters again (December, 1943), this time to develop a system for analyzing all field troubles with Westinghouse electrical and mechanical equipment installed in the United States.

All this laboratory, field, and apparatus experience made him a logical choice for the position of manager, Industry Application Engineering in the fall of 1945, which position he now holds.

Benedict absorbs technical subjects like a sponge. Any new engineering book in his field—and that covers a wide spectrum of engineering—is on his desk as soon as it is available. And they are not just bookshelf decorations. Benedict is a man in a hurry. He plays golf the same way. Never have we seen a golfball hit so hard or travel so far as when propelled by his swing, backed with a frame and a pair of shoulders of which any fullback would be proud.



INDUSTRY'S ELECTRICAL DRIVES IN THE 20 TH CENTURY

by L. R. LUDWIG

At the turn of the century the stage was already well set for the motorization of American industry. The two principal actors—the d-c motor and the induction motor—although amateurs by today's standards, had nevertheless undergone their rehearsals and had developed all the essential forms required for their outstanding roles in the industrialization of the 20th century.

As of 1900

Both motors could be said to be gaining maturity. Although the d-c system had an earlier start than the a-c, the two motors had reached comparable states of development. Westinghouse had been the first to offer industry a "line" of d-c motors of various ratings. This family of motors (type MP) appeared in 1894 and was still the standard model in production at the East Pittsburgh Works. Already it had acquired most of the physical forms of present-day machines. The odd-shaped bipolar construction of earlier "laboratory" models had given way to the four poles projecting inward from a circular frame, just as in present d-c machines. The value of laminated poles to reduce iron losses had been learned. The armature windings were no longer simply fastened to the surface of the rotor; they were shaped, insulated, and—importantly—laid in open slots. This innovation in the first line of d-c motors was conceived primarily to eliminate the annoying tendency of windings to slip on the surface under short circuit, yet it proved to have another and even more valuable result. It permitted reduction of the air gap from about an inch to almost one-eighth inch, which is only slightly greater than the gaps used today. Commutators were constructed substantially as they are now. The thick strips of solid mica used in pre-1894 commutators had given way, in this first line of motors, to thin, laminated mica. Early experience with railway motors showed that the rate of wear of this thinner mica corresponded more closely to that of the copper. The idea of undercutting had not yet appeared. The d-c motor of 1900 was a practical, successful motor, being applied in rapidly increasing numbers throughout industry principally to replace steam engines that were driving line shafting and for powering overhead cranes.

The induction motor had undergone a similar rapid evolution. It, however, had achieved the distinction of having its second series or line of models in production as the century mark was reached. This, even though the commercial a-c motor was born only 12 years before—in 1888. Events had moved swiftly in that memorable year. Nikola Tesla, a citizen of Austria-Hungary, had been granted a patent on the fundamentals of the polyphase induction motor on May 1, 1888. Mr. Westinghouse instantly sensed the possibilities of an a-c polyphase motor and by July 7—only 68 days later—had not only purchased the exclusive rights for this motor but also secured the services of Mr. Tesla himself. Tesla arrived, with a working model of his motor, in East Pittsburgh before the year was over. Fast work even by today's standards of communication and travel!

Then induction-motor development came to a halt. It was ahead of its day. There were no polyphase power systems on which to use it. Also, such single-phase systems then existing were of too high frequency (133⅓ cycles per second) to build motors of practical construction for speeds then reasonable. A mild business recession was a further damper to expensive development of the young a-c motor.

Not until 1893 did 60 cycles become the standard frequency—a development aided greatly by the successful demonstration at the World's Fair in Chicago that same year. A campaign was undertaken by the Westinghouse Company to popularize the polyphase generator, in fact, to make a fad of it. This met with quick success. By 1894, the polyphase system had become popular and the path was then open for further promotion of the induction motor. In the meantime, operating experience had been gained from Tesla's first motors. Clearer understanding of magnetic circuits had been achieved, and better methods of calculation had been developed. With these new resources available, the first line of induction motors (type B) was developed and put in production by 1894, and were used mostly to replace steam engines or waterwheels driving line shafting.

In sizes above five hp the stator was the secondary. It consisted of a cast-iron yoke enclosing a laminated core with partially closed slots. One bar was inserted in each slot and these were joined by end connections into a closed, two-circuit winding. Because the a-c system lines were of limited capacity, it was necessary to limit the starting inrush current. To do this, taps were brought out from the winding to resistors that limited the starting current. A switch on the frame was provided to short circuit these resistors after the motors had been started. The motor primary windings were similar to those now used on present-day stators.

This first line of induction motors had a short life—only three years—but it laid the foundation for the family of polyphase motors (type C) that was in vogue at the century's end. This was truly an epoch-making line of motors. It established the induction motor in its present leading position.

In general appearance the motor was similar to modern ones. It had a squirrel-cage rotating secondary. The stator or primary was formed of a solid cast-iron yoke enclosing a laminated core with open slots. Here was introduced the idea of stator conductors composed of form-wound coils completely insulated and arranged two layers deep in the slots, which is still modern practice. The secondary was a cast-iron spider carrying a laminated core with partially closed slots. The secondary winding consisted of rectangular copper bars connected to end rings.

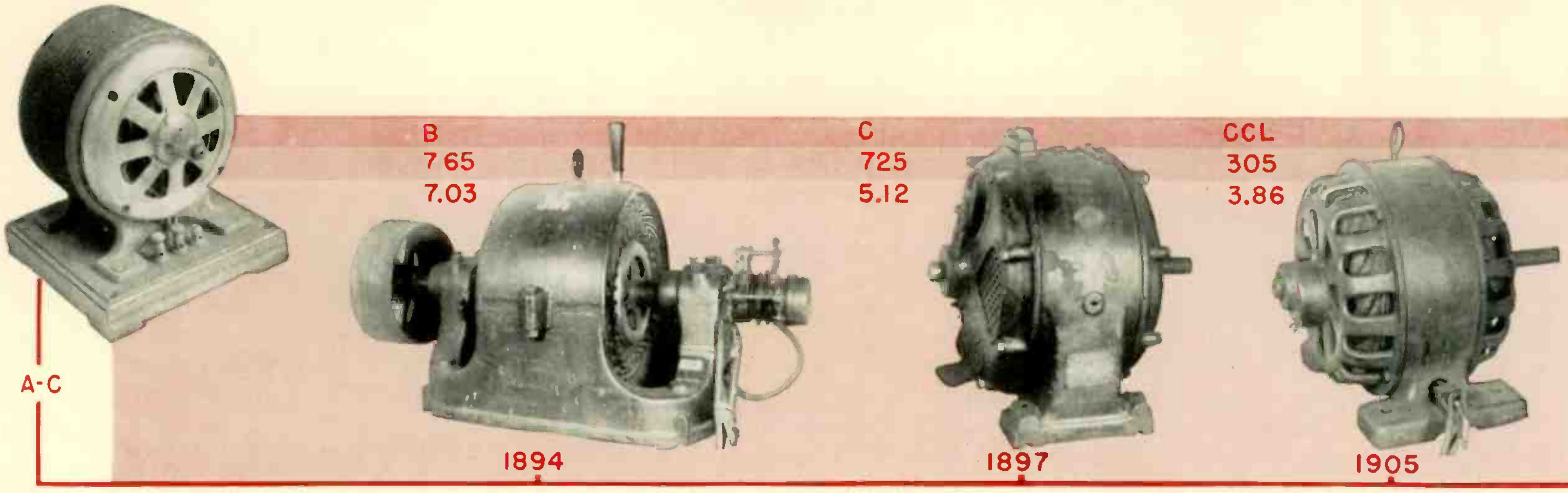
Such were the d-c and induction motors of 1900; truly good machines as indicated by the fact that requests for repair parts for them still are occasionally received.

Five Decades with the A-C Motor

The type-C induction motor of 1900 was an excellent machine. Some people at Westinghouse even considered that it had reached its ultimate design. B. G. Lamme said in retrospect, "Some fully believed that the Westinghouse motor was 100 percent perfect. However, I had my doubts."

Apparently Lamme's doubts were confirmed, because in 1905 the highly popular type-C motor had a successor (the CCL). Already the induction motor was meeting with an experience common to most new developments. When something entirely new appears, users are satisfied to have it work at all. Soon, however, their critical faculties begin functioning, resulting in a demand for refinement. Users of the induction motor began to ask for a lower cost motor ('twas ever thus!), for one with higher power factor and efficiency. Also, experience showed that the motor was greatly underrated. Doubtless, too, the decision to redesign the line was spurred by the realization that the demise of the Tesla motor patents in 1905 would augment competition.

During the first decade the use of the a-c motor was accelerating rapidly and its development was rapidly reaching the point where the benefits of mass production became significant. Improved factory methods had become available. A new motor, type CS, was designed to take advantage of these fac-



tors to obtain improved performance and lower costs. Production began in 1913.

The type CS machine was the first really designed for mass production. Modern methods of producing punchings and riveting them together to form a stator core began to be used. The slots were opened somewhat to facilitate winding. Magnetic wedges were then used to decrease the effective air gap, to lower magnetizing current, and to improve power factor.

The stator windings, of round wire or rectangular ribbon, continued to be insulated with two layers of cotton. The rotor "cage" also continued, in all sizes, to be formed of insulated conductors that might be round asbestos-covered wire, double-cotton-covered round wire or ribbon, or bare conductor insulated from the core by paper or cement.

Such was the general-purpose induction motor—the workhorse of the industry—at the outbreak of World War I. Like its running mate in the d-c family—the SK—it became a standard of comparison. This motor in its basic form was to have a long life, a fourth of a century, spanning two wars and the years of enormous industrial expansion in between.

While the essential form was retained until 1947, many important improvements were made in this interval to keep the machine up to date. About 1925 a major improvement in sleeve (journal) bearings was developed at East Pittsburgh. This was the "sealed-sleeve" bearing and it put an end to troubles with oil leakage. Industry was showing increasing interest in a greater degree of enclosure for the motor. In compliance, bracket arms were reshaped in 1925 to allow use of flat covers if desired.

Die casting of the rotor cage was a major improvement appearing in 1925. The idea was by no means new as Lamme had described a "winding of 'poured-in' copper" in 1893. But die casting to be successful and economical had had to wait on both the availability of aluminum at low cost and improved shop techniques. Die-cast rotors were much lower in cost and mechanically stronger than an assembly of many pieces. At the outset of die casting, separate blowers were retained, but in a couple of years the blowers were cast as part of the cage, with further savings in cost and a significant improvement of structure.

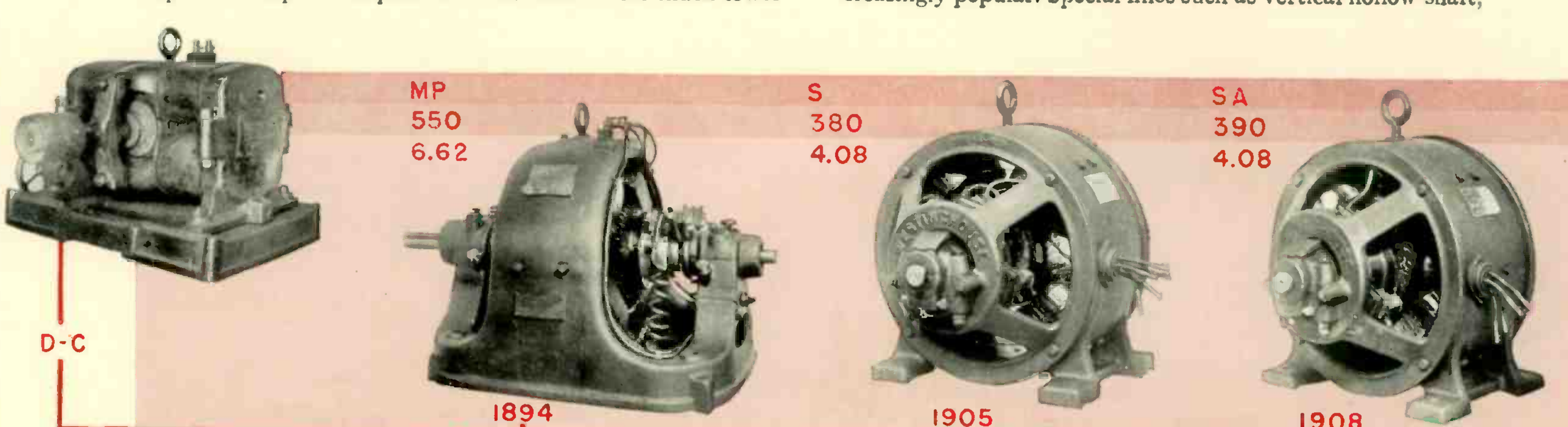
Primary-winding insulation began to show the first marked tendency to change as a result of better enamels. Enameled wire with a single layer of cotton gave improved insulation and use of space (i.e., more output from a given size machine) than two layers of cotton on bare copper.

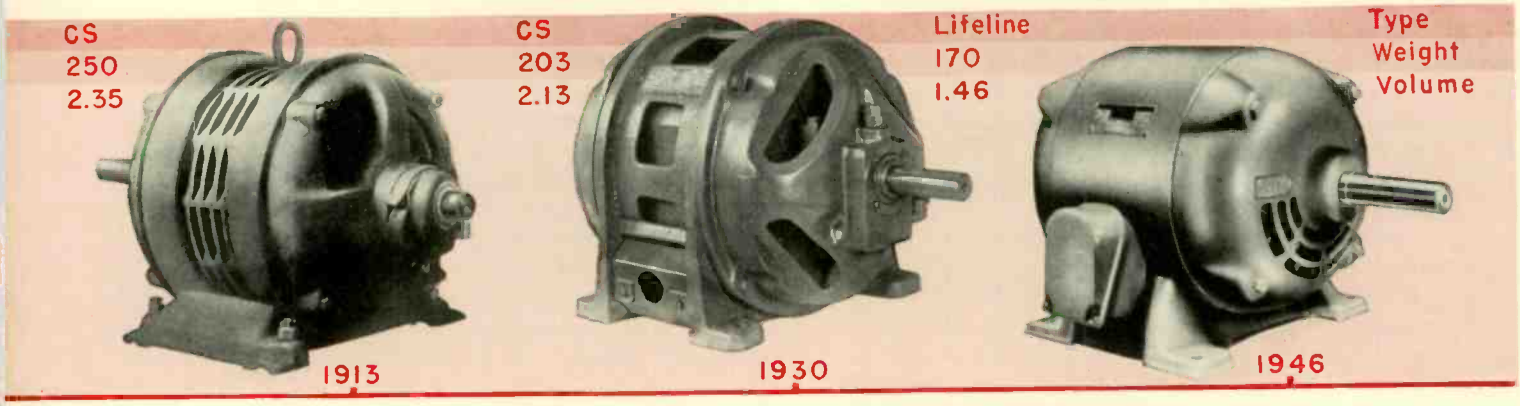
During the late 20's considerable demand had arisen from machine-tool builders and automobile makers that electric motors of different manufacturers be interchangeable. This involved the development by all manufacturers of completely new lines of motors, and required the expenditure of large sums with the user being the principal beneficiary. About 1930 the Westinghouse version of this motor appeared (the W line of the CS motor). In this line the sealed-sleeve bracket features were retained. A cast-iron frame was adopted, into which a removable stator core was pressed.

During the preceding years there had been a great increase in the variety of frames desired, such as open, splash proof, totally enclosed, fan cooled. The cast frame with removable core was selected as the best construction because it was believed that this would confine the manufacturing variations to the frame, and leave the core and windings unchanged.

The trend to new insulations, begun a few years before, continued. Round-wire primary conductors were changed from single cotton and enamel covered to paper and enamel covered about 1931, and to Tufvar enamel covered about 1944.

During the life of this design, the number of special varieties of motors increased greatly. Drip-proof, splash-proof, totally enclosed, totally enclosed fan-cooled, and explosion-proof types were developed. Ball-bearing motors became increasingly popular. Special lines such as vertical hollow-shaft,





shell-type, hermetic, and lint-free textile motors appeared.

An amazing variety of a-c motors was required from the manufacturer in order to keep pace with the various needs of industry. A 5-hp a-c motor must be available in 72 000 different forms. This large number results from the many possible combinations of phase, voltage, type of enclosure, speed, mounting, bearings and so forth.

The quantity of motors manufactured increased and finally the manufacturers decided that, due to improvements in materials and skill in design, many motors should be put on frame sizes smaller than previously. Industry standards changed accordingly. Westinghouse decided that this need plus the anticipated high demand for general-purpose induction motors in postwar reconstruction warranted a complete redesign of both the motor and the methods of building it. Taking advantage of the accumulated improvements in materials, manufacturing methods, and the specialized tools for volume production, the result, in 1946, was the Lifeline induction motor (type CSP).

This motor is all steel. That is, it uses no castings. The frame is rolled from a slab of steel and welded. The feet and end bells are deep drawn of heavy-gauge steel. Stator punchings are stacked and held between thick end plates by locking pins whose ends are tapped to receive the bolts that hold the motor end-bells. Insulation of the punchings is provided by surface oxidation obtained as part of the sheet annealing rather than by the conventional water-glass coating. Slots are more open, have rounded bottoms. New winding techniques were developed by which windings are inserted with less physical damage to insulation. The completely wound stator is treated with a synthetic varnish (Thermoset) that insulates the coils and serves as the primer coat for the steel. The ball bearings are sealed for life and require no additional lubrication throughout motor life.

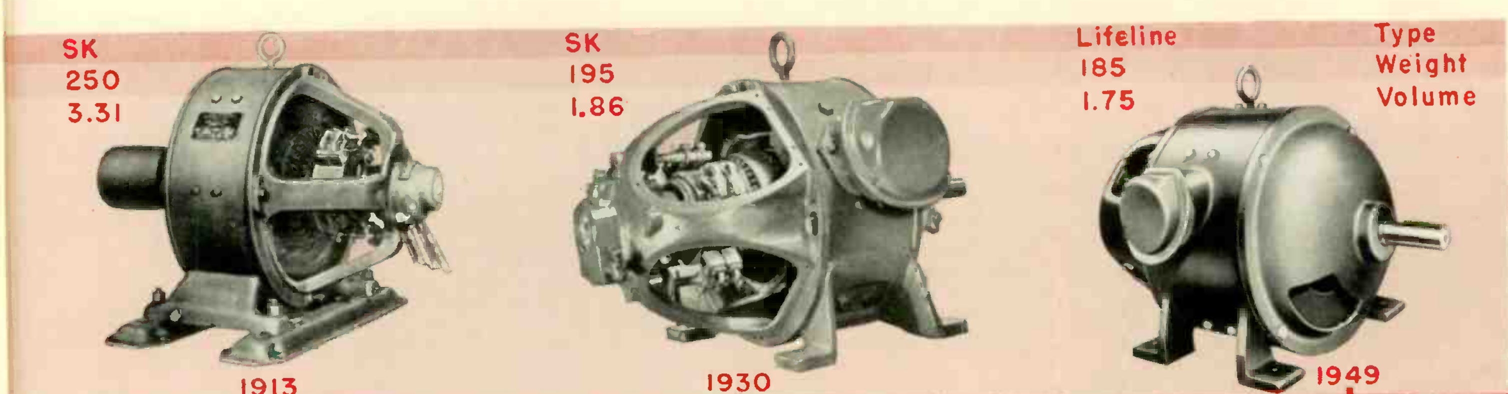
The motor is the product of special precision machines. The machining and assembly procedure is entirely new and has been planned to provide a far higher degree of concentricity than normal. The air gap is much more uniform and is held to much closer limits. As compared with its predecessors, the motor is much more precisely built, giving inherent quietness.

