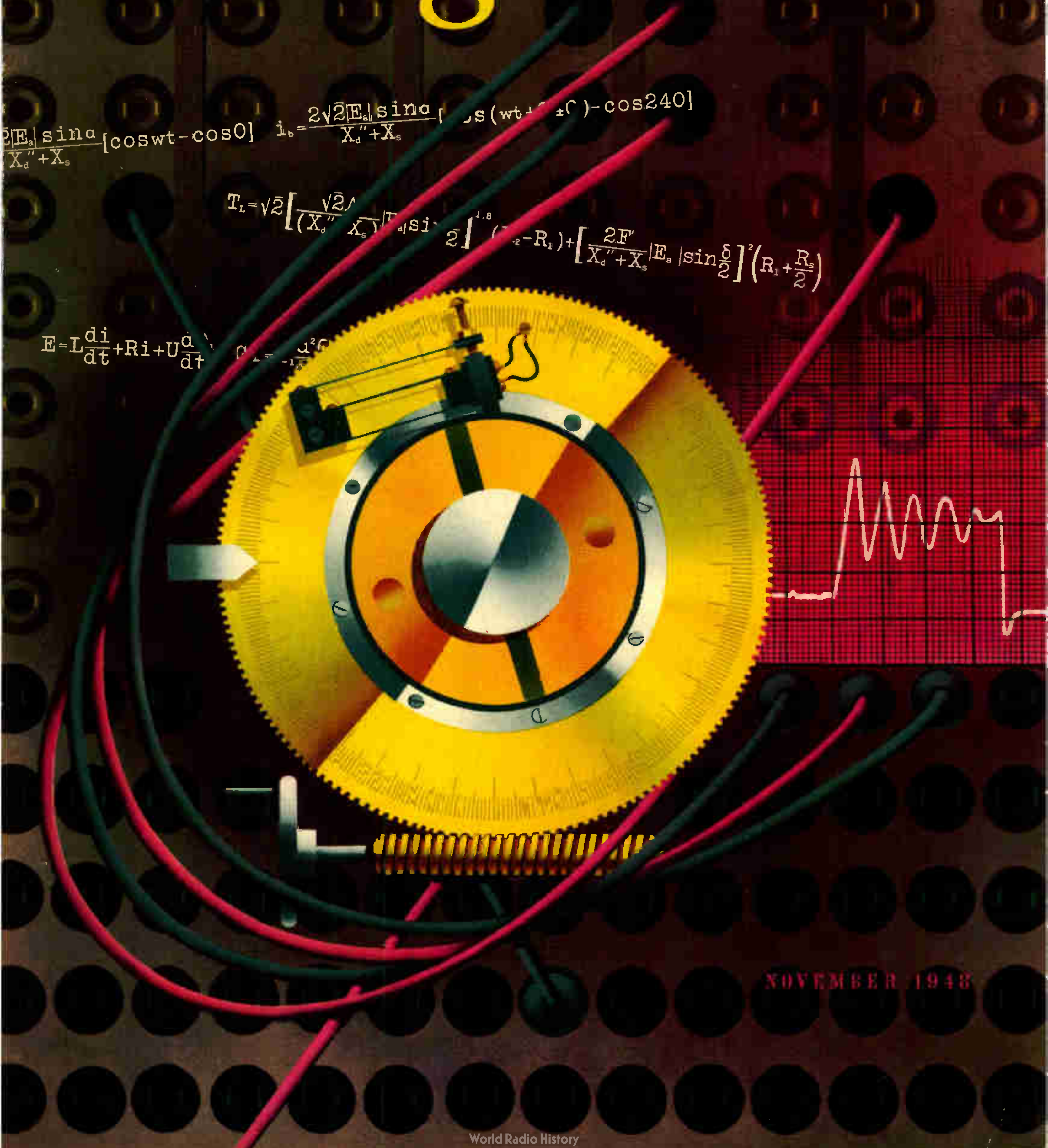
WESTINGHOUSE

Engineer



NOVEMBER 1948

The Electric Locomotive—
Aristocrat of the Rails

Railroad electrifications have not progressed as many have expected. Time was when electric locomotives were envisioned as virtually replacing the old iron horse. The fact is, complete electrification of the nation's railroads never was justified. It still isn't. Nor is it likely to be in the near future.

This, however, does not mean that the electric locomotive is without a major place in railroad society. Or that its importance is declining. On the contrary, the soundness of the electric locomotive is more apparent than ever. The meteoric rise of the diesel-electric does not eclipse or outmode the older electric type. Furthermore, long-term trends, now coming into sharper focus, are advantageous to electrification.

Electrification has everything in its favor—except first cost. As to the ability of the electric locomotive to haul trains, its maintenance, availability for service, quietness, cleanliness, fuel economy, it far outstrips all other locomotive forms. But the system costs more. Furthermore, a railroad electrification must be financed and built all at one time before a wheel is turned by electricity. The venture, a blue-chip operation, cannot be begun with the purchase of a few locomotives.

However, fuel charges, already a major consideration to railroad managements, promise to carry increasing weight in the future. Costs of both solid and liquid fuel will rise inevitably. Also, the stores of natural liquid fuels are declining. Their eventual disappearance may not interrupt the swing to liquid-fuel motive power, but the cost of man-made liquid fuels is likely to increase the advantage of locomotives operating on electric power, which is more efficiently produced in coal-burning central stations. Also, the increasing availability of low-cost publicly financed hydroelectric power will tend to reduce the overall economic disadvantage of electrification.

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In a half century electric locomotives have evolved into two major, well-defined forms—high-voltage, direct-current, and single-phase, alternating-current, although there are variants of each. The d-c locomotive came first, just as direct current itself antedated alternating current. The first electric locomotives in service on main-line railroads were those built by General Electric to haul trains of the Baltimore and Ohio Railroad through its Baltimore tunnels beginning in 1895, although the first actual electrification of a railroad had been accomplished some months earlier over a nine-mile line between Nantasket Junction and Pemberton, Massachusetts, now a part of the New York, New Haven, and Hartford system. Operation here was not with locomotives as we now think of them but with electrically powered cars, equipped by Westinghouse, each of which hauled several coaches. Even before these dates a d-c electric, trolley-supplied locomotive had been in service at the East Pittsburgh Works and exhibited at the Chicago World's Fair in 1893.

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The interest of Mr. Westinghouse in railroad electrification came naturally. He had already developed the air brake and had become interested in signaling. Almost as soon as he was convinced that the hope of electric power lay with alternating current, he envisioned its extensive application to railroad service. He began an aggressive program to develop an a-c railroad-electrification system. Out of this came the single-phase a-c commutator motor that, in improved form, is still the generally accepted motor for modern a-c electrification systems. Several successful small single-phase motors for transit service were built about the turn of the century. Alternating-current electrification of a main-line railroad made its debut in 1906 on the New Haven lines extending out of New York City. This was followed, in 1908, by the single-phase electrification of the Grand Trunk's St. Clair Tunnel under the Detroit River. In 1911 the Hoosac Tunnel of the Boston and Maine was similarly electrified.

