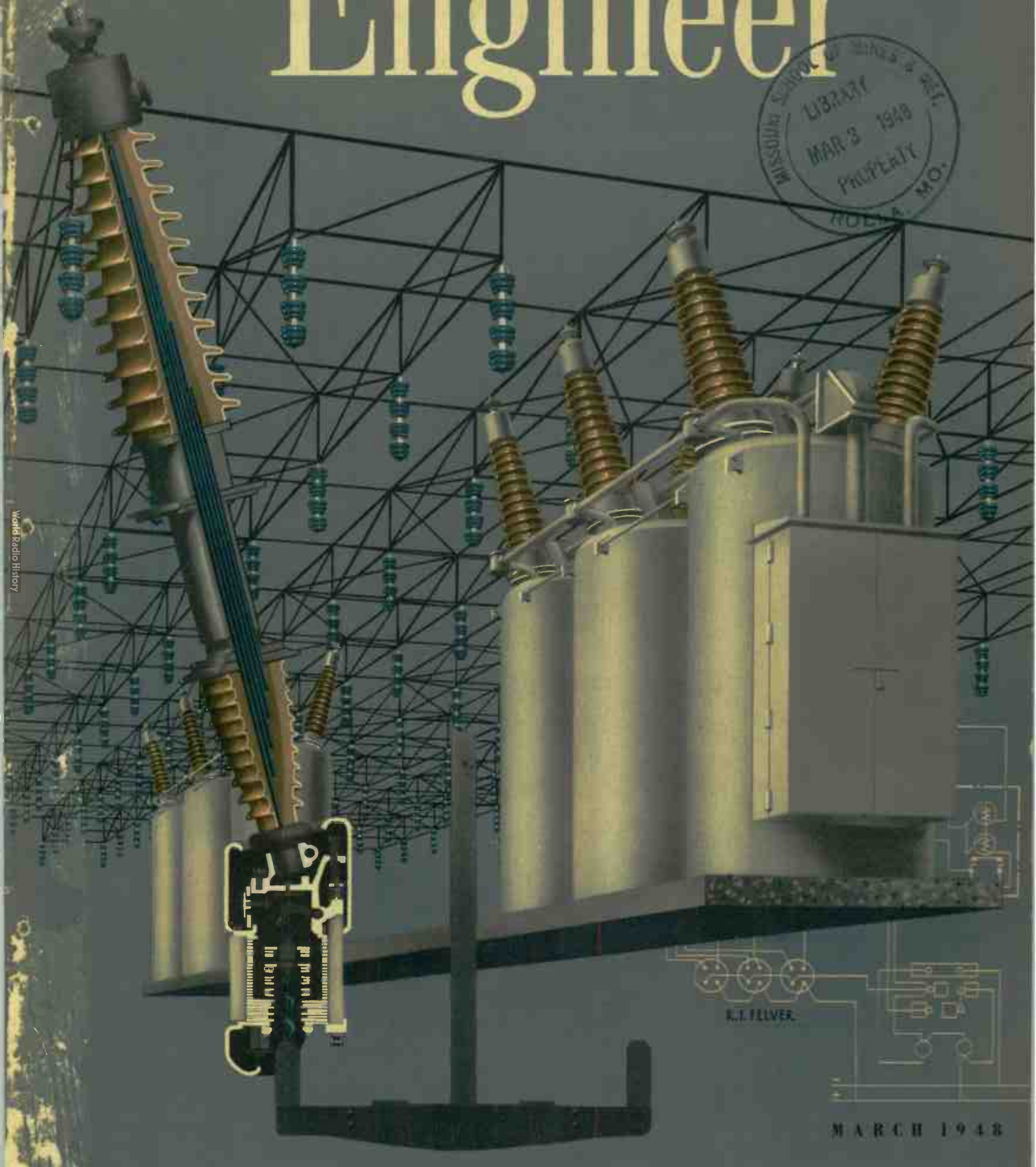
WESTINGHOUSE

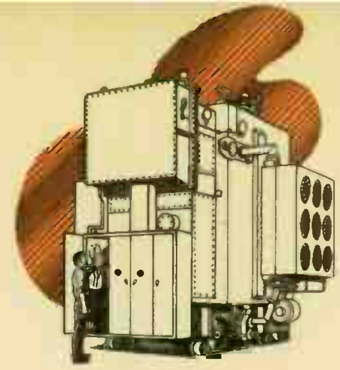
Engineer



MARCH 1948

The Transformer—

A Foundation of the Electrical Industry



The transformer, correctly considered the foundation of the electric-power industry, has recently passed two milestones—100 000 kva and a half-million volts, as discussed in this issue.

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Almost exactly sixty years have been required for the transformer to reach these peaks. In the early 1880's the industrial world was still thinking of electric power in terms of direct current. Almost the only use then envisioned for electricity was for lighting. Direct-current lighting systems were regulated satisfactorily by a solenoid arrangement, which would not work on alternating current. Furthermore, alternators were generally considered to be unsatisfactory and beset by more difficulties than d-c machines. The three-wire system, with dozens of installations in service, seemed well entrenched.

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But, with the inherent restriction of distance on direct current, it was inevitable that someone would develop a method of readily altering potential. Many in this country and abroad were seeking the answer. Among these was William Stanley, a young engineer in the employ of George Westinghouse in Pittsburgh. Until 1884 he, like others, had been working in blind alleys. Then Mr. Westinghouse heard, through his contacts with the Pantaleoni family of Italy, of an a-c system developed in England in 1883 by a Mr. Lucien Gaulard, an Italian engineer, and a Mr. Gibbs, an English promoter. As this system seemed to offer some promise, Mr. Westinghouse obtained the rights to its use.

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The Gaulard and Gibbs' installation in England was, to be sure, an a-c system. Power generated by a Siemens' single-phase, 133-cycle alternator was supplied to lamps through induction coils, which they termed "inductoriums." However, these were connected with their primary windings in series. The secondary windings were wound with the same number of turns as the primary and supplied independent circuits to which the lamps were connected in parallel. The system thus employed constant current instead of constant voltage. This worked well enough while the number of lamps paralleled on one transformer secondary remained unchanged but if lamps were added or removed the output of the others varied accordingly. To reduce the fluctuations as much as possible the inductoriums were made with open-circuited magnetic cores. Regulating resistances also were necessary. Thus while much credit is due Gaulard and Gibbs for focussing attention on the a-c system, their scheme of series-connected transformers as such had little practical value.

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The principle of the transformer is now taken for granted. But, three-score years ago the idea of impressing several hundred volts across a coil of a few ohms resistance without drawing excessive current was obviously a violation of Ohm's law. The concept of counter-electromotive force in a transformer and its function as a finely balanced automatic regulator was a great achievement. Great tribute is due Stanley for being able to visualize that abstract but absolutely essential notion.

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Early in 1885 Stanley, at Mr. Westinghouse's request and in anticipation of the arrival of the Siemens' alternator from Europe, designed several induction coils with closed magnetic circuits, which he called "converters." These he intended for parallel connection. Thus the transformer as it is known today was born. Twenty-six of these units wound for 500 volts primary and 100 volts secondary were built.

The original installation was made at Great Barrington. It consisted of a steam-engine driving the Siemens' alternator located in an old rubber mill, and a 500-volt line running 4000 feet to the center of the village, to which was connected two 50-light and four 25-light converters. As Stanley told it later*, these half dozen transformers "were placed in customers' cellars—in wooden, skeleton boxes covered with mosquito netting and kept under lock and key." These supplied 150-, 50-, and 16-candlepower lamps in thirteen stores, two hotels, two doctors' offices, one barber shop, and the telephone and post offices.

The installation was formally placed in regular service on March 6, 1886, although it had actually been in occasional service for several months. As Stanley tells it: "We made a gala night of it. The streets and stores were crowded with people, the big 150-candlepower lamps were running at about double their candlepower, and my townsmen, though very skeptical as to the dangers to be encountered when going near the lights, rejoiced with me. This plant continued to operate successfully until an attendant, in the summer of 1886, dropped a screwdriver into the alternator and ruined it."

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The Great Barrington installation was an unquestioned success. It was quickly followed by a three-mile line in Pittsburgh between Swissvale and East Liberty when a distribution system was installed using some of the original 26 transformers. The system speedily caught on. Similar Westinghouse systems were soon installed in Greensburg, Pennsylvania and Buffalo, New York. By the fall of 1887 at least 27 of the Westinghouse a-c systems were in service.

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Between Great Barrington and the half-million-volt lines at Tidd Station lies an enormous field of development; a mere listing of the individual steps would occupy this page. At each point in the progress of transformer development engineers have been faced with mountain-size obstacles—which always seem easy after they have been scaled. Mention can be made of but a few. Designers had to use "stovepipe" iron, with its erratic, mysterious aging and varying electrical properties until 1906 when low-loss silicon steel was invented. Condenser bushings solved the high-voltage terminal problem in 1908. The no-load tap changer came in 1921 followed in 1924 by change-underload equipment. The Inertaire system of preserving oil was first applied in 1923. Surge-test equipment first built in 1925, and Dr. Fortescue's enunciation of the direct-stroke theory of lightning activity led to a rational design of insulation that has given the lightning-proof transformer. Grain-oriented steel, Hipersil, after a long period of development, was introduced in 1940. Form-fit tanks appeared in 1940; loading by copper temperature in 1941.

Progress has been steady. Further improvements are to be expected. From the experimental work being done at Tidd will come lines requiring larger transformers operating at higher voltages. Assuredly the power-transformer designer will be ready.

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*Journal of the Franklin Institute, vol. 173, 1912.

WESTINGHOUSE
Engineer

VOLUME EIGHT MARCH, 1948 NUMBER TWO

On the Side

The Cover—The smooth, simple exterior of the modern high-voltage circuit breaker enfolds a more complex mechanism for interrupting and clearing fault currents. This guardian of service and its operation are artistically portrayed by R. I. Felver.

• • •

Of special interest to manufacturers of machine tools will be the 12th Annual Westinghouse Machine Tool Electrification Forum. To be held at Buffalo on April 22nd and 23rd, the purpose of the Forum is to discuss problems of motorized equipment common to both the user and manufacturer. Papers will be presented by representatives of machinery builders and Westinghouse.

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There is really no need to revise the theories of atomic energy but a new type of "atom bomb" has recently been built by Westinghouse. It consists of fifty mousetraps, each "armed" with two rubber corks representing neutrons. When a single cork is thrown into the closely bunched mousetraps, it sets off the first trap releasing two corks, which in turn set off two other traps. All fifty go off in a few seconds, demonstrating chain action.

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Something new in the techniques of reducing voltage fluctuations caused by surging loads is the application of a record-size 10 000-kva series capacitor on a 66-kv line feeding four 10 000-kva electric arc furnaces. Prior to installation of the capacitor, voltage dips due to load peaks caused some difficulty in starting motors. But with the capacitor in series, a leading kva that automatically increases and decreases with load is provided and voltage fluctuations are minimized.

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In This Issue

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

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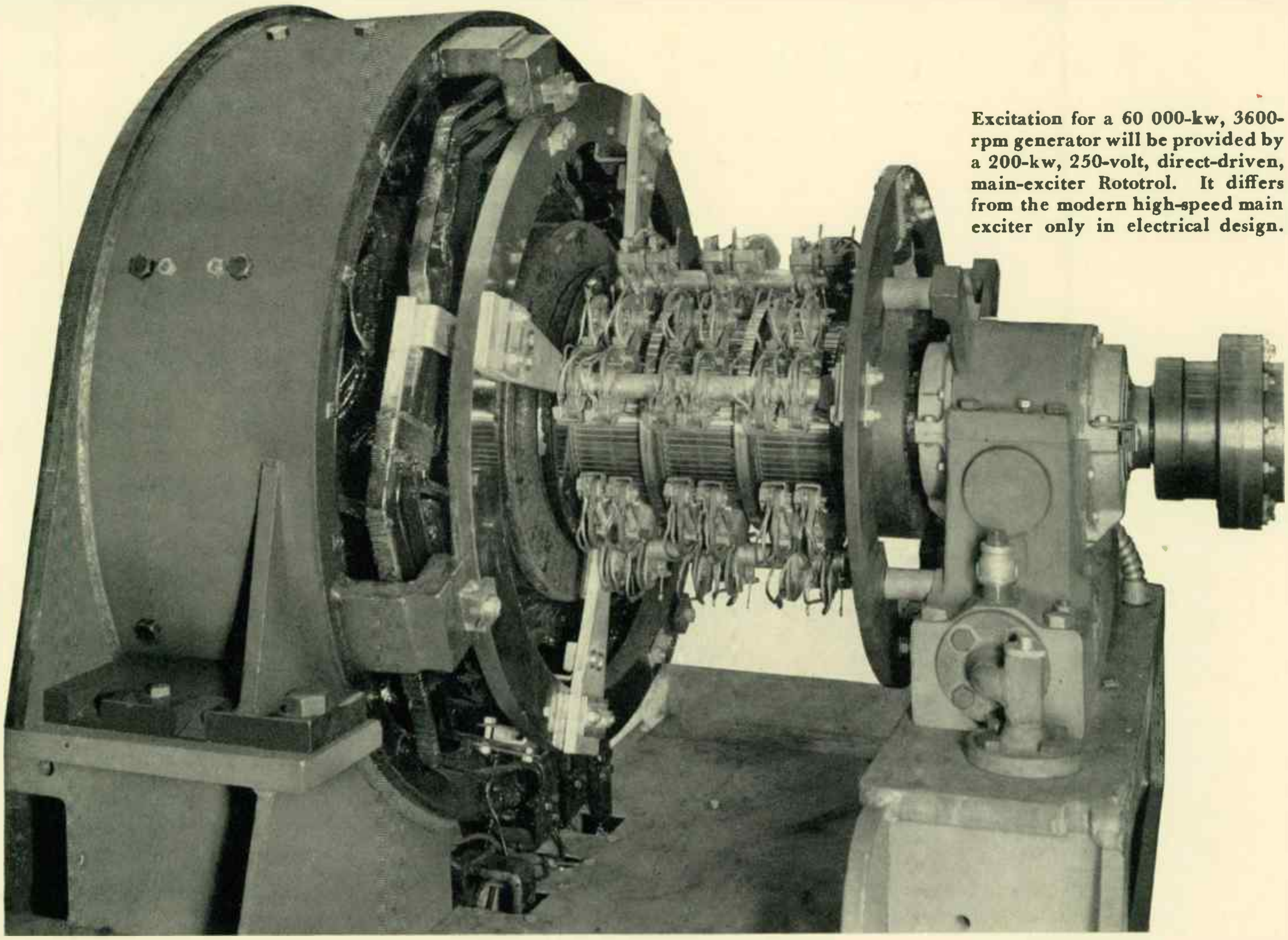

Excitation for a 60 000-kw, 3600-rpm generator will be provided by a 200-kw, 250-volt, direct-driven, main-exciter Rototrol. It differs from the modern high-speed main exciter only in electrical design.

Rototrol Provides Generator Excitation

Being auxiliaries to the main job of generating power, excitation systems should be as simple as possible, be readily serviceable, but require little of it, and offer the least possible opportunity for trouble. Construction of a main exciter on the principles of the two-stage Rototrol eliminates at one swoop the contact-making regulator and pilot exciter. Tests indicate no sacrifice in electrical performance, in fact, some improvement.

C. Lynn
Manager, D-C Engineering Department

C. E. Valentine
Manager, Regulator Engineering Department

Westinghouse Electric Corporation

A 70 500-kva, 3600-rpm generator now being installed has an excitation system without either a contact-making regulator or a pilot exciter. Excitation is provided by a single rotating machine, a 200-kw, direct-connected main exciter, which is a two-stage Rototrol. This marks a significant step in the long evolution of excitation and voltage-regulation systems for large a-c generators toward simplicity, reduced maintenance, and greater reliability.

The main-exciter Rototrol receives voltage-regulating intelligence from a static network. The rotating machine is a d-c generator, identical in appearance to a conventional high-speed exciter and differing in construction only in that it has the special field windings that make it a two-stage Rototrol. Thus a single-unit main exciter provides complete excitation, stability, and regulation. The only addition is a static voltage-regulating network, which, being static, has no moving parts. No additional brushes, short-circuited windings and connections, or other constructions critical in adjustment or possessing potential possibilities of trouble are required. Control-power amplification is produced in the main exciter itself. In order to require only a nominal amount of control energy from the static network, it is built as a two-stage rotating amplifier* instead of as a single-stage unit.

Regulation of Voltage

Regulation of the Rototrol main-exciter terminal voltage

Much of the information in this article is taken from a paper by these authors presented before the AIEE Midwinter Convention, Pittsburgh, Jan. 26–30.

*Discussed in "Rototrol and Its Applications," by E. Frisch, Westinghouse ENGINEER, July, 1947, p. 121.

and of the a-c machine it serves requires a voltage-responsive device or circuit that can transmit the proper intelligence to the Rototrol control field. The multi-stage Rototrol exciter or d-c generator differs from the conventional d-c generator or exciter in the magnitude of its amplification. Because the object is to provide maximum amplification in output terminal voltage for a small change in the control-field input energy, this type of machine can be controlled with a small amount of energy from a voltage-responsive regulating device or circuit. The regulating action is provided by a circuit consisting of transformers, reactors, condensers, resistors, dry-type rectifiers, and the Rototrol windings.

The voltage-responsive static circuit employs a self-contained reference, which takes the place of the spring in the electro-mechanical-type regulator. It consists of the intersection of a non-linear impedance characteristic of a reactor and a linear impedance characteristic of a condenser. The voltage-responsive regulating circuit is satisfied or "balanced" at the point of intersection of the impedance characteristics as is illustrated in Fig. 1. Any deviation from the level of voltage for which the intersection is designed results in a current difference in the static network circuits. This current difference is used to provide energy to increase or decrease the strength of the Rototrol control field.

The voltage chosen for the intersection of the impedance characteristics is somewhat less than the normal voltage of the a-c generator, reduced through potential transformers. A suitable range of adjustment for the level of voltage the generator will hold is obtained by variable resistance connected in series with the circuit that sets the fixed reference level.

An excitation system with the static regulator network is shown in Fig. 2. The automatic-control unit includes the saturating reactor and capacitor circuit. Other component parts are the potential unit and the voltage-adjusting unit. In the potential unit, alternating current and voltage provide positive-sequence voltage for the automatic-control unit, and adjustment for equalizing the reactive load between a-c machines operating in parallel. The Rototrol exciter can be operated from manual controls when the voltage regulator is not in service.

When the intersecting impedance circuit is satisfied, the current and voltage outputs of each rectifier are alike. No difference in current appears in the Rototrol control field. Should the a-c voltage drop below normal, current in the reactor circuit becomes less than that in the capacitor circuit, thus causing a current to flow in the Rototrol control field with the polarity of the capacitor rectifier. The current is in the raise direction to increase the Rototrol output, thus restoring the a-c generator voltage to normal.

Should the a-c voltage rise above normal the current in the reactor circuit becomes greater than that in the capacitor circuit, resulting in a difference current in the output of the rectifiers. The polarity is that of the rectifier in the reactor circuit and is opposite to that resulting when the a-c voltage is low. The Rototrol control field is thus energized in the lower direction, decreasing its output voltage and reducing the a-c generator voltage to normal.

Performance of the Rototrol Exciter on Test

The Rototrol main exciter was tested in the factory by loading it on the fields of a large a-c generator comparable in characteristics to that of the generator for which it was built. For comparison, tests were made on a conventional exciter of similar size, comprising a main exciter, a pilot exciter, and a modern exciter-rheostatic voltage regulator.

The a-c generator employed is a 20 000-kva, 6600-volt, 3-phase, 60-cycle, 600-rpm laboratory test machine. Its excitation requirements are comparable to those of the 70 500-kva, 3600-rpm turbine generator. The 250-volt, 3600-rpm main-exciter, two-stage Rototrol was separately driven and connected to energize directly the field windings of this generator. A three-phase reactor load was suddenly applied, resulting in a load of about 20 percent rated a-c generator amperes. The voltage dip and recovery plotted from an oscillogram are shown in Fig. 3. This voltage dip of 5½ percent was followed by a return to normal voltage in 23 cycles and by final recovery in about two seconds. The static-network regulator and machine adjustments in general, which provide for recovery in the shortest possible time, are accompanied by a greater overswing and underswing of the regulated voltage,

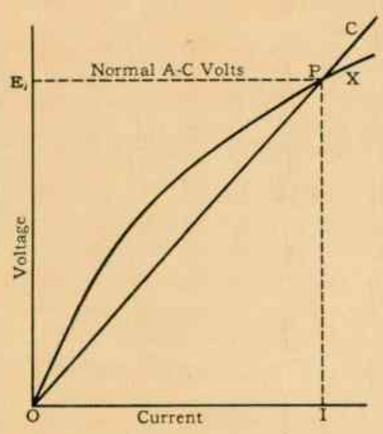

Fig. 1—Voltage reference point is obtained in a static network by the intersection of a linear and non-linear response characteristic.

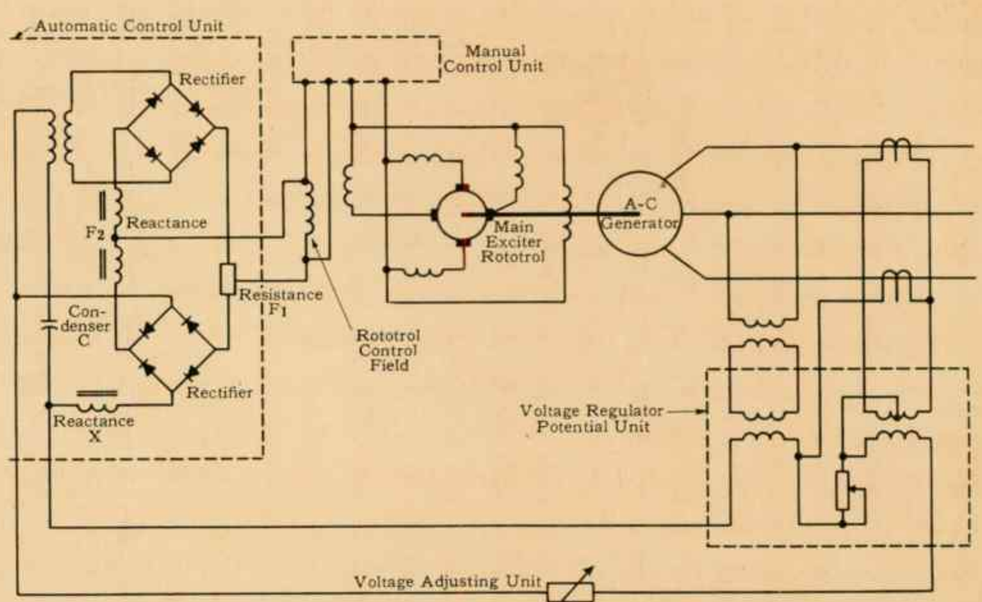

Fig. 2—Simplified circuit of the Rototrol and regulating network.

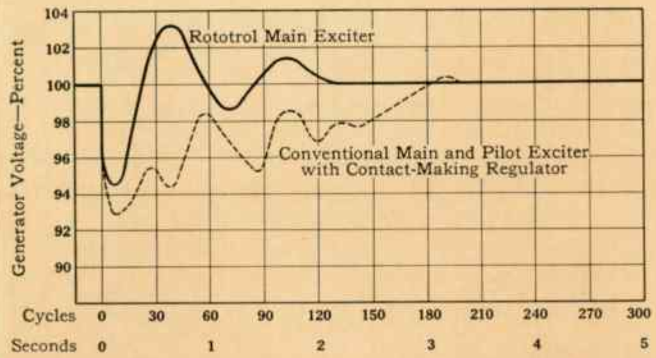

Fig. 3—A comparison, taken from an oscillogram of voltage dip and voltage-recovery time, of a main-exciter Rototrol regulating system and a conventional excitation system using main and pilot exciters with contact-making regulator.

compared to those occurring with slower rates of recovery. The available test facilities did not permit applying loads of greater magnitude. The test as made, however, indicates relatively rapid response of the Rototrol voltage, with the required forcing ability to return the a-c generator voltage to normal in spite of relatively long time delay inherent in the a-c generator field circuit.

The dash curve in Fig. 3 shows typical performance of the conventional exciter. In this test, reactor load was slightly greater than that used for the Rototrol exciter tests, and was suddenly applied in the same manner. The dash curve shows an initial voltage dip of seven percent and a recovery time of three seconds. With the exciter-rheostatic regulator the rate of recovery of the a-c voltage depends on the contact gap and timing adjustment used with the high-speed contactor, and also upon the speed of the motor-operated rheostat. The dash curve of Fig. 3 is the result with an adjustment of the regulator contacts that energize the high-speed contactors to limit voltage changes to plus or minus 2½ percent. The normal-response contacts, which control the motor-operated rheostat, were set at plus or minus one half of one percent.

The voltage dip and recovery of the exciter-rheostatic regulator can be improved by setting the contacts that control the high-speed contactors to a small percentage value. The practice of different operating companies varies considerably in this respect. Where the generator load is likely to fluctuate widely or violently, the contact gap setting for the regulator quick-response contacts may be only a little greater than that of the normal-response contacts. For the majority of power-company system regulators, however, the setting of the quick-response contacts is usually greater, for example, between plus or minus three and plus or minus five percent. With this setting the high-speed contactors operate very infrequently, providing mainly for high-speed voltage-regulator action, which occurs only during serious a-c system disturbances. For the usual system load changes the normal-response contacts regulate the a-c voltage by controlling the motor-operated rheostat alone.