A degree of interchangeability of parts never before achieved is obtained. The more common varieties—open, splash-proof, open-protected, totally enclosed fan-cooled—are made from the same basic parts, with the appropriate external components. The great reduction in total number of parts simplifies stocking of spares and shortens the time between motor purchase and delivery.

The economy of space is of great importance for those applications where the motor must be shoehorned into a small space. The machine-tool field is rife with such situations. Specifically, the new $7\frac{1}{2}$-hp open motor is only 83 percent as large in diameter and 94 percent as long as its predecessor. The corresponding reductions for the totally enclosed type are 83 and 82 percent, respectively.

The Direct-Current Motor Since 1900

Although the first family of d-c motors (type MP) continued to be popular for a few years after the turn of the century, the designers began to accumulate ideas for its improvement; some stemming from the great success achieved with the type-C induction motors. The superiority of the bracket-type bearing supports over the integral cast frame and pedestals had been demonstrated on the a-c motor. As a consequence this feature was employed in the redesigned d-c motor, with considerable economy in weight. A method whereby laminated poles could be bolted rigidly to a round frame rather than having the poles cast integrally with it was found. This simplified manufacture and made it unnecessary to have detachable pole shoes to allow the field coils to be slipped into position. These and other improvements were embodied in a



new type of motor (type S) that appeared in 1905. By 1908 the idea of interpoles had been introduced in industry and Westinghouse incorporated them into its d-c motor in 1908 (the modification becoming type SA). Interpoles represented an enormous advance in the d-c motor art because of the improved commutation obtained and the elimination of the device to shift brushes with load changes.

But d-c motor design art was moving swiftly. Even with the improvement made by addition of interpoles, this construction was to have a short life of only six years. In 1911 a new d-c motor appeared. It was so advanced in design that it was destined to be the leader in the industry for many years to come. Even its type designation—SK—became a symbol of excellence. Only within the last few months has its retirement begun in favor of a new design.

The SK motor incorporated many new features, several being innovations to be adopted later by other manufacturers. Many are still in vogue. The cast frame was abandoned in favor of rolled-steel frames. Pressed-steel feet were riveted to the circular frame. Brushholders were mounted on rods pressed into the end brackets instead of rocker rings made up of a multiplicity of parts. The gain was both simplicity and rigidity. The shunt and series field coils for the first time were made separate.

Two matters are important in interpreting d-c motor progress throughout the recent decades. One is that the creation of the SK motor was one of those occasional occurrences in engineering in which a new design is far in advance of its time. Without question that motor in 1911 represented far more than the usual advanced thinking embodied in a new design. The exceptional performance of this motor, with only detail improvements from time to time, for so many years stands as excellent tribute to its creators four decades ago.

The d-c motor must, in addition, be viewed in the light of a basic change that occurred in the industry it serves. Originally, industrial plants were equipped with d-c distribution systems. This made the d-c motor the natural, logical choice for run-of-mine use. Thus the industrial environment was favorable to the extensive use of the basic varieties of d-c motors. Then began a gradual change in that environment. Alternating current began to be the system for electric-power distribution in factories. Since the early 20's the swing to a-c distribution in plants had accelerated, becoming particularly pronounced during the recent war as the network system found favor for newly constructed plants. Thus the induction motor began to usurp jobs previously assumed to be the province of the d-c motor. For general-purpose, constant-speed work, the induction motor is being used more and more; the d-c motor less and less. Now the d-c motor is almost never used if an a-c motor can do the job.

In view of this trend, many have predicted for two decades the virtual disappearance of the d-c motor. But again the prophets were wrong. The d-c motor has not disappeared. Far from it. The sale of d-c motors has increased by about one half since the early 20's. Furthermore, the d-c motor will continue in heavy demand far into the future. Not as a constant-speed motor, but to do those things for which the d-c motor remains unchallenged—adjustable and precise speed control. Even here surface appearances suggest that the d-c motor is waging a retreating, defensive fight. As the swing to a-c distribution becomes more complete, the pressure to use induction motors for work previously done by d-c machines mounts. Frequently ways are found to permit the a-c motor to take over some of the d-c motor's adjustable-speed functions. But as with Hydra, the multi-headed serpent, for every old job taken away two more spring up that only the d-c motor can handle. Furthermore, the pronounced trends in industry for higher speeds and for much more exact process control emphasize this situation. Uses for d-c motors are increasing, not decreasing.

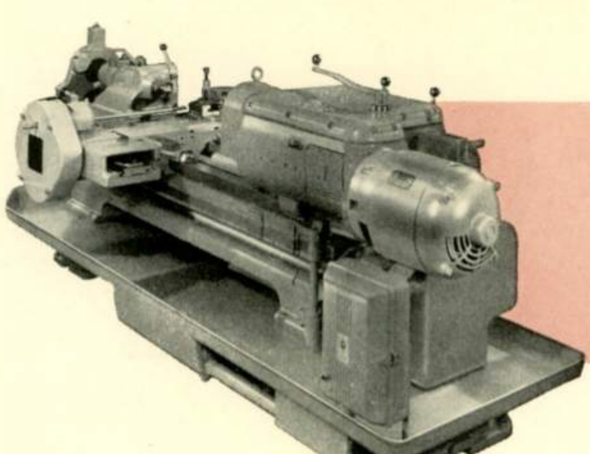
The changing industrial picture has had an important bearing on the development of the d-c motor. It has become more and more a specialist. The emphasis has been to improve its performance as such with minor regard to those things like efficiency and no-load losses, which are of primary importance for a constant-speed motor.

The D-C Motor of Today

Technical progress is inexorable. Eventually the time comes when any design—no matter how much genius it contains and how much detailed improvement is fed into it—needs to be completely overhauled. The long successful SK motor is now undergoing replacement by a new design. The new machine is being termed the D-C Lifeline.

As has happened before, the d-c motor is profiting by design and manufacturing techniques developed in connection with the high-volume polyphase motor. The swing to steel, away from cast construction, is now complete. Because of the favorable experience with pre-lubricated, sealed ball bearings on the a-c motor, these are being adapted to the d-c machine. The new motor, too, adheres to the trend that motors be more completely enclosed against dirt and moisture. Armature coil conductors, bare, enameled, either round or ribbon give higher insulation strength with less space occupied by insulation. This and changes in proportions reduce the overall size.

As motor designs have improved and costs have been reduced, the application of motors has increased tremendously, not only in volume, but also in the type of industries and drives to which they have been applied. The steady application to new industrial problems has often been the result of a sprint in growth of a particular industry. For example, the onset of air conditioning, about 1930, brought with it a need



At left is a typical use of a modern induction motor and, right, a battery of similar splash-proof motors in a food plant.

for a tremendous number of compressor, pump, and fan motors. Many of these had to be highly specialized types since they operate in the atmosphere of a refrigerant such as freon.

The danger of fire in mines caused the development of greatly improved explosion-proof motors. The difficult operating conditions encountered by mine equipment demanded a new standard of ruggedness and protection against dirt and coal dust.

In the machine-tool industry, a single motor for each machine used to be the rule. Now, however, there are often several driving motors and a number of auxiliary motors. It is not unusual to find six to twelve motors on one machine tool; occasionally, as on transfer-type machines, as many as 50 motors are used. Vibration problems are critical on machine-tool operations and this led to a demand for precision and balance of the electric motors employed.

The chemical industry has made demands on the motor designers' ingenuity to utilize materials and means of construction to resist highly corrosive chemical fumes and moisture. Splashing liquids have caused many motor failures, not only in the chemical industry but in packing plants and the paper industry. In oil fields the exposure to severe moisture, rain, sand, and dust led to the use of motors that are nearly totally enclosed.

Many other special problems have appeared and have been dealt with. Such things as: the demand for quiet operation requiring precision machining, perfect balance and elimination of magnetic noise; the necessity for high or low speeds requiring vertical or horizontal gear motors; the conditions of motor operation in exceptionally high temperatures requiring the use of glass or silicone resin insulation and special bearing grease; and the multitude of single-purpose motors requiring particular mechanical constructions (such as the close-coupled pump motors) have all required a vast amount of special development. Many special forms are now in use.

Since no one motor design can readily meet all of these special requirements, the business of manufacturing motors has become highly specialized with thousands of unusual designs in production to meet industry's demands. To discuss even a fair number of them in the space allowed here would be an obvious impossibility. Hence, this discussion has been arbitrarily limited to the general-purpose d-c and induction motor. Synchronous and wound-rotor motors are skipped.

Control Parallels Motor Development

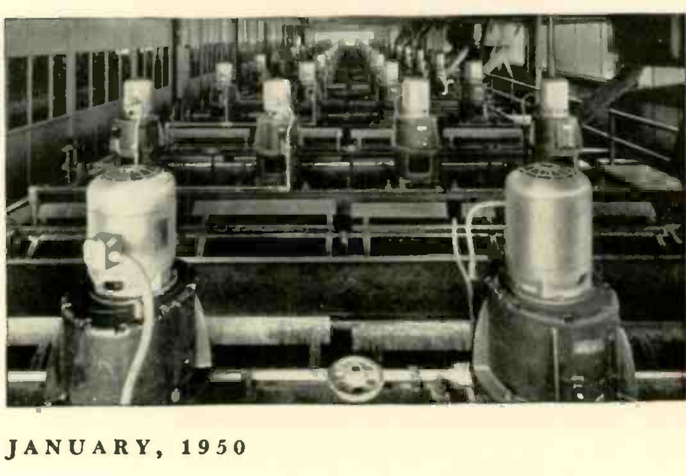
The same factors that have had a marked effect on the fortunes of the d-c motor have applied to the evolution of motor control as well. The motor and the control for it have been coming closer and closer together. Increasingly greater importance is being placed on the concept of the fundamental function—that of a complete drive and not so much as motors and controls as separate entities. While this is particularly true of the d-c equipment, it also holds to some extent for the a-c apparatus.

Control Devices—Originally, no doubt, motor control consisted of a simple knife switch of one, two, or three poles as the situation necessitated. Very quickly—as motor sizes increased—other control elements were required. Resistors—either permanent or variable in the form of rheostats—became necessary for a-c and d-c motors. Early polyphase motors were started with resistances built into the machine or external to it for limiting starting current. For speed control of d-c motors, adjustable resistances for use in varying the field current were required. As a consequence there was begun a development of resistances and rheostats that is continuing today and comprises a subject in itself.

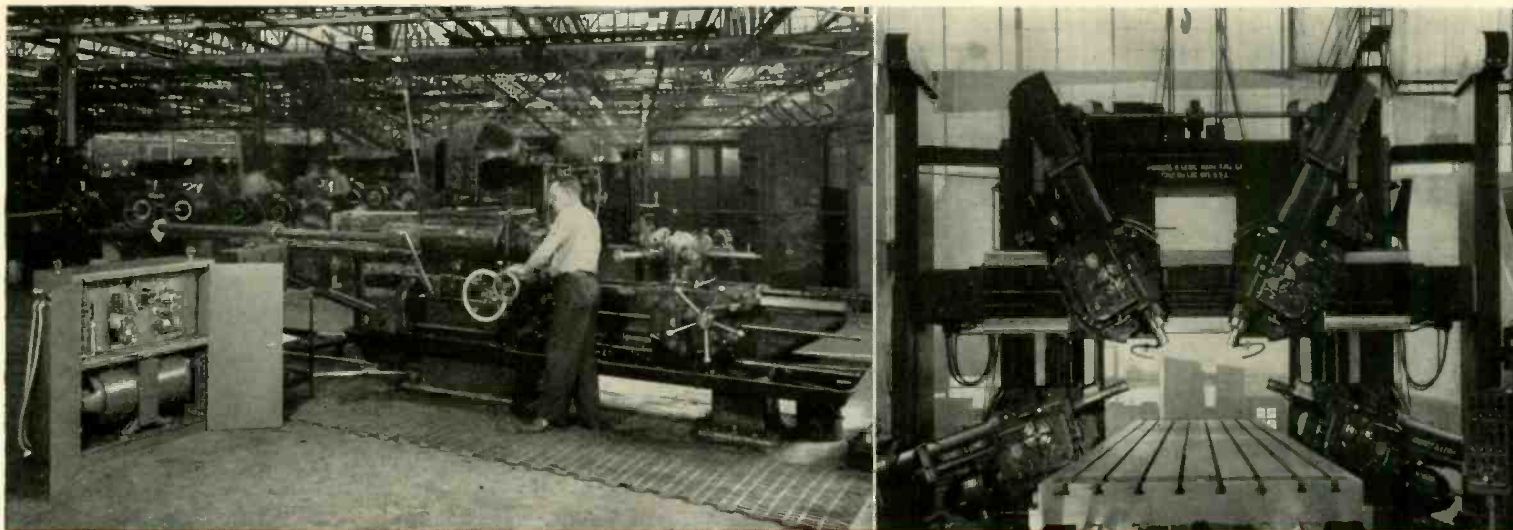
One important early control device that necessity mothered into existence was the autostarter. This novel device appeared along with the Westinghouse type-C induction motor in 1897. The starting current on full voltage of these motors was from six to eight times normal full-load current; more than commercial circuits would permit. B. G. Lamme suggested that by properly proportioning the self-induction of the squirrel-cage motor, greater than full-load torque could be obtained at standstill, even at less than full line voltage. He then proposed a reduced-voltage starter—heresy at the time. Engineers generally believed a squirrel-cage motor inherently possessed a low starting torque and that, therefore, a combination of an auto-transformer with it to reduce the starting torque further bordered on the absurd. Nevertheless, the autostarter appeared and continues today as an important equipment where limitations on starting current exist.

About 1912 distribution systems had grown in capacity and induction motors had increased in ruggedness to the point that full-voltage starting was often possible. This gave rise to the linestarter, which now predominates as the method of starting induction motors.

As in the early days, motors became larger and a means of stopping them, i.e., of interrupting the load current, became an increasingly severe matter. The arc resulting from the opening of knife switches soon became too vicious. Some methods for disposing of these arcs had to be provided. At first the circuit was opened in several places simultaneously—the principle of divide and conquer—but these devices were bulky and expensive. A decided improvement resulted when magnetic blowouts were used. The origin of this idea of using the electric current to destroy itself is obscure, but it was one of the early major inventions among electrical apparatus. This important principle is still used, although magnetic blowouts have undergone an evolution into the effective form of a single current-carrying coil in series with the arcing contacts. Arc-box shapes and materials have been improved to reduce burning.



A forest of vertical Lifeline gearmotors power flotation cells at a large phosphate mine. Most of the 119 motors are 7½ or 10 hp. At right is an induction motor with sealed bearings built into a milk homogenizer.



The Westinghouse motor plant uses many d-c motors but has no d-c bus. Each d-c motor has its own a-c to d-c conversion unit, of which one of the rotating type is shown at the left of the machine tool. In the right view is a multiple-head machine tool made possible by the flexibility of modern motors and control.

An invaluable development in contactors was an outgrowth of Dr. Slepian's promulgation, in 1928, of the De-ion principle of a-c arc interruption. It was shown that if an a-c arc be split up into a number of short arcs between plates or grids it would not re-ignite after the first current zero. Here was a return to the old idea of breaking up the arc between several sets of terminals. However, the function was improved immeasurably by placing the terminal grids close together where their rapid de-ionizing action produced almost instantaneous ability to resist re-establishment of the arc after reaching the zero point of the current wave. Unlike the magnetic blowout, which permitted the arc to exist for several cycles until it was stretched to its breaking point, this idea prevents re-ignition of the arc a half cycle after it has struck between the grids. Noise and flame are materially reduced and reliability is increased because there is less ionized arc gas to give trouble. More compact construction is possible; a lower cost results from elimination of blowout coils, and load losses are smaller. The use of the De-ion principle in a-c controller designs has brought about almost complete abandonment of magnetic blowouts in the lower ratings of magnetic controllers for a-c motors.

Other motor-control devices were created and underwent important evolution. These include overload relays that give motors a better degree of protection than is provided by fuses. Magnetic contactors, by which the closing of the switch is accomplished magnetically instead of manually, came into extensive use during the first decade of the century. Pushbuttons in a variety of enclosures have undergone steady improvement.

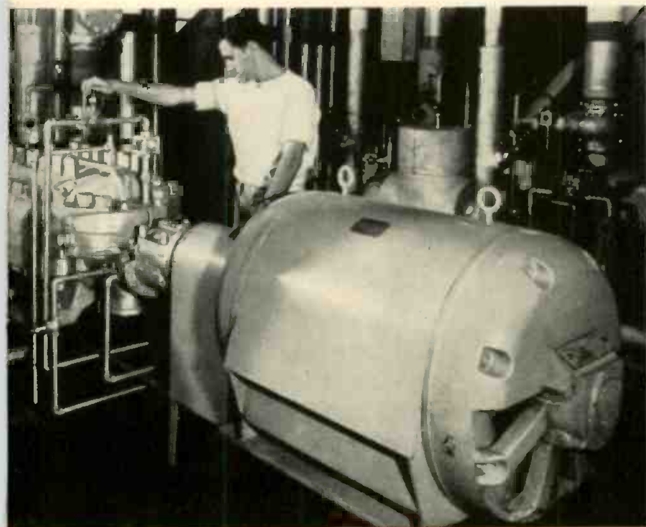
Control Application—The many devices used in different combinations and sizes for motor control took their essential form several decades ago. They have been importantly but unspectacularly improved in detail. But for the most part, the work of the control engineer, particularly in the last quarter century, has been something else. It has been the creation of control systems—the assembly and coordination of a wide variety of control devices and motors, often of special characteristics—to perform some specialized service in industry. This has particularly been true with d-c motors.

Originally the control engineer had only to provide a means by which a motor could be started and stopped. Then the idea developed that by introducing special control devices the work of the operator could be simplified or he could accomplish more if certain basic motor-control functions could be made all or partially automatic. Such were the provisions for automatic acceleration at a predetermined rate independent of how the operator moved the controller. Passengers in elevators and streetcars get a smoother ride thereby. With such control a hoist motor cannot be made to draw excessive current during starting.