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Most of the earliest electrifications were made to solve smoke and traffic-congestion problems arising out of operation through tunnels. Soon, however, electric operation, because of numerous advantages, was adopted for more general railroad service. After the electrification of the New York, New Haven, and Hartford there came that of the Norfolk and Western, the Virginian, and other single-phase electrifications culminating with the New York to Washington and Philadelphia to Harrisburg electrification of the Pennsylvania Railroad during the middle 30's. All of these were 11 000-volt, single-phase systems, although three phase was employed as the original Great Northern electrification. The motor-generator type of locomotive, such as used later on the Great Northern, combines the advantages of single-phase power supply and d-c operation of the locomotive itself.

All a-c systems have used 25 cycles, the frequency being established at the time of the Niagara Falls development when it appeared that this frequency would have widespread industrial usage. From the railroad-electrification engineer's point of view, the adoption of a lower frequency for railroad use would have been preferable. The outstanding example of the high-voltage d-c system is the 3000-volt installation of the Chicago and St. Paul Railroad.

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Electric locomotives have become more and more powerful. Single cabs capable of developing 5000 rail-horsepower continuously are in service on the Pennsylvania system. Engineers have made the basic studies and are prepared to build even larger locomotives. For example, a 7500 rail horsepower locomotive has been brought to the blueprint stage. However, in general, the trend seems to be away from such large amounts of power in single cabs. It is more likely that we will see multiple-cab locomotives, each of moderate power. For example, a three-cab locomotive of 8400 hp total is being actively considered. Each cab could be operated independently to provide about 2800 hp evenly distributed over six axles. Such a locomotive would permit small axle-hung motors, eliminating the drive to the wheels through quills, and would provide desirable flexibility, in that the motive power unit could be well suited to the particular operation by using one, two, or three cabs. The shorter wheelbase of a multiple-cab unit is also desirable as it enables operation around sharper curves.

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Electric-locomotive engineers are looking to the future and confidently expecting many developments, such as in insulation, smaller motors, and simpler controls. Standardization of types and equipments is doing much to minimize the costs of electrifying railroads.

WESTINGHOUSE Engineer

VOLUME EIGHT NOVEMBER, 1948 NUMBER SIX

On the Side

The Cover—The analog computer, artistically symbolized by Dick Marsh, creates an electrical analogy to solve mechanical, thermal, and other problems. The worm and wheel are part of the rotating synchronous switch of the Westinghouse Anacom.

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Words new to our vocabulary—meson, neutrino, Geiger counter, betatron, etc.—are found on the lips of men, women, and children, indicative of the interest of the layman as well as the scientist in atomic energy. To help answer the questions of the man on the street, the Westinghouse Research Laboratories have created a "Theater of Atoms." It demonstrates chain reaction, atomic fission, and the operation of atom smashers by means of Christmas-tree balls, jet-propelled rockets, balloons, and mousetraps, and in terms understandable by the average man. The Theater will tour the country.

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When the 110 000-kva, 3-phase transformer for Buffalo Niagara Electric Corporation was completed last spring it became King of the transformers by virtue of having the highest rating. But its throne is already shaky, for now in construction is a 145 000-kva, 3-phase unit for Detroit Edison Company. It will be forced-oil and water cooled. Its coolers will be unusual in that they will be mounted separately in a room below the tank to avoid the hazard of the water freezing.

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The contents of the *Westinghouse* ENGINEER are now being classified in the Industrial Arts Index, which is available in most public libraries. Articles are classified according to subject along with articles appearing in other publications.

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Controlled-Atmosphere Electric Furnaces—
Their Present State and Application

Like a prize cake, a precision alloy depends as much on how it is "baked" as what is in it. To keep pace with the growing demands of the heat treater furnace, engineers are adding refinements to the several different types of electric furnaces and the four basic kinds of oxygen-free atmospheres that can be used with them.

C. E. Peck, *Industrial Heating Division, Westinghouse Electric Corporation, Meadville, Pa.*

Heat treatment of metals used to be a hit-or-miss proposition—now it is a highly developed, precise, and accurate process. Old methods of "curing" had no accurate means of controlling temperatures, so the exact state of the end product depended upon the experience and judgment of the processor. Even the best results left much to be desired. The surface of the metal was often scaly or discolored due to oxidation, and its carbon content entirely different from the starting conditions. Shiny, smooth surfaces were practically impossible to obtain without machining or grinding.

Controlled-atmosphere electric furnaces have been a big factor in bringing heat-treating techniques to their present high level of development. Temperature is made uniform and easily controlled to close limits, and oxygen is barred from the metal surface by the use of various types of atmospheres in the air-tight furnace chamber. With oxygen absent a metal can be heat treated to the desired metallurgical condition and yet have a smooth, shiny surface. Furthermore, the carbon content of the surface can be precisely controlled, even increased, by use of atmospheres.

Electric furnaces for heat treating are not new; their commercial use dates back some 25 years. Similarly the reactions of metals in the presence of heat and various gases have long been known. However the combination of these factors into a single heat-treating process is a development that was greatly accelerated and improved upon just prior to and during the recent world war.

Heat treatment can be used to change the structure and characteristics of a given metal in many ways. Annealing, which relieves strains and renders a softer and more ductile metal, is one of the more common processes. Others in wide use and applicable to electric furnaces are: hardening, in which the metal is heated and then quenched in oil, water, or salt to give the required hardness; brazing, in which two metal objects are joined by using another metal as an adhesive and filler; sintering, which consists of compressing powdered metal into a desired shape and then heat treating to "cement" the particles more closely together; and carburizing, which is

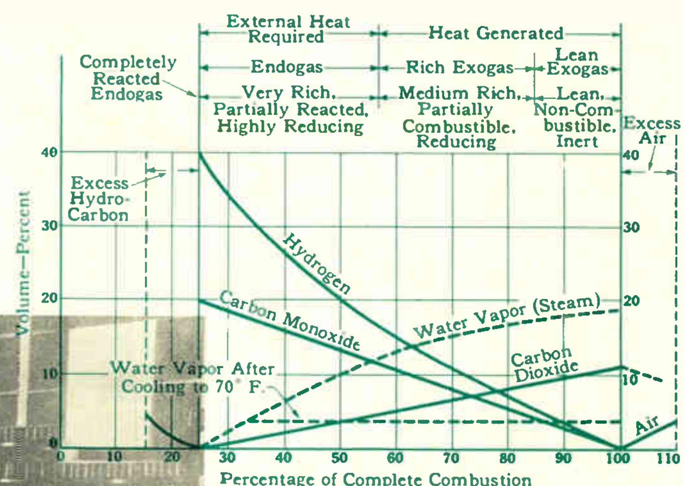


Fig. 1—For each composition nitrogen constitutes the remainder of the gas.