Conclusions

The main-exciter Rototrol has the advantage of combining in one rotating machine the amplification necessary for control directly by the voltage regulator and ample power output for connection directly to the field of the turbine-driven generator. Since the Rototrol is series tuned it utilizes the inherent transient characteristic of the a-c generator field wherein current increases or decreases momentarily under the condition of sudden application or removal, respectively, of load. This amounts to an anticipatory action as far as the regulator is concerned because the Rototrol starts to change its output prior to action by the regulator in the Rototrol control-field circuit.

The voltage-regulating system has the advantage of a regulator without moving parts, without contactors, and requiring no large, motor-operated, main-exciter field rheostat. The overall performance of the regulator, Rototrol exciter, and the a-c machine, shows marked improvement in voltage dip and recovery time. The quicker recovery of the a-c voltage, and even a somewhat reduced overswing, is in a direction to improve the stability greatly during the transient period. Such a system also eliminates need for a pilot exciter without affecting the stability of the main exciter. The Rototrol main exciter is connected directly to and driven by the turbine generator, and is controlled by the regulating equipment, thus simplifying the entire system.

The two-stage Rototrol exciter employs the same principle of construction* that provides accessibility and reliability utilized in the modern high-speed exciter. Roll-away covers permit maximum exposure of the operating parts for inspection or maintenance. Plug-in brushes make it possible to change brushes safely with the machine in service and without tools. The machine is special only in that the windings of the rotor and the fields of the stator are those of the two-stage Rototrol, none of which detracts from the machine's reliability or accessibility.

Experience with the two-stage Rototrol and static-network regulator as a main exciter will be in order before the full scope of its application will be delineated or before other installations are attempted. However, the upper limit to size is whatever applies to the direct-connected exciter. This first Rototrol unit is one of the largest direct-connected, high-speed main exciters ever built. Larger ones could be built. Economics will probably dictate the lower range of practical ratings. The two-stage main-exciter Rototrol appears to be one of the all-time major steps in the development of excitation systems for power generators.

*"Excitation Systems for Turbine Generators," by C. Lynn, Westinghouse ENGINEER, July, 1947, p. 115.

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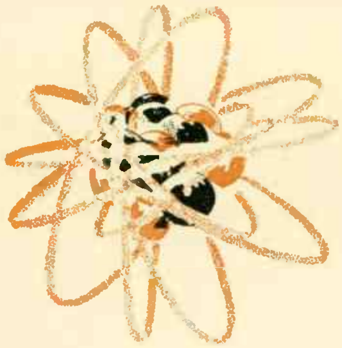


ATOMIC ENERGY—

Engineering Problems in Its Industrial Application

Dr. J. A. Hutcheson
Associate Director
Westinghouse Research Laboratories

The jump from the realization of the atomic bomb to the idea of commercial use of fission energy is easy. But ahead of the actual accomplishment lies a vast, tangled, little-known jungle of problems. Some were suggested in the famous Smyth report, others were little anticipated. As we come closer to them, all become more formidable than was earlier believed. Confidence in the eventual outcome has not changed, but the concept of the size of the job definitely has.

No one questions that it is technically possible to achieve the controlled release of atomic energy in a form that can be converted into heat or electricity. However, before this is actually an accomplished fact there is a great amount of work to be done. This work falls into two general classifications: namely, research and engineering development. At present there is under way in this country a research program, coordinated and directed by the Atomic Energy Commission, which, as time goes on, will uncover fundamental knowledge of this new science that is essential before industrial applications of atomic energy are practical. Undoubtedly, therefore, as the store of available knowledge increases, there will come a time when answers to the many questions relating to practicality of atomic energy in industry can be determined with reasonable certainty.

That the application of atomic energy in industry will eventually be proved practical is assumed. What then are the engineering problems that must be solved before the first practical electric power generating station can be built?

The method by which a chain-reacting pile or nuclear-reactor operates has been discussed.* It is known, for example, that when a neutron, whose kinetic energy lies within a certain range, strikes the nucleus of a uranium-235 atom in such a way as to be absorbed, fission of the U-235 atom results. Products of that fission are two elements, each of substantially lower atomic weight, gamma-ray radiation, the discharge of one to three neutrons, and the release of extremely large amounts of energy. Further, some of the neutrons released eventually strike the nuclei of other U-235 atoms, whereupon the process is repeated, i.e., a chain reaction is established. However, the chances of a neutron striking the nucleus of another atom of U-235 are subject to several factors. Obviously other kinds of atoms are present in a reactor. For example, there are those of the reactor coolant or heat-transfer medium, the structural material and surrounding shielding, those of the many control elements and devices essential to the operation of the reactor, as well as atoms of the many other elements that are the products of previous fission of U-235 atoms.

A few materials are partially "transparent" to neutrons. In some, such as carbon, absorption of a neutron is relatively unlikely. A neutron that enters such a material may collide with atoms of the material and be slowed up or lose part of its energy as a result, but in general it does not combine with these atoms and therefore is not absorbed. Again, the chances of absorption of a neutron depend in a complex way on the energy of the neutron. For example, it is much more likely that a neutron possessing an energy of a few tenths of an electron-volt will be absorbed by the nucleus of a U-235 atom with resultant fission than a neutron of a few hundred or more electron-volts energy.

These facts were employed in designing the reactors at Hanford, Washington. In these reactors the fission-produced neutrons released with high energy are slowed down by collisions with atoms of carbon in the moderator to the point that the average energy of the neutrons that re-enters the U-235 is most favorable to their absorption.

Most materials investigated show a marked tendency to absorb neutrons, a characteristic that disqualifies them for structural uses in reactors. This is dramatically demonstrated by the use of cadmium in control devices. Cadmium has such an affinity for neutrons that a very small amount stops completely the operation of a reactor. Cadmium absorbs enough neutrons to reduce the ratio of the number of neutrons available for fission, to the number of fissions required to maintain operation to less than one. When this occurs action ceases, since a single neutron can produce but one fission. Obviously such a material is useless as a structural material in a reactor. Unfortunately, the same is true of the common structural materials such as steel. This also explains why the materials must be of unusually high purity. The existence of impurities to the extent of a few parts per million in materials in which neutron absorption is relatively low makes these materials unsuitable for use in a reactor.

Similarly the fact that the fission products act as neutron absorbers explains the necessity for removal of these products from time to time during continued operation of a reactor. As more and more of these products are formed, an increasing percentage of the available neutrons is absorbed. This requires a reduction in the amount of control material in the reactor. Ultimately there comes a time when this process cannot be continued, i.e., when all of the control material has been removed. Unless means are provided to remove "poisoned" charges during operation, the reactor must thereupon be shut down and the fuel charge replaced. In any power-generating application it seems essential, or at least highly desirable, that continuous operation be possible.

From considerations such as the foregoing, one type of engineering problem appears. Once complete information is obtained as to the neutron-absorption characteristics of materials it will then be necessary to obtain the structural charac-

*"Physics Gives Us—Nuclear Engineering," by E. U. Condon, Westinghouse ENGINEER, November, 1945, p. 167.

teristics of those that appear applicable in reactors. This is an engineering problem that can and will be handled by engineers.

Another element that will require engineering consideration arises from the fact that the reactor will in all probability be required to operate at high temperatures, where heat engines are more efficient. This requirement creates additional problems for the engineer. For example, questions will arise as to the corrosion of materials subjected to high temperatures. Probably data must yet be obtained relative to the corrosive effect of various gases or liquids used as coolants or heat transfer media in contact with materials suitable for use within a reactor. These are typically engineering problems.

The high temperatures expected in power reactors introduce additional unknowns that must be determined prior to practical use. The mechanical properties, particularly at high temperatures, of those materials that now appear practical for use in construction of a reactor are largely unknown. Acquisition of the required data is possible by well-known methods but the job is lengthy.

Radiations incident to the process of nuclear fission pose a large number of new problems for the engineer. The need for adequate shielding for operating personnel has been mentioned many times. This problem is more complex, however, than may be first realized. Consider, for example, the probable electric-power generating system. Heat generated in the reactor is transferred by a suitable gas to a heat exchanger in which water is boiled to produce steam for use with a conventional turbine generator. The possibility of leaks through which radioactive material might pass poses a serious problem. At first glance it might be assumed that the only radiation problem is that concerned with the reactor. However, this is not the case. The gas coolant itself may become radioactive and in addition probably would gather other radioactive substances such as dust from the reactor. Presumably the heat-transfer unit in which steam is formed is such as to prevent transfer of radioactivity to the steam by direct radiations. However, a leak would permit radioactive material to contaminate the steam. Depending on the magnitude of this effect, it might be necessary to shield the turbine and piping also. Obviously this is undesirable, therefore much engineering effort would be expended in assuring the absence of leaks.

Continuous operation of a nuclear power-generating equipment is desirable if not essential. This means that the "fuel" must be replaced at intervals during operation. Because of the intense radiation within the reactor, extraction of the "ash" laden nuclear fuel can be accomplished only by remote control. The detail problems connected with the mechanical design of such devices are determined by the particular requirements of the reactor with which they would be associated. However, several general types of problems arise. Presumably the fuel will be distributed throughout the reactor, therefore the device must be so designed as to permit selection, removal, and replacement of fuel elements in any section. The device itself will be continuously bombarded by radiations so that it in turn becomes radioactive. This suggests the impracticality of servicing the device once it has been placed in operation. Trouble-free operation will require extreme care in design.

Factors such as the effect of radiation on lubricants are at present unknown. These must be determined prior to the use of lubricants with the equipment. Also, assuming that it will be found desirable to have electrical elements in the fuel-handling equipment, their reaction to radiations must be fully explored. For example, it would be fatal to use equipment in which the electrical insulation deteriorates under long-continued radiation bombardment to the point of failure.

Another matter is important, although little has been said regarding it. For many years radiations such as x-rays have been known to affect the properties of certain materials. For example, crystals of potassium chloride change color under x-ray bombardment but return to normal upon removal of the radiation. Radiations within a nuclear reactor are many times more intense than any previously available. The possible effect of such radiations upon the crystal lattice of materials used in a reactor when exposed continually for long periods of time is yet to be determined. It is likely that the properties of materials will be altered sufficiently to bear on their suitability for use in a nuclear-energy reactor. This problem, if indeed there be one, rests squarely today in the hands of the research worker.

The foregoing has touched on some of the problems that become apparent when one considers the application of atomic energy to generation of electric power. Many will require additional knowledge, to be obtained by fundamental research work, before the engineer is able to tackle the design problems to be expected.

The speed with which these and other problems are solved depends, obviously, in large measure on the number of men that can be applied to the work. Most of the fundamental work will have to be done by nuclear physicists and chemists working in government and industrial research laboratories. However, as these men progress with their work many problems will arise that can be turned over to engineers and scientists not necessarily specialists in the field of nuclear physics. Members of the Atomic Energy Commission have recently stated their realization of this possibility and propose to take advantage of it. This is indeed encouraging. If the limited pool of nuclear physicists and chemists now available had to do all the work necessary for the practical application of nuclear energy in the electric power field, many years would pass before the first demonstration could be made. However, with a basic plan that envisions tapping the much larger supply of trained engineers and scientists available in industry and applying them to work on appropriate problems, it seems certain that the advent of nuclear energy in the electric power field is much nearer than otherwise.

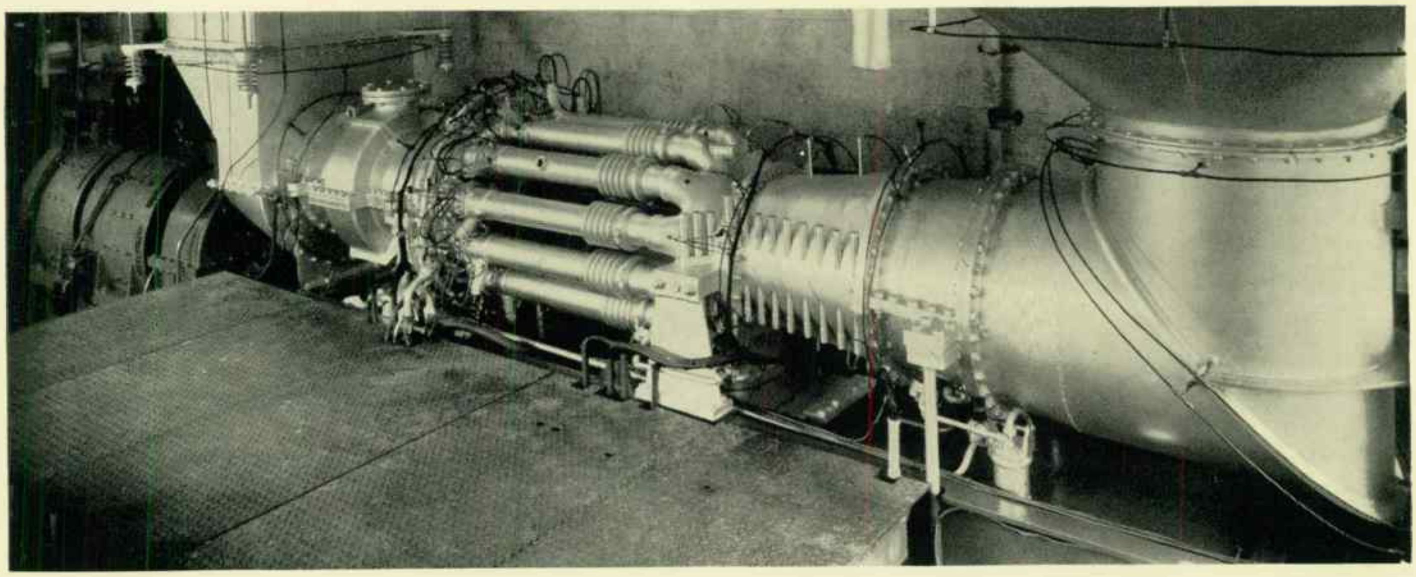
As it stands today, comparatively little of man's store of knowledge is applicable toward hastening the day of controlled atomic energy. Handbooks and manuals chart and tabulate physical and chemical properties of the many available materials, metallic and non-metallic, under a variety of conditions of temperature, humidity, pressure, solvents and so forth—but not under those expected in an atomic reactor. The immense task of measuring, recording, and tabulating these properties, with the additional variables of atomic conditions, may have to be done all over again; for some materials and some properties, it certainly shall.

There is indeed a big job to be done, so big, in fact, that one could not be blamed for being pessimistic about the possibility of a successful outcome. Perhaps the most optimistic note to be found lies in the fact that atomic energy is still a young science, not yet half a century old, and that knowledge of it is still meager. So, then, man is not really in a good position to judge the future of atomic energy, its possibilities, its nearness, or the true value of apparent problems. Perhaps, instead of being pessimistic, an "ignorance is bliss" attitude would be better. Nevertheless, the realization of the magnitude of the job and the steps being taken to put adequate manpower to work on it give assurance that the necessary research and development will be done and done in as short a time as can reasonably be expected.

The 2000-hp Gas Turbine on Trial

T. J. Putz • *Manager, Gas and Locomotive Turbine Engineering Section* • *Westinghouse Electric Corporation*

Exactly a year ago these pages carried a description of an experimental, locomotive-type gas turbine and a statement of what its creators expected of it. The tests, while incomplete, have gone far enough to confirm those hopes. The experience has disclosed no fundamental weakness. It gives evidence of the gas turbine's eventual success for industrial and transportation use.



The experimental 2000-hp gas turbine is a complete unit on a common bedplate. The elements, from left to right, are: two d-c generators, gear, air intake, axial-flow compressor, multi-element combustors, gas turbine, and exhaust. The compact unit lends itself to a narrow, in-line arrangement, particularly desirable for locomotive use. It is 26 feet long, 6 feet high, and 3½ feet wide and weighs 38 000 pounds.

In more than 1000 hours' test operation the performance of the 2000-hp gas turbine has been essentially in accord with design predictions. Operation under all types of load conditions and up to the design temperature has caused no objectionable distortion and no serious creepage. The unit has not operated without difficulties. However, these have not been of fundamental nature but such things as can be readily corrected in new designs. On the whole, at this stage, the experimental evidence points to the soundness of the general design employed in this form of simple, open-cycle gas turbine.

The turbine tests began on August 1, 1946. The unit has been operated approximately 1000 hours, of which more than 850 hours have been accumulated since July 9, 1947. Three hundred hours of operation have been spent in evaluating the performance of the unit and its components. The remainder of the time has been used in simulating the more severe operating cycles expected in actual service.

Accurate overall performance has been established by reliable measurements of power output, fuel flow, speed, air inlet temperature, and atmospheric pressure. The overall fuel rate at full load is 0.78 pound per brake horsepower per hour, which corresponds to a thermal efficiency of 16.7 percent based on fuel having a higher heating value of 19 500 Btu per pound. The maximum output obtained from the unit was 2350 hp, when operating with an air inlet temperature of 31 degrees F; more output is possible with colder weather.

Evaluation of the component performance of even this simple type of gas turbine is difficult. It required many changes in instrumentation and laborious heat-balance calculations. Compressor performance was established by measuring air flow, inlet and discharge pressures, and temperature rise. The adiabatic compression efficiency was found to vary from 80 to 86 percent over the entire operating speed and load range.

To determine turbine efficiency in a complete plant without a dynamometer between compressor and turbine requires the accurate measurement of inlet and exhaust temperatures and pressures. Of these, temperature of the combustion gases as they enter the turbine is particularly difficult to determine. Three methods are used:

1—Direct measurement, using specially designed, shielded-type temperature probes. 2—Calculation, taking combustion efficiency as 95 percent, measured air and fuel flow, measured combustor inlet temperature, and neglecting all radiation losses. 3—Calculation, using the measured turbine exhaust pressure and temperature, measured inlet pressure, and turbine work by heat-balance calculation.

The turbine-component efficiency as obtained using the temperature recorded by direct measurement gave least reliable results, while the second and third methods were quite consistent and in close agreement. This efficiency varied from 84 to 86 percent over the operating range, which is about two points lower than that obtained with earlier test results. The difference is due to the increased radial-tip clearance found necessary for rapid changes in load.

The combustion efficiency using specially designed air-atomizing nozzles was found by heat-balance calculation to

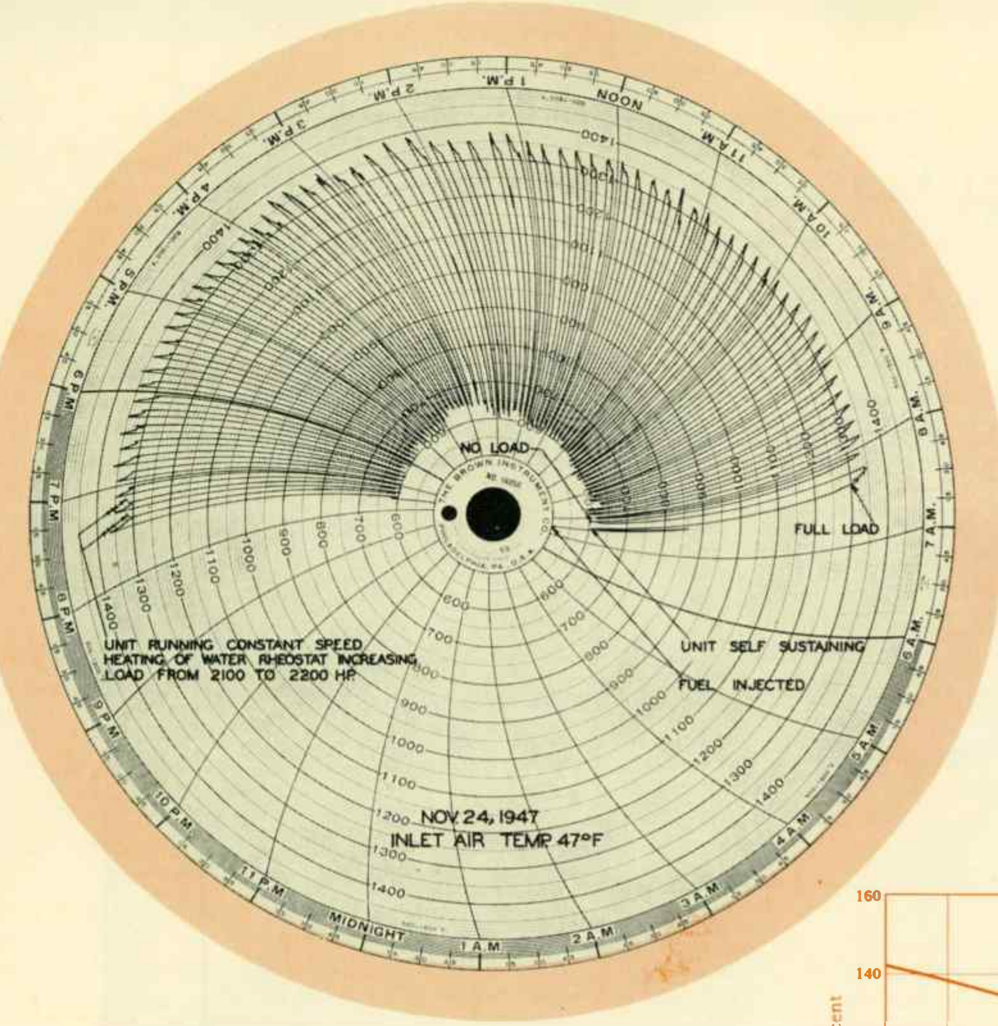


TABLE I—HOURS OF TEST OPERATION AT VARIOUS TEMPERATURES (AS OF JANUARY 15, 1948)

Temperature Degrees F	Time—Hours
500– 600	18
600– 700	160
700– 800	178
800– 900	75
900–1000	102
1000–1100	123
1100–1200	81
1200–1300	138
1300–1400	156

Fig. 1—A representative chart recording gas-turbine inlet temperature showing cyclic tests on the unit simulating locomotive service. Temperatures of 1300 to 1350 degrees F correspond to full load while 600 to 650 degrees represent no load. The actual loading and unloading of the turbine, as measured electronically, are faster than the chart shows because of the time lag in the thermocouples used to actuate the recorder. At full load the chart shows a gradual increase of temperature from 1300 to 1350 during a five-minute period. This corresponds to a load change of from 2100 to 2200 hp and results from the type of control and method used for absorbing the turbine output.

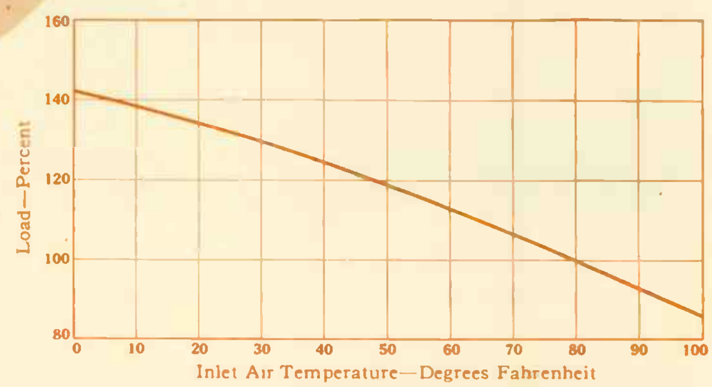


Fig. 2—Effect of inlet air temperature on capacity based on the gas turbine running at maximum speed and assuming a constant gas-turbine inlet temperature of 1350 degrees F.

vary between 94 and 96 percent. These values agree closely with those obtained on separate combustion tests at the Research Laboratories.

The unit has been started from a cold standstill condition 350 times and has undergone several thousand rapid load-cycle changes from no load to full load. Loading and unloading cycle tests have been made to prove its load-response characteristics. Probably the most severe load cycle to be encountered in actual service will be in locomotive operation where continuous loading and unloading occur. This corresponds to rapid temperature changes of from 600 to 700 degrees F on the turbine and combustor, the turbine inlet temperature being 1350 degrees F at full load and 600 to 750 degrees F at no load. To simulate locomotive operation, the unit was run at full load for 30 minutes, then immediately unloaded and run for 30 minutes at no load, whereupon load was reapplied in 10 to 20 seconds, and the cycle repeated. This cycle was then changed to limit the loaded and unloaded time to 10 minutes instead of 30. To accelerate the test program, a further change to 5 minutes was made when tests established that this time was sufficient to heat or cool the parts of the unit subjected to rapid temperature variation. A typical load cycle is shown in Fig. 1.

The unit is very easy to start, one generator being used as a motor. The time required is a function of the starting power available. When this power is limited to a maximum of 35 kw, the unit can be started in about 2½ minutes. With a maximum of 80-kw starting power the unit can be started in 1 minute; with 20-kw the time is 8 minutes. When the rotor reaches 15-percent speed the acetylene igniters are turned on, and at 25-percent speed the fuel is injected. The starting power is shut off at the end of 1½ minutes, and the unit reaches a stable self-sustaining speed in about 2½ minutes. A gas turbine of this type can be operating at full capacity ten minutes from the time starting is initiated or even less if necessary.