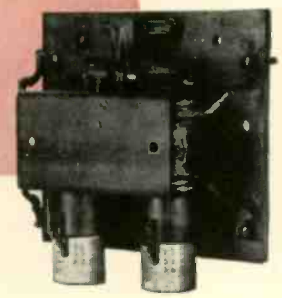
But these early control contributions were primarily aimed at taking over some of the tasks of the operator, but which he might conceivably have continued to do. Industry, however, did not stop here. Processes grew in complexity, requiring not one drive but many, necessitating coordination of their actions. Complicated duty cycles appeared. Machine speeds increased enormously. Precision operation became the order of the industrial day. The modern cold-reduction mill illustrates well this point. Steel races through four or five roll stands, spaced only a few feet apart, emerging at speeds in excess of a mile a minute. The d-c motors driving the individual rolls, each of several thousand horsepower, must run at synchronized but different precise speeds, maintaining proper tension so as not to develop slack in or tear the thin sheet. These motors must accelerate and decelerate with exactitude. The motors driving the unwinding and winding reels must change their speed as the coil diameter changes, all the while maintaining the prescribed tension.

These things, and many, many others no human operator could hope to do. It has fallen to the control engineer to contrive systems by which all this can be done for him. In fact, the control apparatus and application engineer are asked to work in two contrary directions at once. Industry, under the pressure of increasing output and quality per worker, calls for more and more intricate and precise drives. Yet, in the interests of reliability of service, maintenance, and costs, he is asked to make them simpler. A large order indeed, but the control engineer has accomplished this to a surprising degree.

One of the brightest chapters in control history opened when engineers began to use a rotating machine to control rotating machines. This form of rotating regulator—called the Rototrol—made its first appearance in 1928, as a means of regulating speed of elevator motors. Essentially, the Rototrol



One of the largest Lifeline induction motors is the 600-hp, 3600-rpm unit (shown at left) driving a boiler feed pump. Each of these direct-current motors (right) drives a section of a papermaking machine. All machines must remain in step regardless of output speed.



Representative tools of the control engineer are this single-pole contactor (right) and magnetic overload relay with oil dash-pot (lower right).

One of the "old-reliable" controls is the reduced-voltage manually operated autostarter, which is still widely used.

is an a-c driven generator equipped with additional control fields. These fields are supplied with a current representative of the quantity to be regulated. Variations in this current are amplified in the Rototrol output, theoretically a million times if necessary, becoming ample to operate the correcting machine.

From the inception of the use of electrical circuits, the simple expedient of a mechanically moving contact has generally been used to start or stop current. With radio, however, came a new method of controlling electric currents of small magnitude. In 1907 DeForest invented the three-electrode vacuum tube. This amazing device had the property of being able not only to open or close a circuit, but also to control the magnitude of current, and to do it without the use of mechanically moving parts. While this invention itself had no effect on power circuits, it, in combination with the discovery by Peter Cooper Hewitt in 1904 of the basic principle of the mercury-arc rectifier, did have a profound effect. Some years later the third electrode or grid employed by DeForest was used to control the rectifier and, as a result, power electronic tubes became available. In 1930 a new form of the power tube, the ignitron, was invented. This device made it possible to start and stop electric currents at will without a grid, simply by energizing the ignitron electrode.

These power-tube developments opened vast new possibilities to the control engineer. Now, instead of using switches or magnetic controls to open and close electric circuits, he could employ an electronic power tube with its greater advantages. In highly repetitive operations, the mechanically moving contactor does not lend itself to great rapidity of operation. The inherent burning by the arc in such a contactor of necessity limits contact life. The electronic power tube, however, can go through billions of operations and can open and close a circuit at nearly any rate of speed. An additional advantage of either the grid-control tube or the ignitron is the possibility of delayed circuit closure each half cycle, thus giving control of the output voltage. In other words, these tubes can do more than simply open and close the circuit, they can control the rate of power flow through it.

Control engineers have introduced these electronic devices into practically all phases of industrial electrification. Resistance welding, for example, became really important with the development of the power tube. Variable speed d-c motors, in which the speed control is obtained by varying the current flow in both armature and field circuits, became possible. In consequence the Mototrol was developed. This is the combination of power tubes with a d-c motor and auxiliary tubes to effect ignition of the main supply tube. Exact speed control is obtainable over a range as high as 100 to 1.

Another interesting electronic application is the detection of fault in sheet steel or tin plate by photoelectric tubes, which in turn control electronic regulators. The electronic regulator itself has been widely developed and applied to many special drives such as paper mills, in which extreme accuracy to 1/10th of 1 percent in speed is required. Voltage regulation as well as speed regulation is easily obtained by electronic means and many applications of electronic controls are found in the voltage-regulator field.

While improvements in control components are important, the main task in control is to take these many elements—including one or perhaps several adjustable-speed motors of either standard or special characteristics, regulators of the Rototrol, electronic, or electromagnetic type, tachometers or other sensing elements, electronic tubes, rectifiers, contactors, relays, and many others—and weld them into a harmonious whole to perform some special industrial function. This may be to control the loop on a moving strip of paper or steel; the control of welders and motors on a continuous pickling line in a steel mill; the printing of multicolored designs on paper; the cutting of rapidly moving steel sheet to correct length or the trimming of printed designs at precise locations.

Tomorrow's Drives

Engineers are pleased with the modern motor and control that have been the product of six decades of intensive development. The basic fundamentals of these devices are well understood and details of design have been worked out to a fine point. It is an interesting question, therefore, as to how much further development is possible in the designs of motors and control, which have been re-worked so many times already. Can we expect that the future still holds real possibilities for development and, if so, along what lines can these improvements be made?

No skill in prescience is required to see a continuation in some of today's marked tendencies. For example, the degree of enclosure has been steadily increasing. Today not only are there various degrees of enclosures of the general-purpose motor but also enclosures to make motors suitable for specific services—such as the explosion-proof construction for hazardous atmospheres, the chemical motor, the lint-free (textile) motor, the sanitary food-industry motor, and so on. This seems to be leading to a single, completely enclosed, self-cooled motor that can be used for all the jobs now requiring the general-purpose fan-cooled motor and for many, if not most, of the other applications demanding special enclosures.

The problem is principally one of ventilation. Today's totally enclosed motor larger than 5 hp must be on a larger frame size than the open, ventilated machine for an equivalent horsepower rating. To overcome this disadvantage it is, of course, possible to permit the motor to run at a higher temperature—if insulations are available that permit it. The recently developed silicones may supply the answer to higher temperature insulations. However, a "hot" motor has disadvantages from the standpoint of bearings and personal hazard. Therefore, some way must be found to maintain a reasonably cool motor frame even though the electrical parts may run at quite elevated temperatures. There are, of course, other possible solutions to the problem which may involve a radically new method of cooling, such as employing the latent-heat of vaporization of a liquid.

It is interesting to speculate as to what might happen if the means used to develop such totally enclosed motors were applied to the simple open motor. For example, it is quite possible to use silicone insulation and build an open motor on a two-hp frame that will handle ten hp continuously. This would mean a great reduction in size and weight. A new problem arises, however, in that the power-factor and efficiency of this smaller design motor would be objectionably low. Also, consequent problems of thermal expansion must be considered. The materials and process engineer may some day aid the designer by providing electrical sheet steel with sufficiently improved characteristics. If this could be done, the power

L. R. LUDWIG

Had this review been written ten years ago, L. R. Ludwig, instead of authoring the section on motors and control, would have, with equal authority, written about circuit breakers. Ten years before that, he was writing as an expert on the newly invented ignitron rectifier, in which he had an important part. This rapid diversification suggests one of two outstanding Ludwig characteristics, adaptability. The other is the capacity for intense concentration, which probably is father to the first.

This ability to switch from one field to another—and quickly become a master in it—has been demonstrated many times in both his vocations and avocations. There was an indication of this early in his career at Westinghouse, which began shortly after graduation (B.S. in E.E.) at the University of Illinois in 1925. After three months in Westinghouse engineering school and three months in design school he was selected to work in the office of R. E. Hellmund, Chief Electrical Engineer of the Company. In 1929 he was awarded a Lamme Memorial Scholarship, which allowed him to spend a year at the University of Berlin, Germany, making a special study of conduction of electricity in gases, vacuum tubes, and mercury rectifiers. Returning to Pittsburgh in 1930, he was named section engineer in charge of mercury-arc rectifiers. It was then that he worked with Dr. Slepian at the time of his discovery of the ignitron principle. Ludwig also helped reduce this valuable discovery to commercial form.

In 1935 came the first abrupt shift in duties. He was made manager of the Protective Devices Engineering Department, which included lightning arresters and circuit breakers. As such he made several important contributions to the compressed air circuit breaker, then making its debut. During the war Ludwig played a prominent role both at Westinghouse and in the industry at large in the development of shock-absorbing breakers needed by the Navy.

For the better part of a year, in 1943, Ludwig became virtually a commuter between Pittsburgh and Berkeley, California, as Westinghouse rushed to completion essential switchgear apparatus for the then super-secret work of Dr. Lawrence of the University of California, which led to the atomic bomb. He averaged one trip every three weeks.

Late in 1943 came another sharp break in his career. He was asked to assume full charge of the Motor Division, which activity bears about as much relation to circuit breakers as a motor does to a circuit breaker. At the war's end came the monumental task of moving, physically, the entire motor activity—engineering, sales, and manufacturing—to a big-as-all-outdoors factory near Buffalo, New York, and at the same time preparing for manufacture of a revolutionary new type of induction motor.

Rapid change of pace, we say, is a Ludwig characteristic. When in Pittsburgh his photography was good enough for his prints to hang in invitation exhibitions. His woodshop and his cabinet-making skill were the envy of his friends. But the accumulation of managerial responsibilities and the move to Buffalo has put an end to those time-consuming pastimes. Now it is sailing and accordion playing—and in these he is becoming proficient, a logical result of intense application.

factor, torque, and efficiency of these physically smaller motors might be made acceptable.

Induction-motor stators are still relatively complex structures, as the rotors once were. The stator structure will probably sometime be simplified by die casting a frame around the core of laminations.

A considerable amount of the labor spent in building induction motors is in placing the coils in the slot. In the future the motors produced in largest quantity may be machine wound. This would make it particularly desirable to eliminate the slot cells now used to insulate the stator conductors from the stator core, perhaps by an insulating coating over the core. Experimental motors have been built and operated successfully in which the slot cells were replaced by a varnish coating. Perhaps an electro-chemically produced or chemically produced insulating coating may offer a better answer to this than a varnish coating.

Reduction in maintenance is always desirable. The principal causes of motor failure continue to be bearings and windings. The recent progress in adapting sealed ball bearings is a long step in reducing maintenance cost. Such motors have been in service for 12 years with no lubrication or change in the bearings. Progress in this direction is being made in insulations to reduce winding failures, but there is still room and demand for much further improvement.

It is still the motor designers' dream that he will some day design and build a winding that cannot be burned out or caused to fail. The winding, too, could be made to endure for the life of the motor. This, of course, if continued indefinitely would lead to a motor with infinite life. Actually, however, it will have a practical life, as the life will end when a still better motor makes retirement necessary.

The need for a drive adjustable in speed over a wide range —up to a ratio of several hundred to one—and subject to precise control and perfect regulation is still a pressing one. It is the reason for the long-continued demand for and use of the d-c motor. Schemes have been devised to employ the d-c motor on an a-c power supply. The motor-generator set (adjustable voltage) is unbeatable in performance, but is costly. A number of simplified rotating adjustable-voltage drives are in wide use. Various combinations of rectifiers and d-c motors, such as the electronic rectifier and motor combination, called the Mototrol, have their place. In the Buffalo plant, most modern of all motor manufactories, no d-c power supply is available. Each of the many d-c motors in use has its own a-c to d-c power supply. But these systems call for the d-c motor with its commutator. While the commutator—essentially an assembly of hundreds of elements, metallic and nonmetallic with widely different mechanical and thermal properties—has long been looked at askance, the fact remains that it is still the cheapest wide-speed-control device. This may not always be so. It would seem that development of a superior form of tube-type frequency converter might challenge its position and enable the simple induction motor to remain supreme. A highly desirable goal, but one that is not immediately obtainable.

Better motor controls are needed. Control engineers, always being pushed for schemes to control more complex drives, have need for electronic tubes of vastly increased life and rating. The trend toward smaller tubes and ones more consistent in performance characteristics will be a great help to the control engineer. Likewise he is looking toward improvements in other components such as resistors and condensers.

Semi-conductors have already invaded the industrial control field in the form of copper oxide and selenium rectifiers.

Electronics has now taken over many industrial plant-regulating functions. This one is an electronic regulator for the speed control of a sectional paper-making machine.

These simple devices do not permit the control that the grid provides in an electronic tube. However, the recently developed Transistor, using semi-conductors, does permit the tube type of control. At present they are limited in power-handling ability, but probably a way will be found by which the magnitude of current and voltage, which these devices are able to handle, can be increased. The ruggedness, lack of vacuum, and heat for the cathode make them inherently applicable to many control problems. They may, therefore, make obsolete many present electronic devices and extend control applications where the tubes and components of today's construction are considered inadequate.

We can look some day to the end of the present contactors with their open arcs. The arc flame is a nuisance, is noisy, is gas-producing, is destructive of materials. The need is for some form of circuit-opening device in which the arc is completely enclosed. This may take the form of a mercury switch, with an atmosphere of inert gas, or perhaps a substantial vacuum. With such a contactor, control panels would be smaller, simpler, and tend toward less maintenance.

Looking boldly to the future, we believe we see as our long-range objective a drive that is quite unlike any in today's catalogs. This will be a burn-out-proof motor. The windings, like the ball bearings of today's Lifeline motor, will have indefinite life. Moreover, the motor will have complete built-in thermal and overload protection, as do transformers, and will contain its own starting equipment. It will be a packaged drive in the full sense of the term, requiring only a foundation, electrical leads to pushbutton and power supply, and a shaft connection. Motor and control designers look forward hopefully to the day when they can offer to industry not just the many elements of control, protective devices, and a means of converting electrical to mechanical energy, but an integrated drive, compact, fool-proof, self-protecting, maintenance free. They are mindful that the day must come when a process shutdown, with its enormous cost, must not be chargeable to the motor or its control.

Never have designers enjoyed the luxury of so many new materials, so many improved ones, or so many superior manufacturing techniques as now. With this in mind it would seem that the development to be expected in motors and control in the future would proceed at an increased rate. In all probability, more new things can be expected in the next few decades in this field than have been produced in those past.

LIGHT YESTERDAY AND TOMORROW

by **S. G. HIBBEN**

As the New Year's eve bells rang in the 20th century, celebrants danced under the yellow light of carbon-filament lamps or—in the less ornate places—under gaslight chandeliers. After the ball, they walked home in streets sketchily lighted between pools of gloom by either gas or carbon-arc lamps. Arc or "arch" lamps, known as "electric candles," had lighted some streets of Paris during the 1878 Exposition, and by 1885 were rather widespread—sometimes clustered on high masts in the city square, sometimes in front of the merchant's store. Gradually they advanced across the American continent to illuminate the streets of places as remote as Salt Lake City. But they were too big and too awkward to bring indoors, except in the largest establishments, and fresh carbons had to be inserted every few dozen hours. Gas was still the champion.

Hansom cabs carried kerosene wick lamps in 1900. Steam trains had kerosene headlights, and Pintsch gas lamps flickered overhead in the coaches. Actors performed in front of acetylene footlights and miners' lamps burned whale or lard oil—and smoked! Chiefly because of the cumbersomeness of the illuminants, the uses of light for decoration and many other present-day practices were then unknown.

In the towns, gaslights were popular in ceiling chandeliers and wall brackets, particularly burners wearing incandescent fabric caps impregnated with thorium and cerium oxides—the familiar Welsbach gas mantles. In the less-populated areas, where natural or manufactured gas (from soft coal) was not available, kerosene lamps provided the only portable light source. Dry batteries, small, portable lead-acid storage batteries, and flashlights were yet to be born.

Although the "practical" electric lamp bulb actually was over 20 years old by 1900, electric lighting was not universal until well into the 20th century. In general, electric lights in the first decade of this century were restricted to homes of the wealthier citizens, clubs, hotels, and some streets, or to the decorations of pageants and world's fair buildings such as the Pan American Exposition in Buffalo. Understandably enough, the convenience and cleanliness of electric lighting were featured more than economics. For example, consider the advertisement of a large utility company:

> "Electric Light is Bright as Sunlight! . . . Why offend your nose with vile smelling oil? . . . Why handle a dirty, smelly oil can? . . . Why be constantly bothered with trimming of wicks? . . . Why be constantly breathing smoke soot? . . . Why—if you can get Electric Light? . . . If you know a reason why—phone us. . . . If not—phone us anyway!"

Because of the physical and economic obstacles, the change to electric light was necessarily slow. Alternating current of 60-cycle frequency had yet to be accepted, rubber-covered wire approved, and voltages upped from 50 or 55 to 110. Even in 1910 there were still some ten million American homes lighted wholly by gas or oil. Nevertheless, when a scintillating 2000-bulb electric sign in New York City welcomed the advent of the 20th century, man-made electric incandescent lighting, albeit with timid steps, was on the march! When the Spanish-American War ended, the era of incandescent electric lighting had truly begun, and the growth-rate of doubling every decade had been established.

The Incandescent Lamp

Even before the century was well on its scientific way, it became evident that this was to be the era of rapid and dramatic lighting progress. The stage had been set during the late 1800's by the development of voltage transformers, polyphase alternators and meters, and of good carbon-arc lamps, and promising lighting-fixture glassware for both gas and electric lamps. Distribution systems of 10 000 volts and higher were carrying alternating current afar to a plurality of lamp sockets, where incandescent carbon filaments in bulbs were, in growing numbers, duplicating the same quality of yellow but steady light that had amazed the visitors at the Columbian (Chicago) Exposition of 1893.

Carbon Filaments and Their Limitations

This, then, is where our story rightfully starts—with George Westinghouse's promotion of the electric light as a means of demonstrating his a-c generating system. This was successfully accomplished in Chicago with 89 000 "stopper" lamps, consisting of a glass globe "corked" by a glass stopper, upon which a carbon filament and iron lead-in wires were mounted.

Mr. Westinghouse had entered the lamp business by purchasing the Sawyer-Man Electric Company in 1888, five years before the Columbian Exposition opened. The firm, founded ten years before by William E. Sawyer and Albon Man, Sawyer's patent attorney, owned several basic lamp patents including one for a carbonized-fibre filament.

The Edison patent on a one-piece glass bulb, which had been in litigation at the time of the Fair, expired a few years thereafter and Westinghouse resumed manufacture of one-piece carbon-filament lamps—but with a notable improvement. Engineers found that when the filament was treated in a hydrocarbon atmosphere, lamp life was extended, and its burning was more uniform. The filament material, a cellulose of nitrated cotton called tamadine, was dissolved in zinc chloride and squirted through platinum dies into alcohol to harden. In retrospect this seems a simple process, but even the final step—carbonizing the filaments in crucibles packed with carbon dust—required a masterpiece of effort to avoid warping.

At best, however, carbon-filament lamps produced only about four lumens per watt, and their burning life was irregular, averaging but a few hundred hours. Trouble was, these filaments were prone to evaporate in a high vacuum. However, the metalizing or hydrocarbon-treating process did result in a significant advance—it caused the filament to be self-regulating, because its resistance, as in a metal wire, increased with the temperature and limited the current.