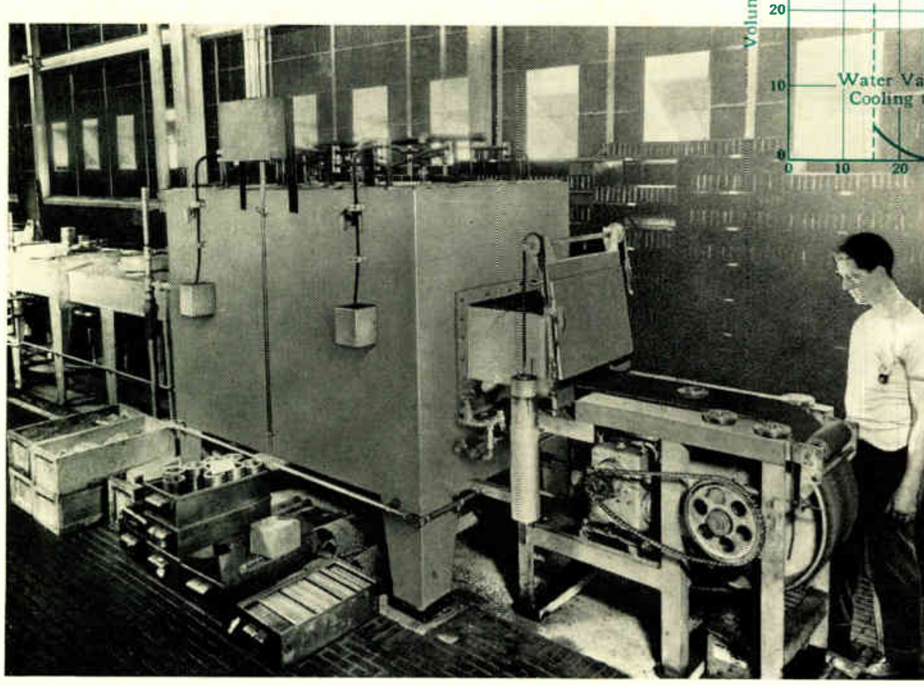


Fig. 2—A mesh-belt conveyor-type furnace suitable for brazing or sintering.

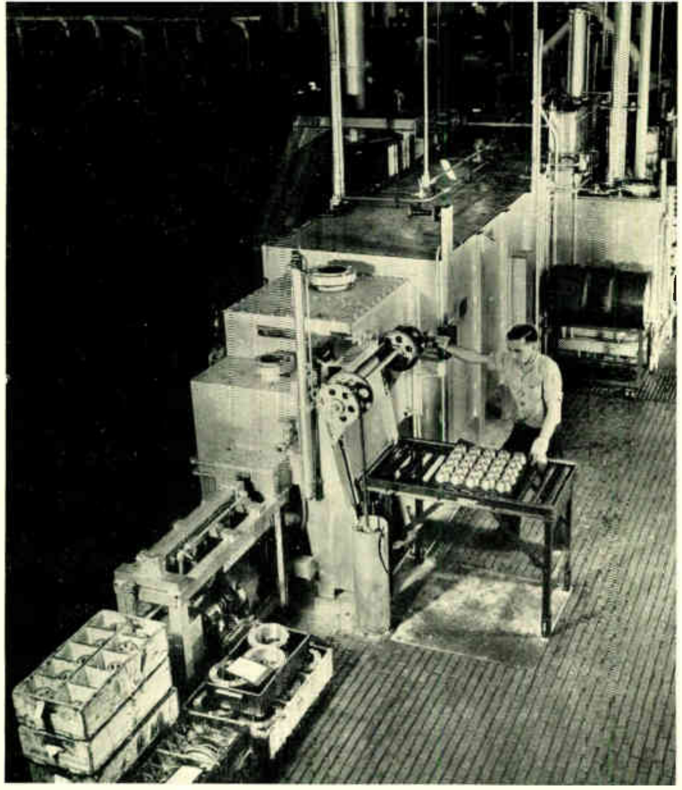


Fig. 3—The tray pusher-type hardening furnace.

simply the process of adding or removing carbon from the surface of a metal.

Four general types of atmospheres are commonly used in these processes, the exact choice depending upon the kind of reaction desired and economic aspects. These are Endogas (reacted fuel gas), Exogas (combusted fuel gas), Monogas (Exogas with CO_2 and water vapor removed), and Ammogas (cracked anhydrous ammonia).

The Atmospheres

One of the commonly used atmospheres is Endogas, which is made by applying external heat to a mixture of commercial fuel gas and a small amount of air. The resulting reaction (an endothermic process) produces a gas rich in hydrogen and carbon monoxide and free of oxygen. Endogas is particularly useful in bright hardening and in such processes as adding carbon to the surface of steel (carburizing). Under conditions of high temperature the atmosphere can be adjusted to be in approximate chemical equilibrium with the given carbon content of the steel. By close control the exact thickness of the carbon surface can be regulated, or a given initial carbon content can be maintained without gain or loss.

As fuel gas is combusted beyond the endothermic range, the process becomes exothermic, giving off heat. The gas produced under these circumstances is Exogas, which is low in hydrogen and carbon monoxide content and high in carbon dioxide and water vapor. If the carbon dioxide and water vapor are removed from Exogas, the result is Monogas, which is used principally for bright annealing high-carbon and alloy steels.

Obviously the amount of oxygen mixed with the fuel gas and the degree of combustion determine the exact chemical composition of the atmosphere obtained. The approximate combustion ranges of the various fuel-gas atmospheres are shown in Fig. 1.

Ammogas is the only common atmosphere not obtained from commercial fuel gas; it is made by cracking anhydrous ammonia, performed by subjecting commercial ammonia to heat. High in hydrogen content (and thus very suitable for "capturing" oxygen impurities), it is particularly valuable in such reactions as the bright annealing of stainless steel and sintering of various metals.

The particular range or type of atmosphere used depends upon a number of factors, including the kind of metal being heat treated, the process used (annealing, hardening, etc.) and the exact surface desired in the finished product. Economic considerations also enter into the choice of a gas for a particular process, since the choice of a particular atmosphere generator depends upon the size and scope of the operation. In many instances the atmospheres can be used interchangeably without undesirable effect on the end result of the metal processing. In these cases the choice becomes purely economic.

The Furnaces

Electric furnaces are available in a wide range of sizes and shapes, suitable for many different applications. Essentially the heating chambers are of the same construction, electric coils strategically placed in a brick-lined metal-clad furnace. Here the similarity between models stops. The production rate desired, size and shape of the article to be treated, and economics determine the final form of the furnace.

Fast-moving production lines use the continuous type of furnace, of which there are three general forms: the continuous conveyor, the continuous pusher, and the continuous roller hearth. The conveyor type (Fig. 2) has a mesh belt, running through the entire furnace length, on which articles to be heat treated are placed. They are then automatically passed through the furnace according to a definite time sequence. The use of a metal belt naturally limits the operating tem-

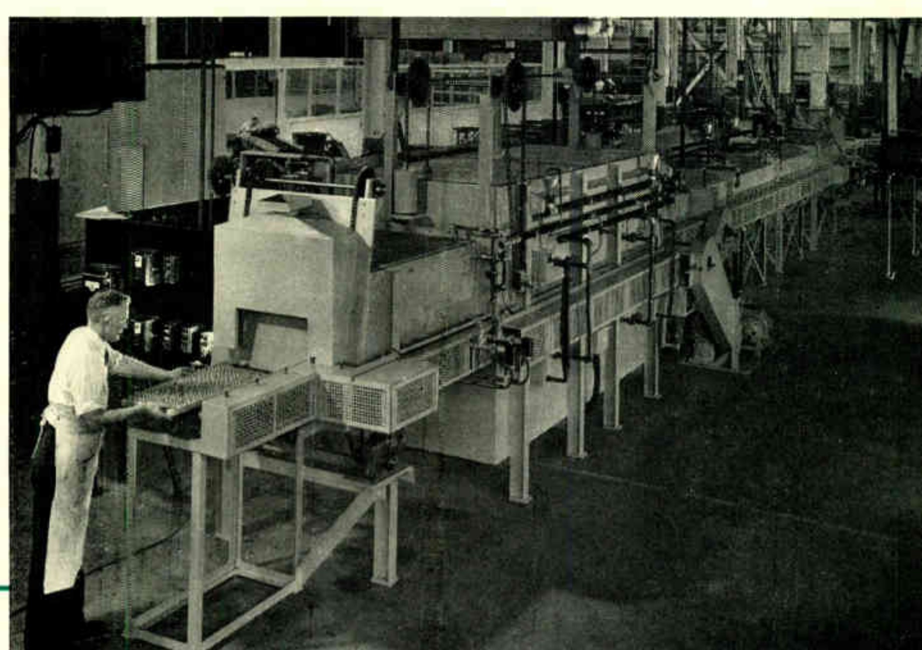


Fig. 4—A roller-hearth furnace used for brazing or sintering operations.