During the early weeks of the test period, the compressor inlet and exhaust ducts were equipped with sound suppressors. When it became apparent that the noise level in the test house and the surrounding areas was reasonable and not objectionable to the operators or the workers in adjacent areas the suppressors were removed.

The unit has also been operated without an air filter at the compressor inlet. In this respect we are less fortunate than our Swiss friends who have clean, fresh, mountain air available. The compressor blading becomes excessively dirty after approximately 100 hours of operation. This fouling with oily, dirty soot causes a drop in compressor efficiency of about two percent, and it is then necessary to wash the compressor blading. The washing operation consists of turning the unit over slowly with a starting motor, spraying a non-corrosive commercial solvent into the compressor inlet, allowing it to soak for a few minutes, and then washing it off with a steam spray. This can be done in a short time without dismantling any part of the compressor.

Operation of the unit has not been entirely devoid of trouble. Two serious casualties have occurred, one on the turbine and the other on the compressor. In anticipation of such difficulties, partially completed replacement parts were available; nevertheless, approximately three months were required to restore the unit to operating condition in each case.

The first mishap was a failure of the turbine blading after 57 hours of operation. This was the result of a severe rub of rotor with stator caused by movement of the turbine inlet bearing support on rapid temperature changes. Tests made subsequent to the failure indicated the inlet bearing support deflected downward approximately 1/16 inch with sudden increases in temperature, returning to its correct position after temperature equilibrium was established. The method of supporting the turbine inlet bearing was changed and no rubs have since occurred.

The second casualty was a failure of the stationary compressor blading after 125 hours of operation. The blades failed because of fatigue at the blade root due to forced vibration. Fortunately, the accident was discovered before many blades failed completely. The rotating blades, except for the last row, which was replaced, were undamaged. The stationary blading was replaced using the original blade design, modified to accommodate a riveted shroud.

Strain gauges were installed on this blading, which revealed the nature of the forced vibration. Because of the difficulty of incorporating all the desirable features in the original design, some minor mechanical failures in the stationary blading are still occurring. Future designs should be free of this trouble.

A no. 3 furnace oil was used as the fuel for most of the testing. Tests have also been made with bunker C oil, which showed an increase in plant fuel rate of approximately eight percent, partly due to its lower heating value and partly to lower combustion efficiency. Investigations made after 30 hours of operation with the bunker C oil revealed erosion of a critical part of the fuel nozzle that seriously affected its spray angle. Subsequent tests made with these nozzles showed that this change in spray angle, while seriously affecting the efficiency when using the bunker C oil, had no appreciable effect when the no. 3 furnace oil was used. A new set of nozzles, designed to eliminate erosion, have been constructed and have been applied to the test turbine.

The future experimental program consists of continuing the cycle testing to gain further operating experience and to design and test controls for particular industrial and transportation applications. Further tests will be conducted using the heavy bunker C oils for fuel.

Life characteristics of this unit can be determined only by actual field application. Testing has progressed to the point where actual life tests must be made. To prove this type of power plant, consideration is being given to some field application where fuel costs are low and 100-percent reliability from a prime mover is not immediately essential, although there is no reason to believe that the gas turbine, even though experimental, will lack in reliability.

The test results and operating experience have been most encouraging. The unit is easy to start and control, runs smoothly, and is not excessively noisy. Some sacrifice in efficiency has been made to gain reliability by increasing blade clearance.

Examination of the heated parts of the unit has not shown any signs of distress. There has been no measurable creep of any stressed high-temperature part. Fluorescent-penetrant tests have revealed no cracking or heat checking on the parts subjected to rapid temperature variations.

The experience gained from this unit indicates that this type of prime mover can be made practical for power generation using heavy fuel oil or gas. The tests have clearly shown that a simple, open-cycle, gas-turbine power plant having a fuel rate of 0.6 pound per brake horsepower-hour can be built. To obtain this higher efficiency, units of larger capacity are necessary, because turbine and compressor efficiencies are affected by clearance areas, which do not increase in the same proportion as capacity increases. Maximum or near maximum component efficiencies occur with blade heights at least twice those used on the present machine. In addition, the initial cost per horsepower of a larger gas-turbine unit should be substantially reduced.

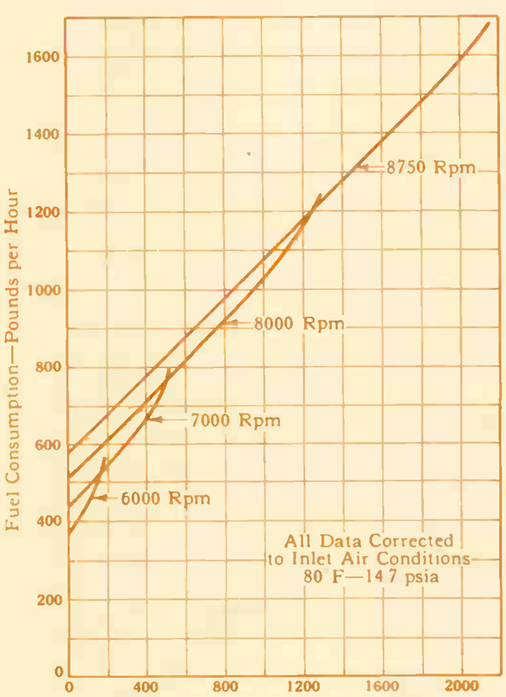


Fig. 3—The relationship of fuel consumption of the gas turbine to power output for various operating speeds. Fuel has higher heat value of 19 500 Btu.

Fig. 4—Variation in the fuel rate and turbine inlet temperature to power output for variable-speed and constant-speed operations. Fuel value is the same.

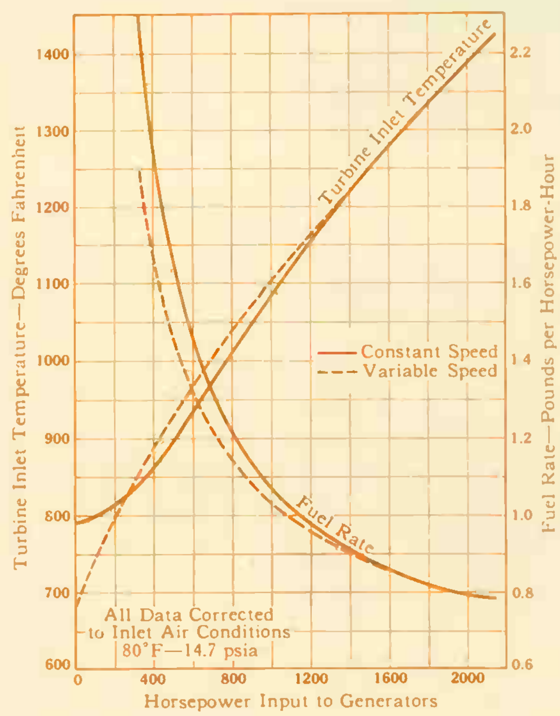
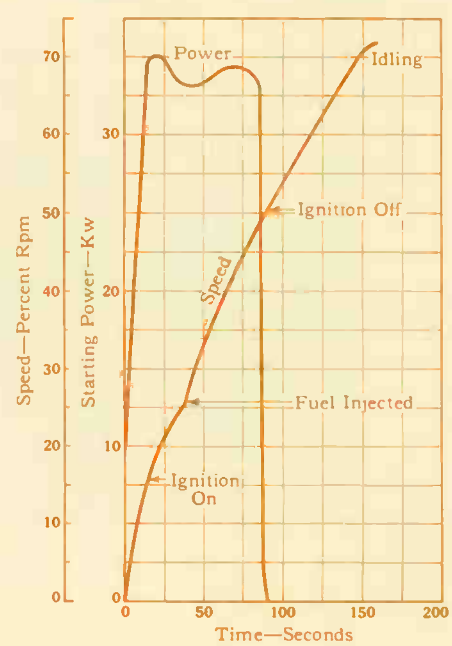


Fig. 5—Performance during typical start from cold standstill together with the starting power required. It has been started from a cold condition about 350 times.



Measuring Thickness Without Contact

"How thick is it?" is a question always facing the production engineer wherever sheet materials are made. Electronics—in particular a combination of x-ray and photomultiplier tubes—provides a gauge that gives a continuous, accurate indication of product thickness without moving parts.

WALTER N. LUNDAHL • *X-ray Engineer* • *Westinghouse Electric Corporation*

X-RAYS offer a promising solution to one of industry's difficult problems, the continuous gauging of rapidly produced sheet material without marking it. An x-ray thickness gauge has been installed in the shear line of a Pittsburgh mill producing high-quality steel sheet.

When materials were produced at more leisurely rates than now, a brief delay between thickness determinations and correction of the processing apparatus was not too serious. But, with mills turning out sheet materials at speeds up to a mile a minute, a few seconds' delay between gauging and corrections means an enormous amount of off-gauge and possibly wasted material. Also, the availability of a continuously indicating gauge of permanent accuracy permits considerably greater production from a given mill by allowing it to run more nearly full speed for a much larger proportion of the time. Also such a device might make it possible to correct automatically for thickness changes due to temperature variations in the gauged material, which results in a higher proportion of the product falling within the allowed tolerances.

Numerous thickness gauges have been devised, most of them requiring mechanical contact with the processed material. Mechanical gauges have numerous obvious limitations. They are subject to wear, particularly at the high speeds of modern mills, to change in calibration as a result of accumulation of scale or foreign material on the gauging wheels, to rather frequent need of repair, to inaccuracies resulting from centrifugal forces, and they are prone to mark the surface of highly finished sheet.

An x-ray gauge is inherently free from most of the defects of mechanical gauges. The radiations leave no mark. The absence of rotating parts eliminates those sources of inaccuracies and their attendant maintenance. The absence of contact eliminates gauging drag and permits the gauging of high-temperature material such as steel or semi-molten glass.

The basic scheme of the experimental gauge is shown in the sketch, although several other arrangements are possible. The x-ray gauge is based on the principle that the amount of x-radiation passing through a given material bears an exponential relationship to thickness. Absorption is independent of temperature, physical state, or state of grain aggregation of the substance.

The gauge employs two identical x-ray generators that alternate rapidly in emitting radiation. The radiation from one tube is directed through the processed sheet. The x-rays from the other are passed through a sheet of the material used as a standard. The radiations emerging alternately from the sheet and from the standard fall on a fluorescent screen surrounding a photomultiplier tube. The screen fluoresces to a brightness proportional to the x-radiation striking it. Thus, in effect, the photomultiplier tube, by "watching" the illumination of the fluorescent screen, measures the residual radiation from the product and the standard and transmits this information in the form of electrical pulses to associated electronic circuits. These circuits amplify and compare the pulses, and the results are finally applied to an indicating instrument.

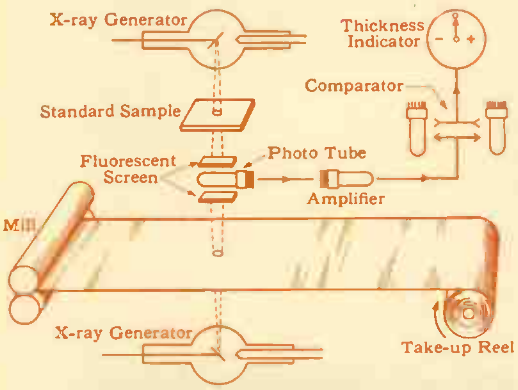
This article is a condensation of a paper by the same author presented at the AIEE Midwinter Convention, Pittsburgh, Jan. 26–30.

All the electronic and auxiliary equipment for operation of the gauge are mounted in the main control cabinet, shown here both with the front panel closed and swung back for inspection.

The present device is designed to be used with steel sheet within a thickness range of five- to fifty-thousandths of an inch. The instrument scale readily shows one ten-thousandth inch deviation from standard. Laboratory tests show that sensitivities of one half of one percent and accuracies of one percent are easily obtained.

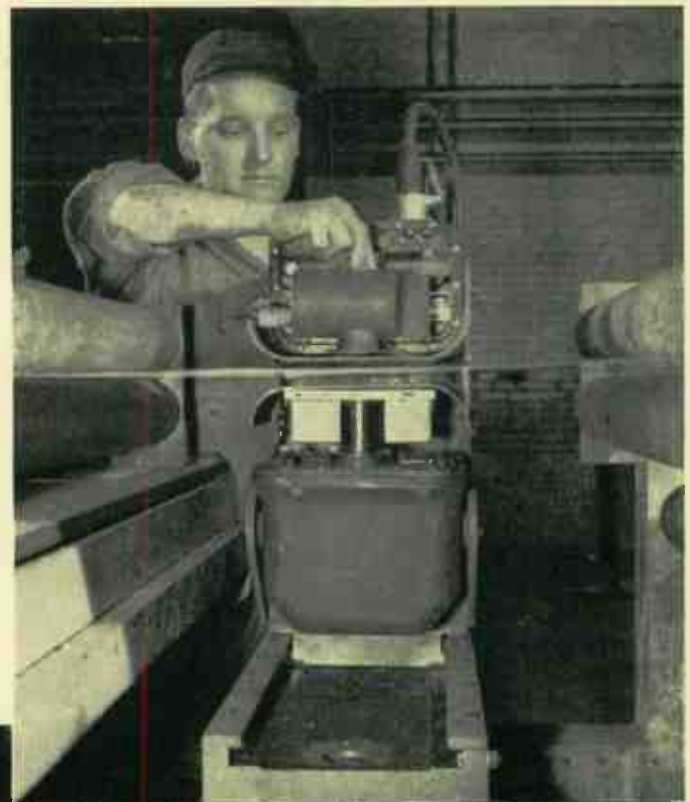
The operator can check the accuracy of the gauge from his remote position any time he questions it. By a solenoid arrangement a test piece can be inserted in place of the product.

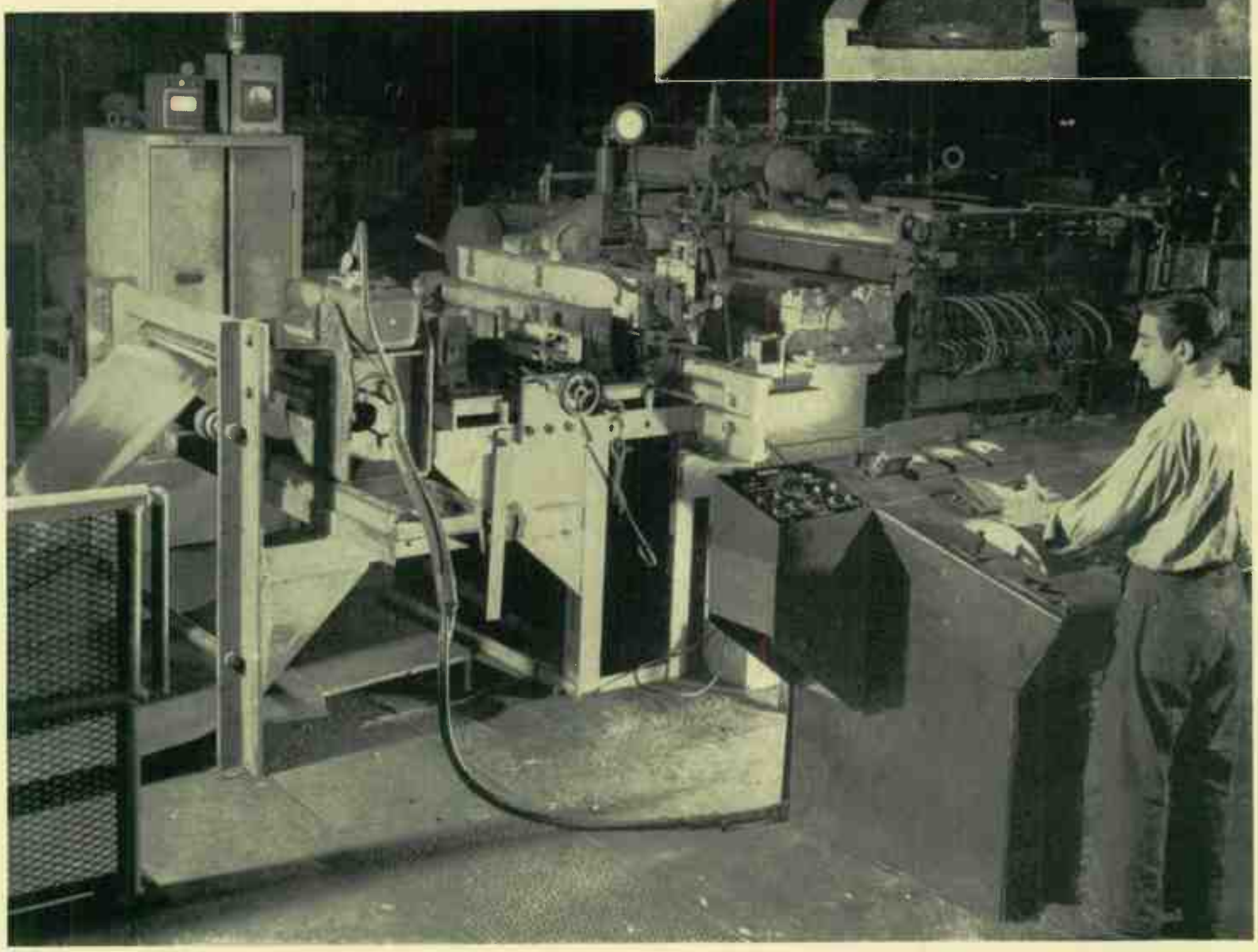
While the present gauge was designed for sheet-steel applications, the same basic ideas appear applicable to the gauging of other materials. Among these can be mentioned non-ferrous metals, wall thickness of glass bottles, the thickness of sheet glass, linoleum, plastic, paper, cardboard, and similar products that must be held within close limits.



The thickness gauge uses two x-ray generators. The radiations from one pass through the sheet in question; those from the other through a standard. The surviving radiations fall, alternately, onto the x-radiation sensitive screen surrounding a photomultiplier. The results are amplified, compared, and any difference applied to an indicator.

Both x-ray tubes and their transformers are mounted in a single, oil-filled cast head. Being a self-contained unit the x-ray generator requires no high-tension leads. In the experimental installation on a shear line the steel strip is shown passing between the lower x-ray generator and the pick-up photomultiplier above it.





STORIES OF RESEARCH

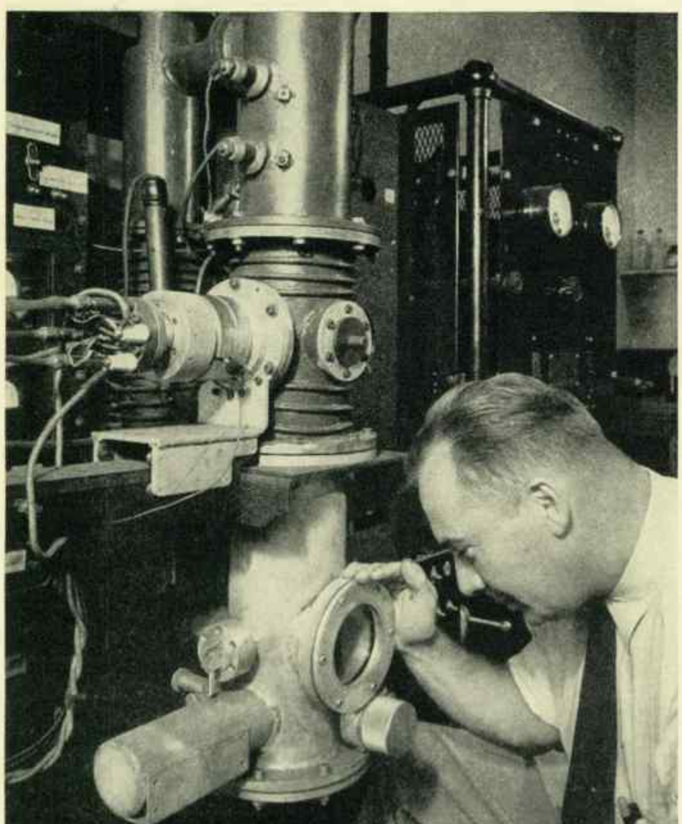
Some Like It Hot...

While engineers are now coping with the problems of putting the best high-temperature alloys to work in gas turbines, jet engines, and industrial-heating equipment, research men are already preparing the way for future harnessing of still higher temperatures. And like any other pioneer work, this problem requires new tools and techniques.

The new high-temperature electron diffraction camera at the Westinghouse Research Laboratories is a good case in point. As the result of engineering by Dr. J. W. Hickman, Dr. E. A. Gulbransen, and R. J. Bertl, metal surfaces can now be studied continuously at temperatures up to 2000 degrees F. This is several hundred degrees above the best previously obtainable.

A tiny tungsten-wire "hairpin" furnace mounted in a beryllium-molybdenum cylinder produces a temperature of about 3300 degrees F. This heat is transferred to the metal sample through a chrome-nickel-steel block on which the sample to be studied is mounted—about 1300 degrees being lost by radiation during the transfer. Hydrogen pumped through the heating unit not only prevents the tungsten from vaporizing but also guards against undesirable oxidation.

A special advantage of the new system is that the heater is not a part of the vacuum system of the diffraction camera proper. This means that the heat can be left on all during the process of taking electron pictures of metal surfaces. At this writing the furnace has been used continuously for nine months without burning out or any major difficulty.



Dr. J. W. Hickman examines an electron diffraction pattern of a metal surface in the new high-temperature camera. The small but powerful furnace, which heats the sample to 2000 degrees F, is attached to the shaft of the camera at left.

With the new camera, the research men can study the physical structure of oxide films at any temperature, observe how this structure may change as temperature varies, and give special attention to the effect of cyclic shifts in temperature, as in heater alloys. A wide variety of metals has already been studied, including gas-turbine and jet-engine alloys, nickel-chrome alloys used in heater units, and iron-moly-nickel alloys that are particularly resistant to chemical corrosion.

One general conclusion already reached by the scientists is that virtually all alloys presently used for high-temperature application develop one of two types of oxide films which protect the metal against further corrosive attacks. One is chromium oxide (Cr_2O_3) and the other is an oxide in which two or more metals may be present, including iron, chromium, cobalt, manganese, and nickel. The next goal is development of an empirical table that will show what oxides are produced over the whole temperature range.

Radar and Raindrops

Nuisance values often pay off in research. Take the case of raindrops during wartime operation of radar sets. As long as wavelengths of three centimeters (the so-called x-band) and up were used, no particular difficulties were encountered. But when the new k-band of wavelengths (1.25 cm) went into operation during rain, snow, or conditions of very high humidity, radar observers noticed a definite drop in the quality and range of echo reception. The dip was attributed to absorption and scattering of the microwave energy by the rain, snow, or water vapor.

From that "nuisance" has developed a considerable amount of research aimed at finding out exactly what happens when microwaves of the 1.25-cm variety meet up with raindrops. A primary objective is to test the weather-forecasting possibilities of radar, based on the assumption that if raindrops act as reflectors to microwaves in the k-band, then a means is at hand to detect storm and hurricane areas many hours and miles in advance. And, of course, military men would like to know just how good k-band radar is in the presence of rain, snow, or humidity for its usual task of search and detection.

Edward J. Duckett of the Westinghouse Research Laboratories is attacking this problem with precision instruments for the measurement of microwave scattering. Instead of waiting for a rainy day, Duckett is using artificial raindrops in a range of carefully calculated sizes and fashioned from a mixture of ceramic powder and carbon black to give just the right dielectric constant.

The artificial raindrops are fastened to a background made of special material that absorbs nearly all of the radiation not striking the raindrop. The microwave energy emanates from a horn-shaped transmitter, strikes the raindrop, and is reflected into a receiver placed at various distances and angles from the target. Actual measurement of the amount of scattering from the raindrop is accomplished by means of a neat balancing circuit. First the transmitter is fired without the raindrop in the field, and the amount of scattering here is balanced with a lower level signal

Mr. Duckett adjusts the attenuator of the waveguide system used in the measurement of microwave scattering caused by raindrops. The radar transmitter is to his left. The simulated raindrop is placed on a special screen (lower left) that absorbs radar waves. Waves reflected by the raindrop are picked up by the receiver.

feeding from the transmitter into the balancing circuit. Then the target is placed in the field, causing an increase in scattering that unbalances the circuit. The additional power needed to rebalance the circuit is, of course, the amount of scattering from the raindrop. Amplifiers build up the very weak scattering signal to where it can be read easily from meters.

Duckett's chief aim is to verify two basic "guesses" for which there has been much fragmentary evidence. One is that scattering of microwave energy from raindrops is most intense at a certain optimum frequency. The other is that this optimum frequency is a function of the diameter of the individual particles of rain. This leads to the interesting speculation that, if this tricky relationship between frequency and particle size can be definitely pinned down, radar might be used literally to map out and trace the formation of storm clouds in terms of particle size, distribution, density, and other important information.

The Westinghouse research engineer is working with raindrops ranging in size from 0.05 cm (about the size of a pinhead) to those ten times larger. Actually, however, Duckett's models are larger than this because he is using microwave energy in the three-centimeter band, and has scaled the diameter and other important constants of the raindrop proportionately.

Sensitivity to extremely small amounts of energy is required. The equipment used must be capable of detecting and measuring changes as small as 10^{-14} watts—or one hundredth of one millionth of one millionth of one watt.