In 1897 Mr. Westinghouse bought the American rights to an incandescent lamp developed by Dr. Walter Nernst, a German physicist. This lamp utilized "rare earth" oxides as illuminants, and was popular in store lighting until more convenient filament lamps appeared. With an efficiency about 50 percent greater than carbon lamps, the Nernst "glower" lamp could be burned in open air, and produced a beautiful white light, close to sunlight quality. Essentially the light source was a rod of calcium oxide, separately heated by a resistance coil (in shunt) to make it a conductor.

The Tungsten-Filament Lamp

The first tungsten lamps, introduced to the American public in 1906, were made by squirting a paste of tungsten powder and binder through fine dies to form hairpin-shaped filaments, which were then mounted in the bulb and pasted to lead-in wires. Since about ten inches of straight filament wire were required to obtain the resistance necessary for use on a 110-volt circuit, several short hairpin filaments were used in series in each lamp. Several fusions were necessary to fasten these filaments together and to attach lead-in wires, the end result being a lamp so fragile that workmen learned to expect a snapped filament if they merely jumped too heavily on the shipping-room floor. If these lamps escaped mechanical breakage of the filament, however, they burned well.

Two years after the advent of squirted-tungsten filaments, Westinghouse engineers developed the continuous-wire tungsten filament, which vastly improved shock resistance. This involved a one-piece squirted filament, which construction improved the flexibility, and lessened heat losses by elimination of a plurality of supports. The filament was squirted through a series of dies in a special atmosphere, and then sintered. This produced, for the first time commercially, a continuous tungsten lead-to-lead filament.

Although the continuous squirted-filament process was a revolutionary advance over fragile hairpin-type squirted filaments, its advantages did not remain for long. In 1911 the achievements of Dr. Coolidge of the General Electric Company made possible an even better filament. He succeeded for the first time in swaging, or hammering, and then drawing a fine tungsten wire. This drawn ductile wire at once asserted its superiority over squirted wire because of its enormously improved tensile strength, permitting lamps to operate successfully in trains, automobiles, and other places where mechanical shock is encountered.

But neither squirted nor drawn ductile tungsten wire might have been successful had it not been for a tungsten crystallization control devised in 1906 by Dr. Anton Lederer of the Westinghouse Vienna factory. Pure tungsten tends to form large crystals when burned on alternating current. These tend to "slide" by each other, or offset, along the cleavage planes, so that the effective cross-section varies, and fragility increases. But when Dr. Lederer added small amounts of thoria and other oxides to the tungsten, he found that small, nonweakening, longitudinal crystals were formed, and the wire remained strong while burning. Thus, "offsetting" was avoided.

Incandescent Lamp Nears Present Form

In 1912, Westinghouse made a mutual agreement with the General Electric Company that provided for the pooling of past and current lamp engineering, research, and machine-design information. (This agreement was terminated on August 1, 1945 by mutual consent.) The result was at once beneficial to the customer in standardization and in reduced prices.

By this time the present form of the incandescent lamp was established. In contrast with only 4 lumens per watt yielded by carbon-filament lamps in 1906, the gas-filled tungsten lamp produced some 14 lumens per watt.

Since the beginnings of gas-filled lamps in 1913, developments in tungsten incandescent lamps have been largely confined to perfections of construction and manufacture. However, they aggregate to sizable improvements in design and efficiency. Today's 1000-watt general-service lamp, for example, produces about 22 lumens per watt. Household types have held to burning lives of 750 or 1000 hours as the most economical, since light-giving efficiency decreases rapidly if

Many new lamps have been introduced at large fairs, such as the Columbian Exposition (left), and the Chicago World's Fair (right).

the life is lengthened by increasing the filament resistance.

The rise in efficiency, and the sustained emission of more lumens has also been accompanied by steadily dropping lamp prices. Herein occurs a shining example of millions of dollars of research expenditures returning constant dividends to lamp users! A 60-watt tungsten-filament lamp retailed for $1.75 in 1907; today a vastly improved lamp, producing 835 lumens compared with the older lamp's 474, retails for 12 cents. During this period the price declined steadily—to 45 cents in 1913, 36 cents in 1917, 25 cents in 1927, and to 15 cents in 1937—and all this while light output, usability, ruggedness, and good looks were multiplying manyfold!

Lamp Manufacture—A Vital Factor in Progress

The lamp industry is unusual in that its machines cannot be bought on the open market; they are custom-built by lamp-company specialists. Thus, advances in the mechanics of lampmaking assume the same importance as lamp design. The many magnificently integrated and almost super-human lampmaking machines, which incorporate the crystallized thinking of many scientists throughout these fifty years, have contributed to the low price, stability, and uniformity.

The wide disparity between early lampmaking and that of today is illustrated by the fact that now a single great machine turns out in just two hours a volume equivalent to the entire daily output of the Westinghouse plant of 1900. And then less than a dozen varieties of filament lamps were regularly manufactured—mostly the 16 and 32 candlepower sizes. Today there are from 5000 to 6000 varieties.

In succession, developments enabled faster and better production. Machines were devised to produce flares mechanically from pre-cut lengths of tubing; stem production and sealing gradually became automatic processes; the laborious and often inconsistent hand work was gradually eliminated—the accuracy of a good watch was inbuilt on a volume basis!

As the incandescent lamp and electrical distribution systems progressed, it became increasingly clear that standardization was to be an essential step from the standpoint of both manufacturer and consumer. Early lamps were individual units, largely handmade, with no assurance of uniformity.

One curious difficulty came with voltage ratings. Early lamps were photometered at fixed candlepowers, and marked for corresponding voltages. Often three voltages were marked on the bulb label, the user and the utility company endeavoring to get together on a common one. Eventually candlepower ratings grew meaningless since this rating of intensity was not constant for all directions; hence watts (for input) or lumens (for output) were substituted.

The first "standard" voltage was fixed at 50 to 55 volts; later this was raised to 110 or 115 volts, and then to 120. Here in the main it has held for the past decade. Higher voltages for incandescent lamps would involve less rugged filaments and lower efficiencies; lower voltages would require heavier amperages and more copper and iron in the wiring systems.

Another troublesome feature of early lamps was that each manufacturer had a different base and socket, with the result that many lamps were carried in stock unbased, and later fitted with whatever type the customer needed. The standardization of bases about 1908 not only minimized possible sales obstacles, but also accelerated mechanization of the industry. Indeed it is a tribute to the lighting industry that each day some two million standard lamps are sold, each fitting into any regular socket.

Soon after World War I, lamp manufacture was further improved by the combination of two steps—exhaust and sealing—into a machine sometimes known as the Sealex. Automatic stem-making and filament-mounting machines came into being soon after. Meanwhile giant strides were being taken in another phase of lamp making—glass fabrication. Hand glass blowing, always a bottleneck in lamp construction, was gradually replaced by automatic bulb-blowing machines. Bulb design itself, however, with the exception of the introduction of the tipless bulb made possible by the new method of exhaustion through the lamp stem (inside the base), has changed but little since 1913. Ever-increasing requirements have, however, led to some 15 different kinds of glass, plus many coloring, frosting, and ceramic treatments.

At right, the undersea lamp. Below, left to right, laboratory testing of the Sterilamp, the krypton flashing lamp, and the new short-arc cadmium-mercury lamp.

Such are some of the highlights of lamp-making progress. The evolution of lamp-making machines gains stature when it is considered that each of today's machines is capable of producing 8000 to 9000 lamps a day compared with the 300 turned out by the 1910 equipment.

Later Incandescent Lamp Developments

While machine designers were developing automatic lamp-making equipment, lamp engineers were not idle. Filament arrangement, a problem from the beginning, began to take new forms. From the unimaginative double loop of the carbon-filament lamp, the filament developed to a draped uncoiled tungsten wire in 1917, to the single-coil filament (a helix) in 1927, and finally the coiled-coil or double helix design in 1936. This compacting of the filament metal offers the best method of conserving heat and thus of getting the most light per watt from a gas-filled incandescent lamp.

Many different filaments—some of them unusual in formation—have also been developed for special services. High-wattage projection lamps, for example, have a "floating" filament, necessitated by extreme temperature changes and corresponding expansion and contraction.

The Westinghouse biplane-type filament for motion picture and stereopticon projection lamps, developed in 1932, made it possible to double the wattage of the light source without increasing the effective filament area. The net result was a 75 percent increase in the brightness of the projected picture.

A leader among special-purpose incandescent lamps is the "sealed-beam" automobile headlight. An all-glass unit with sealed-in reflector, it requires a precisely positioned filament for accurate focusing. Around this design has grown up a host of sealed reflector bulbs—for fog and spotlights, bicycles, locomotive and aircraft headlights, and the spotlighting of merchandise in stores.

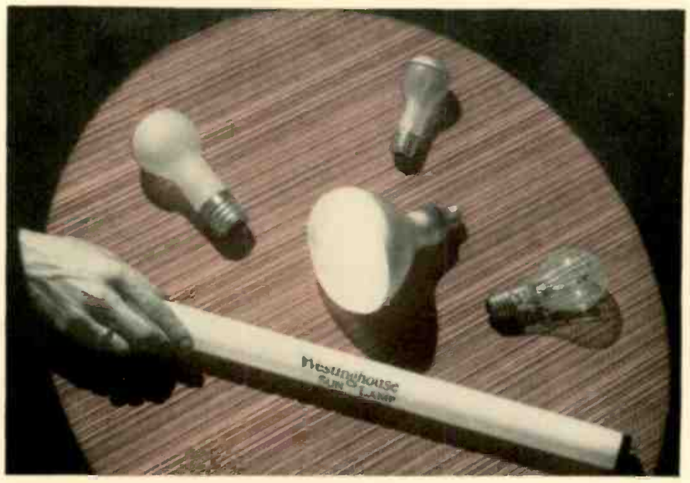
In a special lamp for deep-sea diving, engineers took advantage of the cooling effect of water and put a super-quantity of wattage within a bulb sufficiently small for convenience in handling under water. These tough, spherical glass bulbs, capable of withstanding crushing pressures in excess of 300 pounds per square inch, simplified salvage operations on several submarines and other sunken vessels; they have aided in deep-sea photography and fish capture, and assisted the emergency repairs of many ships.

Such has been the progress of the incandescent lamp in its short but illustrious development period since the turn of the century. But though it covers a broad range, from glow lamps to searchlights, from "grain-of-wheat" lamps to those rated at 50 000 watts, this great mosaic of brilliant successes is by no means the whole picture.

Vapor Lamps

The production of visible light by the incandescence of tungsten filaments likely will continue to be the chief basis of our lighting for many years because of its standardized simplicity and flexibility; nevertheless, the production of light by an electric discharge through a gas or a metallic vapor actually is more efficient intrinsically. For this reason, scientists down the years have pursued vigorously the studies of metallic vapors, fluorescent phenomena and electron performance, and have sought all the other avenues of vapor-lamp research.

Strictly speaking, the carbon-arc lamps that lighted Paris streets in 1878 were vapor lamps operating on the electric discharge principle. Energy in the stream of free electrons was transformed to light, and luminous vapor was a source of radiation. At the dawn of the new century, Mr. Westinghouse



A collection of sun lamps, old and new. The three top lamps are predecessors of the RS (center) and the fluorescent sun lamp.

was solidly engrossed in this new method of generating light, although undoubtedly his engineers fell short in their imaginative evaluations of vapor illuminants because electronics was then an unexplored wilderness.

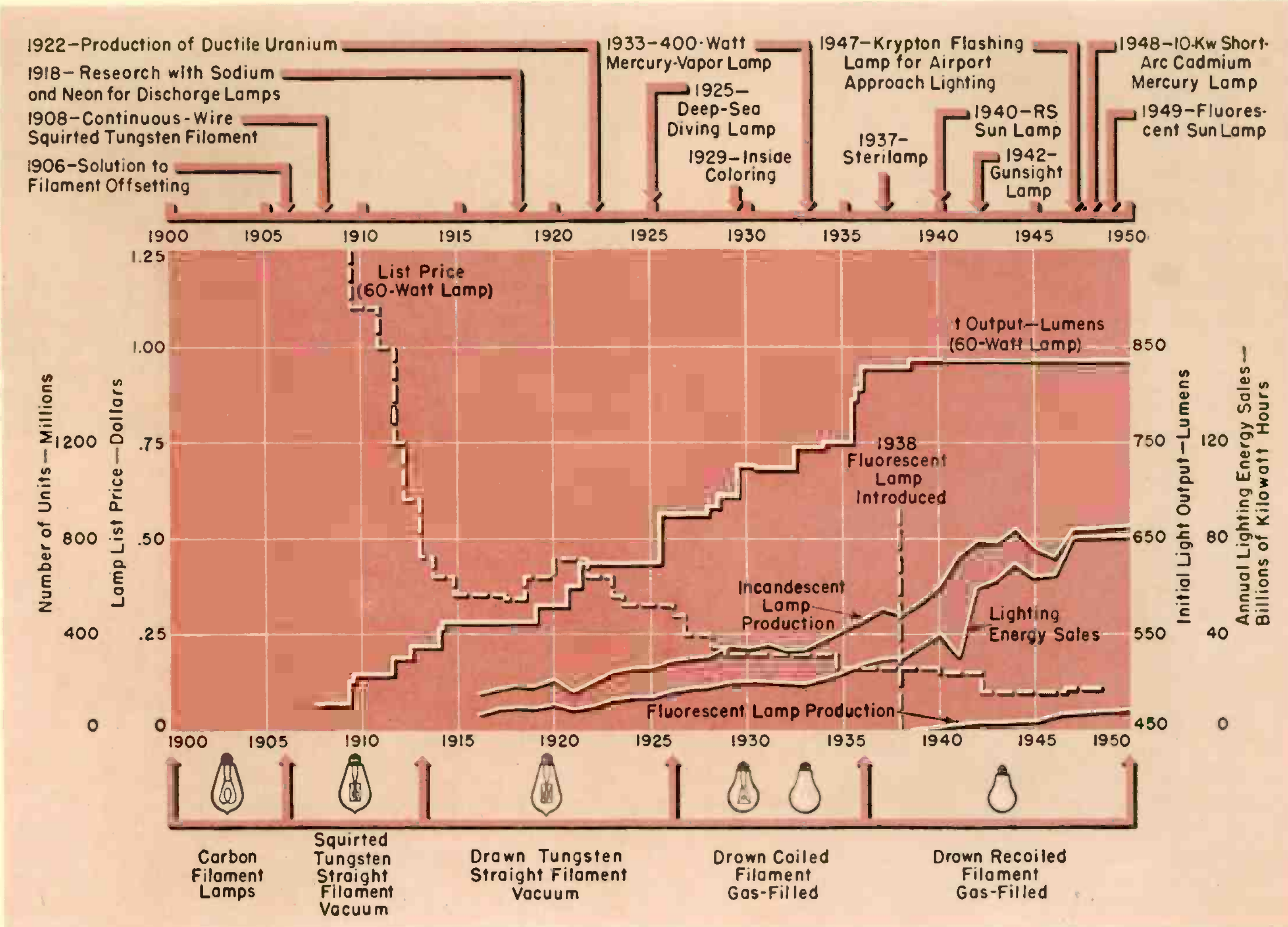
Nevertheless, he agreed in 1900 to finance and exploit the new low-pressure, liquid-pool, mercury-vapor lamp, which had been developed two years before by Dr. Peter Cooper-Hewitt. Mercury-vapor lamps did not reach wide prominence until many years later when higher pressures and efficiencies were attained, but Cooper-Hewitt lamps were familiar industrial light sources until, shortly after World War I, large wattage gas-filled incandescent lamps proved simpler and more economical. Because of their richness in actinic light, mercury-vapor lamps continued to be used in early portrait photographers' studios and in blueprinting.

In 1918 Dr. Arthur E. Compton, working in the Westinghouse Research Laboratories, decided that sodium and neon were the most likely materials at that time for gas-discharge lamps, because of their rich emission lines in the visible spectrum. Other noted pioneers—Dr. McFarland Moore working with carbon-dioxide gas and Dr. Claude with his neon tubes—were extending the art. Finding that sodium was capable of producing light with at least double the efficiency of good filament lamps, Compton made a special glass to withstand the corrosive effect of heated sodium vapor. This was exciting progress and Dr. Compton's work materially aided the later development of the lemon-yellow sodium lamps, still sometimes used in highway lighting.

Recognizing that the efficiency ceiling of the tungsten-filament lamp was well below 50 lumens per watt, and that some vapor illuminants could exceed this, lamp designers and scientists pressed further in their studies of vapor lamps. They found that a high-pressure, high-efficiency version of the old Cooper-Hewitt lamp produced a more balanced color of light than the yellow sodium lamp.

A 400-watt mercury-vapor lamp of this new design (type AH-1) was introduced at the Century of Progress Exposition in Chicago in 1933. Since that time higher wattage lamps, up to 3000 watts, have been developed, with lives of approximately 4000 hours and excellent efficiencies. The 1000-watt size, for example, produces 60 lumens per watt, and a water-cooled super-high-pressure type may do slightly better.

Research and engineering on mercury-vapor lamps have been aimed primarily at improving color and efficiency, partially accomplished by using higher and higher vapor pres-



sures inside the bulb. As pressures increase, the lines of the mercury-vapor spectrum tend to broaden and more long-wave or red color is added. Higher amperage, or more watts per unit length of the arc stream can be reached. An illustrative design, rated at about 5 kw, has an arc less than one inch long, and operates at a temperature of about 1000 degrees C and ten atmospheres pressure. An inseparable development has been the search for better refractory materials to hold these pressures at their corresponding high temperatures. So far, pure clear quartz has served well.

Because of their excellent efficiencies and high wattages, high-pressure mercury-vapor lamps have become popular in the larger industries, and—because of modest maintenance costs—for street and highway lighting. Where the "cold" color is undesirable, mercury lamps are used in combination with the more yellow-red tungsten lamps. For example, in the Statue of Liberty, lighting engineers achieve a realistic "flame" in the torch by mixing mercury and incandescent lamps. Modifications of the 3000-watt lamp also achieve magic-like photochemical transformations by means of the combination of ultraviolet and visible radiations emitted. Choice of glass bulb and control of pressure govern the percentage of ultraviolet in the emission. It can be much, or zero.

Fluorescent Lamps

The Columbian Exposition was the backdrop for the public introduction to the wholesale usage of incandescent lighting. At the Century of Progress forty years later, mercury-vapor lamps were introduced, although so modestly that not until World War II did they come into consequential industrial use. And in keeping with the traditional unveiling of lighting achievements at huge expositions, the New York World's Fair in 1938 provided the setting for the introduction of fluorescent lamps in the United States. This illuminant truly represents the leading light-source achievement of the 20th century!