TABLE I—COMPOSITION AND COST OF TYPICAL CONTROLLED FURNACE ATMOSPHERES

Atmosphere	Description	Air to Gas Ratio	N_2*	H_2	CO	CO_2	CH_4	O_2	Dew Point Degrees F	Gas for M Cubic Feet Atmosphere	Cost Per Atmosphere	Nature of Atmosphere
Endogas	Completely reacted fuel (Auxiliary heat needed)	2.75:1(a)	41.7	38.0	19.0	0.0	1.3	0.0	10	200 (c)	\$0.12 to 0.25 (e)	Combustible; Toxic; Most reducing
Lean Exogas	Completely burned fuel	10:1(a)	89.0	0.5	0.5	10.0	0.0	0.0	(b)	115 (c)	0.08 (d)	Noncombustible; Slightly reducing
Rich Exogas	Partially cracked fuel (self propelled)	6:1(a)	69.0	15.0	10.0	5.0	1.0	0.0	(b)	145 (c)	0.10 (d)	Combustible; toxic Medium reducing
Lean Monogas	Lean Exogas scrubbed of CO_2 and H_2O	10:1(a)	94.0	3.0	3.0	0.0	0.0	0.0	−50	125 (c)	0.14 to 0.40 (e)	Noncombustible; Inert
Rich Monogas	Rich Exogas scrubbed of CO_2 and H_2O	6:1(a)	72.0	16.0	11.0	0.0	1.0	0.0	−50	150 (c)	0.16 0.42 (e)	Combustible; toxic Reducing
Ammogas	Dissociated ammonia	No air	25.0	75.0	0.0	0.0	0.0	0.0	−60	22.2 pounds NH_3	1.20 4.00 (f)	Combustible; Reducing
Lean Ammogas	Ammogas completely burned	1.88:1(g)	99.0	1.0	0.0	0.0	0.0	0.0	(b)	13.35 pounds NH_3	.80 to 2.40 (f)	Noncombustible; Inert
Rich Ammogas	Ammogas partially burned	1.25:1(g)	80.0	20.0	0.0	0.0	0.0	0.0	(b)	15.0 pounds NH_3	.95 to 2.60 (f)	Combustible; Slightly reducing

(a) Air-to-gas ratios are representative for natural gas containing practically nothing but methane. For high hydrogen city gas, ratios are about 50 percent of values given; for city gas with medium hydrogen and high CO ratios are about 40 percent of values given. For propane, ratios are approximately twice the values given in the table and for butane about three times.
(b) Dew points correspond to room temperatures unless auxiliary drying equipment is added. Dew point may be reduced to 40 degrees F by simple refrigeration equipment; to minus 50 degrees F or less by use of absorbent towers.
(c) Values are in cubic feet for high methane natural gas. For various types of manufactured city gas, double the values given. For propane, requirements are half of values given, and for butane, one third of these values.
(d) Costs figured on raw natural gas at 50 cents per M cubic feet, electricity at 1 cent per kwhr, water at 5 cents per M gallons. Use of city gas usually doubles the cost figures given.
(e) Low value when reactivating moisture absorbent with steam; high value when using electrical heat steam at 30 cents per 1000 pounds.
(f) Costs based on 3.5 cents per pound NH_3 in tank car lots, and 16 cents per pound for cylinder quantities. Electricity for dissociation at 1 cent per kwhr.
(g) Dissociated ammonia.
(*) All gas compositions are given in percent values.

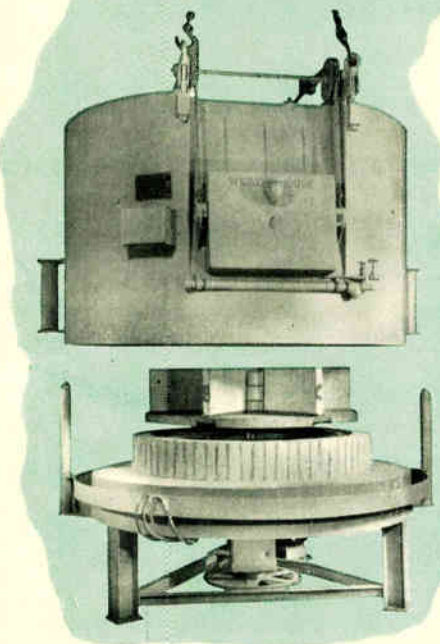


Fig. 5—The rotary-hearth electric furnace, with hood lifted, showing the pie-shaped compartment units.

perature of the furnace, as well as the size of article which can be accommodated.

If parts are too heavy to be placed on a belt, either the pusher or the roller-hearth furnace can be used (Figs. 3 and 4). A hydraulic cylinder pushes a tray loaded with parts through the pusher furnace; in the roller-hearth type heavy articles are passed through the chamber on rollers.

Where high rates of production are unnecessary or undesirable, either the box-type or rotary-hearth furnace is used. The box furnace, the simplest type of all, consists of a heating chamber into which articles are placed and removed manually. The rotary hearth shown in Fig. 5 has pie-shaped compartments into which articles are placed manually. These compartments rotate, allowing each compartment to be loaded and unloaded at definite time intervals.

The shaker-hearth furnace is particularly adaptable to small odd-shaped articles. It is loaded by placing the items to be treated on a metal plate; a shaking motion is then imparted to the plate, which acts to propel the articles through the furnace, and also continually agitates them so that all sides are uniformly treated.

The bell-type furnace (Fig. 6) is especially suitable for accommodating coiled strip metal or wire. The heating elements are arranged in an outside shell. An inner shell, which serves to contain the atmosphere, is placed over the coiled metal; the outer hood is then lowered over the inner shell and strip. One advantage to this construction lies in the fact that the outer shell may be removed when the heating is finished, allowing the coiled metal to cool under the atmosphere-filled inner shell, thus completely eliminating any chance of oxidation. The heater element or "bell" can then be moved on to another stage and continue operation on other metals while the first group is cooling. Thus one heater can serve two or more furnace bases.

These general types of furnaces are adaptable to most any of the treating processes and may be equipped with any one of the atmosphere generators, the combination selected depending upon the heat-treating process utilized.

The Processes

The combination of electric furnace and controlled atmospheres makes possible several new techniques and improves upon older methods of heat treating.

Bright annealing differs from ordinary annealing in that it renders a clean and shiny surface on the finished product. Most types of annealing in the presence of air leave a discolored or stained surface due to oxidation. In some instances this is not a satisfactory feature from the standpoint of appearance or further finishing work.