Cold Facts

THINGS begin to happen at temperatures approaching absolute zero. The phenomenon of superconductivity, for example. Take a ring of copper, put it in a magnetic field, and then supercool it to about 10 degrees above absolute zero (−449 degrees F). When the field is withdrawn, current continues to flow in the copper ring. The reason: at these very low temperatures, the resistivity of certain metals disappears completely and allows the current free rein.

Scientists have known about superconductivity for 35 years, but a whole host of questions about it and other low-temperature phenomena still remain to be answered. What happens to the magnetic properties of metals in this supercold? How do high frequencies affect superconductivity? Or even more fundamental: what is superconductivity and why do certain metals have it while others do not?

To answer these questions is the aim of a new low-temperature research program being undertaken at the Westinghouse Research Laboratories by Dr. Aaron Wexler. Using liquid helium as his cold source (it boils at four degrees K) Dr. Wexler will work with temperatures ranging upwards from one degree K above absolute zero, −457 degrees F, or −272 degrees C.

Fortunately for researchers in this field, cold-producing machines of great efficiency have been developed in recent years. Dr. Wexler will use one of the best of the helium liquefiers. In this equipment, ultra-pure helium is raised to about 250 psi by a four-stage compressor system and then put to work driving a piston engine. The energy used up in performing this work is lost in the form of heat, and the temperature of the gas drops to around 75 K. Work on a second engine lowers it still further to 12 degrees K. Then the gas, still at high pressure, is throttled through a tiny orifice (the so-called Joule-Thompson effect) with a consequent drop to four degrees K and its condensation to the state of liquid helium.

To get down even lower than this, Dr. Wexler turns off his apparatus and draws a vacuum in the space above the liquid helium. Reduction of vapor pressure hastens evaporation and cools the helium to around one degree K. Some idea of the difficulties in the way of going down even lower than this is the fact that for a temperature of 0.1 degree K, the vapor pressure above the helium would have to be in the neighborhood of 10^{-38} mm of mercury—far beyond the reach of the best vacuum pumps available at present.

The practical possibilities of supercooling are too fascinating to overlook: the reduction of losses in power transformers is remote but not beyond consideration, for example. But first must come a thorough understanding of the behavior of materials at low temperature. When this is achieved, supercooling may play a very important role in the design and operation of electrical power and electronic equipment.

Dr. Aaron Wexler makes a thermocouple measurement on the Collins helium liquefier. He heads up a fundamental research program to explain behavior of electrical and magnetic phenomena at temperatures near absolute zero.

High-Voltage Power-Transformer Progress

Transformer engineers have been called upon for their utmost in ingenuity to permit units to rise steadily in rating without exceeding railroad clearances. That they have succeeded is indicated by a reduction in weight of about one sixth and in floor space of over a fourth in 15 years. Transformers have passed the 100 000-kva mark. Outstanding among the factors making this possible are shell-form construction, Hipersil steel, and form-fit tank.

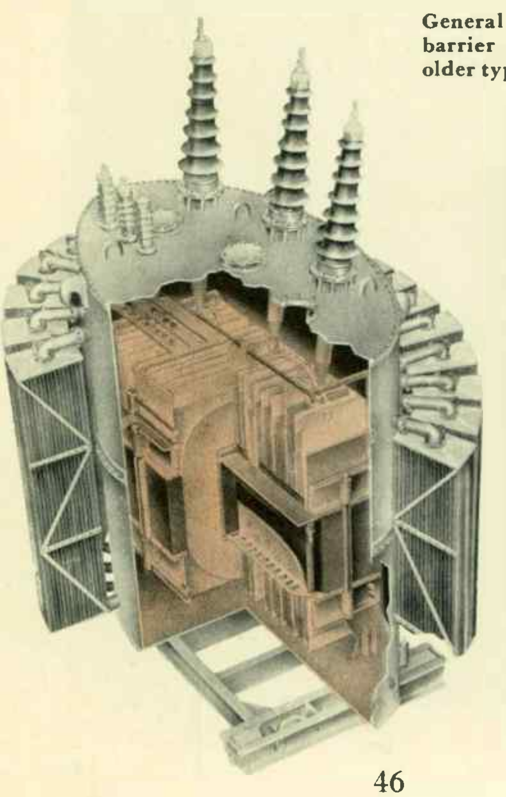
Frank Snyder • *Manager, Transformer Engineering Department* • *Westinghouse Electric Corporation*

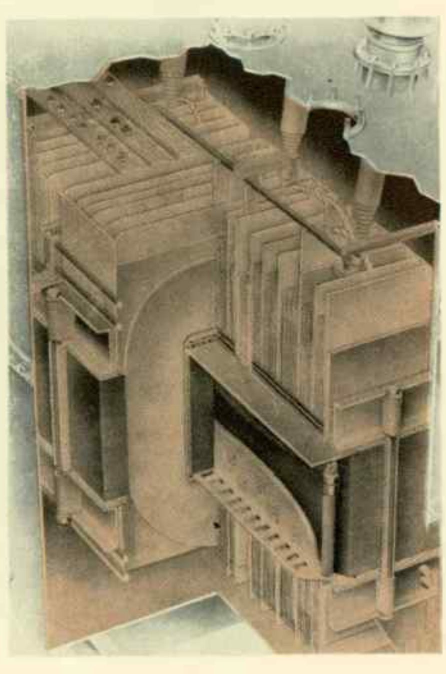
Some of those who witnessed the factory tests on the three 500 000-volt transformers for the experimental high-voltage lines expressed amazement and a little disappointment at their small size. In spite of their size these transformers were neither under-insulated nor overexcited when operating at full-test voltage. The bank is designed to supply 5000 kva continuously at 500 000 volts and to withstand not only this normal operating voltage but also the switching and lightning surges. The facts are that high-voltage power transformers have been completely revolutionized in recent years so that for comparable kva and voltage ratings they are no longer the structural giants they used to be. As a consequence ratings of single units assembled have steadily increased without exceeding the allowable shipping dimensions.

Three major developments are responsible for these changes in design and fabrication of the modern high-voltage power transformer. The first stemmed from the discovery that lightning voltages—once the bugaboo of all power transformers—could be tamed or at least shunted harmlessly to ground without damage to the transformer. The first step in this development was to determine the problem, that is, the magnitude and duration of the voltage and current impressed on the transformer by the lightning stroke. This problem understood, the engineer was able to develop ways and means of meeting the attack. He soon found that he could not only provide much greater surge strength but also do it with greatly reduced insulation structure. As a consequence the size and weight of the complete transformer for a given rating were substantially reduced. The basic principle involved in this development was the discovery that lightning surges are very good at creeping over barriers but are relatively poor at puncturing them. Whereas both normal operating and surge voltages were originally confined by extending pressboard barriers to provide ample creepage surface, the windings of the modern high-voltage power transformer are completely enclosed with barriers. The only way in which a surge voltage can now get out of control is to puncture a barrier.

Interleaved Box-Type Insulation

Once the problem was properly understood, it became clear that the windings could be designed so as to distribute the surge voltage more or less uniformly instead of permitting it to pile up on the ends. This enabled the designer to place the major insulation in equipotential planes. Thus the insulation was fully coordinated with the voltage stresses to be withstood, resulting in increased surge strength and more economical use of materials. The resulting overall structure is termed the interleaved box-type construction, while the older and superseded type is referred to as the extended barrier form. This change has resulted in a substantial reduction in overall weight and dimensions and at the same time has made high-voltage power transformers practically lightning-proof.





General view and close-up of the extended barrier insulation structure employed on the older types of high-voltage power transformers.

Grain-Oriented Steel

The second major development leading to the reduction in transformer size and weight was initiated by the realization that the core required for an efficient magnetic linkage between windings represents a considerable proportion of the weight and space in a high-voltage transformer. Until about 1937 high-silicon, hot-rolled steel was the best material available for the cores. The designer had to put enough of this material into the transformer to keep the losses, exciting current, and temperature down to values acceptable to both manufacturers and users.

Engineers discovered that electrical sheet steel can be processed to orient the grains or crystals, as compared to the older hot-rolled steel sheets, so that it can carry much more flux in one direction than the other. This placed a new and valuable tool into the hands of Westinghouse transformer designers. Called Hipersil, it enabled them

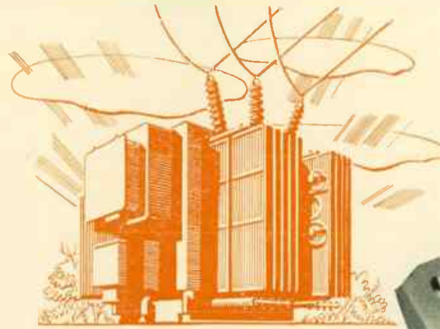
The form-fit also lends itself advantageously to forced-oil cooling. Because of the small amount of space between tank wall and core practically all oil pumped through the transformer must flow through ducts provided to cool the windings and core. Only a small amount bypasses the windings by flowing along the inside surfaces of the tank wall.

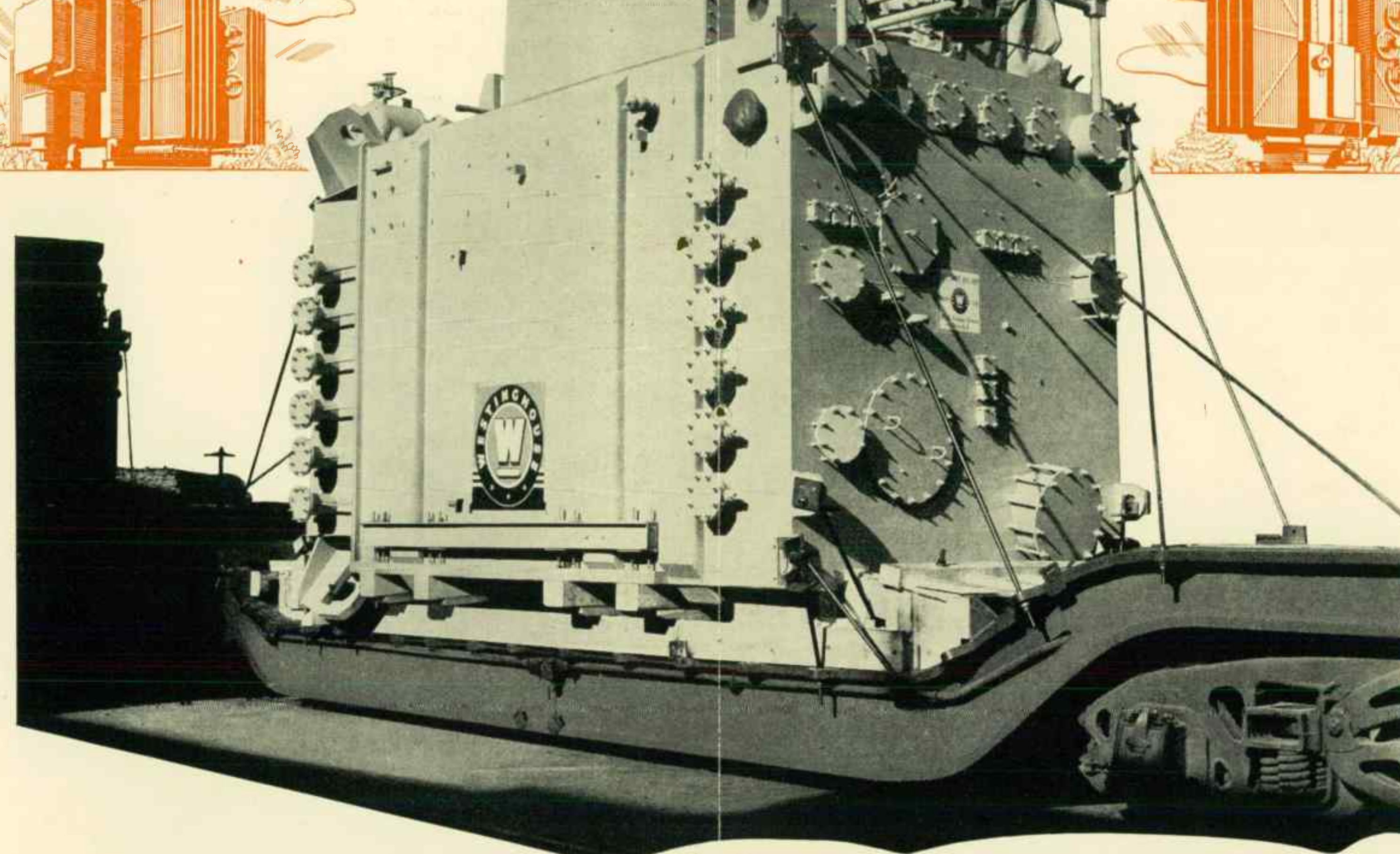
The form-fit construction, therefore, is a natural for the "triple-rated" transformer, which has three very real ratings, depending on whether it is self-cooled, forced-air cooled, or both forced-air and forced-oil cooled. Assume a self-cooled transformer is rated at 20 000 kva. If air is now forced over the external radiators or coolers by fans, their cooling efficiency is greatly increased, permitting an increase in rating to approximately 25 000 kva. If, in addition, it is equipped for pumping the oil through the core-and-coil assembly and the external radiators or coolers, the rating is again increased by approximately one-third, so that it can now carry 33 333 kva continuously. In spite of the increase in load, the gradient between cooling oil and copper is generally less than for the self-cooled rating because the oil now flows along the windings and through the radiators or coolers much more rapidly than with simple thermo-siphon cooling. To achieve such a range in operating capacities with other types of transformers requires a complicated and expensive system of barriers to force oil through the windings.

Triple-rated transformers are particularly suitable for those applications where the basic load is only 60 percent of the peak loads. It permits the application to be met by a smaller transformer, thereby reducing the capital investment.

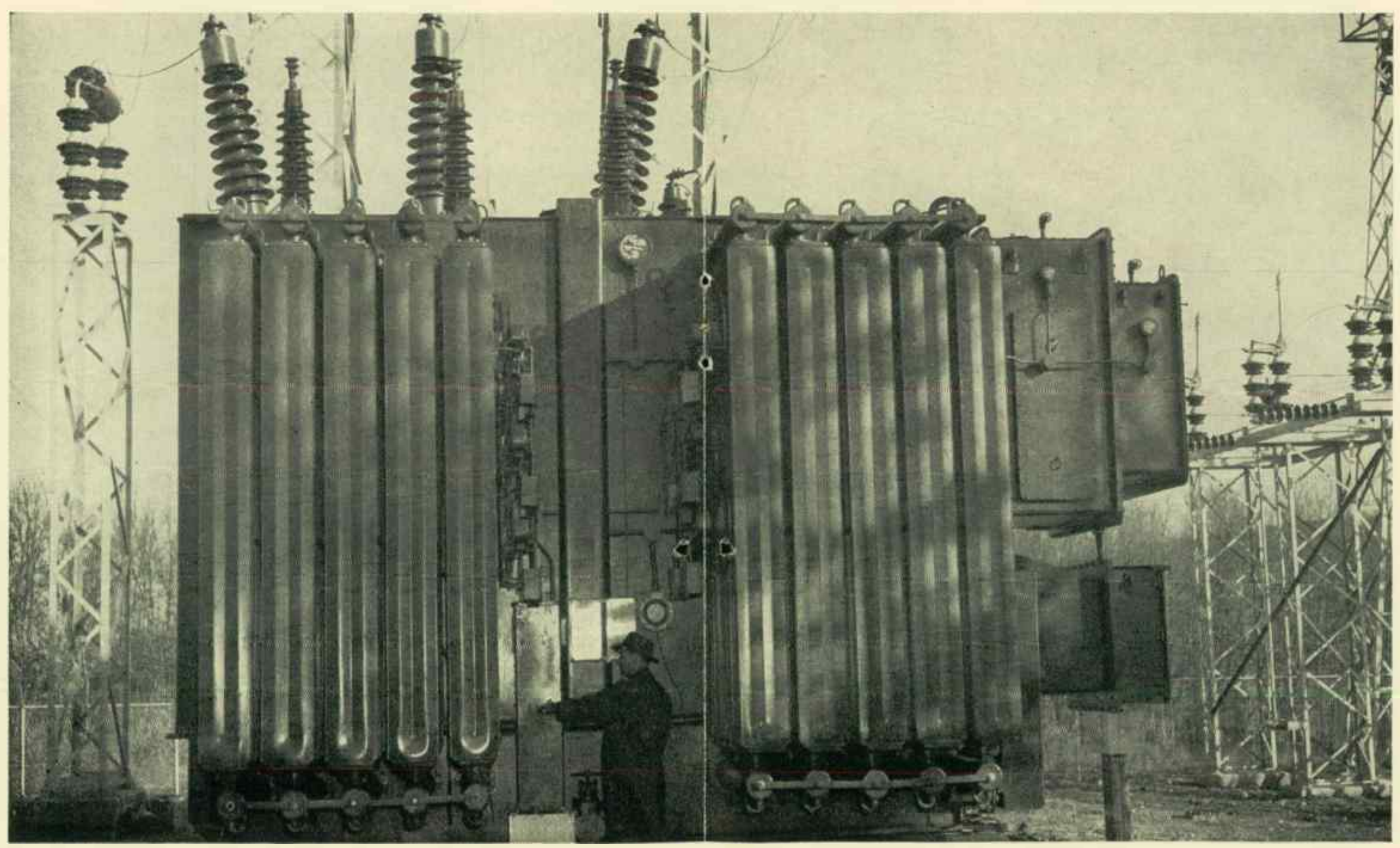
The form-fit construction encourages use of welded tanks. The final assembly weld is made between the bottom end-frame structure and the bottom tank flange at the normal working

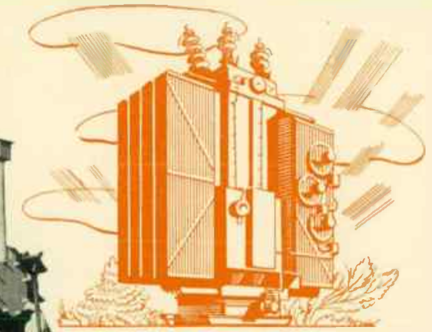
The shell-form construction permits the tank to fit closely to the core. This greatly reduces the oil and total weight.





The 230-kv transformers for the Bonneville system, although rated at 83 333 kva, were shipped complete, except for radiators and bushings, on flatcars. The transformer below is a 66 667-kva, three-phase, 138-kv unit installed in New England.





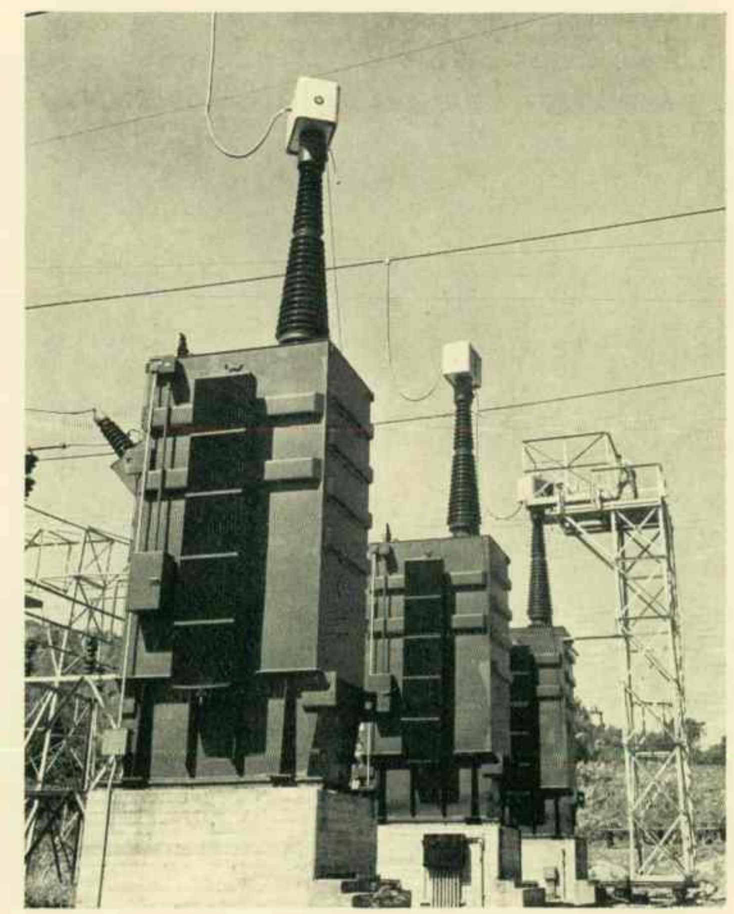
level for a man standing on the same level as the transformer base. This permits the weld to be broken and remade under normal working conditions. Also, such a transformer can usually be shipped completely assembled and sealed, making it unnecessary to dry out, fill with oil, and blow out the gas space in the field. These are very real items in reducing installation costs of form-fit power transformers.

Accessories on the Modern Power Transformer

Most new high-voltage power transformers are equipped with modern accessories. Among these is a load tap changer either automatically or manually operated for controlling the transformer ratio without interrupting the load. An arrangement for automatically maintaining a cushion of inert gas above the oil, such as Inertaire or its equivalent, is highly desirable. This greatly lengthens the useful life of both the oil and the solid insulation by keeping out their enemy, oxygen. To maintain the oil in the best possible condition a newly developed oil conditioner may be used to keep the oil dry, recondition it, and remove impurities. Protection of the transformer against overload is generally provided by a relay that operates on the basis of copper temperature. Such a thermal relay is the TRO, which is mounted in an oil well in the side of the tank and may be removed for calibration or adjustment without lowering the oil or breaking the tank seal. This relay performs three functions: (1) it automatically turns on fans or oil pumps; (2) it sounds a warning or lights a signal lamp; and eventually, if the load continues to increase, (3) it sounds a second warning or trips a breaker before the transformer is damaged through overload.

With form-fit construction the conventional base is usually omitted. Taking its place are trucks that are adjustable so that

The transformers on the test transmission line have been operated at voltages up to one half million.



the transformer can be moved either sideways or forward and backward. The construction is such that many operators have found it possible to eliminate the trucks and still be able to move large transformers into position.

One of the most difficult problems confronting the designer of large high-voltage power transformers is how to bring the high-voltage leads safely through the transformer cover. An appreciable percentage of the overall height of the transformer tank depends upon the ingenuity with which this problem is solved. The high-voltage, oil-impregnated and oil-filled condenser bushing gives a better result and requires less space than any other arrangement known. In the condenser bushing voltage stress is uniformly distributed between the lead passing through the center of the bushing and the mounting flange that supports and seals the bushing into the tank. Therefore, the diameter and overall length of the bushing are reduced. Consequently condenser bushings are almost a necessity in the design and construction of very large, extra-high-voltage power transformers.

Aggregate Improvements

It is difficult, in fact, impossible to specify how much reduction in weight and dimensions and improvements in insulation strength are contributed by each of the three major developments. However, these three, together with some economies brought about by other minor factors, have resulted in a large aggregate reduction. This is shown in table I.

Notable Units

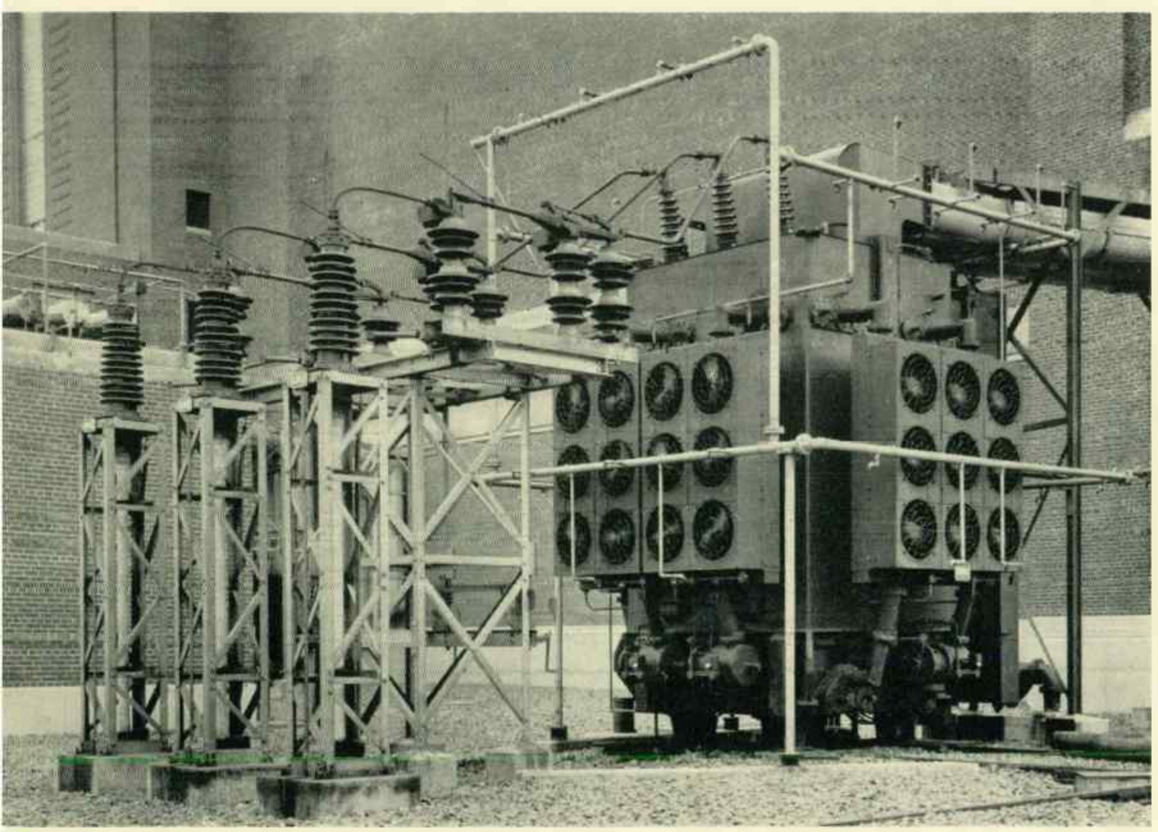
Several outstanding transformers, built and equipped in accordance with the foregoing, have been installed recently. The high-voltage units at the Tidd station of American Gas and Electric Service Corporation are rated 500 000 volts, almost double the highest present operating voltage. These are not just testing transformers but full-fledged power units, designed to withstand the normal 60-cycle operating voltage, switching surges, and lightning surges that will be experienced on a commercial 500 000-volt transmission line. Although rated at only 5000 kva they use the same design, principles, and features as larger units. They are shell form, have Hipersil steel cores, and form-fit tanks with condenser bushings, all standard features of Westinghouse transformers in operation at 230 000 and 287 000 volts.