Fluorescent lamps are essentially low-pressure mercury-vapor lamps, but with a new feature. Instead of producing visible light directly, the discharge or arc stream of a fluorescent lamp generates invisible ultraviolet radiations of chiefly 2537 Angstroms wavelength; these in turn are transformed into visible light by a thin coating of peculiarly crystallized inorganic compounds inside the bulb or tube, called phosphors. These phosphors provide the variety of tints and the soft, enduring quality of emission needed by any good light source. Constant research has uncovered a wide range of phosphor compounds, each of which converts 2537 Angstroms wavelength and similar radiations to some different wavelength, thus producing different colors. For example, zinc silicates transform to green, calcium tungstates to blue, and cadmium borates to pink. Further research is improving the qualities and extending the colors, sizes, and shapes.

Today there are tubular fluorescent lamps of circular and semi-circular shape, as well as one or two of bulb form. Others range in length from pencil-size tubes to those eight feet long and one and one-half inches in diameter.

Another goal of progress has been to simplify the auxiliary devices essential to the operation of all vapor lamps. One Westinghouse development, the glow-switch starter, supplanted a less reliable thermal device for lamp starting. This starter automatically connects the electrodes of a fluorescent lamp in series for preheating before the arc is struck, thereby lengthening lamp life. This simple device has aided materially in the standardization of all starters.

Recent Vapor-Lamp Developments

Within the last year, a fluorescent-mercury lamp has been devised that combines the excellent efficiency of high-pressure mercury lamps with the more flattering warm color of fluorescent light, but with greater wattage in a more compact bulb. A special phosphor, which, unlike previous compounds, can function well above 150 degrees F, transforms some of the excess ultraviolet radiation to visible pink, with subsequent improvement in the usually red-deficient color.

Other metallic vapors, used alone or combined with mercury, provide illumination for special purposes. One example is the experimental, short-arc cadmium-mercury lamp being studied for motion-picture and television studios. Its five to ten kilowatts produce powerful light, rich in all three primary colors, and from an arc only half an inch long.

Vapor lamps for special color effects also have proved feasible. They utilize zinc, cadmium, tellurium and thallium vapors and produce colors ranging from green to gold to deep pink. Caesium-vapor lamps have also been used for the unusual purpose of confidential signaling with an invisible beam.

Another recently developed mercury lamp is filled with krypton and produces a brilliant flash of light some 17 millionths of a second in duration from a timed condenser discharge. This cigarette-sized quartz tube is the key unit in a runway approach-lighting system that can penetrate several hundred feet of dense fog to guide pilots to safe landings.

Today we have a whole new family of lamps that exist for purposes other than illumination—those that can kill disease bacteria and spores of fungi, others that produce healthful erythema or tan, or tenderize meats and preserve foods.

Outstanding among these is the Sterilamp. A low-pressure mercury-vapor device, it generates ultraviolet wavelengths in the narrowly limited wave-band fatal to bacteria, viruses, and the propagation of mold. Developed as a practical lamp about 1936, by the late Dr. Harvey G. Rentschler, it made possible the first convenient, effective and economical method of controlling these air-borne bacteria, viruses, and mold spores. These lamps are of numerous shapes and sizes, including one of golfball size for use inside a domestic refrigerator, and a 30-inch cold-cathode tube for hospitals, offices, and homes.

Two major types of lamps now provide year-round body tan without going outdoors. The newest is a fluorescent sun lamp that emits about five times the total ultraviolet volume (E vitons) of the RS screw-in bulb sun lamp. Utilizing a special phosphor and resembling an ordinary fluorescent lamp except for its small output of visible light, the fluorescent sun lamp was designed primarily for group irradiation of human beings and animals. For individual indoor suntanning, the older RS type, a medium-pressure sun lamp, remains in favor.

The Search for Metals

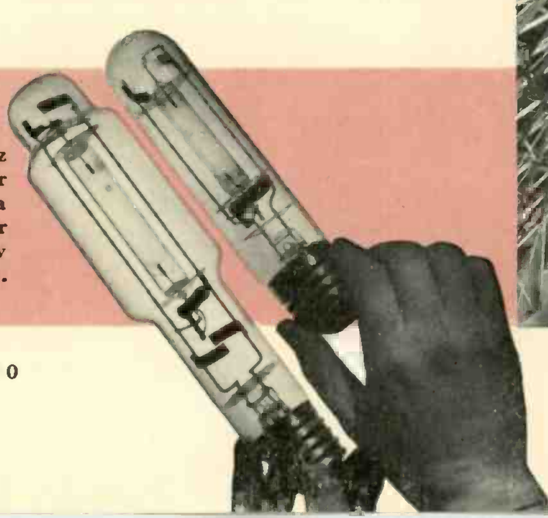
The dependence of nearly all the newer electric illuminants upon metal vapors made it mandatory that Westinghouse scientists appraise even the rarest metals. It was a search for an incandescent filament material better than tungsten, for example, that accounted for one of the outstanding contributions of the Westinghouse Lamp Division in World War II. In their lamp investigations, Westinghouse scientists had made samples of pure uranium as far back as May, 1922, so they were well equipped to supply the initial samples of pure uranium for the first experimental atomic-energy pile at Chicago in 1942. During the course of the experiments Westinghouse supplied more than 65 tons of U238 and reduced the cost of pure uranium from $750 to $7.34 per pound. And this despite the fact that uranium had previously been made only in the laboratory and at the rate of only a few grams at a time! Thus does lamp research have far-reaching influences.

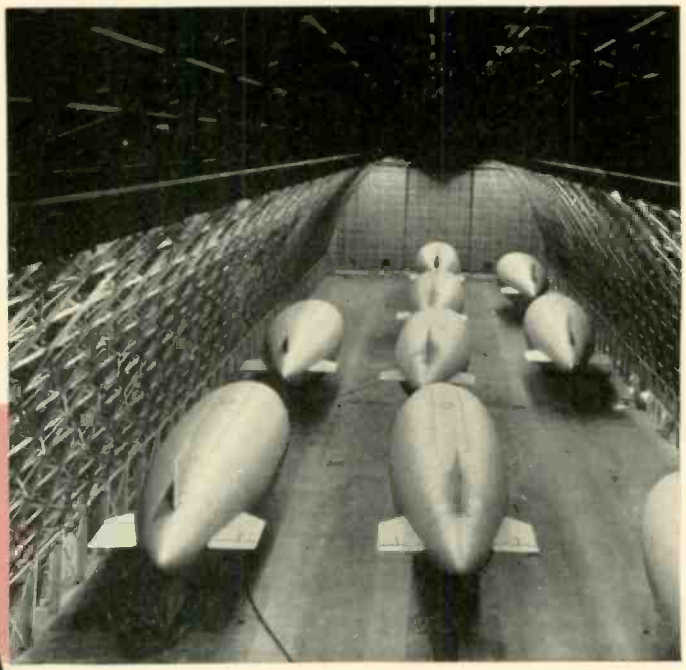
A golden thread of romance and adventure runs through the tapestry of lighting history. Promises of new materials, newer methods, and still newer uses beckon workers on to widening fields. New language terms, new measuring instruments, even the changes in man's treatment of his eyes and his life, all grow apace as radiant energy becomes more abundant. No Aladdin ever received more wealth from any lamp!

The Long Vistas Ahead

During these past five decades since the days of open electric-arc lamps and fish-tail gas burners, man's ingenuity has successively evolved and improved the carbon-filament incandescent electric lamp, the metalized-carbon lamp, some few tantalum and similar wire-filament illuminants, and then the tungsten-filament lamps with improved alloys, coiled in the heat-retaining atmosphere of an inert gas. All but the last are obsolete. Undoubtedly others will be born—and pass.

In volume usage three major types of electric light sources remain—the perfected tungsten-filament lamp, the high-intensity mercury-vapor lamp (plus sodium and neon and a few other less-popular ionized vapor or gas sources), and the rapidly developing fluorescent lamp. These three are expected





Two typical quartz mercury-vapor lamps. At right, a blimp hangar lighted by 3-kw mercury lamps.

to continue indefinitely. But they will change! Evolution is rife in the lamp industry.

Looking ahead into the next half century, lighting scientists can justifiably expect progress to continue unabated because man's need for more and better light has not yet been satisfied. No one is convinced that present methods of generating light are more than early steps in a long journey!

Incandescent Illuminants

The first question might be—what about advancements with metallic wire or incandescent illuminants? The answer seems fairly definite. A filament material superior to tungsten is unlikely (all the available known elements have been investigated), and there is but little prospect for better gases to surround it excepting krypton or xenon, both of which are inherently expensive. These rare gases exist in the atmosphere in minute percentages and are difficult to segregate. True, they can increase incandescent lamp efficiencies some 10 percent; but so long as a liter of krypton costs about ten dollars, and xenon five times more, the use of these lethargic gases as heat blankets will likely be confined to the smaller bulbs—such as miner's lamps—and only where highest efficiency is paramount. Mechanical and metallurgical perfections will undoubtedly continue to produce superior filament ruggedness, smaller and stronger bulbs and more pleasing surface finishes, but withal, the present-day efficiency of the tungsten lamp could at most be increased by a small percentage. The three-hour photoflood lamp leads this class, at 36 lumens per watt. The ultimate ceiling is set at the softening temperature of tungsten, just short of melting, and certainly the efficiency of this illuminant will never exceed 50 lumens per watt, because molten tungsten emits but 52.

Nevertheless, there is no evidence of any major decline in the usage of this convenient and versatile source. Curiously enough, the advent of the fluorescent lamp ten years ago did not decrease the consumption of incandescent lamps. For several years to come, the tungsten filament lamp will likely represent more than 75 percent of the illuminants in general lighting service. Today, in numbers, the sales of fluorescent lamps represent about 10 percent those of the incandescent lamps, but the former are exceeding this percentage.

Fluorescent lamp testing and manufacturing.

Metallic-Vapor Sources

High-pressure mercury-vapor lamps have a hopeful future because their efficiencies are already well in excess of 50 lumens per watt and may reach 100—perhaps more—depending on the discovery of improved methods of handling the high temperatures (1000 degrees C) and pressures (10 atmospheres) of the mercury arc. Water cooling seems a cumbersome expedient, so air cooling will likely continue. Present objectives are not primarily to increase efficiencies. Rather they are concerned with improved methods of shortening and condensing the arc to obtain better focusing and superior projection control, since neither lenses nor reflectors can efficiently handle the light from a large area. Also the shorter the arc, the brighter it becomes. Other objectives include improving the color of the mercury arc, obtaining a better balance between useful life and lamp cost, and making the lamp capable of instant restarting after a current interruption. Today's mercury lamps have to cool for five to ten minutes before they will re-start, but methods are now known of overcoming this annoyance, and will in certain cases be put into practice.

The discovery of a bulb material more refractory than clear quartz would be a long step toward better high-pressure mercury lamps. Another giant advance would be a means of utilizing the large amount of invisible ultraviolet radiation generated by the typical mercury arc. This brings into focus the matter of some type of fluorescent glassware or enclosure, or perhaps a fluorescent paint or other material incorporated into the surfaces illuminated. The object would be to change the useless, short-wave radiations to longer wave quality, thus increasing the usable illumination. For example, in the case of mercury lighting for highways, fluorescent markers and safety painting could be used, or even fluorescent dye material sprayed on the gravel of the roadway edges.

Other types of electric arcs, especially in small wattages, are being carefully studied. One is the pin-point zirconium arc. However, high-pressure vapor lamps are not likely to enter the fields of store or home lighting because these places cannot conveniently use great volumes of light in a single package. Much remains to be learned about photochemical uses of these illuminants and herein is an intriguing, undeveloped field.

Fluorescent Illuminants

Today's fluorescent lamp has come a long way in ten years, and bids fair to continue its meteoric career, growing in efficiency, variety of color, useful life, and in simplified methods of operation. With the exception of the extremely large and extremely small lamp sizes, it may be able to do most of the world's lighting jobs better than any other known lamp. Today's efficiencies of about 60 lumens per watt may be doubled in the next decade, this through improved phosphors to provide a better transformation of ultraviolet to visible light, coupled with gradual betterment of the inert gas mixtures within the tubes, and perfected electrodes. Superimposed upon all physical improvements is the gain that would result from using alternating current at frequencies higher than 60 cycles. For instance, going from the conventional 60 to 400 cycles would increase the luminous output roughly 20 percent, and halve the ballast size. Unfortunately, there is the matter of high-frequency generation and distribution.

Conceivably, other methods of generating short-wave radiant energy may compete with the present method of an electric discharge through low-pressure mercury vapor, but phosphor responses must be geared to the wavelengths generated, so the task is a lengthy one. Tomorrow's research may clarify the "one-way traffic" movement or down-hill procedure of

S. G. HIBBEN

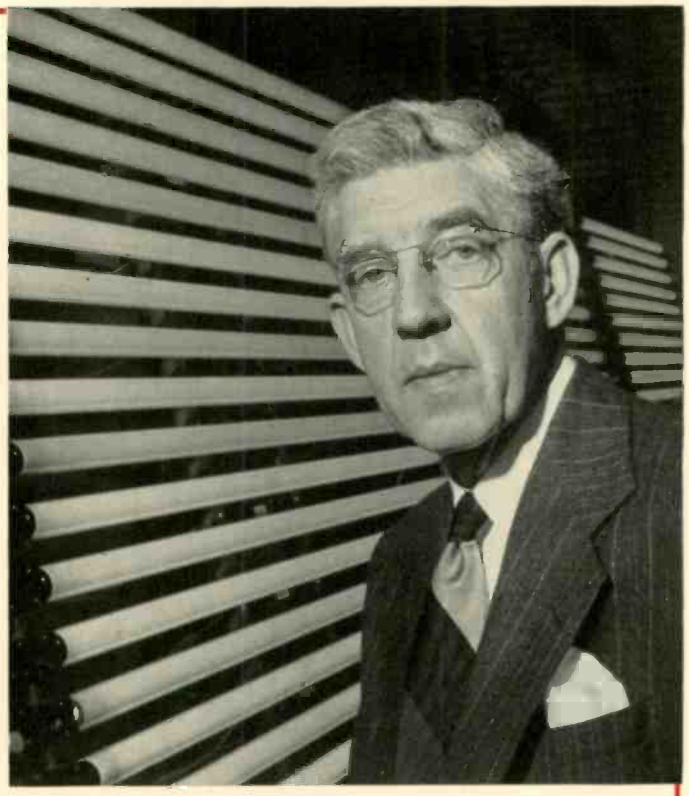
A firm believer in the opinion that, once informed, the public is quick to grasp new ideas, Samuel G. Hibben has spent much of the past four decades stumping the country, demonstrating the latest in lamps and lighting practices before every conceivable type of audience, from students to lighting experts here and abroad. Possessing a fertile imagination coupled with a fine engineering talent, he has probably done as much as any other man to spread good lighting practices and demonstrate the versatility of lighting. Widely known for his unique demonstrations, Hibben's words carry the authority born of experience.

Hibben's start in the lighting field was business-like, if hardly constructive. At the age of ten he discovered that he could net a tidy profit by collecting burned-out carbon-filament lamps, smashing them, and salvaging their platinum leads. At this enterprise he averaged about five dollars a summer—not bad for a junior scientist.

After his graduation from Case, Hibben spent several years with the MacBeth Glass Company in Pittsburgh, designing lighting glassware, lenses, and reflectors; then he spent two years as a consulting engineer before coming to Westinghouse in 1916. His lighting career has been interrupted only by an interlude as a captain in the army during World War I; much of this interval was spent in helping to design the first portable searchlight for anti-aircraft use.

After establishing and developing what is now the present Commercial Engineering Department, Hibben was selected as Director of Applied Lighting for the Westinghouse Lamp Division, the position he now holds. Here he functions as ambassador-at-large on all lighting activities, keeping in touch with new developments and following them through to final application. Recently his tireless efforts toward better lighting were expanded by election to a vice-presidency in the Illuminating Engineering Society.

Despite his occasional flights into the realm of prophecy, Hibben is definitely a practical engineer. Witness his part in the development of the first system of transcontinental airway beacons, the underwater lamp for salvage operations, modern floodlighting, and semi-indirect lighting. Indeed Hibben is one of those rare individuals who can keep both feet solidly on the ground while allowing his soaring imagination freedom in the scientific stratosphere.



converting only the short-wave radiation to longer waves.

Phosphors that would work in the opposite direction—namely, converting long-wave energy or heat to short-wave visible light—have not been discovered, and may not be possible. As a single action, this would seem truly and fundamentally impossible! But wait! The "impossible" often turns out to be a task that requires just a little longer to do! Let us not forget that numerous attenuated gases can be ionized or excited by long waves of, say, radar energy, causing these gases to emit considerable light.

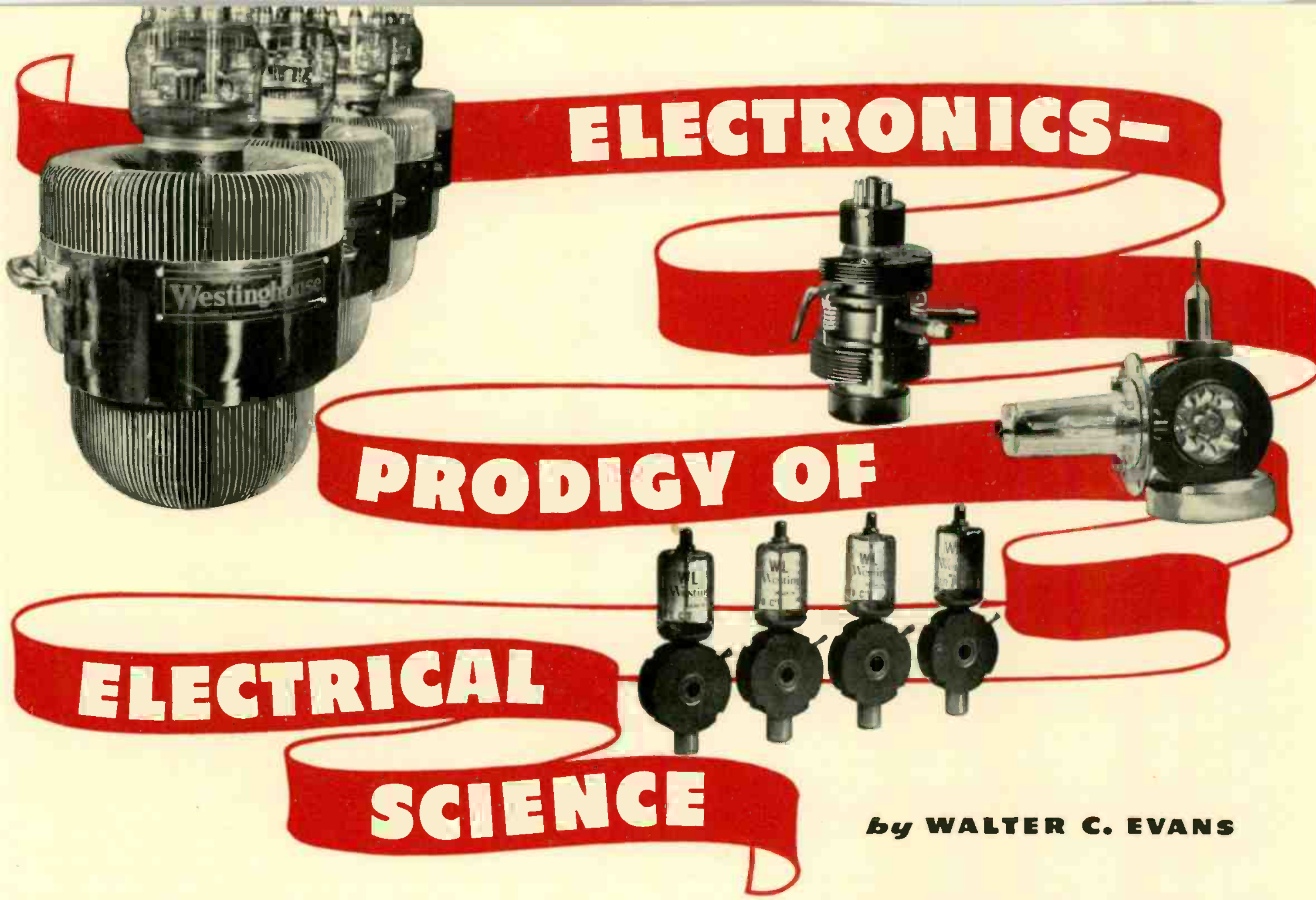
Furthermore, on the future horizon is glimpsed the possibility of utilizing a phosphor material—perhaps an inorganic sulphide—on walls or ceilings of rooms, or incorporated into plastics and building materials. This unknown or unperfected phosphor could conceivably absorb and later re-emit what is now the wasted ultraviolet as well as some visible portions.