Bright annealing of low-carbon steel has been accomplished in atmosphere furnaces, using rich Exogas, for quite some time. The bright annealing of high-carbon steels was difficult because of decarburization of the surface. Now it is possible to bright anneal high-carbon and alloy steels without oxidation or decarburization. This is accomplished at extremely high temperatures and for long cycles by the electric-bell-type furnace and a Monogas atmosphere. The controlled atmosphere in this application is essentially neutral so that the surface neither gains nor loses carbon.

High-carbon steel strip, wire, etc., can be bright annealed without loss of any of the high carbon content metallurgically necessary for high-quality products such as razor-blade stock and spring wire. A typical electric-bell furnace installation which can be used for this process is illustrated in Fig. 6. The Monogas atmosphere system to produce the necessary metallurgical atmosphere is shown in Fig. 8. In this case the basic Exogas atmosphere equipment is shown at the right-hand side of the equipment. Exogas becomes Monogas when it is purified by removal of CO_2 in the tower-like structure shown in the center and dried in the gas-atmosphere drying apparatus at the extreme left.

Bright hardening is a method of heat hardening in which the carbon content of the metal surface is closely controlled. A basic problem here is to harden an article while preventing the carbon content of the surface from changing. Here again, as in bright annealing, it is extremely important that no oxygen is allowed in the furnace, since oxidation of the surface would result in the formation of scale.

The development and application of reacted fuel-gas atmosphere (Endogas) makes it possible to harden intricate machine parts without oxidation or decarburization of surfaces. Close control of surface conditions, which eliminates scale and soft skin on the piece, makes finish machining, grinding, cleaning, sandblasting, or descaling unnecessary, with an attendant saving in both time and money. A typical Endogas atmosphere generator is shown in Fig. 7.

Atmosphere furnaces have been developed and improved for specific use with bright-hardening atmospheres. The box type is adaptable for pieces of a wide range of sizes and weights requiring individual quenching (in oil or water). In this case the pieces are moved through air from the time they leave the furnace atmosphere until they are quenched, and during the period of transfer a slight tarnish appears on the work being heat treated. In most applications this tarnish is not objectionable and is so slight that no further cleaning operations are required after heat treating.

The rotary-hearth furnace shown in Fig. 5 is also suitable for handling a wide variety of parts requiring individual quenching or machine quenching. Here again the work is transferred through air for quenching, and very slight tarnishing occurs on the metals.

Fig. 6—Three electric-bell furnaces show various stages of the heating operation. At the right, coils of strip metal are positioned, ready for treatment. In the center, the atmosphere-containing hood is in place and at the left, the heating-element shell has been lowered over the atmosphere hood and the coiled strip metal.

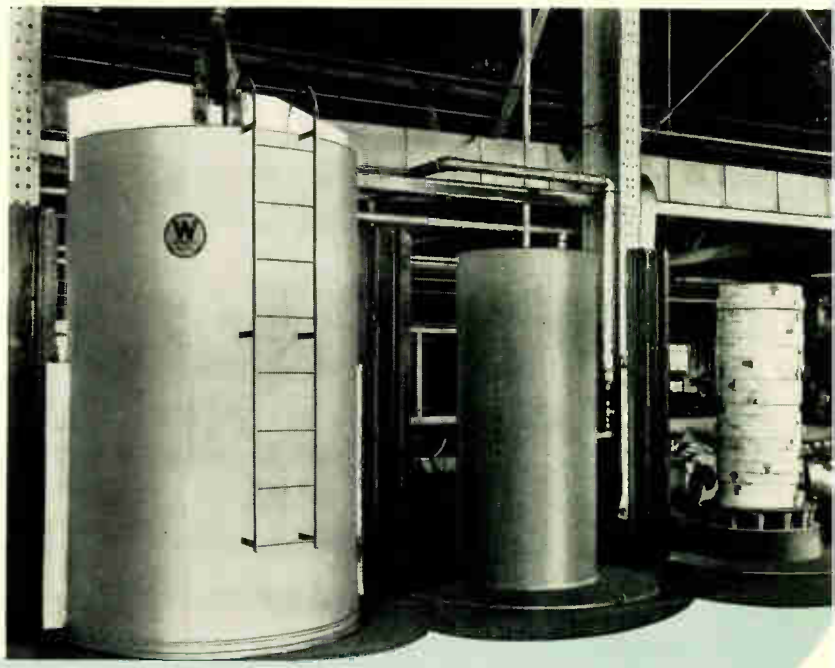


TABLE II—ATMOSPHERES SUITABLE FOR HEAT TREATMENT OF DIFFERENT METALS

Material Processed	Process	Temperature Range Degrees F	Cycle Time (Long if over 2 Hr.)	Required Surface	Atmospheres Commonly Used
		Bright or Clean Annealing			
Low-carbon steels	Anneal	1200 to 1350	Long	Bright	Exogas
Medium-carbon steels	Anneal (no decarburization)	1200 to 1450	Long	Bright	Monogas
High-carbon steels	Anneal (no decarburization)	1200 to 1450	Long	Bright	Monogas
Alloy steels, medium and high carbon	Anneal (no decarburization)	1300 to 1600	Long	Bright or Clean	Monogas
High-speed tool steels, including molybdenum high speeds	Anneal (no decarburization)	1400 to 1600	Long	Bright or Clean	Monogas
Stainless steels, chromium and nickel chromium	Anneal	1800 to 2100	Short and Long	Bright	Ammogas
High-silicon steel, electrical sheet	Anneal	1900 to 2100	Long	Clean	Monogas and Ammogas
Copper	Anneal	400 to 1200	Long or Short	Bright	Exogas
Various brasses	Anneal	800 to 1350	Long or Short	Clean	Exogas
Copper-nickel alloys	Anneal	800 to 1400	Long or Short	Bright	Monogas
Silicon-copper alloys	Anneal	1200 to 1400	Long or Short	Bright	Monogas
Nickel	Anneal	1600 to 2000	Long or Short	Bright	Exogas and Ammogas
		Automatic Brazing or Sintering Operations			
Low-carbon steels	Copper brazing	2050	Short	Bright	Exogas
Medium- and high-carbon steels	Copper brazing (no decarburization)	2050	Short	Bright	Endogas
Alloy steels, medium and high carbon	Copper brazing (no decarburization)	2050	Short	Bright	Endogas
High-carbon, high-chromium steels	Copper brazing	2050	Short	Bright	Ammogas
Stainless steels	Copper brazing	2050	Short	Bright	Ammogas
Copper or brass	Phos-copper brazing or silver soldering	1500 to 1600	Short	Bright	Exogas
		Bright Hardening and Tempering			
Medium-carbon steels	Hardening	1400 to 1600	Short	Bright or Clean	Endogas
High-carbon steels	Hardening	1400 to 1800	Short	Bright or Clean	Endogas
Alloy steels, medium and high carbon	Hardening	1400 to 1800	Short	Bright or Clean	Endogas
High-speed tool steels, including molybdenum	Hardening	1800 to 2400	Short	Bright or Clean	Endogas
All classes of ferrous metals	Tempering or drawing	400 to 1200	Short	Bright or Clean	Exogas

Complete elimination of tarnishing and automatic control of all operations are accomplished with the pusher hardening furnace (Fig. 3). The work to be treated is fed consecutively through an entrance purging chamber, the heating chamber, and the quenching chamber without human handling. The presence of the atmosphere in both the heating and quenching operations completely eliminates discoloration due to oxidation of the surface. The absence of the human element in the quenching process makes for less marking and nicking of parts. The entrance purging chamber (similar to an air lock) removes air from the parts and makes it possible to maintain a high purity of atmosphere in the furnace proper. Thus high quality, as well as high production, is maintained.