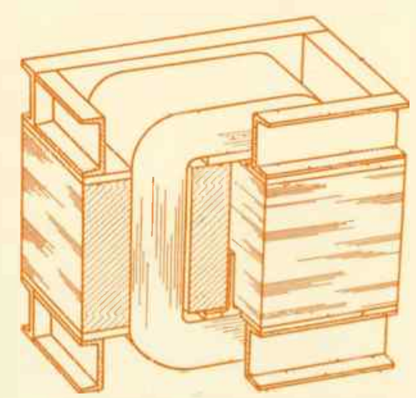
The largest bank of transformers ever manufactured, 250 000 kva at 230 000 volts, was recently installed by the Bonneville Power Administration at its Snohomish substation near Seattle. This bank consists of three 83 333-kva, single-phase, three-winding transformers. The three windings are for 230-kv and 115-kv secondary voltages and for 13.8-kv primary voltage. These transformers are triple rated. They can be operated as a 250 000-kva bank, without air blast at 200 000 kva, and without either the air blast or oil pumps in operation, at 150 000 kva.

Larger than any three-phase transformer installed in this country is the 135 000-kva, 138/15-kv unit being completed for Detroit Edison Company. Other outstanding high-voltage power transformers recently installed include the 105 000-kva, 69-kv, three-phase units at the Philadelphia Electric Company, and the 62 500-kva, 138-kv units obtained by the Consolidated Edison Company of New York. All of these transformers employ the interleaved box form of insulation structure, Hipersil cores and form-fit tank. All of these transformers were shipped completely assembled in their own tanks and with underload tap-changing equipment in place, reducing materially the time, expense, and hazard involved in their erection in the field.

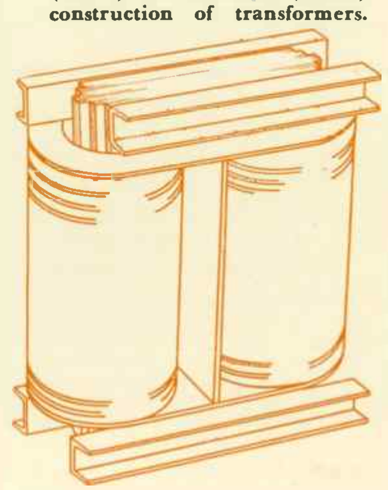
The three fundamental changes in design have resulted in the creation of a number of distinct engineering trends in the general character of large high-voltage power transformers. For example, the kva rating of many units is practically

A 105 000-kva unit installed at the Southwark Station of the Philadelphia Electric Company.





Comparison of the shell-form (above) and core-form (below) construction of transformers.



again to reduce appreciably the size and weight of the core and, consequently, the transformer as a whole, and at the same time improve its performance.

Shell-Form Construction

The old argument as to whether the core or shell form of construction is better has, or at least should have, largely disappeared. The facts are that the core form is more advantageous for small kva capacities and lower voltage classes, while the shell form presents many advantages for larger kva ratings, heavier current, and higher voltage classes. Consideration of the basic difference in construction of the two forms of transformers makes this apparent. The problems of attaining adequate insulation strength, mechanical strength, and cooling are not major problems in small- and medium-size low-voltage power transformers, so that for this class of apparatus the core form is entirely adequate and, at the same time, more economical than the shell form. However, the design of large, high-voltage power transformers revolves about the proper solution of insulation and mechanical and thermal stress problems, and these can be more easily and more economically solved with the shell form. While the line of demarcation between the two forms is not distinct, the core form is generally considered to be preferred for 132 000 volts and below and for 10 000 kva and below, and the shell form is preferred when either the voltage or the kva exceed these approximate limits.

In the shell form, the surges impressed on the windings are distributed more or less uniformly throughout the windings without the aid of auxiliaries such as shields, etc. Also it is easier to brace such transformers against mechanical stresses developed in large units when the secondary is short circuited. The fundamental reason for this is that in the shell form, unlike the core form, the windings are completely supported by and enclosed in steel.

For large transformer ratings it is likewise easier to cool both the core and windings when shell-form construction is used. Here practically all oil ducts are vertical including those for cooling the core. This construction thus takes advantage of the natural "chimney" effect. The core form usually entails some horizontal ducts. With these a little more urging is required to force the oil through the ducts.

Form-fit Tank

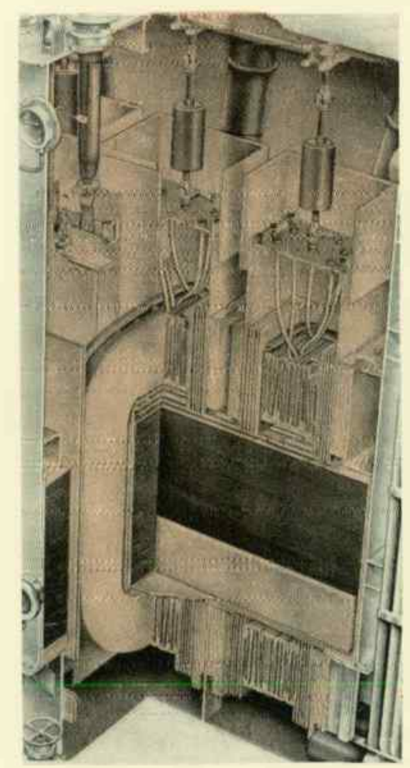
The fact that the core of a shell-form transformer encloses the windings leads to a third major development, the "form-fit" tank for large units. Prior to introduction of form-fit construction, the core and coils of a transformer of either type made up one integral assembly that is inserted in the enclosing tank, which, with its base, cover, bushings, cooling equipment, and accessories, comprises another assembly. On the other hand, in the form-fit construction the tank is shaped to fit snugly around the transformer "works." The bottom supporting end frame for the core-and-coil unit and the base section of the transformer tank are all one piece. The core and coils are built into this receptacle. The transformer is then completed by setting the top part of the tank down over the upper extension of the core and coils. The construction of a form-fit shell-form transformer is shown on page 50.

The form-fit construction has several conspicuous advantages. It is unnecessary to lift the complete core-and-coil assembly into or out of the tank. Only the top section of the tank need be lifted. This saves time, equipment, and headroom in both factory and field. The transformer core and the tank walls complement each other as to mechanical strength. In other words, the core supports the tank walls against deflection due to external pressure, which fact is particularly useful in filling the transformer with oil under a complete vacuum. On the other hand, the tank wall hugs the core tightly on all four sides, eliminating possibility of core and coils shifting from position during handling or shipment. The amount of steel required for the housing, and the amount of oil needed to fill the transformer tank are both greatly reduced with form-fit construction.

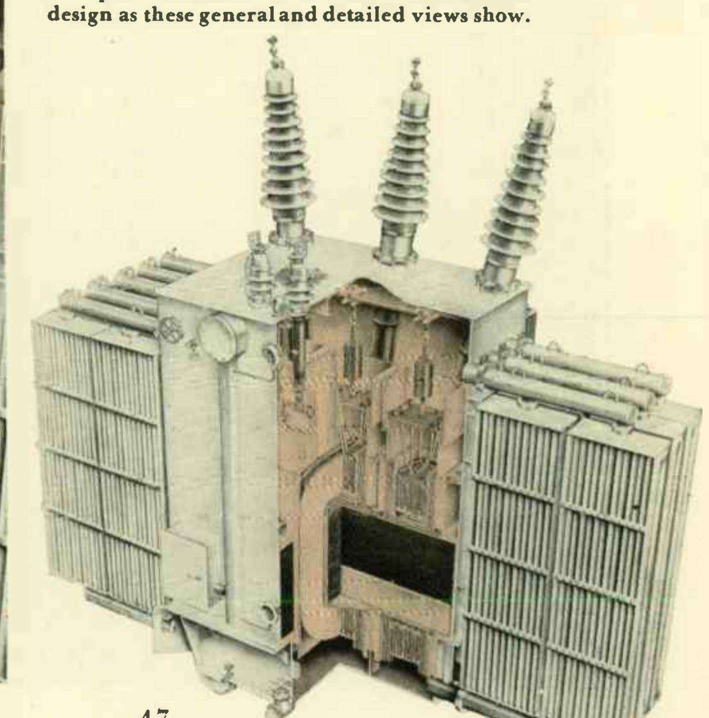
Other important advantages of form-fit construction are not so obvious. For example, such a transformer can be turned on its side for shipment, thereby permitting much larger units to be shipped completely assembled.

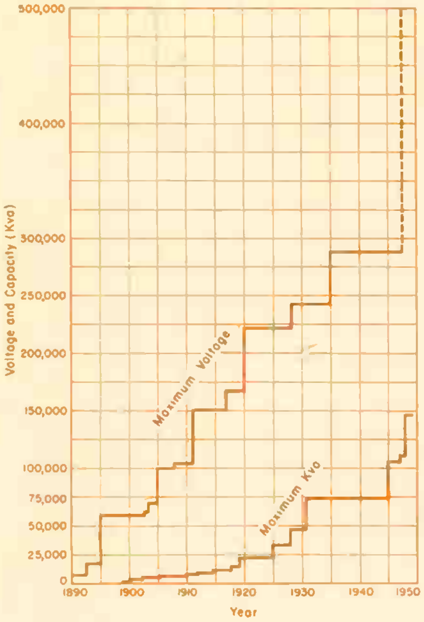
TABLE I—REDUCTION IN WEIGHT AND DIMENSIONS OF A REPRESENTATIVE 10 000-KVA, SINGLE-PHASE, 60-CYCLE, 138/13.8-KV TRANSFORMER

Year	1920	1930	1947
Weights, Pounds			
Core and Coils	45 000	44 000	37 000
Tank and Fittings	27 000	25 000	23 000
Oil	28 000	27 000	21 000
Total	100 000	96 000	81 000
Dimensions, Inches			
Floor Space	156 x 160	148 x 158	110 x 152
Height	280	284	256



The insulation structure of the modern shell-form power transformer is of the interleaved box design as these general and detailed views show.





The history of transformer ratings

double that which was considered practical a few years ago. There is also a definite trend toward three-phase units. For example, Westinghouse is now building more three-phase than single-phase units. A few years ago the single-phase outnumbered the three-phase by two to one.

The voltage of the average power transformer is gradually increasing. This is because extensions of transmission systems are in general being built in higher voltage classes to carry larger blocks of power for longer distances.

Finally, there is a trend—although it is slight—toward standardization of power-transformer characteristics. For example, voltage and kva ratings, methods of cooling, and methods of oil preservation, are slowly and gradually becoming standardized. Credit for this progress belongs to the standardization work of engineering societies and associations of central-station operators and equipment manufacturers.

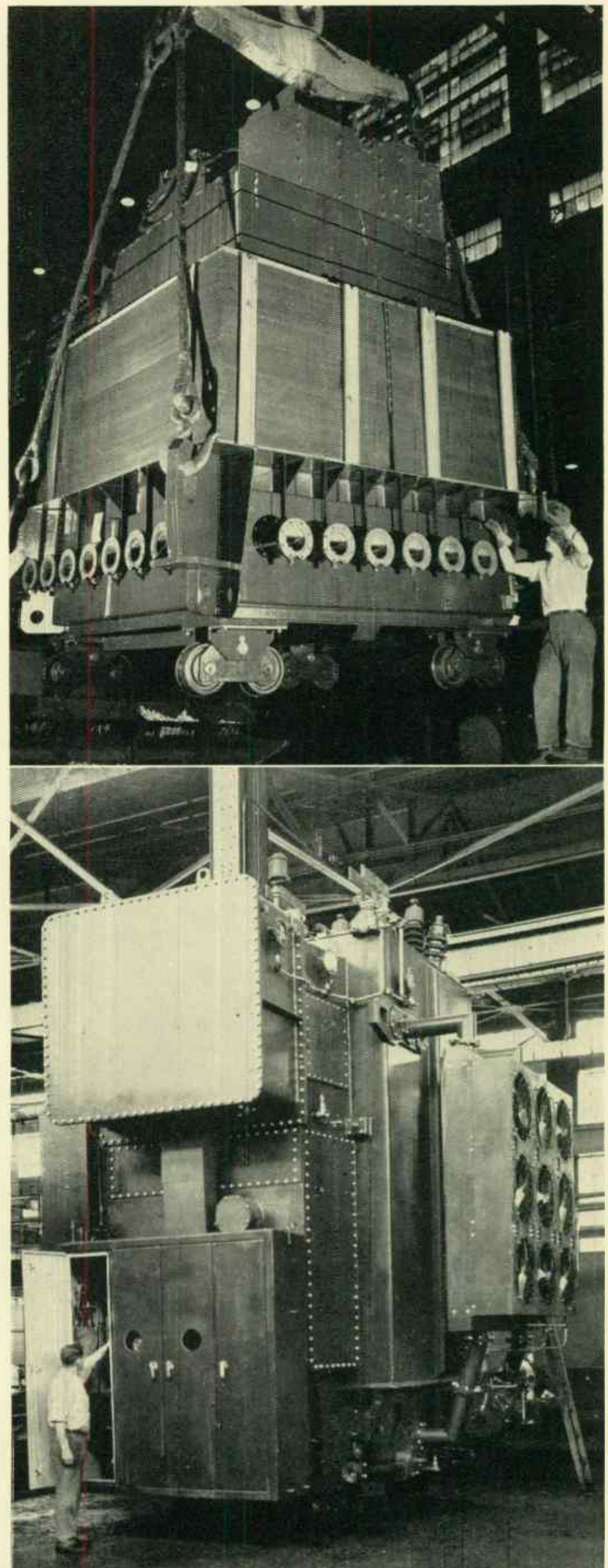
Conclusion

With so much experimental work being conducted on transmission of electric power at extra-high voltages, the top operating voltages will almost certainly be lifted to at least 400 000 volts and perhaps even higher. This means not only higher voltage power transformers, but also more kva in single units, inasmuch as power will be transmitted in larger and larger blocks as transmission voltages increase. Transformer banks of 300 000 kva at 400 000 volts are not, therefore, beyond the realm of possible future requirements.

In general, the limit on the kva and voltage of a large power transformer is determined by shipping clearances. To ship still larger, higher voltage units it will be necessary to take advantage not only of the three fundamental principles of design but also the fact that the neutrals of transmission lines operating at extra-high voltages will be effectively grounded. This will permit reduction in the insulation class of the high-voltage windings by at least one voltage class. This reduces the effective voltage of the transformer and, therefore, permits the designer to increase the kva rating without exceeding shipping clearances.

The overall weight and dimensions of large transformers can be materially reduced and the field installation expedited if it is forced-oil-cooled instead of self-cooled. To get the largest high-voltage power transformers to their destination completely assembled it is not just desirable but necessary to use forced-oil cooling.

If, after taking all of these modern design principles into consideration, the voltage and kva required are still such that shipping clearances cannot be met, then it will probably be much more economical to operate two transformer tanks in parallel on a single transmission line rather than to build the required rating in a single unit, necessitating field assembly and erection.



The construction of the core and coils for a form-fit shell-form power transformer is shown at the top. A view of a typical unit completely assembled is shown below it.

Applications of Mercury-Vapor Lamps

Mercury is our only liquid metal. In electrical discharge tubes it is transforming human life by giving us more light for better vision, more color brilliance for added beauty, and new striking effects for interesting living. In photochemistry, mercury lamps are producing new products and improving old processes. Beneficial radiations from sunlamps and bactericidal lamps are raising the level of human health to a new high.

E. W. Beggs • *Illumination Engineer* • *Westinghouse Electric Corporation*

New developments mean new applications. And such is the case with mercury-vapor lamps. The coming of bigger and better industrial-purpose lamps, black light, photochemical, bactericidal lamps, and sunlamps, as well as new, improved fluorescent paints and pigments, has broadened old fields of use and found many new ones.

Mercury-vapor lamps are commonly used in general industrial lighting service for high-bay mounting where areas are large. The distinctive color is sometimes an advantage and their high output and long life reduce maintenance costs to a minimum. Where rough work is done, as in steel mills, vapor lamps are used alone but where a fairly high degree of color discrimination is required, they are combined with incandescent-filament lamps.

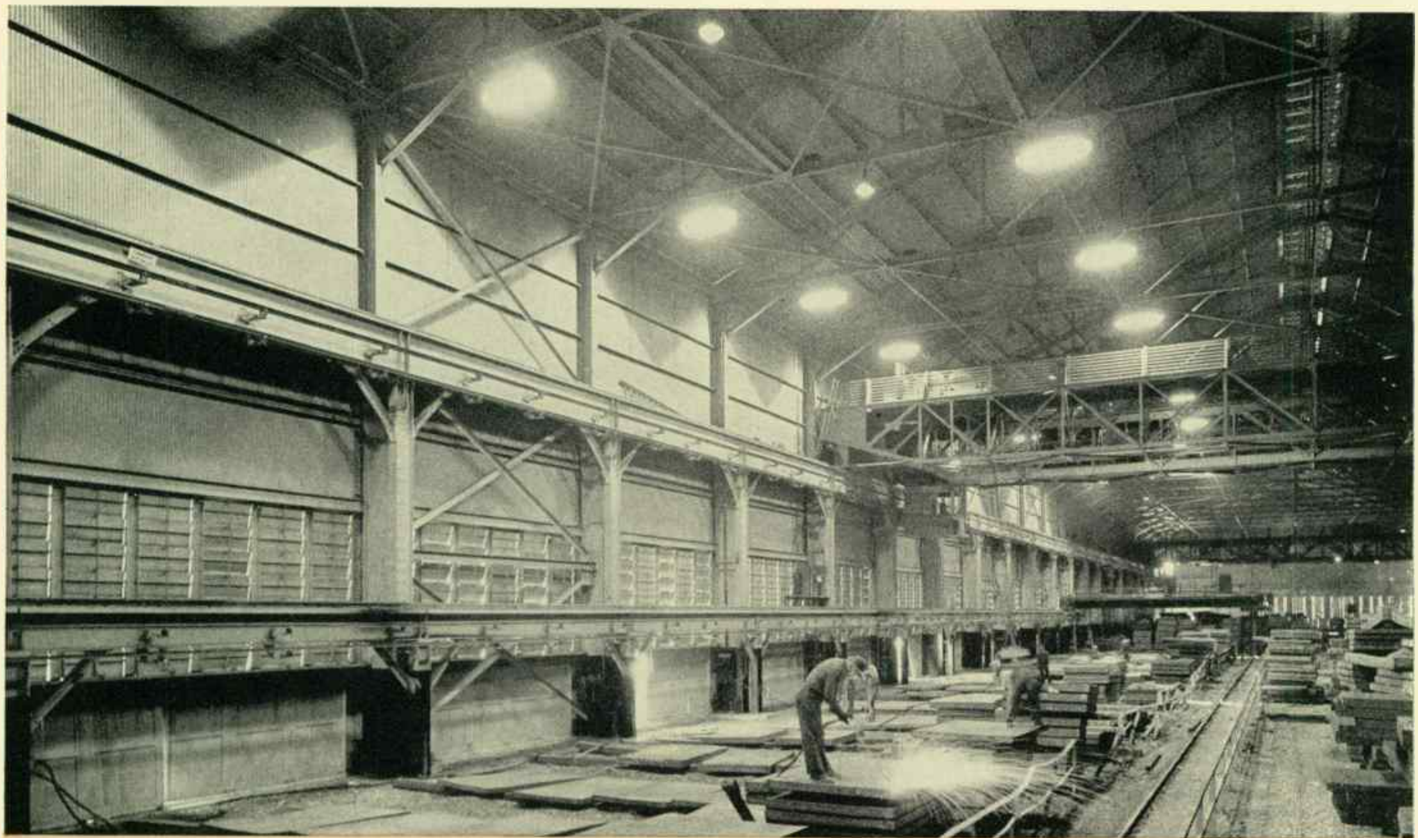
In the field of general lighting, use of the new double-bulb, quartz arc-tube lamps has only just begun. In this application their somewhat shorter useful life is compensated by higher efficiency of light generation and the slightly better color quality. In addition, the smaller arc length of these lamps allows better control of the light and is desirable to prevent the direct brightness from becoming an annoyance to employes working on balconies above the main floor.

Street Lighting and Floodlighting

Mercury-vapor lamps are solving difficult problems of street and highway lighting. One of the newest and most promising developments in street-lighting equipment is an oval reflector and refractor with a horizontally mounted quartz lamp.* Because of the relatively small size of the mercury arc its light can be more efficiently directed and therefore higher utilization of the light produced is possible than with previous vapor-lamp sources.

This article is the second and concluding section of a paper on "Progress with Mercury Lamps" by the same author in the November, 1947 issue of the Westinghouse ENGINEER.

*Westinghouse ENGINEER, November, 1947, *What's New!* p. 191



Combined with filament lamps to give the minimum degree of color correction (incandescent lumens equal 15 percent of total), these 3-kw, A-H9 mercury-vapor lamps mounted 42 feet above the floor illuminate a steel plant to 50 footcandles.

Mercury-vapor lamps have in the past been used but little in floodlighting, partly because they could not be tilted at will. Quartz lamps now not only make possible burning in any position, but also result in greater effectiveness because of small size and high brightness of the arc. The high efficiency, high output, and blue-white light of the lamps promise to open a wide new field in floodlighting. In combination with incandescent lamps, they provide a close approximation of daylight practical for all of the many applications for floodlight projectors.

Color Correction by Incandescent Lamps

Data on color correction of mercury light by means of incandescent lamps is summarized in table I. The information was obtained by comparing the appearance of various colors under mixtures of incandescent and mercury light with their appearance under standard 4500-white fluorescent lamps. The mercury lamps were the familiar 400-watt A-H1 type and the illumination levels were maintained practically constant throughout the series of tests. Most usable mixtures of incandescent and mercury lamps produce a color of light similar to that of a black body at 4500 degrees Kelvin (8624 degrees F) although with a greenish cast. The comparison was therefore made with 4500-white fluorescent lamps whose color approximates that of 4500-degree-K light. Also, comparison with daylight and white fluorescent lamps generally gave similar results.

The "minimum" degree of correction listed in table I is the amount of incandescent light needed to provide noticeable color improvement, particularly in appearance of the human complexion. This value was found to be approximately 15 percent of the total combined lumens. The "maximum" is a ratio of approximately 60 percent incandescent lumens to 40 percent mercury lumens. Beyond this point it is ordinarily not advantageous to add incandescent light since the additional improvement is very small and the overall efficiency of the lighting system is reduced.

Mercury plus incandescent light has long been considered a fairly satisfactory "synthetic daylight" well adapted to industrial use, but now it may be suitable for other applications such as sports lighting and floodlighting. The new quartz lamps remove restrictions as to burning position, which is especially important with floodlight projectors. They also slightly improve the appearance of colored objects so that a mixture gives results equal to or better than those of table I.

A new method of color correction now being tested is by the addition of small, carefully measured amounts of other metals, such as metallic cadmium, to a mercury lamp. Cadmium adds the red color lacking when mercury is used alone and makes possible the application of mercury lamps to certain high-fidelity color photographic processes and perhaps to industrial lighting and floodlighting service. Still in the development stage, the cadmium-mercury lamp is expected in a few years to enlarge greatly the potential field of application for vapor lamps.

Color Pigments and Filters

The line spectrum of mercury lamps is rich in yellow, green, blue, violet, and ultraviolet, but lacking in red. For many applications this may be a handicap from a color standpoint, but certain circumstances can turn it into an advantage. Pigments selected for high reflectivity in the spectral region of one of the four major visible mercury lines produce especially pure and brilliant colors and make possible achievement of unusual and striking effects.

Various paints and pigments have been investigated with this application in mind, and many have been found with a high reflectance for one or more of the strong lines in the visible spectrum: violet, 4047 Angstroms; blue, 4358 Angstroms; green-yellow, 5461 Angstroms; orange-yellow, 5770–90 Angstroms. The green of grass and the foliage of flowers, shrubs, and trees is known to react particularly well to mercury light.