A somewhat fantastic but enticing idea is that natural daylight can be absorbed into a species of light "storage battery," peculiar paints or dyes emitting a luminous radiation after sundown. Already known are phosphorescent materials that, after exposure to almost any kind of light, and especially sunlight, glow for several hours after they have been excited. A slower rate of light "decay" is needed. Generally these materials repeat the process indefinitely without deterioration. The efficiency of this method is undoubtedly low, but the inexhaustible supply of exciting energy in sunlight leads to the hope that some day these storage batteries of light might at least meet the needs of safety markers for hazardous areas, such as on highways, on vehicles, or in paving blocks.

The span of man's life is on the increase. It should and can be longer. This desire in turn should lead to the more universal acceptance and usage of fluorescent types of sun lamps for space irradiation, and the use of ultraviolet Sterilamps and germicidal lamps for the purification of air and food products and the suppression of infectious diseases. Today it is easily possible to incorporate either long-wave (3000 Angstrom) or short-wave (2500 Angstrom) ultraviolet emission into light sources that heretofore gave us radiation only within the visible spectrum. However, it seems more flexible to segregate our sources of radiant energy into certain classes, and produce lamps designed to emit a single selected group of radiation, rather than to obtain all wavelengths from a single lamp.

Tomorrow's lighting needs could be fulfilled with the many thousands of types, sizes, and colors of today's illuminants, were it but possible to know and to use available lighting tools to their fullest extent. For example, white-light illuminants having efficiencies of 200 lumens per watt are theoretically possible, but progress does not await this attainment. Full efficiency of light production is by no means the whole problem. The improvement of human eyesight physiologically, and the betterment of human vision through higher levels of lighting, lower levels of glare, and pleasing varieties of color suggest that tomorrow's job is to put today's man-made light to work more abundantly and more intelligently.

Man's need for more and better light obviously will require vast amounts of research and development—and education! The new age of lighting is thus scarcely under way; its future stretches on to remote horizons.



ELECTRONICS—PRODIGY OF ELECTRICAL SCIENCE

by WALTER C. EVANS

Future historians of the electronic art may well conclude that electronics was conceived in a war to save the world for Democracy, nourished by the world's desire for entertainment, and grew to manhood in a second war to defeat Nazism.

Of the several branches of the electrical industry discussed in this Mid-Century issue, electronics alone has had its development entirely within the half century. Although the emission of electric charges from a hot filament was noted by Edison during his early lamp experiments, and the electron was given its name by Stoney in 1891, it was not until 1904 that vacuum tubes came into existence with the invention of the two-element tube by Fleming. The all-essential grid did not arrive until 1906 with the work of DeForest. These were but foundation steps. It is fair to say that practical application of electronics—with the single possible exception of the medical x-ray—began with radio—and commercial radio as we know it will celebrate its thirtieth birthday this year.

Radio Broadcasting—Commercial radio broadcasting was born at Pittsburgh on November 2, 1920, when station KDKA, in the world's first scheduled broadcast, gave the returns of the Cox-Harding presidential election. Construction of KDKA, begun only one month prior to the election, was entrusted to the late Dr. Frank Conrad, then assistant chief engineer. Dr. Conrad had been an enthusiastic radio amateur since 1915 and had already built a reputation in the communications field through his work on Westinghouse radio telephony for the government during World War I.

The background that Dr. Conrad brought to the assignment came from the construction and operation of his own station 8XK, in 1916. Although a security ban on amateur broadcasting during World War I silenced the lineal forebear of KDKA, except for testing military radio equipment, Dr. Conrad's 8XK resumed normal operations when security regulations were lifted on October 1, 1919. Before the month was out, Dr. Conrad introduced a new note in "ham" telephony of the era by placing his microphone before a phonograph. The resulting musical programs delighted hams all over the country, and he was deluged with requests to play music at special times to convince certain skeptics that music really could be transmitted through space. Unwittingly initiated as radio's first "disc jockey," Dr. Conrad, in self-defense, announced that he would "broadcast" records for two hours two evenings each week.

These broadcasts soon exhausted Dr. Conrad's supply of records, and a local music store offered a continuing supply if he would announce that the records could be purchased at the store. Thus arrived the world's first radio advertiser—who promptly found that records played on the air sold better.

By late summer of 1920, interest in these broadcasts had become so general that a Pittsburgh department store advertised "Amateur Wireless Sets . . . $10.00 up" to receive "Victrola music, played into the air over a wireless telephone . . . (by) Dr. Conrad . . . a wireless enthusiast (who) . . . 'puts on' the wireless concerts periodically for the entertainment of the many people in this district who have wireless sets."

If this was a fair example of popular reaction to Dr. Conrad's broadcasts, it seemed reasonable to H. P. Davis, Westinghouse Vice President, that the real radio industry appeared to lie in the manufacture of home receivers and in supplying radio programs that would make people want to own such receivers. Convinced that here was a great new business opportunity, a station was authorized, license application submitted October 16, and election night—then only a little more than two weeks away—selected for the grand opening.

Arrangements were made to bring election returns by telephone to the broadcast equipment located in a tiny, makeshift shack atop one of the Westinghouse manufacturing buildings at East Pittsburgh. There was no studio. A single room accommodated transmitting equipment, turntable for records, and the first broadcasting staff.

Company officials, recognizing the widespread and immediate success of KDKA as a pacemaker of the new industry, turned at once to consideration of stations at Westinghouse plants in other cities. Stations at Newark, New Jersey, and Springfield, Massachusetts, and Chicago, Illinois, were licensed and began operating by December, 1921. From this beginning the standard-band radio broadcasting industry was launched. The result—more than 1600 stations in the United States, broadcasting to 66 000 000 receivers.

Radio Receivers—But along with the development of broadcasting from the modest 100-watt transmitter in service at KDKA to the 50-kw transmitters now in use, there was need for a parallel development in the receiver business to build audiences for the radio stations.

World War I had done much to stir interest in radio and with the removal of the wartime ban on amateurs late in 1919, Westinghouse turned to the development of equipment to meet the growing needs of the "hams" of the day. Late in 1920 two receiver units, combinations for either code or voice, were ready. These were the RA tuner to pick up carrier waves at from 200 to 600 meters (500 to 1500 kilocycles), still the heart of the broadcast band; and the DA detector amplifier to convert these signals for listening. Available shortly after KDKA's first broadcast, demand for the equipment was sufficient to warrant combining them in 1921 as the Westinghouse RC regenerative receiver, which was the first to use vacuum tubes. These units sold for $65 each or $125 in combination, and a special adapter was available so that the horn of any convenient phonograph might be used as a loudspeaker. In addition, loudspeakers, using the same adapter on the coiled brass horn section of the early rubber-bulb type automobile horn, were available for an extra $15.

Radio took the next familiar step in all new developments —to the mass production of low-cost apparatus. The first set was simple to operate and inexpensive enough to fit the average family budget—Aeriola, Jr. It appeared in 1921 and was the first popular priced radio receiver—a tiny crystal set, six-by-six-by-seven inches in size. It employed earphones, had a range of from 12 to 15 miles, and sold for $25. Six months later two new and improved models were ready—Aeriola, Sr., and the Aeriola Grand, first self-contained radio receiver.

The most conspicuous feature of the Aeriola, Sr., which was of about the same size and appearance as its predecessor, was the use of a newly developed receiving tube, the WD-11. The comparatively low filament power required by this new tube—it used only a single dry cell—made this set the first "portable" radio receiver using a vacuum tube. This set sold for $60. The Aeriola Grand represented a still greater technical advance. This four-tube set was a table-cabinet model 12 by 15 by 16 inches, which sold for $175. With this cabinet model, representing as it did a completely coordinated design, radio receivers began to take on their familiar appearance.

In 1926 came another milestone in the improvement of radio receivers. This was the a-c tube. With the corollary development of rectifier tubes, batteries were forever eliminated and radio reception became possible by using ordinary alternating current. This principle is basic to all modern radio except those that must operate away from an a-c outlet.

Short Wave—In the early days of radio, knowledge of the propagation of radio waves was largely based on experiments made on long-wave stations. These indicated, for the range of wavelengths investigated, that transmission improved steadily as the wavelength increased. It was assumed that this law held good over all wavelengths not investigated. Elaborate mathematical formulas were developed, which showed that unsatisfactory results would be obtained below 200 or 300 meters. As these short waves were considered undesirable for commercial use, they were assigned to amateur use.

Dr. Conrad challenged these theories. He suspected that the KDKA transmitter was not as efficient as it should have been. He believed radiations were being given off at other frequencies, that is, at harmonics of the fundamental. Consequently he built a receiver capable of working on the harmonic frequencies and listened on wavelengths of about 100 meters. To his surprise he found the signals on the harmonic frequencies as strong or stronger than those on the fundamental. He then started listening to distant stations for their harmonics and again his previous observations were confirmed regarding signal strength. He also observed that there was much less static disturbance on the shorter waves.

Out of these experiments came a better understanding of the confusing "skip-distance" behavior of short waves—the phenomenon that had led many radio experts to the erroneous conclusion that this portion of the spectrum was useless. The tests revealed that short waves are reflected, mirror fashion, by the Heaviside layer and other ionized strata of the earth's rarified outer atmosphere. As they bounce back and forth between these layers and the earth they can be received only where they strike the earth's surface.

The first short-wave transmitter was established on an East Pittsburgh factory roof-top in August, 1922, licensed 8XS. To conduct tests at greater distances and to explore possibilities of receiving and retransmitting the same program by short wave, Westinghouse engineers established a second short-wave transmitter in Cleveland, Ohio, early the next year. This was KDPM, radio's first "repeater" station: it demonstrated the basic principle of the radio link-transmission requiring no land-line connection.

Other short-wave stations have since been added, one of the most famous now being WBOS at Boston. This powerful transmitter, which can be beamed toward either Europe or South America, carried 12 hours of specialized programs each day before World War II with 13 specially trained announcers broadcasting in English, French, Spanish, and Portuguese. Since November 1, 1942, all WBOS programming has been handled by the United States Department of State, and now carries the Voice of America.

Although television and frequency-modulation services are considered new, since they have come into extensive use only after World War II, the first work in both fields came almost simultaneously with standard broadcasting. History records many attempts, some surprisingly successful technically, but not practical.

Physical limitations of the mechanical process used were retarding television development when in 1923, Dr. Vladimir K. Zworykin, employed in the Westinghouse Research Laboratories, applied for a patent on an electronic-beam television pickup. It in turn broke the bottleneck of mechanical scanning—limited to 240 lines—and made possible new and phenomenally high scanning speeds. After extensive development, this system led to the Iconoscope—seeing eye of the modern television camera.

Six years later, in 1929, Dr. Zworykin demonstrated a second basic television development at the Research Laboratories. This was the Kinescope, which eliminated mechanical scanning from the receiving operation as well and established television as an all-electronic science.

The Iconoscope and the Kinescope—both standard television equipments of today—made possible the first all-electronic demonstration of television over a five-mile distance in the 20's. Not a little credit for the television development is due to the important improvements made in cathode-ray tubes originally used to avoid some of the inertia weaknesses of the galvanometer types of oscillographs for recording rapidly recurring electrical phenomena.

Meanwhile, Dr. Conrad was pioneering in the frequency-modulation field as early as 1920. His experiments from 1920 to 1928 won more than 20 FM patents by applying frequency modulation to telegraphic communications.

The early work in radio broadcasting did much to provide a "bread and butter" market for manufacturers of electronic equipment from 1920 to 1940. Developmental work through the years has brought us high-powered transmitting equipment for amplitude and frequency modulation, and now television transmitting equipment promises to open further markets. In addition, television-receiver manufacture is a fast-growing field surrounded by the AM and FM market.

The rapid growth in the broadcast field was necessarily paced by major power-tube developments. In 1920 the most common transmitting tube was the so-called 50 watter, a popular amateur tube. While a pair of these tubes sufficed for the original KDKA, the demand soon rose for more and more power. Water-cooled tubes made their debut first by using pieces of copper tubing, then later by using drawn copper anodes made by techniques learned in World War I. This single step vastly increased the power-handling capabilities of the tubes and high-power broadcasting began.

Experience gained in making large quantities of tungsten wire for lamps contributed to the vast increase in the life of pure tungsten filaments as used in power tubes for transmitters. Replacement of the old-style grid seal with a thimble seal made it possible to raise appreciably the frequency ceiling of water-cooled tubes. Careful design resulted in large power tubes for five-meter operation. They lay dormant for some years until they were somewhat reluctantly adopted for the first experimental television transmitters.

To simplify the cooling auxiliaries, the air cooling of large power tubes was devised, particularly for broadcast transmitters. The attachment of a special fin-type "radiator" to the anode made it possible to use an air blast to achieve cooling. So popular has this feature become that almost all of the newer broadcast stations use tubes cooled by this means, and its use in new tube designs has become general.

While radio broadcasting furnished nourishment for the industry during the lean years of the 30's, electronics had its birth during World War I in the communications industry, and this remains an important part of current operations.

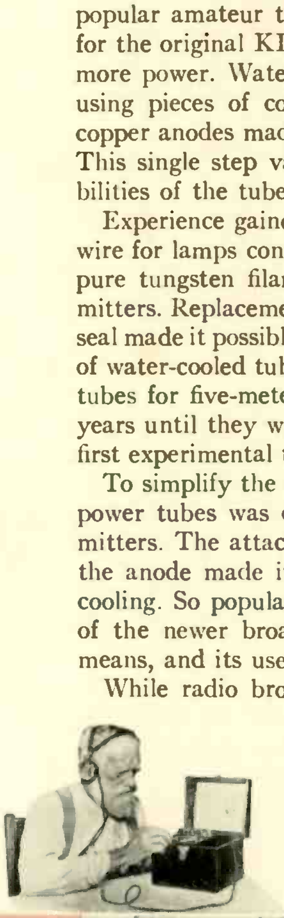
In the radio industry, transmitter and receiver manufacture has been expanded to include production of television and frequency-modulation equipment as well as the conventional amplitude-modulated transmitters. One development is the Symmetron, a new radio-frequency amplifier for use with very high and ultra-high frequencies. Now utilized in a 50-kw FM transmitter, future applications promise new and higher power levels, not only for frequency modulation and black-and-white television but power levels one and one-half to five times greater than those obtained with commercial equipment currently in manufacture for the 50- to 100-mc region for black-and-white or color television.

Stratovision—One of the major problems to be faced by television once the larger metropolitan markets have been provided with service, has prompted the development of Stratovision. This is a system of airborne television and FM transmission, originated as the answer to the television problem of increasing the coverage area and providing relay facilities for these services. Reception of broadcasts from flying television stations is practically free from interference and distortion caused normally by the repeated amplification of relaying stages required by other proposed systems to carry television and FM broadcast over a comparable area. The major technical problems in the use of Stratovision have been solved and the system is ready for commercial development. Three years of extensive flight testing show that this is a practical and useful method of expanding television service and provides a wide variety of functions in relaying this and other high-frequency communications. How it is to fit into the broadcast setup lies largely with regulating bodies.

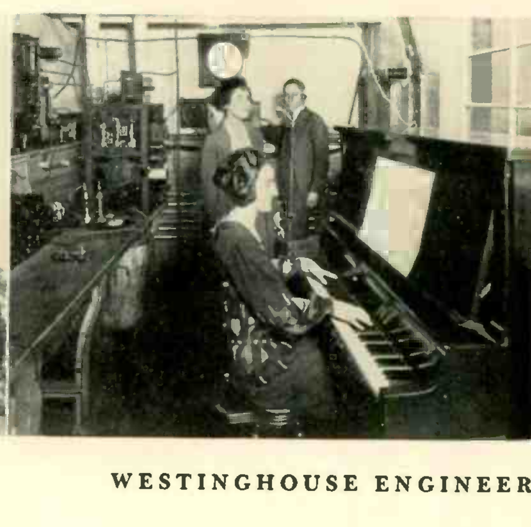
Communications—Before World War I radio communication was of the dot and dash variety and was restricted almost entirely to ship service, with a few high-power land stations for long-distance communication. With the outbreak of hostilities in 1914 the need for communication facilities became urgent and greatly stimulated the development of radio devices, especially the vacuum tube, which made possible a commercial form of radio-telephone equipment.

One of the earliest successes was a revolutionary new type of radio for the U. S. Signal Corps—one of the first vacuum-tube wireless sets. This represented a drastic departure from previous design, which had depended upon spark-gap transmitters and crystal receivers. This equipment, the SCR 69 and 70 sets, utilized continuous-wave transmitters and receivers (CW). The equipment was portable.

With aviation coming to the fore in World War I, wind-



The beginnings of broadcasting . . . Dr. Conrad at his workbench . . . his home where much early experimental work was done . . . early studio and control room scenes . . . broadcast equipment of two decades ago . . . and as it is today.



driven spark-gap alternators were also developed at this time. The aircraft transmitters were of 200 watts output and were mounted on the leading edge of the wings.

As this work progressed other radio developments were undertaken, and, as a result, Westinghouse became the first supplier of combination radio telephone-telegraph receivers for the Navy and a pioneer supplier of ship-to-shore radio transmitters as well as airplane receivers.

During World War I, Westinghouse developed high-voltage generators and dynamotors for supplying power to the plate circuits of vacuum tubes. One of these dynamotors and one of the wind-driven spark-gap alternators mentioned above made the historic flight with the Navy NC-4 from Trepassy, Newfoundland, to Plymouth, England, and provided the power for the first long-distance plane-to-shore transmissions.