Where marking or nicking is not a critical problem in heat treating, the belt-conveyor hardening furnace is also a very useful production tool; with this equipment continuous heat treating and quenching are accomplished without exposure of the work to the air during any part of the heat-treating cycle.

These furnaces meet certain specific individual applications. The choice of types depends on the user's individual problem and the kind of work that he intends to handle in the furnace, together with the production rate required.

Gas carburizing is necessary where a metal surface is not of the correct carbon content. Adding carbon to the surface is known as carburization, removing carbon as decarburization. These processes are now closely controlled by using Endogas adjusted to the approximate carbon potential corresponding to the skin content desired in the finished product.

In those cases where finish machining or grinding operations are very light or where it is impractical to machine further due to complicated shape of the part, it is desirable to heat treat

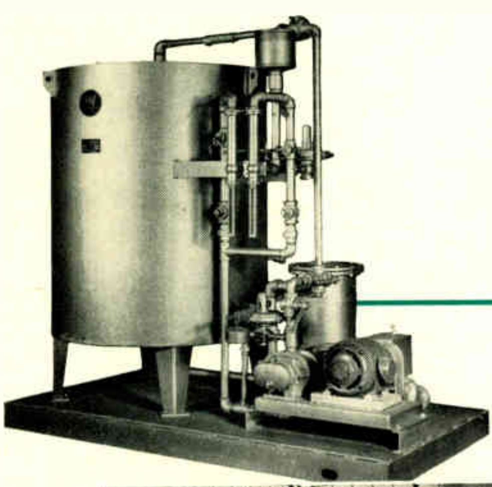
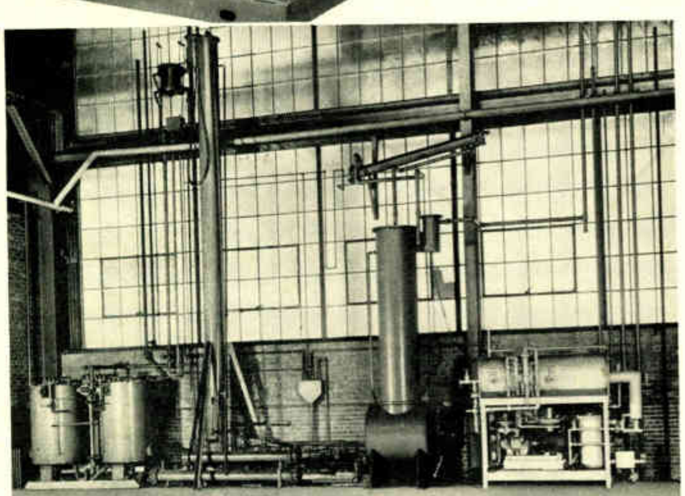


Fig. 7—The Endogas atmosphere generating unit.

Fig. 8—The complete Monogas atmosphere system for long-cycle annealing of high-carbon steels.



to the exact carbon requirement since super- or high-carbon cases cannot be machined off to obtain the required lower carbon content, which is below the surface. Endogas properly adjusted gives this result.

The same method can be used to restore carbon to the surface of high carbon or alloy steel having a decarburized surface. This is particularly useful in the case of thin sections, such as steel propeller blades, etc., which may have a decarburized skin due to previous hot-forming operations.

Since Endogas itself has a reasonable carbon potential, it is necessary to add but a small amount of additional hydro-carbon to attain rapid and uniform carburizing; thus it is possible to carburize with little or no free carbon or soot formation on the work or in the furnace.

Brazing of metals or *sintering* of pressed powdered-metal articles is another wide field of application for controlled atmosphere electric resistor furnaces. Highly reducing atmospheres such as Rich Exogas, Endogas, or Ammogas make possible metal joining and sintering in an oxygen-free atmosphere and actual reduction of any metal oxides present. Copper brazing of steel or alloy parts is one of many applications.

A high rate of production in this process is best assured with a continuous-type atmosphere furnace. A continuous roller-hearth furnace is shown in Fig. 4. This unit can be operated at temperatures up to 2100 degrees F. Higher production is obtained due to the longer length of the furnace, since the greater the length the higher the number of articles which can be heat treated simultaneously. The charging width (furnace width) is relatively limited for medium- and heavy-weight pieces by the strength of the alloy rollers in bending.

For lighter assemblies the mesh belt, conveyor-type continuous furnace shown in Fig. 2 is a handy precision brazing or sintering tool. Suitable for light loads, this type is also limited in length; strength of the mesh belt and high temperatures are the restricting factors.

Controlled atmospheres and electric furnaces are playing an ever-increasing role in the processing of metals for modern equipment. The development of controlled atmospheres has turned the problem of heat treating metals into an exact science. With these new developments the exact surface content desired in a finished steel product can be closely controlled. This also applies to many non-ferrous metals and alloys, such as most aluminum and magnesium alloys, and copper alloys such as aluminum bronze and beryllium copper.

A summary of the various types of atmospheres and their principal applications is shown in tables 1 and 2. These atmospheres applied with the proper type of furnace make available a wide variety of precision heat-treating tools. Diversity of application and fields of use are still growing.

One of the important trends in industry has been the increasing use of alloys and the development of numerous new ones. Accelerated by the war, this trend shows no sign of slackening. This, in short, is the day of precision alloys. The complexity of alloys is increasing, thus the need for extremely close control of heat treating is continuing to grow. This necessity portends a big future for controlled-atmosphere electric furnaces.

Heat treating is not an isolated manufacturing process. It is used by nearly every industry concerned with the processing of metals. Controlled atmosphere methods are popular not only because of their precision but also because of their widespread savings as compared to older methods. New combinations of atmospheres and new uses for conventional types appear frequently and the continuing addition of still more processes to which they are applicable is certain.

Generator Voltage Regulators and Their Applications

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From the early and faithful vibrating-type regulator, long familiar to both eye and ear, generator voltage regulator development has diverged along different paths. Multiple-contact, exciter-rheostatic, impedance, and electronic types have separate fields of applications.