Extensive use of paints containing selected pigments is predicted for such applications as outdoor advertising displays and billboards, filling stations, restaurants or roadside stands, and places of amusement. Treated with such a paint and illuminated by mercury floodlights, a building or a sign stands out in vivid contrast to its surroundings.

Where light of various colors is required for floodlighting or other purposes, mercury lamps with properly selected filters are suitable for production of violets, blues, yellow-greens, and yellows. Colors at the orange-red end of the spectrum are of course readily obtainable from filament lamps.

This high bay installation of 1000-watt A-H12 lamps provides high-level, low-maintenance illumination for general shop purposes, material handling, and accurate machining.

TABLE 1—COLOR CORRECTION BY MIXING INCANDESCENT LAMPS WITH 400-WATT A-H1 MERCURY-VAPOR LAMPS

Degree of Correction	Incandescent Lumens in Percent of Total	Rendition of Colors as Compared with 4500 White Fluorescent						Net Initial Lamp Efficiency Including Transformer Loss (Lumens per watt)
		*Purple	Blue	Green	Yellow	Orange	Red	
None	0	Poor	Fair	Fair	Fair	Poor	Poor	36.3
**Minimum	15	Fair	Good	Good	Fair	Fair	Poor	32 4
***Maximum	60	Good	Good	Good	Good	Good	Good	25.7

*The purple dyes and pigments tested had a red reflecting component.
**300-watt PS-35 incandescent lamps used. ***1000-watt PS-52 incandescent lamps used

This principle was utilized in the color floodlighting of the famous Lagoon of Nations fountain display at the New York World's Fair in 1939–1940. Dual projector units, each containing a mercury-vapor and an incandescent lamp equipped with appropriate filters were used to light the water jets.

Filters for mercury light should of course have as high a transmission as possible in the region of the line to be used. Both pigments and filters should be selected for their spectral characteristics and then checked for appearance with mercury light prior to actual installation.

Color correction and improved optical and visual results using fluorescent pigments coated on reflectors or on the ceiling and walls of a room have always held promise but the materials available have had too low a reflection factor for visible light. Recent progress has been made, however, and no doubt these losses will some day be eliminated, resulting in still higher efficiencies and better color through utilization of ultraviolet rays that are now wasted. For example, so-called "daylight fluorescent" pigments and dyes used for signal flags during the war develop notably augmented brilliance under mercury light.

A practical use of fluorescence has already been made in an excellent double-coat paint that produces a good red color under straight mercury light as well as under daylight, fluorescent, or incandescent light. This paint consists of an undercoat of standard red pigment covered with a translucent reddish lacquer that fluoresces a bright orange-red under the influence of violet and near ultraviolet. This paint has been in use for several years in war plants to distinguish fire hydrants and other objects that must appear red at all times. The same principles can be extended to other colors.

Experiments are in progress on utilization of the 3650-Angstrom radiation generated in such abundance by quartz lamps and other bands of energy now wasted. New pigments are being developed for wall and ceiling paints to convert ultraviolet lines into useful visible light without simultaneously raising absorption of the visible spectrum excessively. Other important tests are being carried out on pigments that convert 3650- and 4047-Angstrom energy into useful visible light of wavelengths that not only add footcandles, thereby improving effective output, but also correct color.

Fluorescent zinc oxide is an example of the first group designed to add to the total footcandles without much color correction. It is now made quite white, a basic requirement for, otherwise, absorption of visible rays exceeds the gain through fluorescence. Improvement in whiteness under visible light will determine its ultimate utility. Fluorescent zinc-cadmium sulfide is typical of pigments that will be of interest chiefly because of their ability to add the orange-red lacking in mercury lamps. Many other pigments of both groups are being investigated. The results are not yet decisive.

Reaction of Insects to Mercury Light

Mercury light may have special merit because of its attraction for insects. Entomologists must give the final word on proper design and use of outdoor lighting equipment where insect reactions are important, but mercury light definitely has a special effect and deserves special study.

Prior to installation of window screens in a plant it was found that the "catch" of insects in trough reflectors under the mercury lamps exceeded that under the filament lamps by over ten to one. Mercury lamps "draw the bugs" so strongly that areas remote from the lights are left clear. For outdoor sports floodlighting, where lights are mounted high overhead, mercury light, alone or mixed with incandescent light, draws the insects up away from spectators. This may be a solution to an old, bothersome problem and an important factor in selection of illuminants.

Black Light

Theatrical, decorative, and amusement uses are still the principal applications of black light. Large displays, such as the World's Fair Aquacade and theatrical performances, have used carbon arcs, but now that high-wattage quartz mercury lamps are available, these new illuminants will be increasingly applied for such purposes.

In the past year or so new applications of black light have developed. Some are purely military while others have wide peacetime application. One of the more interesting industrial uses developed during the war and still being used is inspection of protective coatings on machine parts or similar objects. During the war many articles were coated to prevent damage from moisture and fungus in tropical climates. The protective coating is practically invisible but fluoresces brilliantly under black light. Inspection of each treated article

Oval-shaped luminaires with 400-watt, 20 000-lumen mercury-vapor lamps provide a high, even level of glareless illumination on the street of this outdoor lighting laboratory.

carried out under black light proved to be the solution. Other similar processes, such as checking completeness of fluorescent embalming fluids, are used.

Cracks in castings and metal parts are easy to detect by fluorescence. The part is immersed in a bath of penetrating fluorescent oil and then washed and dried to remove all traces of oil except that which enters cracks. Later, by special treatments this oil oozes out of the fracture and shows up when exposed to ultraviolet light.

TABLE II—RECOMMENDED APPLICATIONS OF MERCURY-VAPOR LAMPS

Type	A-H4	B-H4	C-H4 E-H4	S-4	A-H5	C-H5	RS	A-H1 B-H1	D-H1	E-H1	F-H1	A-H6	A-H12	B-H12	A-H9	B-H9
Watts—lamp only	100				250		275	400				1000			3000	
General Lighting	x					x		x		x			x		x	
Floodlighting			x			x		x		x			x			
Street Lighting						x		x		x	x		x			
Black Lighting	x	x	x		x				x			x		x		x
Photochemical	x		x	x	x				x			x		x		x
Blueprint and Photography	x				x				x			x		x		x
Sunlamp Service				x			x									
Searchlight and Projection	x					x				x		x	x			

Other industrial uses involving black light and fluorescence trace the product through manufacturing processes and out to its field of use. Charts and demonstrations have a new interest and effectiveness with fluorescence and black light. In the field of education, specially treated working models, diagrams, and pictures have new meaning with fluorescence and black light. For example, the giant model of the atom in the Museum of Science and Industry in New York fluoresces, while the suspending threads and ceiling above do not. The exhibit is illuminated only by black light, so that the model seems to float in limitless space without visible means of support.

Legal papers, ration coupons, sales tickets, and similar documents may be coated with fluorescent ink and traced through black light. The practice followed with the first issue of sugar-ration coupons is of special interest. Here pulp for the coupon paper contained a small percentage of green fluorescent fibers, making it easy to check for authenticity.

In the field of decoration, black light has been used for many years. Now, with tremendously high outputs available, the fluorescent ornamentation of ceilings may become the source of illumination in a room. Ceilings, walls, and other parts can be covered with fluorescent paint and lighted with sufficient power to give them a new brilliance. These panels and forms have the appearance and effectiveness of inbuilt troffers or stained glass lighted from behind. In movie houses, fluorescent carpets illuminated by black light are common. The new lamps are chiefly the A-H5, D-H1, B-H12 and B-H9. They employ, of course, the usual filter plates that absorb visible light but pass black light.

The RS sunlamp can be used in a light, convenient, portable black-light unit requiring no transformer. The principal requirements are that the enclosure to eliminate spill light be large enough to avoid overheating the lamp and that the filter be large enough to prevent it from overheating and cracking.

Photochemistry

The act of seeing is photochemical and the food we eat is created by photochemistry in leaves of plants. Other artificial photochemical reactions are also of great importance in our daily lives. New developments in the photochemical field are primarily creations of new and larger lamps, new techniques, and wider and more effective use of radiations in chemistry.

During the war, the first small quantities of uranium were produced photochemically. All hexaclorethane, "smoke gas" to the "GI," was made by irradiating chlorine and ethane with visible light and ultraviolet primarily of 4047- and 3650-Angstrom wavelengths. Today tons of chlorinated benzine for insecticides and chlorinated paraffin oil for an improved linoleum are being made photochemically. New plastics, better synthetic rubber, and even new foods will come through photochemistry stimulated by war research and now by new developments in lamps, equipments, and methods.

The sun's rays have been used for ages to bleach laundry. Today, shirt manufacturers use the RS sunlamp and moisture to accomplish this same purpose. Tomorrow, wood pulp, textile fibres, and other materials may be bleached under ultraviolet produced by photochemical lamps.

Blueprinting and photocopying represent the widest applications of mercury lamps to photochemistry. These processes will be extended by the availability of new, higher powered, more convenient, and more economical lamps.

Television, Photography, and Photoprinting

Mercury-vapor lamps have been used for several years in television work to reduce heat in the studio. This application is similar to the use of mercury-light sources in the early days of motion pictures. Mercury lamps were then used because of the high actinicity (ability to cause photochemical changes) of their light. Today, this same characteristic results in their application to black-and-white and (with cadmium) color photography, sound-track and motion-picture printing, photo-enlarging, and similar uses. In addition to the general advantage of high actinicity, a narrow band of ultraviolet alone is sometimes used to improve grain quality of the print.

Searchlight and Picture Projection

The high brilliance of mercury-vapor arc discharges suggests them as light sources for searchlights and today thousands of weather bureau cloud-height measuring devices are in continuous use throughout the world. These utilize the tremendous brilliance of the A-H6 and B-H6 lamps. Also, when operating on 60 cycles, the light is completely extinguished 120 times a second, which makes it possible to segregate light originating from the searchlight from any other that may enter the receiver from nearby sources.

Picture projection with mercury-vapor lamps was demonstrated by the Dutch at the New York World's Fair. It is limited by the lack of a complete color spectrum. However, for some black-and-white projectors, such as stock-ticker equipment at the New York Stock Exchange and microfilm projectors, it is excellent and is being used. In the latter application, the small 100-watt A-H4 lamps provide long life, low maintenance, and minimum heat in the projector, and observers generally like the color produced.

The cadmium-mercury experiments promise to open up the field of color-picture projection to vapor lamps. If suitable color quality is successfully produced in the projected picture, the lamps will replace the open carbon arc now needed in theaters for long throws.

Sunlamps

The application of sunlamps has recently been stimulated by development of the self-contained reflector lamp known as the RS. This lamp provides safety, low cost, and a new degree of convenience, along with the inherent effectiveness of the mercury-vapor quartz discharge in generation of vitamin-D producing rays.

In the RS lamp, operation of a mercury-vapor discharge on 120-volt alternating current without auxiliary equipment is made possible by an incandescent filament acting as ballast resistance mounted within the bulb and a starting electrode preheated by the action of an inbuilt thermal switch. The starting electrode consists of a small, coiled tungsten filament which is brought to incandescence during the starting cycle and, by thermal emission, ionizes the argon starting gas. In addition to taking the place of an inductive ballasting reactor, the ballast provides comfortable warmth in the beam.

The rich, blue-green spectrum of these mercury floodlights is particularly advantageous in revealing the bronze-green beauty of the Statue of Liberty in New York harbor.

The new developments in application engineering are primarily in methods and devices for holding and aiming the lamp and in new uses. Of particular interest are built-in arrangements for the RS sunlamp in the bathroom. The shaving light provides a handy source of health-giving rays and also utilizes the abundance of visible light given out by the lamp to make this daily chore easier. The time ordinarily required for shaving is sufficient for a suitable daily dosage of sunlight. Also, the angle at which the rays strike the face develops a "good-looking" erythema. For the housewife, a similar desirable installation is over the kitchen sink.

Bactericidal Lamps

A discussion of mercury-vapor discharge lamps should include bactericidal rays. Tremendously high efficiency in generation of short-wave ultraviolet is a special characteristic of low-pressure mercury-vapor discharges. New lamps are now available with better maintenance and high or ultraviolet output and new developments promote their use for health improvement. Today we irradiate the air we breathe, the food we eat, the utensils we use, and the pharmaceuticals we employ at home or in our hospitals. Space irradiation is being applied to kill air-borne bacteria, and thereby reduce infection in schools, offices, hospitals, and even in our homes.

Fluorescent Lamps

Of all the mercury-vapor family, fluorescent lamps are the most common. They utilize the tremendously high efficiency of generation of short-wave ultraviolet, a characteristic of low-pressure lamps, combined with fluorescence to create a new high quality of white light at previously undreamed of efficiencies. Recent years have indicated a definite upswing in their use and fluorescent lamps are now common in homes, stores, hospitals, and factories. The reasons for this trend are their pleasing streamlined appearance and flexibility, plus long life, low maintenance, and high efficiency.

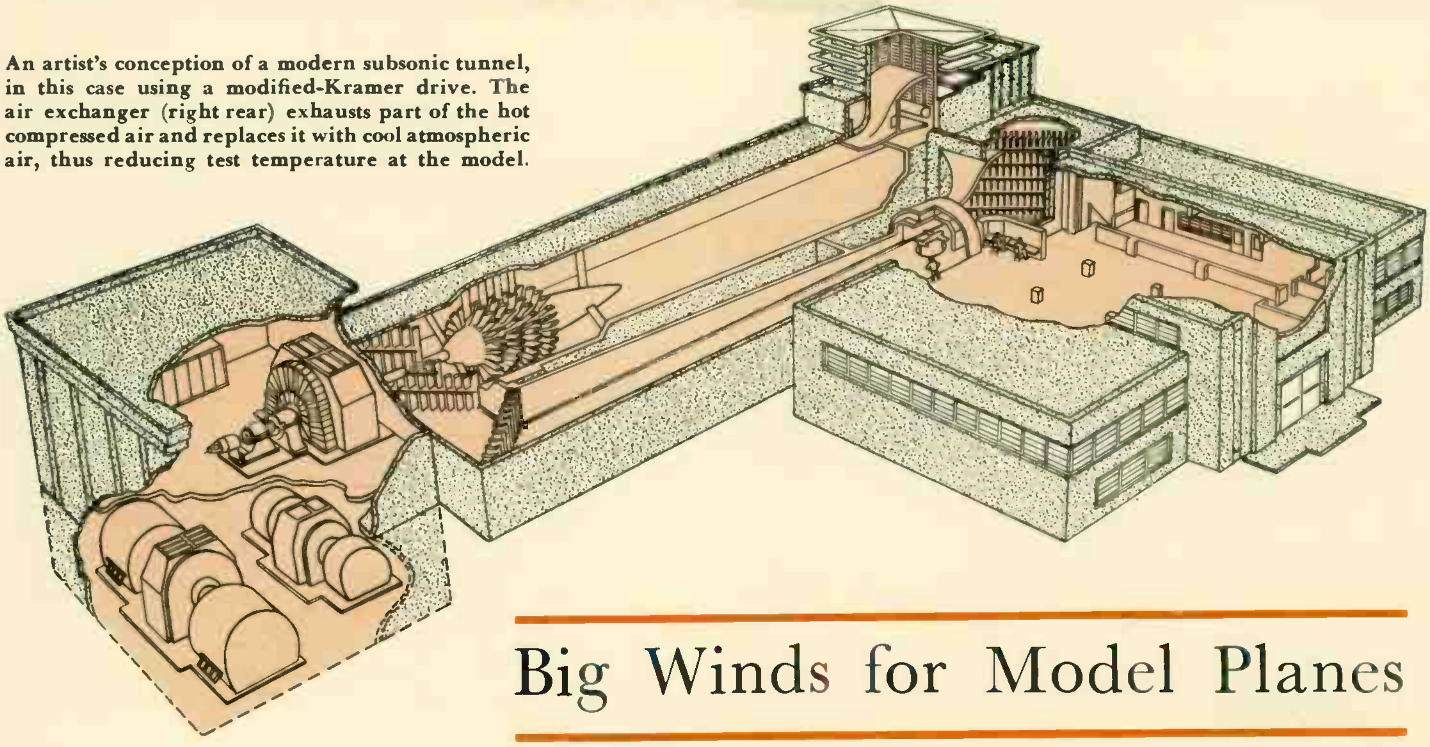
A recent addition to the fluorescent family, one that will greatly enhance its flexibility, is the circular lamp built in two half-circles instead of a single full circle. Besides being easier to manufacture, the 180-degree lamp employs an inexpensive ballast instead of the more costly transformer required with full-circle lamps. Another aid to the application engineer is a merchandising unit consisting of a bank of four 40-watt, 48-inch fluorescent lamps, or a row of banks, combined with dual 150-watt incandescent spotlights at each end. The fluorescent lamps provide a high general level of illumination, about 50 footcandles, over the entire counter area and the spotlights emphasize specific items by lighting them to about 150 footcandles.

Psychology in Application

Moths are attracted by light. Humans, too. This bit of psychology has been added as a valuable tool to application engineering of mercury lamps. In one store it is used to overcome the natural tendency for people to walk up and down lengthwise aisles but neglect crosswise aisles. This is accomplished simply and effectively by lighting the cross aisles more brilliantly. Also greater illumination at the rear of the store brings it "closer," attracting customers.

The next few years will reveal the mercury lamp as the most versatile source of radiant energy. This will come about largely through new contributions by application engineers who, by combining imagination with practicability, will release the magical powers of the mercury lamp and open up new worlds of use beyond even the fancies of its creators.

An artist's conception of a modern subsonic tunnel, in this case using a modified-Kramer drive. The air exchanger (right rear) exhausts part of the hot compressed air and replaces it with cool atmospheric air, thus reducing test temperature at the model.



Big Winds for Model Planes

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We are promised supersonic aircraft that keep abreast of the sun and even rockets to take us to the Moon, Mars, and Venus. The prospect, no longer fantastic, is "out of this world." Yet ahead of such craft must come much work in research laboratories and gigantic wind tunnels capable of driving air at supersonic speeds past models of the future. And with these tunnels will be drives of sufficient capacity to furnish the tremendous power they require—probably one million horsepower, perhaps even more.

How will the forthcoming supersonic aircraft affect wind tunnels and their drives? This question is being asked by the armed forces, aerodynamic research men, aircraft builders, power-company operators, generator and motor manufacturers, and many more. The answers are important. For one thing, tunnels of a million horsepower and up are being seriously considered in this country. The biggest generator ever built is rated at 165 000 kw and the total installed capacity in the United States is about 52 million kva. One supersonic wind tunnel alone would require six such generators and would tie up almost two percent of our total capacity. No wonder that electric-utility operators perk up their ears at the "sound" of approaching supersonic aircraft.

Curiously enough, supersonic wind tunnels entail no new forms of drives; in fact, the equipment will be simpler. To be sure, the larger tunnels will require motors of tremendous ratings. But, because air speeds above sonic are independent of blower speed and can be changed only by altering the throat dimensions, motors of narrower speed range can be used in place of the wide-range machines so essential for subsonic tunnels. While adjustable-speed drives are unnecessary for control above sonic speed, they will continue to play an important role for subsonic operation.

Wind-Tunnel Drives

Prospects of very high-powered supersonic wind tunnels make it interesting to review the present status of drive equipment and to speculate on what the future may bring. The choice of wind-tunnel drive depends, of course, on the model size, the speed of air flow, and the characteristics of the fan. In general, for any given pressure of air in the tunnel, motor power is proportional to the cube and torque to the square of fan speed. When air pressure is reduced, fan torque decreases nearly proportionally. The power and torque curves of the supersonic compressor follow these rules up to sonic air speed, then increase more rapidly.

The size of wind-tunnel drives has increased at an ever-accelerating rate for the past twenty years. Individual wind tunnels of 40 000 to 60 000 hp are in operation or under construction. The largest single-motor drive is the 40 000-hp motor for the 20-foot, 400-mph wind tunnel at Wright Field. Other drives, such as a 50 000-hp drive now under construction, are of higher total power but use two or more motors in tandem or on separate fans.

Almost without exception wind tunnels employ an electric drive as it results in equipment of least size and cost (Diesel engines and steam turbines have been used). Since the test program usually requires operation of the tunnel for only a small total number of hours per year, this reduction of fixed investment is important. Early tunnels were of a few hundred horsepower only and for these an adjustable-voltage d-c motor system was the simplest and most economical. As wind tunnels grew, power requirements increased to the extent that such drives were impractical and it became necessary to use a-c fan motors. Several special drives use the excellent control characteristics of the d-c system for auxiliary purposes but have a-c main drive motors.

Adjustable Voltage D-C Drive

The adjustable-voltage d-c drive (Fig. 2), best suited for sizes up to several thousand horsepower, is used separately and as a part of larger systems. Its great merit, in all cases, is a

This article brings up to date two previous papers published in the November, 1941 issue of the Westinghouse ENGINEER: "Wind Tunnels—Birthplace of Streamlining," by Dr. F. L. Wattendorf and S. Paul Johnston, and "Power for Man-Made Hurricanes," by L. A. Kilgore and J. C. Fink.

Since the Wright brothers, who built one of the first wind tunnels (a box 22 inches square by 60 inches long through which air flowed at 27 mph) airplane designers have used wind tunnels to predict the performance of full-scale aircraft from tests on small models. But, today, as attempts are being made to build ships that fly faster than sound, additional factors enter the picture and model testing plays an increasingly significant part. The most important of these is the result of compressibility of air.

Because air is compressible, a solid object moving at any speed sends ahead a pressure wave. In effect, the air is prepared so that it divides and flows freely around the object. The speed of this pressure wave is equal to that of sound, a pressure wave itself. If, however, the object moves faster than sound, thereby running ahead of its "warning" pressure wave, the air is unprepared. Instead of flowing freely around the object, the air is forcibly pushed aside, causing shock waves with great loss of momentum. The speed of pressure waves in air is dependent primarily on air temperature (it is almost independent of pressure) and varies from 1120 fps (765 mph) at 60 degrees F to 955 fps (650 mph) at minus 67 degrees F, the mean temperature at 50 000 feet. Inasmuch as the speed of sound decreases with decreasing temperature, compressibility effect increases with altitude.

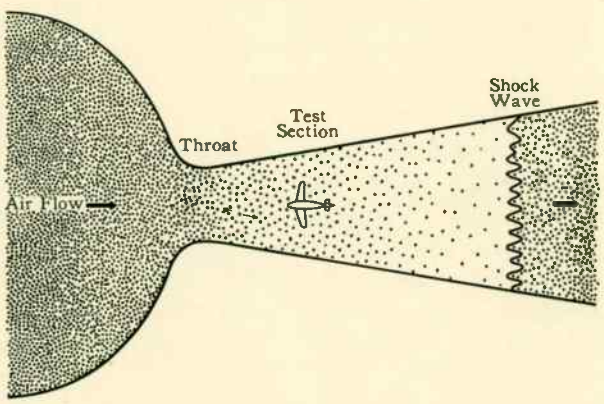


Fig. 1—Relation of supersonic air speed to air density.

Compressibility effect is related to the Mach number, the ratio of air speed to the speed of sound at that temperature. Up to the point where some of the local air velocities relative to the object exceed the speed of sound, compressibility effect alters the preferred shape of the wing or airplane but offers no serious limit to its speed. However, as soon as the speed of sound is exceeded, shock waves give a serious increase in drag (power required to drive the plane) and produce unstable flow conditions and violent pulsating forces. Particularly on supersonic aircraft, it is much cheaper in both lives and dollars to experiment on models in a wind tunnel than on piloted full-scale aircraft.

One can get a clear concept of air flow in a supersonic tunnel as the speed of sound is exceeded by considering a nozzle of increasing cross-section in which air expands gradually into a region of reduced pressure (Fig. 1). Air rushes into this evacuated space but (the pressure being low enough) its forward velocity is limited by the thermal energy its molecules possess by virtue of their temperature (temperature is a measure of thermal energy or kinetic energy of the molecules as they bounce around at random velocities). Aerodynamic and molecular studies indicate that in the throat of the nozzle, the maximum forward velocity of the air is limited to the speed of sound at its temperature in the throat. But as the air passes from the throat into the expanding section of the nozzle, its density is gradually reduced. Consequently, molecules moving with random velocities in the downstream direction encounter fewer collisions than do molecules moving in the upstream di-

wide speed range with good speed control and high efficiency.

A motor-generator set supplies an adjustable d-c voltage to the drive motor, which is usually operated with constant field. Fan speed, then, is proportional to voltage supplied by the generator. For many drives rheostat control of generator voltage for speed adjustment is sufficient. A slight drift of speed with temperature change occurs as the equipment warms up under load and, by regulating generator and motor field currents, increased speed stability is obtained. A regulator measures fan speed directly and controls generator voltage to hold the speed accurate to within a fraction of a percent.

Wound-Rotor Motor with Secondary-Resistance Control

The induction motor with control of the rotor resistance (Fig. 3) provides the most simple and economical method of obtaining adjustable speed with a constant frequency a-c power supply. It is particularly well suited to supersonic wind tunnels where most of the operating time is at high speed. Secondary resistance is varied by liquid rheostats consisting of a fixed and a movable electrode in an insulating cylinder containing an electrolyte. Sodium carbonate dissolved in water is circulated through the cylinder and then through a heat exchanger where it is cooled. The electrodes are motor driven and give an infinite number of speed points. The major power loss occurs in the liquid rheostat. Assuming that power increases with the cube of fan speed, this loss reaches approximately 16 percent of rated power at ⅔ speed. A 50 000-hp, two-motor, supersonic wind-tunnel drive of this type will soon be in operation. Even larger wound-rotor units will be constructed.