Equipment for communicating by radio between fixed points, that is, point-to-point instead of broadcast, is relatively little known to the public but it has grown in importance. It is in continuing demand for such situations where the construction of telephone lines is impractical or even impossible; for example, scattered fruit plantations in jungle areas, ship to shore, or between air terminals.

Modern point-to-point equipment embodies many improvements in components learned during the recent war while building radio for severe service in all parts of the world —from the steaming jungle to the icy north. The new sets follow the building-block idea, now being used so effectively with many equipments. By assembling standardized, coordinated cabinets for the different functions any desired type of service can be quickly provided.

A 20-kw rectifier unit is the basic member of the "building-block" family. Used with other standard units, equipments are provided for key transmission, for voice or facsimile, or for tones as required for teletype or other machine-transmitted signals. Transmitters and their components are both more compact and more efficient than their prewar counterparts. Each section is mounted in a cabinet on wheels that can be pulled forward from the others to provide complete accessibility. Thus the cabinets themselves need not be overlarge to provide "walk around" room for servicing. Floor space is also saved. Use of vacuum-tank capacitors and new postwar tubes add to the compactness of the sets.

An example of extensive use of this equipment can be cited in the recent modernization and expansion of the communication system operated by Tropical Radio Telegraph Company, which handles full public-service radio telegraph and radio telephone communications, local and international, in countries bordering the Caribbean. This network is called upon to function under the most severe climatic conditions, particularly in tropical regions where ordinary radio equipment deteriorates fast. Tropical's communication service must be reliable during the abnormal to handle warnings in storms, disasters, and emergencies—and in the normal, for heavy-traffic services for extended periods. This calls for the utmost in equipment reliability.

Railroad Radio—Ever since the birth of radio, railroad men have visualized its use to facilitate movement of trains. As far back as 1916, telegraph signals were transmitted by induction between a land station and trains, but the equipment was too fragile for that service.

A series of experiments followed this start. A continuous-wave beat-note telegraph setup for front to rear communication was attempted as were other tests with several railroads, including the Norfolk and Western Railroad at Bluefield, West Virginia. Although some results were satisfactory, generally speaking the electronic knowledge of the higher frequencies was inadequate, and the equipment could not be made rugged enough for reliable operation. Work was continued between 1926 and 1934. With each experiment, equipment advanced a little further toward the rugged and reliable transmitters and receivers now available.

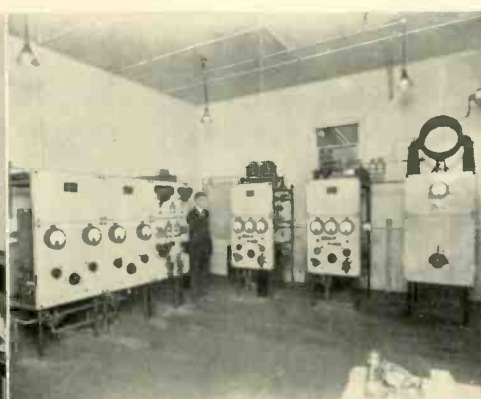
By 1934 tubes and circuits suitable for use at higher frequencies had been developed. New equipment was designed to operate on frequencies of 35 to 62 megacycles and an extensive test was made in cooperation with the New York, New Haven and Hartford Railroad.

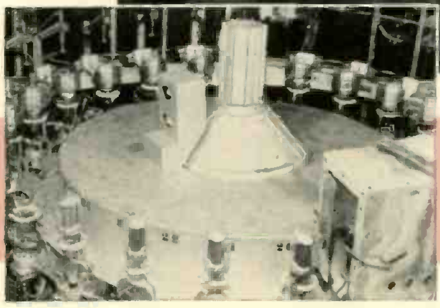
Early in 1944 after reviewing previous experience, it was decided that frequency modulation would eliminate the noise difficulties. From previous experience in the mountainous terrain of New England, the 30- to 40-megacycle band was assigned and a new test was set up with the New York, New Haven and Hartford Railroad, this time to cover all varieties of railroad-radio communication.

After a trial period of seven months with a completely new set of equipment, a demonstration was run for the railroad with excellent results. This experiment was basic in designing postwar railroad-communications equipment.

Although further improvements to increase flexibility of operation can be expected in equipment for railroad service, the major technical problems of radio for this use have been solved. The equipment is amply rugged. Communication under a variety of adverse circumstances is assured. The problems of railroad radio now are more a matter of the railroads determining how to use it, the alteration of rules and operating procedures to take advantage of it, and financing.

Power-line carrier, often thought to be a relatively recent electronic development, is actually older than radio broadcasting. Patents dating back to 1902 show that the idea of





R-F heating has long been used in vacuum-tube manufacture and for hardening (above).

using telephone wires or power lines as a vehicle for high frequencies to carry other information is old. Not until the early 20's, however, did wired wireless—now known as power-line carrier—begin its practical career. Westinghouse had experimental equipments in service about 1920 and in 1923 built 20 commercial sets. Some of these are still in service.

Early carrier equipments were for voice communication only. In the early 30's installations were made only for relaying. It was not until 1945 that power companies began to use power-line carrier extensively for several services, such as voice communication, relaying, supervisory control, and telemetering. There had been previous exceptions to this, such as the Westinghouse equipment provided in 1937 for the Hoover Dam-Los Angeles line for voice and supervisory control.

An important contribution in the power-line-carrier field came in 1927 when Westinghouse developed sets operating solely on direct current. All previous carrier equipments had required apparatus for conversion from battery power to alternating current at the transmitter and from a-c back to d-c at the receiver. In 1945 Westinghouse developed a new type of single-sideband equipment. Use of the single-sideband principle, long known but used in a limited way in this field, almost doubles the channels available in a given frequency spectrum and improves the quality by lowering the noise level. At present the development of microwave equipment promises to expand the usefulness of supervisory control, telemetering and communication equipment as used with power-line carrier by providing a circuit for these signals where the necessary power or telephone lines do not exist.

Heating with Radio Frequencies—One could easily make a case for radio-frequency heating as being the oldest of electronics services. Thirty years before the dawn of broadcasting, d'Arsonval—of electrical instrument fame—discovered while working with a Hertz wireless set that radio frequencies induce heat within the human body. Artificial-fever machines soon became a feature of hospitals and doctors' offices.

Industrial applications of radio frequencies for heating have had a long history too. In the early 20's radio frequencies were used in vacuum-tube manufacture to heat the internal parts without heating the glass walls. This was to drive out the last traces of gas before final sealing. Induction heating continues to be used for this purpose.

Aside from a few applications, such as in electron-tube manufacture, radio-frequency heating—induction for metals, dielectric for non-metals—had a slow development. Frequently they were of a novelty nature, such as the frying of an egg on a block of ice, the cooking of a ham or a hot dog. Many more serious applications were tried, frequently with success technically, but cost and lack of user experience usually were the barriers. Weevils in grain were killed dielectrically; glue between shoe soles was similarly cured; some hardening and soldering were accomplished.

The outset of World War II gave high-frequency heating its great impetus. In particular, the need for selective heating and hardening of the surfaces of countless thousands of metal parts for the machines of war—spindles, crankshafts, rocker-arms, cams, shell noses—brought induction hardening by radio frequencies into its own.

Most outstanding of all wartime accomplishments of r-f heating was its use to help conserve desperately short tin. A total of 9600 kw of Westinghouse radio-frequency generators—more than twice the kilowatts of power employed in all radio broadcasting in the United States—had been supplied to steel mills for this application at the end of the war. Radio-frequency generator capacity of existing tin-plate mills is being augmented to allow further increase in output speed.

The vast experience gained with r-f heating during the war, the numerous improvements that accrued to all electronic equipment during that period, and the prospect that r-f heating would find applications greatly expanded in number and volume led at the war's end to a coordinated "line" of r-f generators. They cover a range of ratings from 2 to 600 kw. These are compact units incorporating industrial-type construction, which are planned for simple installation, requiring relatively little skill, and offering reliability in operation.

A subsequent step has made r-f generators much more useful to industry. This is the incorporation with the generators of apparatus for handling the parts to be heated. In many operations r-f heating of parts is reduced to a pushbutton operation; the operator perhaps tending more than one machine and doing little more than directing the flow of material to and from the generators. The outstanding postwar applications of r-f heating have been for wood-gluing, plastic preheating, rubber curing, and metal hardening.

R-f generators for many heating tasks in industry have arrived. Improvements in electronic components are continuing to appear with sufficient rapidity that r-f generators will be redesigned to incorporate them. The result in each case should be greater reliability, longer life tubes, greater flexibility, somewhat lower cost. The more immediate major task is one of education—of industry learning how to apply effectively this new tool, of operating personnel becoming more familiar with it. R-f heating is still relatively little known. It holds great promise for industry.

Radar—One of the most dramatic and spectacular electronic stories of the war was radar. Considered a wartime development, it is interesting to note that the basic principle of radar was discovered in the United States in 1922 by Dr. A. Hoyt Taylor of the Naval Research Laboratory, and from that time he and his associates were engaged in the secret development of the discovery.

Since the early 1930's the Army had been carrying on intensive experiments in the development of radar for aircraft detection, in fact, had designed its own power-supply equipment, antennas and other vital parts. Westinghouse engineers experimenting with short waves in 1933 had noted that the passage of automobiles on a highway a mile away could be detected by the reflections of the radio waves.

A year before Pearl Harbor this equipment was guarding the approaches to the Panama Canal. At Pearl Harbor on the fateful December 7, 1941, the same type of radar detected and located Japanese planes more than 30 minutes before they came on the target. These units remained in service throughout the war, serving with particular distinction in Pacific battle areas and in our coastal defenses at home.

As radar developed, many units for different uses were built. The largest Westinghouse model was a mobile radar unit first mounted in two trailer trucks and later redesigned into a single trailer. This equipment was used at Salerno, through the "buzz-bomb" attacks on Britain—where it helped to shoot down 90 percent of the jet bombs—on the beaches of Normandy on D-Day, and in the "Battle of the Bulge." A long-range search-type radar for use aboard battleships and other large naval craft served well in many of the major sea battles of the Pacific, searching out enemy planes and ships and identifying enemy targets for American guns. In addition, special airborne search radar for carrier-based fighter planes and a highly effective unit to provide navigational guidance for night-fighting planes were developed.

The production of electron tubes, and especially radar types, rose to astronomical quantities during the war. Many were for equipments of our own services, while large quantities were desperately needed by our Allies whose production facilities were all but destroyed by their proximity to the front. So great was the demand that it was necessary to design, build, and staff a new plant just to help in the production of the types most needed.

While radio had long been edging toward a greater utilization of the higher frequencies, with radar this trend took a sudden leap into a region where design knowledge for such tubes was scant indeed. The newly born klystron and magnetron depended on radically new principles of operation, thus requiring new concepts of construction, assembly, and test. Mechanically the tolerances of assembly were so small that a new set of manufacturing standards had to be established. Not only was it necessary to build magnetrons and klystrons, i.e., transmitting and receiving tubes, in large quantities but it was suddenly necessary to devise other complementary tubes. The generation of the radar signal to be sent on its errand, required an accurate control tube, and here a new gas-filled modulator tube was designed, tested, adopted, and placed in production in an astonishingly short time. Again research and engineering experience with many types of gas tubes over several decades produced a rich reward.

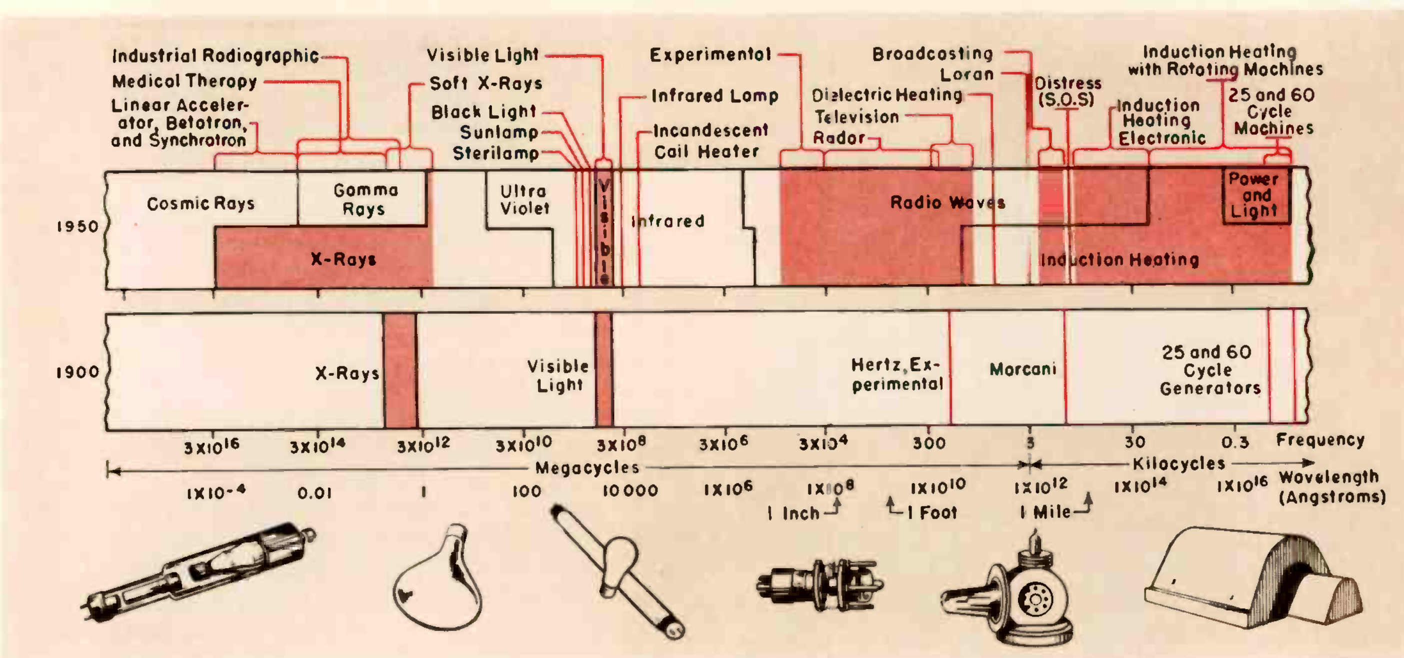
At another time an inertia-less switch was desired, able to divert hundreds of kilowatts of power, yet so sensitive it would not lose the weakest incoming signal. For this another type of gas tube (known as a TR box) was created.

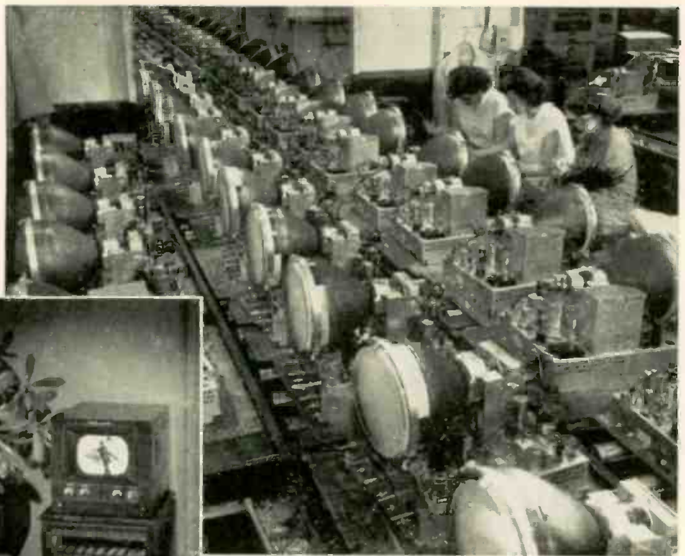
Extensive wartime experience with radar is resulting in many peacetime applications. Outstanding is marine radar—to provide anti-collision protection and navigational assistance to ships on the high seas and on inland waterways despite inclement weather.

Radar has made the major step from a military tool to one for industry, where the requirements are so different that entirely new designs are needed. In contrast to military radar, commercial marine radar must be operable by men with limited training in electronic equipments. Emphasis is on observation of objects miles or even yards away instead of those hundreds of miles away. Life of the components must be long, maintenance and adjustment simplified, and cost low. Sets now in production have gone a long way toward meeting these requirements, although the radar art is yet so young and electronic developments are still coming so rapidly that much further progress can be expected, especially from the standpoint of reduction in size and high resolution on "close-in" targets. Radar sets now require about 50 tubes. The future may see this requirement reduced by half.

Prospects of Electronics

Anyone in the electronics field who attempts to estimate its future finds himself in an uncomfortable position. He realizes that his prognostications are conservative and unexciting by comparison with what the comic strips and Sunday supplements have already promised. Predicting electronic miracles has become almost a national pastime; anything less sounds flat. Adding to his discomfort is the realization that in





Television since the war has skyrocketed to importance as a major industry and as a vital factor in entertainment.

Radar is fast-growing in importance as a navigational aid in marine commerce.

the past some of the most extreme concoctions of these authors have been outrun.

Electronics is still on the steeply rising curve of development. The limit has by no means been reached in improvement in the tools of electronics—vacuum tubes, capacitors, transformers, resistors, and other circuit components. Tubes with longer life and of much higher powers are needed. Both can be expected. There appears to be no absolute limit to power that can be generated with tubes. The practical limits to tube output at any one time are those of materials, which are continually being improved. For example, cathodes with vastly increased emitting power and life are needed and should some day be possible. We have both solids and gases capable of conducting large currents. But we are still not able to cause large floods of electrons to move from one medium to the other. The phenomenon of emission is still relatively poorly known. When it is understood perhaps we will have super-cathodes, with a new order of emitting continuous power equal to the 20 or 30 amperes per square centimeter now obtained in practice under short-duration pulsed conditions instead of two or three as at present. Realization of such super-cathodes would give the electronics science another large lift. It would help make possible high-frequency generators with outputs of many megawatts and would be a large step toward high-frequency energy of less cost.

Only a few years ago a few hundred kilocycles was considered high frequency. Today tubes are available to generate frequencies up to several thousand megacycles. As yet the average powers available from these megacycle tubes is small —a few kilowatts at most—but history promises more.

Capacitors in the future, using titanium oxide and other materials of high dielectric constant, may be only a fraction of the size and also cheaper than present capacitors. These will be used at both low and high frequencies.

Then, what about the present no-man's land of frequencies between the upper limit of electronic devices and those possible with infrared generators? At present the practical limit of tube-generated frequencies is about 30 000 mc, although 60 000 have been realized experimentally. It took the discovery of the properties of resonant cavities to break through the frequency ceilings of conventional multi-electrode vacuum tubes, about 1000 megacycles. Dimensions of cavity tubes are becoming so small that in turn their practical limit is being approached. Research must provide some new principle of generation if the present limit of cavity tubes is to be exceeded.

Suppose that generators of super-frequencies at super-powers become available. What then? Two paths are open. One is an increased use of present electronic functions, and the other is the development of new ones now unknown.