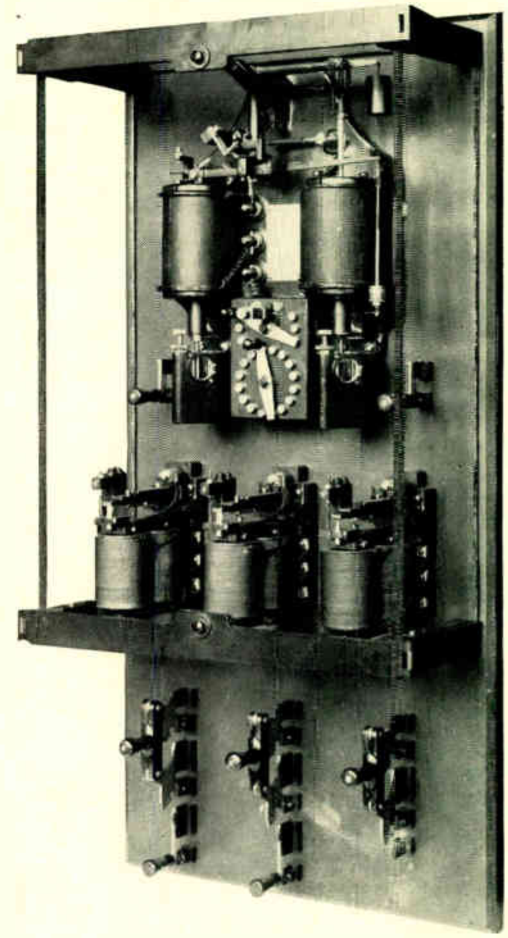


Fig. 1—A generator voltage regulator of the vibrating type. This type of regulator had many moving parts and contacts that required attention.

A generator, a-c or d-c, cannot of itself maintain the desired output voltage under all load conditions. It must have some assistance, some guidance from an outside agent as to what its terminal potential should be under any specific situation. The generator voltage regulator is that agent.

The terminal voltage of an a-c generator driven at constant speed depends on the magnitude and character of the load. This characteristic is commonly called the "regulation" of the a-c generator. It varies over a wide range depending on the size of the generator and the purpose for which it is designed. On small a-c generators, the voltage may rise by 35 percent as load drops from rated load at rated power factor to zero. If the excitation is set to give rated voltage at no load instead of at full load, and the load is increased to full load, the voltage drops by about the same amount. If, in addition, the power factor is low, as it often is with induction-motor load, the voltage droop with increase in load is even greater. The voltage regulator reduces this rise or droop in the generator terminal voltage to a small value by automatically readjusting, directly or indirectly, the excitation of the generator as the load changes in magnitude or character.

Automatic regulation of generator voltage is required for many applications of both a-c and d-c machines, but generator voltage regulators on a-c generators predominate about 9 to 1. Alternating-current generator ratings may be from a few kva to 100 000 kva. Seldom do d-c generator ratings exceed 3500 kw. Direct-current generators are commonly equipped with series windings to hold the same terminal voltage at full load as at no load. A voltage regulator is not ordinarily needed on a d-c generator having a series winding but is frequently used where the d-c generator is shunt wound, or when the inherent regulation of the compound-wound machine is not satisfactory. Voltage regulators are therefore generally used with a-c and d-c generators, when the inherent regulation characteristic is inadequate.

Because the current in the field of the a-c generator or large d-c generator is greater than can be handled conveniently by the voltage regulator, a machine is interposed between regulator and generator. It is called an exciter and usually is a variable-voltage d-c generator having conventional or special characteristics, depending on its control and use. The exciter is usually connected to energize directly the field of the generator. The voltage regulator controls the output of the exciter, and thereby the excitation of the larger generator to maintain the generator voltage normal. With a modern regulator, such as the direct-acting Silverstat type, the size and complexity of the voltage-regulating equipment is greatly decreased by using an exciter and regulating its field instead of attempting to regulate directly in the generator field.

The two main classes of regulators in common use are the electromechanical and the static. The electromechanical includes the vibrating type and the direct-acting and indirect-acting rheostatic type. The static regulators appear in two forms, network and electronic.

The term "rotating amplifier" is sometimes used to describe a regulating system, but this terminology should be confined to the rotating machine, since it is the rotating amplifier. When a simple static circuit, such as a reference field circuit and control field circuit only, is used with a rotating amplifier, the proper designation is a regulated rotating-amplifier system. The regulator portion is specifically the static circuit, because the combination of these circuits provides the intelligence that controls and regulates the rotating amplifier, thereby regulating the generator voltage.

The first automatic voltage regulator to be used was the *vibrating type*, Fig. 1, and was extensively applied between about 1915 to 1937. One form of this regulator had two a-c coils. One was the main operating coil. The other caused continuous closing and opening (vibration) of the main contacts. The main contacts controlled one or more relays and the contacts of the shunting relays were connected in the circuit of the exciter field. Opening the contacts interposed a fixed resistance in series with the exciter or generator field circuit; closing the contacts removed it. The regulator contacts opened and closed at a rate determined and controlled by the voltage-sensitive element. The "contacts closed" time com-

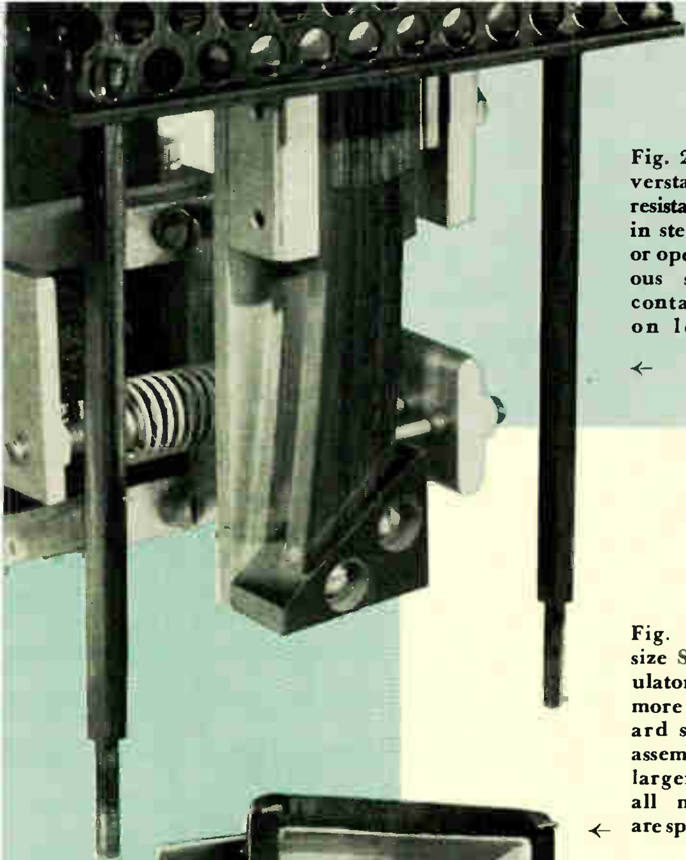
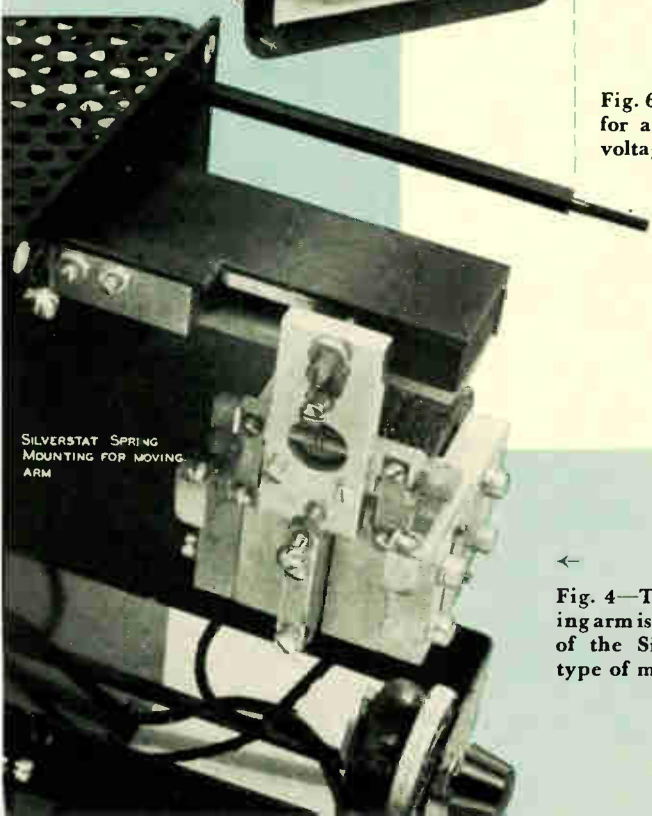