If the wound-rotor motor must be operated at low speed, speed fluctuations with large voltage changes may be objectionable. This effect is not as serious at high speeds, but at low speeds the fluctuation is nearly proportional to voltage change.

Combination Wound-Rotor and Adjustable-Voltage D-C Drive

To overcome the disadvantages of the wound-rotor drive, poor speed regulation and efficiency at low speeds, the tandem combination of an adjustable-voltage d-c drive and wound-rotor motor (Fig. 4) has been used with good success. A 12 000-hp drive of this type has been installed at the cooperative wind tunnel of the California Institute of Technology. The d-c motor is rated approximately 20 percent of the wound-rotor motor. At speeds up to approximately 45 percent maximum the d-c system alone is used. Above this, assuming steady-state conditions, the d-c motor operates at full load. The remainder of the load is carried by the wound-rotor motor. A speed regulator acting on the d-c drive causes it to deliver the increased or decreased torque necessary to maintain constant speed. The liquid rheostat is controlled automatically to hold approximately full d-c motor load.

Synchronous Motor with Slip Coupling

Several wind tunnels have been built using synchronous motors coupled to the fan by an electric induction slip coupling. The largest such drive is the 18 000-hp Boeing Aircraft Company wind tunnel at Seattle, Washington. The efficiency is rection. The effect is an increase in forward velocity and hence the speed of sound, which exists in the throat, is exceeded. Since this additional velocity is obtained at the expense of molecular thermal energy, the gas temperature is decreased, in turn reducing the speed of sound. Hence, it is possible to obtain a high Mach number for testing supersonic models. It is expected that Mach numbers as high as ten will be attained in the near future.

Once air has exceeded the speed of sound, it cannot slow down to less than sonic speed without a discontinuity known as a shock wave. At this point part of the velocity energy is reconverted into thermal energy with a sudden change in density and temperature. Putting more suction on such a nozzle only draws the shock wave farther down the tube. This shock wave must be beyond the model, else it will interfere with running the test.

The volume of air is limited by the fact that only the speed of sound can be attained in the throat. Therefore, the air velocity at any point ahead of the shock wave is fixed solely by the ratio of the area of the section at that point to the area at the throat. For this reason, it is impossible to control air speed by changing the speed of rotation of the blower or compressor, as is done for subsonic testing, since such action only moves the shock wave. For control of a supersonic tunnel, it is then necessary to change either the position of the model in the tunnel or the ratio of throat area to test-section area. Because mounting the model entails much delicate mechanism, moving it is undesirable and most supersonic wind tunnels are built with either interchangeable throats or an adjustable throat using flexible steel walls whose shape can be changed. Drives for moving air at supersonic speeds will be either constant-speed motors or units of much narrower speed range than commonly used with subsonic tunnels. The cost per horsepower in either case will, of course, be less than for the drives discussed on these pages.

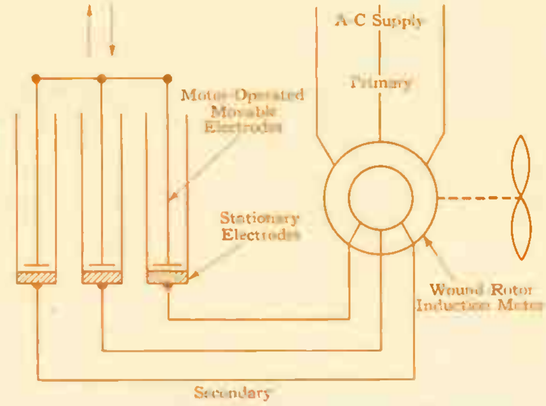


Fig. 3—Simplicity and low cost are advantages of the wound-rotor motor with liquid rheostats.

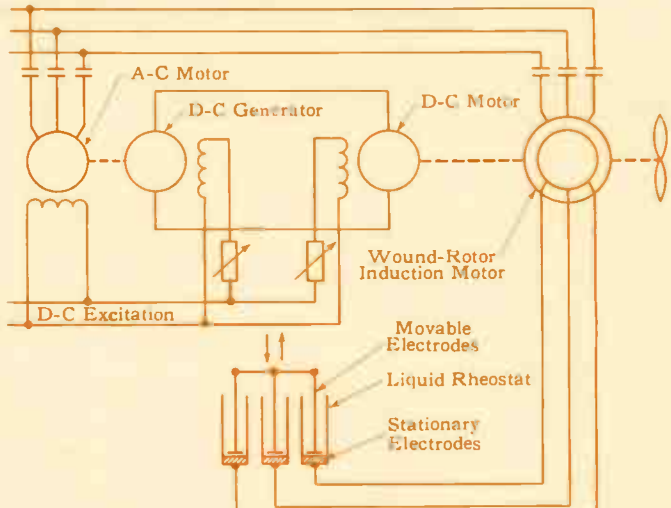


Fig. 4—The tandem drive with the wound-rotor and adjustable-voltage d-c systems combines advantages of both.

similar to that of the wound-rotor motor drive, the power loss being proportional to the ratio of slip speed to motor speed. To dissipate the large amount of heat, nearly 3000 hp in the case of the 18 000-hp drive, the coupling is water cooled.

Modified-Kramer Drive

The modified-Kramer drive (Fig. 5) has been used for large wind tunnels where efficiency and accuracy of speed regulation are particularly important. The original Kramer system employed a synchronous converter to convert the secondary power of the wound-rotor motor, which would otherwise be wasted, into direct current usually delivered to a d-c motor on the main drive. Its lack of flexibility resulted in a modification used for wind tunnels. The secondary of the wound-rotor motor is connected to a varying-speed synchronous motor—d-c generator set, in turn connected to a constant-speed

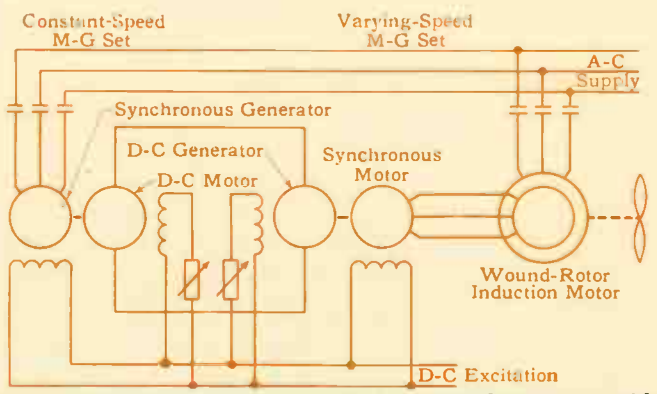


Fig. 5—High efficiency of the modified-Kramer drive over a wide speed range makes it particularly applicable to the largest tunnels.

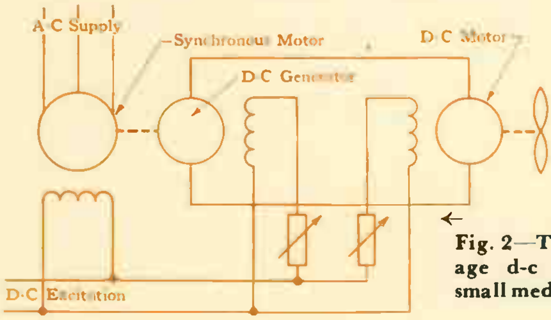
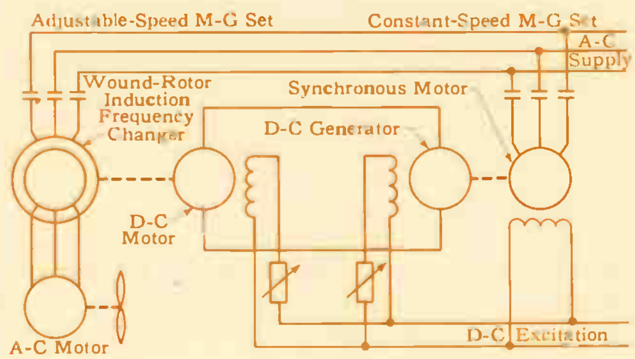
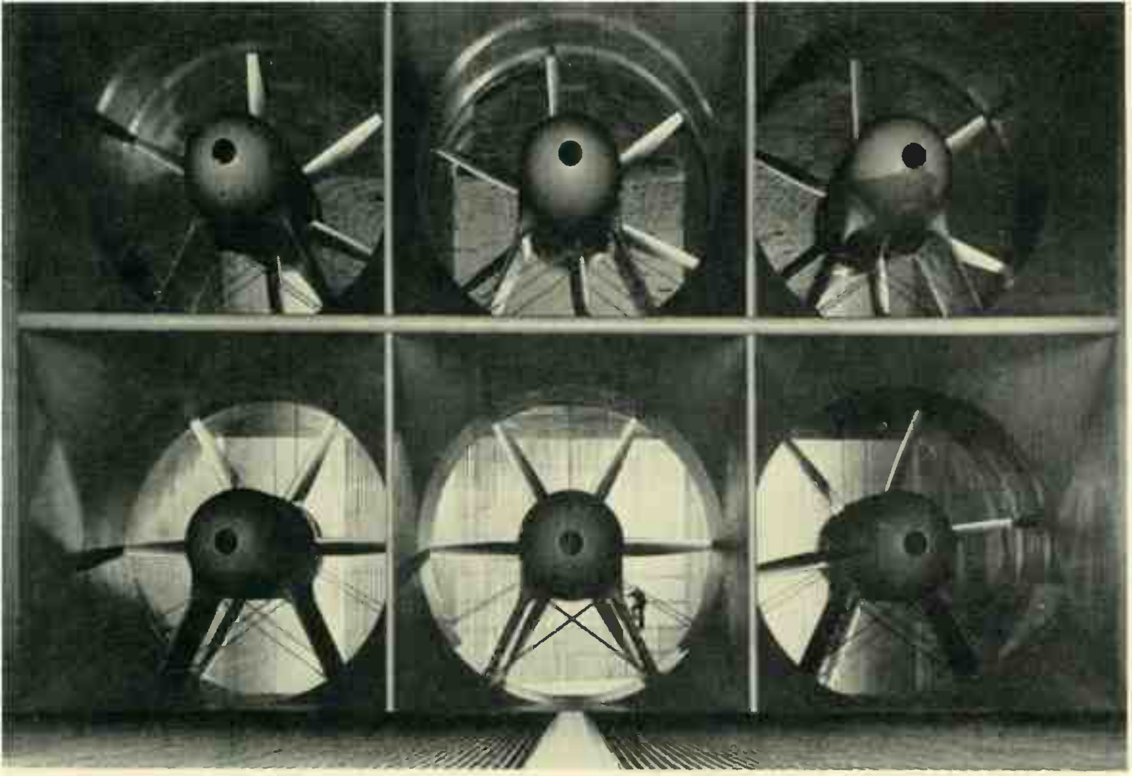


Fig. 6 High-speed propellers are best driven by a synchronous motor fed from adjustable frequency induction-converter. →

← **Fig. 2—The adjustable-voltage d-c drive is best for small medium-speed tunnels.**





This modified-Kramer drive employs six motors of 6000 hp each, which operate with both primaries and secondaries in parallel. Particularly acute here is the problem of damping, which was provided by special design of motors, control, and propellers.

d-c motor—synchronous generator set, which returns power to the line. Efficiency is thereby appreciably improved. Fan speed is maintained at the desired value by regulating the fields of the d-c machines.

In starting the equipment, the constant-speed set, whose rating is approximately 20 percent that of the main motor, is started from the a-c line; this small rating results in low starting current demand. The d-c output is put into the varying-speed set, which slowly accelerates, generating alternating current. The a-c output is continually fed into the secondary of the main motor, whose primary is synchronized with the line when full speed of the varying-speed set is approached.

The a-c motor of the varying-speed m-g set must handle a maximum current (at high speed) and a maximum voltage (at low speed) roughly equivalent to the rated secondary values of the main motor. Hence the rating of this m-g set must be nearly the same as that of the main motor. Actually the power it handles is never greater than about 20 percent of the motor horsepower and some advantage is taken of the fact that maximum current and maximum voltage do not occur together. The large motor, operating with voltages of unlike frequencies established by other machines on the primary and secondary, has a tendency toward instability. This is corrected by providing sufficient damping in the remainder of the system.

The largest drive of this type is the 40 000-hp single-motor unit at Wright Field. Another example is the 36 000-hp full-scale tunnel at Moffett Field using six motors.

Adjustable-Frequency Drives

Several types of drives consisting of an adjustable-frequency supply and a squirrel-cage or synchronous driving motor have been used. They differ primarily in the methods of obtaining adjustable frequency. Two drives, which may become important in supersonic wind tunnels, are the induction frequency converter and the turbine-generator system.

The induction converter (Fig. 6) has been used for several smaller wind tunnels, notably the 1600-hp tunnel at the Langley Field NACA Laboratories and a similar unit at Consolidated Vultee Aircraft Corporation. Sixty-cycle power is supplied to the primary of the frequency changer, which, with its rotor stationary, supplies 60 cycles to the fan motor by simple transformer action. For the usual wind-tunnel drive, this is approximately the full-speed, full-power condition. Reduced speed is obtained by rotating the converter armature in the same direction as the primary flux, thus reducing the output frequency. Adjusting the fields of the d-c motor and generator gives the necessary speed control. As in the case of the modified-Kramer system, the constant-speed m-g set is rated approximately 20 percent full power, but the adjustable-speed frequency-converter set must be rated approximately the same as the main motor. The chief advantage of this system is the fact that the fan motor, being synchronous, can be designed for any speed, high or low, as required by the fan; wound-rotor motors are much more limited in choice of speed. Also the induction frequency converter, being independent of the drive shaft, can be built to operate at the most economical speed. The converter can be driven in either direction, to add or subtract from line frequency.

Of great advantage for large tunnels is the adjustable-frequency operation of turbine generators and fan motors. Here the motor and generator are operated in synchronism, and the waterwheels or steam turbines are governed to give the desired fan speed. Such an isolated power system has not yet been used and will be only when the power requirements reach such size that it is practical to assign generators and transmission lines to a single tunnel. This point will probably be reached when the drives attain a size of a quarter of a million horsepower. In this type of system, the motors and generators probably would be started simultaneously from rest by

TABLE I—COMPARISON OF WIND-TUNNEL DRIVES

Type of Drive	Range of Speed	Accuracy of Speed	Efficiency	Relative Cost per Horse-power	Inrush Current	Application Best Suited For
D-C Adjustable Voltage	10–1	Good	Fair	High	Starting of full-capacity set	Small capacity moderate speed
Wound-Rotor Motor and Liquid Rheostat	3–1[1]	Fair depending on voltage variation	Poor except near full speed	Lowest	Magnetizing current of induction motor	Where momentary deviations in speed are permissible
Wound-Rotor Motor and D-C Adjustable Voltage	10–1	Good	Poor at medium speed	Low	Same as (2)	Where efficiency is not important
Modified Kramer	10–1	Good	High except at full speed	High	Starting current of 20%-capacity set	Large capacity
Synchronous Motor and Slip Coupling	10–1	Good	Poor except near full speed	Low	Starting current of full-capacity motor	Medium-size drives
Induction Frequency Converter	10–1	Good	Good	Medium	Starting current of 20%-capacity set	Medium-size drives
Adjustable-Frequency Generation	10–1	Good	Highest	Low	Entire system is started from rest	Very large drives
Multispeed with Adjustable-Pitch Propeller	4 Speeds	Good	High	Medium	Starting current of full-capacity squirrel-cage motor	Small capacity limited by propeller designs

[1]By using two liquid rheostats in series on large installations it is possible to go to 1/6 speed.

admitting steam (or water) to the turbine; they would then operate in synchronism over the entire speed range. The advantages of this drive are simplicity and high efficiency because no intermediate power conversion equipment is necessary. Also, no power is dissipated for control purposes as in the case of secondary-resistance control of wound-rotor motors.

If this adjustable-frequency system is used, it will probably be desirable to make the generator suitable for integration with a large power system, so that the necessary number of generators to carry the wind-tunnel load can be assigned at off-peak hours. The power system can be arranged so that a number of wind tunnels can be served one at a time, and when not in use a substantial amount of power is available for general distribution.

Control of Wind-Tunnel Conditions

Wind tunnels can be considered in two general classes, depending upon whether the maximum operating speed is subsonic and above. Air speed determines to a large extent the operating requirements of the drive. Supersonic tunnels offer no speed-control problem as air speed is regulated by purely mechanical means, changing the shape of the wind tunnel. But in subsonic tunnels fan speed controls air speed directly; thus if air speed must be adjustable from 50 to 500 mph, the drive must have a ten-to-one speed range. Pitch angle of the fans can also be used to control air velocity, but this method is limited to smaller tunnels where the pitch-changing mechanism is of reasonable size. Multistage fans for high-speed tunnels also increase the difficulties with pitch control.

With constant propeller pitch, air speed is practically proportional to fan speed. Hence fan speed must be controlled with the same accuracy as is desired of air speed. For subsonic wind tunnels, the usual accuracy is one-fourth to one-half percent of full speed. Electronic speed regulators have been used almost exclusively on recent large subsonic tunnels. A closely held, constant d-c voltage is compared with a tachometer voltage proportional to fan speed. The speed error is measured by the difference between voltages, which is then amplified electronically to make the desired change. In this way close control over the entire speed range is obtained.

Special controls are required for special types of wind tunnels. One of these is the vertical tunnel in which models of airplanes or parachutes, for example, are subjected to a rising jet of air. A free-flight tunnel has also been built in which the angle and velocity of the air stream can be adjusted to maintain a model in relatively fixed position supported only by aerodynamic forces. These tunnels are generally limited to small size and low velocity and require relatively small amounts of power.

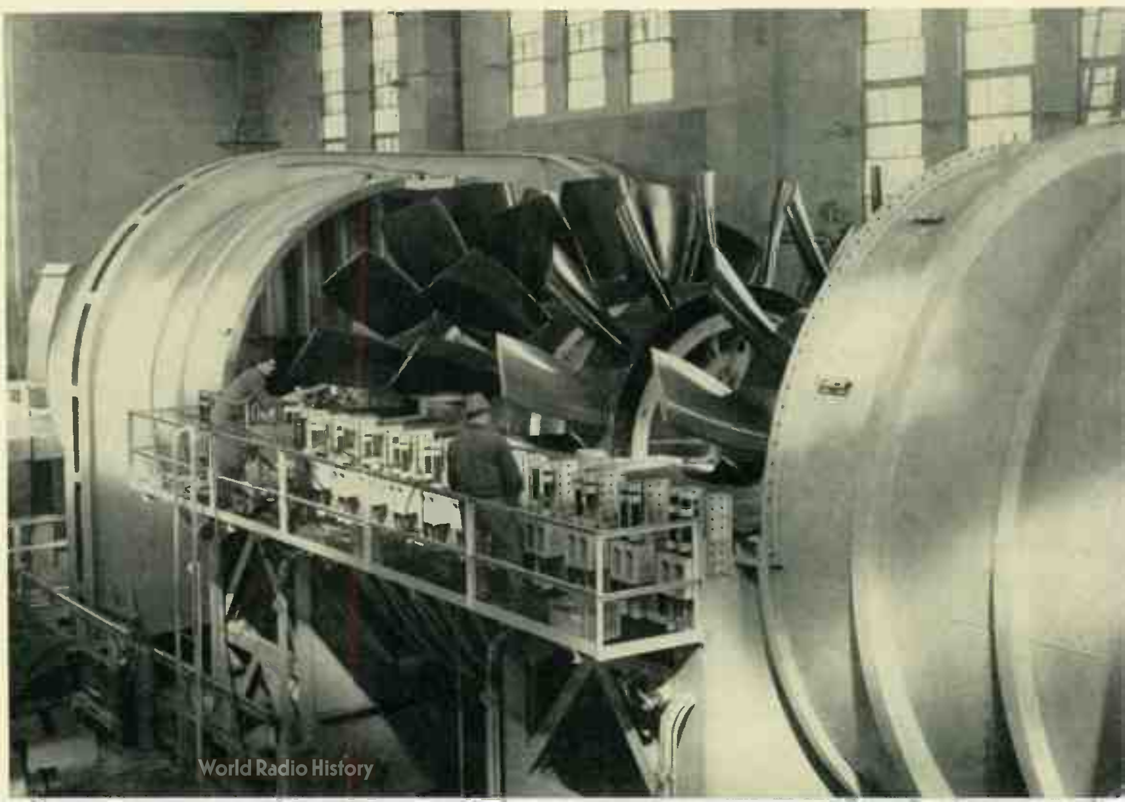
A closed-circuit air system is generally used for wind tunnels of higher power. This permits control of air pressure in the tunnel and, consequently, closer regulation of test conditions. Because the entire fan power is dissipated in the air stream, the resulting heat must be removed.

A number of methods are currently in use to cool air, the simplest being to pour water over the outside surface of the tunnel. Another employs an air exchange tower (sketch on p. 57) that continuously exhausts part of the hot circulating air and replaces it with cool outside air. A third uses water-cooled heat exchangers, the heated water being circulated through an external water tower where it is cooled by circulating air fans. In some cases the air is refrigerated to permit testing temperatures similar to those encountered at high altitudes. The cooling system is generally the same as employed in standard refrigeration plants, cold brine, cooled by evaporation of ammonia, being circulated through heat exchangers in the tunnel. Either an intermittent system, which stores cold brine in huge tanks prior to the actual test run, or a continuous system, which operates during testing, or a combination of

TABLE II—PRINCIPAL WESTINGHOUSE WIND-TUNNEL INSTALLATIONS

Date	Location	Type of Drive	No. of Drive Motors	Total Horse-power
1933	NACA Langley Field	D-C Adjustable Voltage	1	260
1936	University of Washington	D-C Adjustable Voltage	1	1 000
1938	Massachusetts Institute of Technology	Adjustable-Pitch Propeller and 4-Speed Squirrel Cage Motor	1	2 000
1939	NACA Langley Field	D-C Adjustable Voltage	1	2 000
1940	Army Air Corps—Wright Field	A-C Modified Kramer	1	40 000
1940	NACA Langley Field	D-C Adjustable Voltage	1	600
1941	NACA Moffett Field	A-C Modified Kramer	6	36 000
1942	Boeing Aircraft Company	A-C Synchronous Motor and Slip Coupling	1	18 000
1942	AAF Wright Field	A-C Modified Kramer	2	40 000
1942	California Institute of Technology	Combination A-C Wound Rotor—D-C Adjustable Voltage	1	12 000
1943	AAF Wright Field	A-C Synchronous Motor and Slip Coupling	1	5 000
1944	NACA Langley Field	A-C Induction Frequency Converter	1	1 600
1944	NACA Langley Field	A-C Modified Kramer	1	10 000
1944	NACA Langley Field	A-C Induction Frequency Converter	1	300
1944	Consolidated Vultee Aircraft Company	A-C Induction Frequency Converter	1	1 500
1946	Packard Motor Car Company	A-C Wound-Rotor and Liquid Rheostat	1	3 500
1947	Brazilian Aeronautical Commission (2 tunnels)	A-C Wound-Rotor and Liquid Rheostat	1	1 600

Multistage compressors, such as this one driven by two 20 000-hp motors at Wright Field, are being used on wind tunnels.



the two is used. Regardless of the cooling system employed, the only difference engendered by supersonic tunnels will be a matter of size; the methods are expected to remain the same.

Non-recirculating tunnels of either type do not, of course, have a cooling problem. In supersonic tunnels, where temperature of air drops rapidly as it expands in the test section, the air must be dried, else snow or ice will precipitate during cooling and tear the model to shreds. Drying is usually accomplished with silica gel.

A Look Ahead

During the past few years the trend has definitely been away from subsonic and toward supersonic tunnels. The supersonic tunnels now in operation are small in both cross-sectional area and drive horsepower compared to the larger subsonic tunnels. But wind-tunnel history is repeating itself. The trend toward larger supersonic tunnels with faster speeds (as was the case in subsonic) is already apparent. However, the largest supersonic tunnel now under construction is not even within shooting distance of the million-hp size.

The United States is well equipped with subsonic wind tunnels of conventional type. While it is expected that relatively few additional subsonic tunnels (if any, they will probably be for special purposes) will be built, such installations and adjustable-speed drives are yet far from obsolete. Even supersonic aircraft will take off, land, accelerate, and decelerate at subsonic speeds. Many questions are still unanswered about the behavior of aircraft as they pass from subsonic to supersonic speed and vice versa. One major problem is to find a wing design so short as not to offer excessive resistance at supersonic speeds, yet providing sufficient area to support the plane during the slow speeds of takeoff and landing. For absolute safety, models will be tested in wind tunnels over a complete range of air speeds. Furthermore, subsonic tunnels are used, and will continue to be, for aircraft fire and icing experiments, for testing flight components such as wing sections, engines, and engine nacelles, and for checking blading of axial-flow compressors and gas and steam turbines.

Testing of even reduced-scale aircraft at supersonic speeds will require tunnels driven by motors totaling a million horsepower. Such tunnels, which may be constructed in the near future, will probably be driven by several motors, either in tandem, driving a single compressor, or separate, driving several compressors in series or parallel. Motors as large as 250 000 horsepower in a single machine are considered practical at certain speeds. These would be four times the rating of the largest motors now planned, the 65 000-hp units for the Grand Coulee irrigation project.