High-frequency heating, for example, can be expected to expand. Ability to generate r-f energy in blocks of 10 000 kw or 50 000 kw at a cost comparable with the cost of 60-cycle energy would open up whole new fields to r-f heating. Many of industry's drying functions, now closed to r-f because of its cost might become economically feasible, such as accelerated but controlled drying of wood. Not inconceivably the ponderous, block-long, three-story high, multi-roll machine for drying paper after the web has been formed might be replaced with a compact high-frequency drier.

Whereas the development of cheaper and more efficient oscillator equipments for thousands of kilowatts will find an expanding market and application in heavy industries, one cannot overlook the possibilities among the small users of r-f heating. As the users become educated in the application of r-f heating equipment they will apply this equipment as they do now with induction motors. This requires that the equipments be made simple to use and easy to apply.

The possibilities of electronics in the food field seem scarcely touched, mostly because the high cost of r-f energy has been a damper to exploration. The processing of cereals, the precooking of meats, the heating and sterilizing of packaged foods are potential tasks for r-f energy in that tomorrow when its cost per kilowatthour declines.

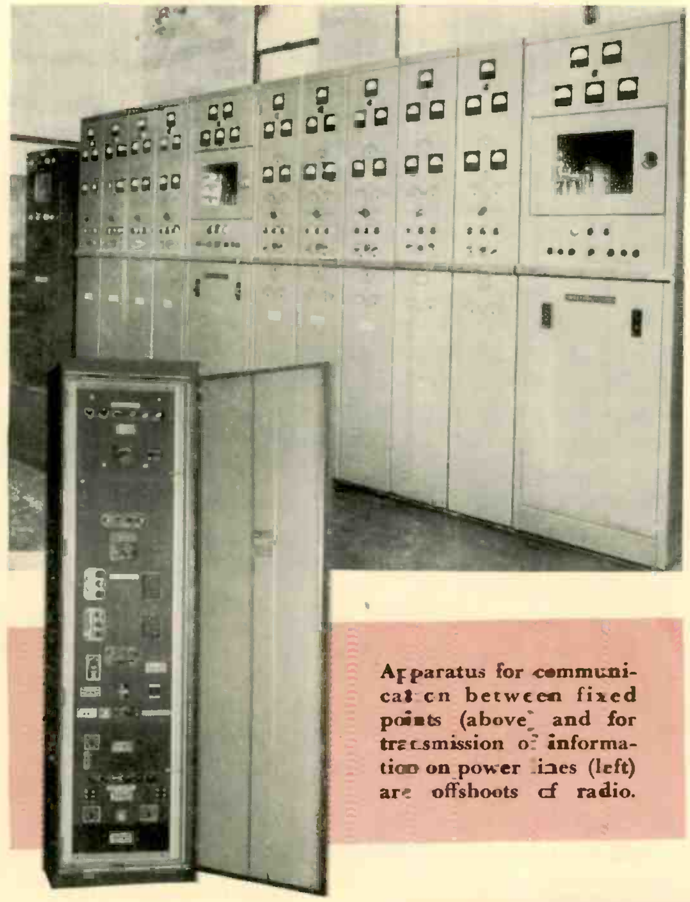
The food-processing industry, the packaging experts, and the electronics engineer may team to make tomorrow's food preparation very different from that of today. Dielectric cooking has met thus far with little success. Possibly that is because it has been used simply as a replacement for present stoves. Its success may lie in new food-processing methods specifically designed to use dielectric heat. Tomorrow, perhaps the housewife instead of buying a steak, which is simply a slice from a side of beef, will purchase a homogeneous piece of meat, de-boned and minus fat, all electronically tenderized and packaged, and frozen in individual serving containers labeled with directions as to settings of frequency and time for the home table-side dielectric cooker. The prospect is for major changes in food packaging—fruits, vegetables, meats, even cereals—trends that may take into account electronic processing at the factory, electronic thawing or cooking at the table. Days "of hours spent in a hot kitchen" may disappear.

Industry has scores of metal-annealing tasks that, in the future, might be done faster or better and at acceptable overall cost with electricity (perhaps at 60 cycles or with high frequencies) instead of present fuel-fired ovens of acre size. Continuous heat treating of metal strip instead of by the present batch method would have considerable benefit.

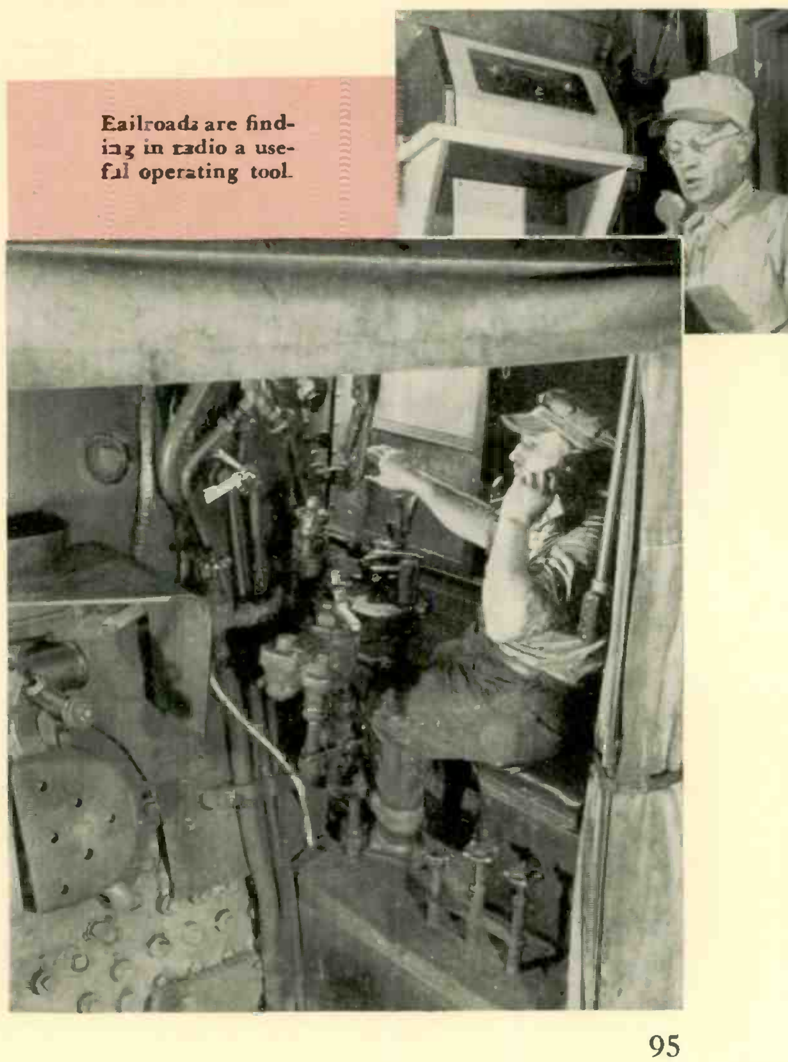
Some improved form of television or radar or both, teamed with electronic controls or actuators, are likely to bring a new order of safety to transportation. As the skies fill with the traffic of high-speed planes the entire work of navigation and the operation of controls may be turned over to automatic devices that fly the planes on a prescribed course, at the correct level, and immune to collison. Vessels, likewise, may be navigated by electronic pilots with radar eyes that no fog, storm, or darkness can blind. Trains may be similarly operated by combinations of radar, television, and electronic controls divorcing safety from dependence on human judgment.

Color television may have uses beyond that of entertainment or news-event projection. With such concurrent developments as the Westinghouse bright-image fluoroscope, television may enable physicians miles away to diagnose human maladies. It might bring the day of the superspecialist. A man or group of men expertly trained in, say, heart diseases, who do nothing but diagnose cases all over the United States. Color television for instruction in surgery has already been tried experimentally. Similarly television and powerful x-rays may permit research into machines or places not safe for man to be or into which he cannot see now.

The mails and telephone may be altered by new methods of information transmission. The ability to transmit enormous quantities of information—already demonstrated—in incredibly short times may eliminate the present delays of correspondence. Information in written form may be conveyed not physically but via microwaves for reproduction essentially at the recipient's elbow. Perhaps individualized color television —or a modified form of it—combined with voice transmission may make conversations between two people miles apart the equal of an across-the-desk discussion—with all the attendant human advantages. Conventions may be held without people leaving their offices. This would obviate the ex-



Apparatus for communication between fixed points (above) and for transmission of information on power lines (left) are offshoots of radio.



Railroads are finding in radio a useful operating tool.

penditure of time and money now incurred as individuals find it necessary to travel long distances for brief meetings.

Radio, oldest of major electronic applications, can expect further expansion and uses. Such developments as the printed or stamped circuit, sealed components, and possibly the replacement of present vacuum tubes with germanium, silicon, tellurium, or selenium crystals will reduce radio sets in size and cost. The use of semi-conductors, such as the type known as the Transistor, would have the great advantage of eliminating the vacuum problems of present-day tubes, and the complexity and power consumption of filaments. Perhaps thereby we might see the introduction of the "citizen's" radio—radio of vest-pocket dimensions—for semi-private communication as between the farmer in the field and his house or barn.

Scarcely a beginning has been made in microwave communication. Its widespread use by electric-power companies, pipe-line organizations, forest protection seem likely.

Computing and memory tubes, among the newest tools of the scientist, are just beginning to permit the use of equipment designs that will perform many complex calculations infinitely faster than can the human mind. Just how far the trend to duplicate the mechanics of the human brain will go is sheer speculation, but undoubtedly many thought processes can be duplicated electronically. They may help bring many phases of human endeavor such as sociology and economics into the realm of more exact sciences. At present these involve too many interrelated variables to permit analysis.

The continuing great need in industry is to increase the productivity of labor; to enable a worker to turn out more goods with less effort and under more pleasant conditions. These incentives should lead to many more automatic controls, many of which are bound to be electronic. In the future many manufacturing and assembling processes may require only nominal human attention. Information may be fed into electronic-operated computers, the integrated results causing mechanized controls to perform the pre-directed functions. The almost workerless factory may not be entirely fantastic.

Uses may be found for those strangers in the electromagnetic spectrum between infrared (0.0001 cm wavelength) and the fraction of a centimeter possible with resonant-cavity generators. The useful effects of any of these for earth fertilization, on botanical growth, for attack on human enemies such as cancer, for acceleration of chemical action, no one can say. As yet we have neither the tools nor the knowledge of properties of matter in that part of the spectrum. But that lack is not a permanent condition.

Man's curiosity led him to conquer the world and he has already solved many of nature's secrets. Radiation-counter tubes, now in use in the x-ray and related fields, permit the measurement of dosages for treatment and the prevention of over-exposure. Such tubes will tell us more about the mysteries of interstellar space and the universe in which we live. Such knowledge will either enlighten or refute the present speculation about the influence of cosmic rays on man.

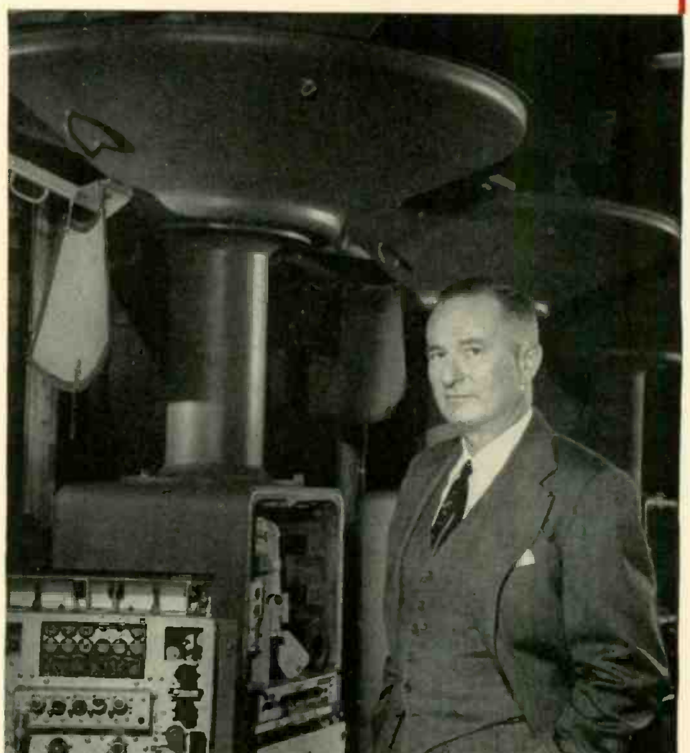
Such speculation could go on ad infinitum. In the retrospect of another half century many of those set down here will show as blind alleys, others may appear as grossly underestimated. In any case, we can rightfully expect much of those research men who are trying to discover the new and the designers who are endeavoring to make better use of the tools at hand.

WALTER C. EVANS

Electronics, if we consider that it had its practical beginnings about 1917, is the only subject of this symposium whose history can be spanned by the activities of one man. Walter C. Evans does this—and more. Electronics as we know it today was born of wireless, and in this Evans was already well experienced when World War I broke in Europe. At the age of 16 he had been a ship's wireless operator on Great Lakes steamers and followed this with two seasons on fruit vessels in Central American waters. His study of electrical engineering at the University of Illinois was interrupted by the war; his experience making him valuable to the Navy as an instructor at the Naval Radio School at Harvard. The war concluded, he finished his work at the University of Illinois and again became a ship's radio operator.

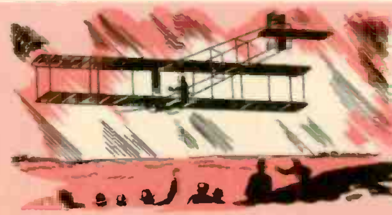
Mr. Evans joined Westinghouse in 1921 as a radio operator at station KYW in Chicago, and has been prominently identified with all Company radio activities since. Within a year he was appointed chief engineer, and, in 1926, general manager of that station. In 1929 he was named superintendent of radio operations in charge of technical matters for all Westinghouse broadcasting stations, and in 1932 he was placed in complete charge of these stations. His duties were expanded in 1933 to include design, manufacture and sale of all radio apparatus of the Company, as well as broadcasting. In 1936 he was elected a director of Westinghouse Radio Stations, Inc.; in 1939, Vice President; and, in 1947, President of that subsidiary. Mr. Evans has been a Vice President of the parent Westinghouse Electric Corporation since April, 1942.

World War II found him participating for the second time in military electronics. This time on an enormously expanded scale. Under his direction the electronics manufacturing activity expanded by 120 times to keep pace with the country's needs for radar, military radio, and many other items of electronic ordnance.



Some Westinghouse Engineering Highlights of a Half Century

1900 Installed first steam turbine for public utility service in the U.S.
1902 Applied ball bearing to watthour meters.
1904 Applied speed-reducing gears to ship propulsion.
1905 Built the first main roll drive for steel mills.
1905 Introduced steel switchboard panels.
1907 Introduced condenser bushing for high-voltage terminals.
1908 Introduced first pool-type mercury-arc rectifier.
1909 Introduced automatic synchronizer.
1909 Introduced first continuous-filament tungsten lamp.
1910 Introduced radial-flow steam condenser.
1911 Applied Kingsbury-type thrust bearings for vertical water-wheel generators.
1913 Announced Faradoid principle of insulation based on work of Fortescue.
1918 Announced symmetrical components, a new mathematical basis for the design of three-phase alternating-current systems and apparatus.
1919 Developed the portable oscillograph.
1919 Began study of rare metals, uranium, thorium, zirconium, etc.
1920 Developed first variable-voltage planer drive.
1920 Developed diesel-electric drive for ships and equipped first vessel for same.
1920 Initiated radio broadcasting with Station KDKA in Pittsburgh.
1922 Applied supervisory control for remote, unattended stations.
1922 Originated with United Electric Light and Power Company, the alternating-current secondary network system of supplying power in large cities.
1922 Introduced commercial forms of Autovalve lightning arrester.
1923 Introduced the reactive kva (RI) meter.
1924 Introduced tap-changing-underload equipment for power transformers.
1924 Announced Hipernik, a high-permeability electrical steel.
1924 Applied Klydonograph, a device for studying effects of lightning on lines.
1925 Installed first high-power laboratory at East Pittsburgh with a short-circuit capacity of 400 000 kva.
1925 Announced the De-ion principle of arc interruption in air.
1926 Developed method of sealing and shipping transformers in nitrogen.
1927 Developed the grid-glow tube.
1928 Developed the socket-type watthour meter.
1929 Introduced the high-speed relay (HZ).
1929 Built the first diesel-electric rail car for revenue service in the U.S.
1929 Introduced De-ion tube for protecting high-voltage lines.
1929 Built first De-ion grid, oil circuit breaker.
1930 Promulgated direct-stroke theory of lightning on transmission lines.
1931 Developed the sectional mercury-arc rectifier.
1931 Developed a-c and d-c electronic voltage and speed regulators.
1932 Announced principle of the ignitron mercury-arc rectifier.
1932 Introduced surge-protected distribution transformers.
1932 Announced surge testing of power transformers, with dynamic power applied.
1932 Introduced boric-acid power fuse.
1933 Developed ignitron control for spot welding.
1934 Introduced completely self-protected (CSP) distribution transformer.
1934 Introduced rotating regulator (Rototrol).
1935 Announced Precipitron—an electrostatic air cleaner.
1935 Introduced the Sterilamp, a bactericidal radiator.
1935 Announced Hipersil, a grain-oriented magnetic steel.
1936 Introduced air-cooled transformers with fireproof insulation.
1937 Introduced Silverstat direct-acting generator-voltage regulator.
1937 Introduced high-speed pilot-wire relaying.
1938 Developed relay (type HCB) for simplified pilot-wire relaying.
1940 Announced K-42-B, a high-strength, high-temperature metal.
1940 Developed short-exposure radiography.
1941 Began work on the first American design jet-propulsion unit.
1942 Built gyroscope control for stabilization of guns on Army tanks.
1942 Developed form-fit design of power transformers.
1944 Equipped first steam locomotive in the U.S. with geared turbine drive.
1945 Announced Refractaloy, a high-temperature metal.
1947 Announced all-weather approach lighting system for airports.
1948 Announced fluoroscope image amplifier.
1949 Announced foamed resinous insulation.


1903—Wright Brothers' First Flight


1906—San Francisco Fire

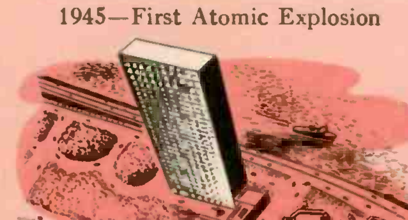

1909—Mass-Produced Ford


1917—World War I


1931—World's Tallest Structure


1941—World War II


1945—First Atomic Explosion


1949—United Nations Building

S. G. Hibben's demonstration of a possible future lighting method—activation of a phosphor-coated globe with radio-frequency energy—suggests a prophet peering into the future. Undoubtedly many engineering feats that today seem like "crystal ball" projects will materialize in the last half of this century. Evidence points to generating units two and three times today's largest.... Basically different and more effective cooling systems.... Packaged drives self-protecting and burn-out proof.... all-synthetic insulations .... These and many other seemingly distant prospects may find solution and application sooner than we realize.