As the requirements for future wind tunnels become more definitely established various types and combinations of drives will be used. The simplest arrangement, of course, would be synchronous motors each fed by independent generators so that the speeds could be individually controlled by regulating the input to each turbine or waterwheel. The motors could drive separate compressors operating in tandem so that they could be started and accelerated one at a time as it became necessary to increase air speed. If, because of local power conditions, such an arrangement were impracticable, modified-Kramer or wound-rotor drives could be used.

The report recently published by the President's Air Policy Commission endorses the NACA "Unitary Plan" recommending establishment of two new research centers. One, the National Supersonic Research Center, will conduct transonic and supersonic research; the other, the Air Engineering Development Center will evaluate aircraft. In addition, 16 smaller supersonic tunnels are suggested for universities. As an example of the magnitude of facilities required for research, the Air Policy Commission lists one tunnel, which it estimates will cost 140 million dollars and will require 500 000 horsepower. The Commission concludes "that the United States is dangerously short of equipment for research in the transonic and supersonic speed ranges" and that "this deficiency should be remedied as quickly as possible."

Exactly how this will be done is still a matter of conjecture. But whatever the ultimate forms of wind tunnels and their drives will be, there is one inescapable conclusion, as told by the following fable:

One day, as the wind tunnel and the airplane were strolling down the bright superhighway of the future, they came to a fork in the road. "Whither away?" asked the wind tunnel, with half a smile. "Follow me!," said the airplane, eager to forge ahead. "No, indeed," was the reply, "you follow me." And the aiplane followed.

From a control desk such as this conditions in a wind tunnel are accurately regulated and measured.

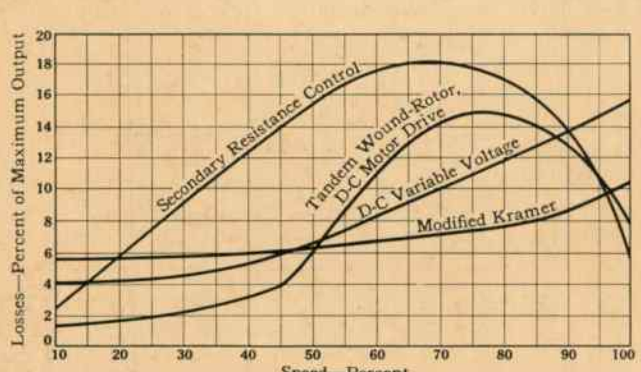


Fig. 7—Comparing losses of different drives gives the simple wound-rotor motor the edge at top speed.

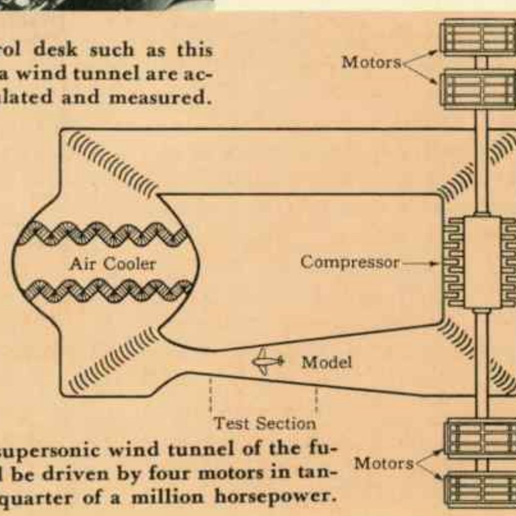


Fig. 8—The supersonic wind tunnel of the future may well be driven by four motors in tandem, each a quarter of a million horsepower.

What's New!

More Light for Welders

An expert arc welder must have a well-developed sixth sense of space. He locates the spot on the work to be welded and brings his welding electrode close to, but not quite touching, that spot. Then he lowers his protective hood. Through the purple-glass window he can see nothing, since it is designed to protect him from the powerful light of the arc. He must then strike his arc by moving the electrode the rest of the distance, using his sense of space and direction.

Expert welders become quite skilled at starting the arc at the precisely intended spot, but it takes practice. Furthermore, there is always the chance of mistake with the resulting ruined work.

Now a high-intensity spotlight has been developed, bright enough for the welder to recognize all details of his work clearly in the critical moment before the arc is struck. When set three feet away, it casts a circle of light about five inches in diameter, so brilliant that the operator is no longer blind. Two of these lights, when used together, provide an intensity of 5000 foot-candles, or approximately 250 times the average general illumination in a modern welding shop.

The light source is a small, sealed-beam bulb rated at 28.5 watts when operated at six volts. Any convenient 115-volt, a-c outlet can supply several of these low-wattage units, which have built-in auxiliary transformers. Each complete unit consumes approximately 30 watts, resulting in a very low heat concentration with corresponding comfort for the welder.

The spotlight is made sturdy for rough handling yet can be set easily for the unusual angles and positions sometimes required in welding. Several can be mounted on the standard available with the spotlight, or can be clamped to a one-inch pipe if desired. The pivot joint provided in the clamping arrangement allows great flexibility for the many adjustments so often necessary in welding operations.

The light is switched on and off by a foot treadle, somewhat like that used with a dentist's drill. Both hands are thus left free for holding the electrode and moving the work. Furthermore, the light need be used only when necessary.

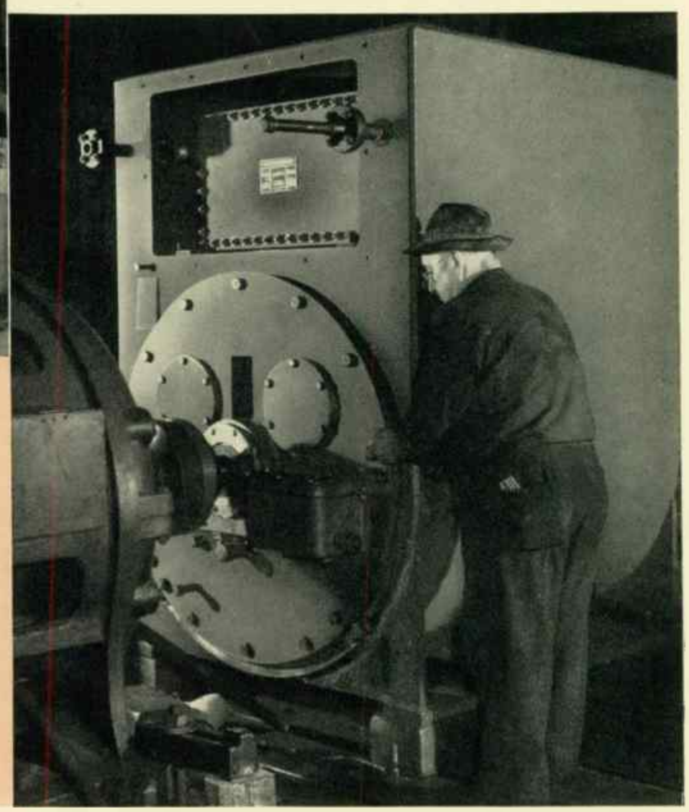
The industrial spotlight is especially adapted for repetitive welding, cutting, or brazing operations within the five-inch field of illumination provided by one light. If the weld is longer, as is sometimes found in production work, several spotlights can be arranged to provide a continuous beam of illumination sufficient for the particular weld. The spotlights can also be arranged to cover any variety of shapes.

War-Trained Gyros Become Automatic Pilots

From wartime activity with gyroscopic stabilizers for tank guns and airplane gun turrets comes a new automatic pilot for airplanes that is unaffected by any maneuver of the plane. An automatic pilot is a device that can be preset by the human pilot to fly the plane in any desired manner, until given a new set of instructions. It can cause the plane to climb or descend at a given rate, to fly at a fixed level, or to adhere to a prescribed course, relieving the pilot to attend the remaining multiplicity of functions that require close supervision.

The new device, the Gyropilot, employs three separate but coordinated gyroscopes, one for each principal axis of motion. These are rate gyros, so-called because they are responsive to change in angular velocity. Position gyros, customarily used in automatic pilots, are sensitive to change in absolute angular position. Held in gimbals that allow them freedom of motion in all directions, position gyros have a tendency to tumble or

At a three-foot distance the new welding spotlight has a beam five inches in diameter, sufficient for most welding, cutting, or brazing work.



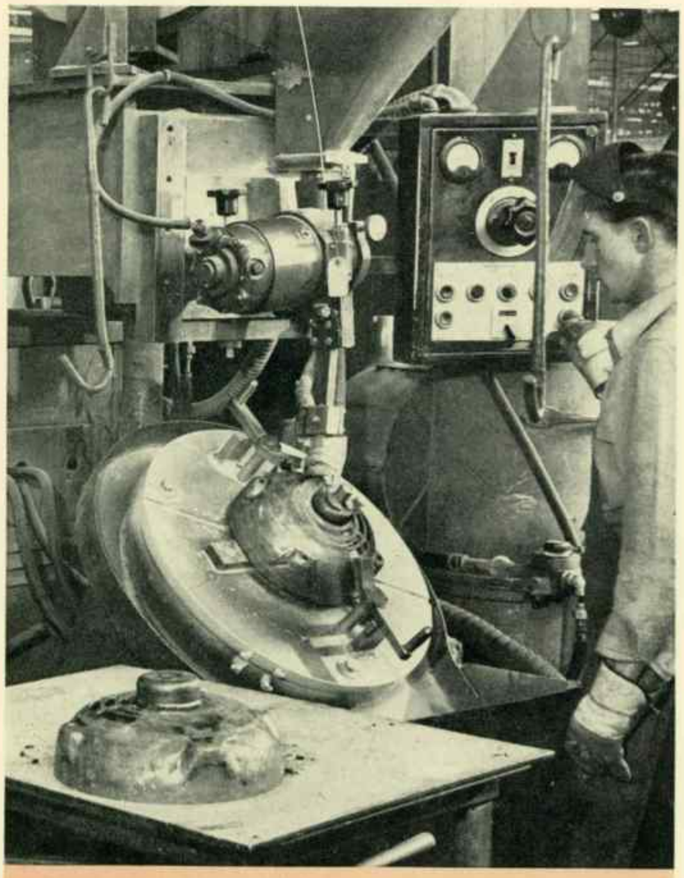
→ This motor on test is the first of a series of nitrogen-cooled, explosion-resisting units being built for a big chemical plant. They are squirrel-cage induction-type, rated 2250 hp at 1800 rpm. Rather than rely on the housing to resist an internal explosion (as is done with smaller motors) air and accompanying explosive gases are excluded from the windings, which are kept in an atmosphere of inert nitrogen. Thus an internal explosion is nigh impossible. The nitrogen, acting as a coolant, is circulated through the windings and then through a water cooler mounted on top of the motor proper. To prevent air from leaking into the windings, nitrogen pressure is maintained slightly above atmospheric. A separate motor-driven oil pump maintains shaft seals when the motor is either running or shut down to prevent excessive leakage.

lose control when forced more than about 60 degrees out of position. But rate gyros are fixed to the plane and allow it to loop the loop and barrel roll, if desired, without loss of control—very necessary for pursuit ships. Furthermore, unlike the position type, the Gyropilot is not adversely affected by high acceleration rates, which suggests its possible use on guided missiles and pilotless aircraft, in addition to the obvious application to both commercial and military airplanes. Other features new with the Gyropilot are a great increase in simplicity, an inbuilt or direct means of providing banking control, and a reduction in power requirements. Because the Gyropilot (which is still in the experimental stage) is small and as light as any type, and much lighter than most, it is expected to be applicable to light, commercial, and private planes as well as military craft.

Automatic Arc Welding in a Single Package

Available for the first time are the benefits of a new family of complete, coordinated, automatic arc-welding equipment containing everything from transformer to flux hopper. In any automatic arc-welding process, the pieces to be welded are held in a suitable fixture or positioner and the arc made to move along the joint either by rotating the work under the arc or by moving the arc. Welding current, arc voltage, and travel speed are preset at the desired values and welding wire and powdered flux (when required) are automatically fed to the work. The entire process is automatically controlled and, once started, requires little supervision, even shutting itself off when the weld is completed.

The Weldomatic unit, as the complete equipment is designated, is especially adapted for circular or straight seams, but can be employed on seams of more complex patterns. It is used with two common automatic welding processes. The first, open-arc welding, employs either flux-coated or bare electrodes and is similar in principal to manual arc welding, except that the deposit of metal is automatically controlled; it is most commonly used for mild steels. The second, the submerged-melt process, employs bare electrodes and a powdered flux sprinkled over the welding arc. The bulk of automatic welding is accomplished by this method, which is advantageous for mild and low alloy steels and some corrosion-resisting steels.



The Weldomatic equipment is set up for submerged-melt welding. Electrode from the wire reel is fed by the welding head to the work where the arc is submerged by a stream of flux powder from the hopper. The nozzle through which the electrode moves, carries the welding current.

Weldomatic equipment is applicable to either a-c or d-c welding. In general, alternating current predominates because of its high efficiency, low maintenance, and absence of arc blow. Direct-current welding is seldom used above 600 to 800 amperes although a-c welding is used with currents up to 2000 amperes.

Most applications with the submerged-melt process employ a-c welding. For these, the equipment consists of a welding transformer, welding head and control equipment, operator's panel, work positioner, wire reel and welding wire, flux hopper, and flux-recovery unit. The welding transformer used depends on the welding current required and can be furnished with ratings of 200, 300, 400, 500, 600, 750, 1000, 1500, and 2000 amperes. Ratings up to 600 amperes operate at open-circuit voltages of only 65 volts while the larger rating transformers have open-circuit voltages of 80 to 85 volts. Their high efficiency of about 90 percent at rated current is excellent even for transformer-type welders. Welding current is controlled by a movable iron core mounted inside a series reactor. This core bypasses a different amount of flux depending on its position and consequently changes the circuit reactance. Thus the current is changed without moving any current-carrying parts and adjustments, even under load, are made with ease and accuracy. The adjusting handle is mounted on the top of the welder and can be operated either by hand or, for remote control, by motor. The uniformly calibrated current-indicating dial makes for easier and more accurate adjustment. The transformer and reactor cores on the 200- to 600-ampere sizes are made of grain-oriented steel, Hipersil, which makes possible small, light-weight units—only 440 pounds for the 400-ampere unit.

The function of the motor-driven welding head is to strike the arc when the welding process is started and to maintain proper arc length by continuously and accurately feeding the right amount of welding wire as the head progresses along the seam. This is done by the automatic control which adjusts the speed of the welding head motor so as to maintain a constant preset arc voltage. The welding head will handle currents up to 1200 amperes (2000 with special nozzles). Electrodes up to ¼-inch diameter can be fed through the head at rates up to 75 inches per minute. The arc voltage and work motion are controlled from a compact operator's panel. Provided on the panel are an ammeter and a voltmeter to indicate welding conditions and an inching switch to feed the welding wire up and down without welding current; this feature is useful for setting up the work. Current for control purposes is obtained from a motor-generator set with a constant-voltage and a variable-voltage d-c generator overhung on opposite ends of a double-end-shaft induction motor.

Motorized work-positioning equipment is available in many types of standard, semi-standard, and custom designs for almost any application. Rotating positioners for example can be supplied in load capacities from 500 to 2500 pounds. These can rotate the work 360 degrees at any welding speed and can tilt at any angle from horizontal to 45 degrees past the vertical.

The wire reel can hold 150 pounds of welding wire, the length of which depends on its diameter (for example, about 3500 feet of ⅛-inch size). Thus, the reel eliminates the use of straightened or cut lengths of electrodes and saves the unnecessary waste of stub ends. The flux hopper for the submerged-melt process has a capacity of 25 pounds. Arrangements can be made so that the flux is automatically fed to the work and reclaimed by suction after welding and returned for re-use. The resulting deposit obtained with an automatic arc-welding process is generally smoother and more consistent than with manual welding.

PERSONALITY PROFILES

C. E. Valentine very early in his career became fascinated by little devices whose job is to control big ones. His undergraduate career in physics and electricity was interrupted by World War I. Returning from France as a member of the Signal Corps he went to work for Boston Elevated Co., where the idea of automatic controls for railway substations caught his fancy. After two years in night school at Lowell Institute, M. I. T., he looked around for a place where he might pursue his interest. This turned out to be Westinghouse, which he joined in 1923. One of his first jobs was to help with the controls for the famous mechanical man, Televox. Valentine remained with the automatic substation equipment section until 1928 when he was placed in charge of the development of switchboard devices.

In 1935 when the responsibility for development, design, application, and manufacture of voltage regulators was coordinated in one group he became its manager. Under his direction many developments in voltage regulators have been fashioned. Among these is the Silverstat, and more recently the Rototrol as it is applied to excitation control. The first use was on shipboard. Special credit goes to Valentine during the war for an enormous amount of work under the greatest of pressure for the development of shock-proof regulators for Naval vessels.

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As Associate Director of Westinghouse Research Laboratories since 1943, *Dr. John A. Hutcheson* knows intimately the problems of atomic power plants, for a frequent stop in his travels is Oak Ridge, Tenn., where a dozen or so of his men are "on loan" studying these same problems. And as chief adviser to Westinghouse on its atomic-energy plans, he is familiar with the project on a nationwide scale.

This isn't the first time, though, that Dr. Hutcheson has been associated with a new industry in the growing-pain stage. When he joined Westinghouse in 1926 as a student engineer, the radio industry was a struggling but ambitious youngster with lots of unknowns. During the next eight years he designed a succession of radio, telephone, and broadcasting transmitters for the Navy and for commercial stations.

It's a long step, he admits, from his first "job" in radio. "I was only eight years old when a neighbor, a crystal-set fan, appointed me his assistant to shinny up trees or poles whenever there were aerials to fasten." By the time he was twelve, young Hutcheson was building his own crystal sets. The hobby paid his way through the University of North Dakota, where he repaired and built sets.

When he was made manager of the Radio Engineering Department in 1940, Dr. Hutcheson found himself with another baby industry—radar. With the urgency of war, however, maturity came quicker here. Under his supervision, some 110 engineers and 50 draftsmen were responsible for all of the radio communication and 50 designs of radar apparatus built by Westinghouse during the war.

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Few machines appear any more unrelated than transformers and electric torpedoes. One has almost no moving parts and a life of many years; the other has scores of fast operating mechanisms and a life of a few minutes. Yet *Frank Snyder*, who before the war had spent about 17 years in all sorts of transformer design, wears an inconspicuous gold button that is an award by the Navy for unusual civilian war service. Snyder was in charge of design and production of one of the most secret and successful of weapons, the electric torpedo, which is a tribute to his versatility and thorough understanding of engineering fundamentals.

Snyder was exposed to the theories of electrical engineering at Gettysburg College, class of '23, and then piled on top of that a year's special work in engineering and mathematics at Columbia. He put those principles to good use in transformer engineering, mounting the rungs of the ladder with marked regularity: he became a designer of large power transformers in 1925; two years later he switched to power-transformer auxiliaries such as tap changers, and special forms of transformers like CSP power transformers and power centers. In 1930 he was made head of the tap changer section; in 1940, he was made manager of the instrument and regulator group. In 1942 his services were needed to head up the extremely difficult electric-torpedo activities. The war over, he was in 1945 made assistant engineering manager, followed a year later by the managership.

It has been five crowded years for *Walter N. Lundahl*. The Navy was waiting for him when he graduated from University of Minnesota in 1943 (with a B.E.E.). He had time only to get married before training as a Diesel engineer. This was followed in rapid succession by: a period as a Navy instructor; sea duty aboard a patrol craft; discharge from the Navy at end of 1945; a short period of student training at Westinghouse; assignment to Westinghouse Research Laboratories where his first work was to help develop the x-ray thickness gauge which he followed first into design and production, and now into actual installation in a Pittsburgh mill.

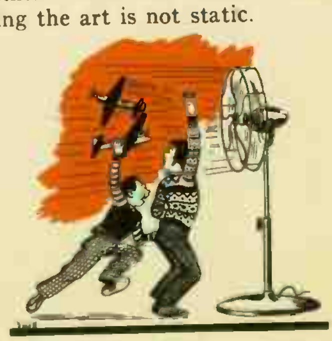
• • •

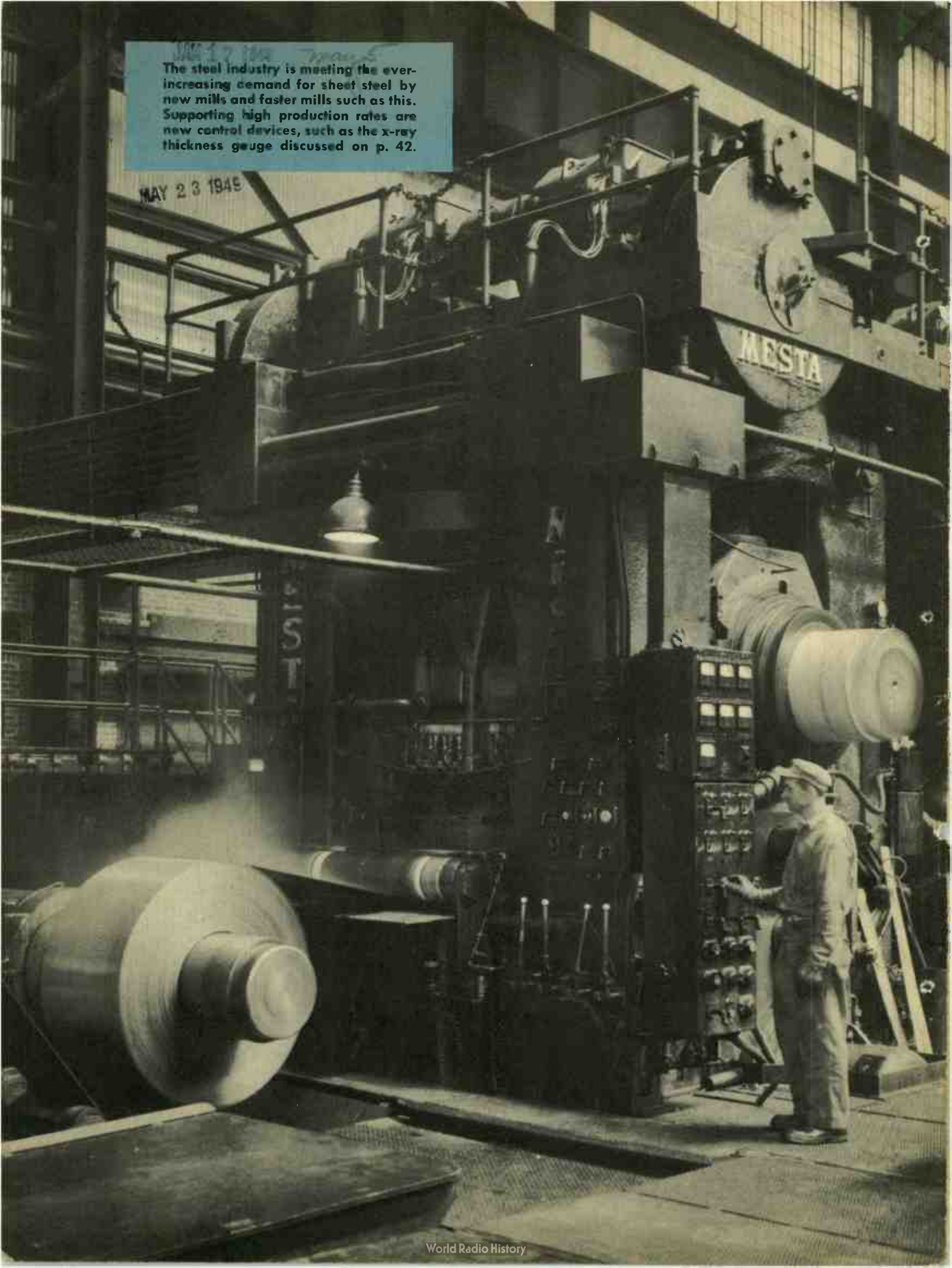
Four of our nine authors have been with us before. One, *T. J. Putz*, is stalking through these pages with marked regularity; in fact this is his fifth time in less than two years. Which is accounted for, in part, by the fact that he is with a phase of engineering now making history—gas turbines and turbine locomotives. Putz came to Westinghouse in 1938 after his graduation from the mechanical engineering department of the University of Illinois. His time since has been spent in turbine work.

One of the most widely read of our articles was that on wind-tunnel drives printed in the third issue, Nov., 1941. *L. A. Kilgore* was one of its authors. Kilgore is back, bringing this important subject up to date. He has continued, these intervening years, supervising the design of the Company's king-size motors and ignitron rectifiers.

Kilgore's collaborator this time, *S. L. Lindbeck*, is a graduate of University of California, B. S. in E. E., 1941 and more recently of the University of Pittsburgh, M. S. in 1944. His work mostly concerns the applications of electrical equipment to marine and aviation service.

Last July, *C. Lynn* summarized the developments in excitation systems for a-c generators. He now tells of the next development—Rototrol main exciters—proving the art is not static.





The steel industry is meeting the ever-increasing demand for sheet steel by new mills and faster mills such as this. Supporting high production rates are new control devices, such as the x-ray thickness gauge discussed on p. 42.