Fig. 2—In the Silverstat regulator, resistance is changed in steps by closing or opening numerous silver-button contacts carried on leaf springs. ←

Fig. 3—A larger size Silverstat regulator uses two or more of the standard silver-button assemblies. In the larger sizes also, all moving parts are spring mounted. ←



← Fig. 4—The spring-mounted moving arm is the main moving element of the Silverstat regulator. This type of mounting entails no wear.

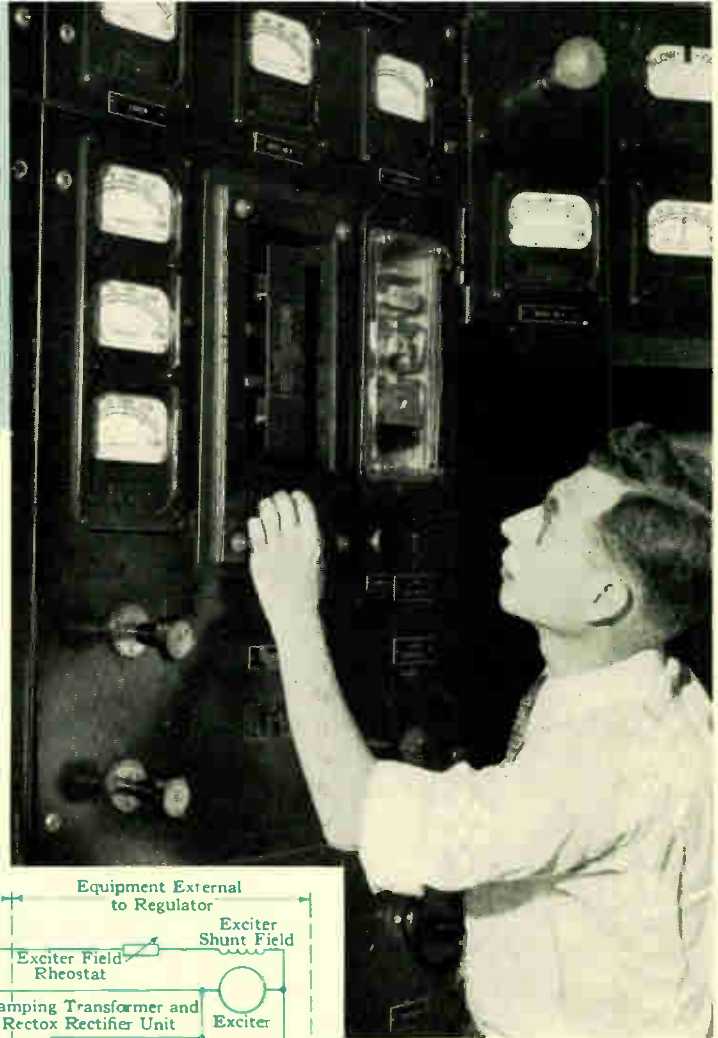


Fig. 5—A Silverstat direct-acting generator voltage regulator mounted on a control switchboard. This type of regulator has largely taken the place of the vibrating type for small- and medium-sized generators.

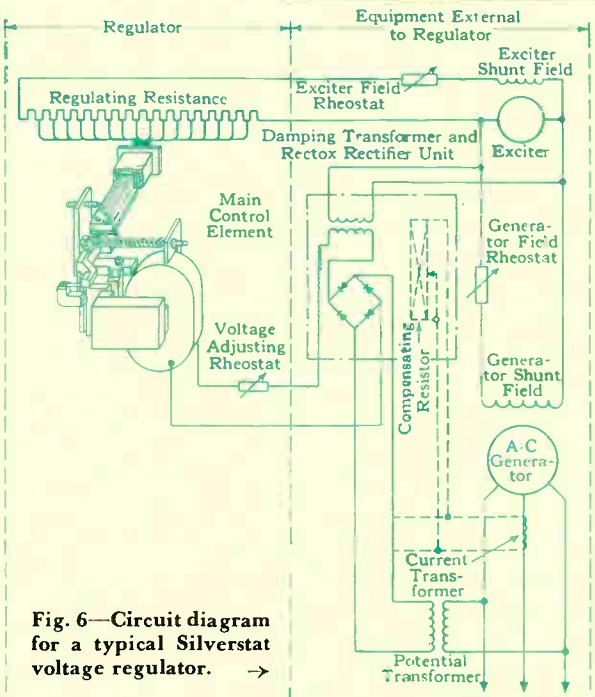
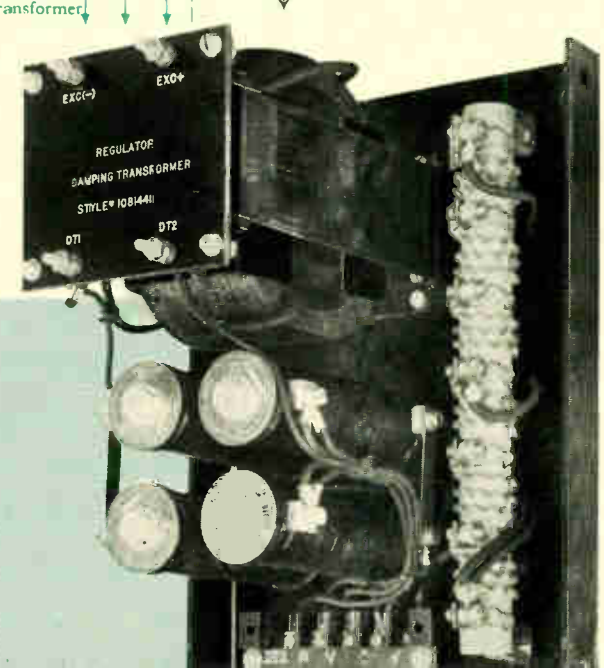


Fig. 6—Circuit diagram for a typical Silverstat voltage regulator. →

Fig. 7—Associated with the Silverstat voltage regulator for a-c applications is a separate damping transformer and rectifier unit. The a-c potential is rectified to provide direct current for the regulating operating coil. The damping transformer is used for stabilizing the action. ↓



pared with the "contacts open" time resulted in an effective resistance in the exciter field circuit. When using the vibrating-type regulator, the exciter field (or d-c generator field) circuit, in simple form, includes the exciter field winding, the main regulating rheostat with the shunting relay contacts connected to short-circuit sections of this resistance, and a voltage-limiting rheostat. The pairs of shunting relay contacts are always connected in series with each other, not in parallel. The parallel connection is avoided because contact wear and change in resistance would result in unequal currents in parallel-connected circuits.

A single vibrating regulator can control one or several exciters by means of a common control head, and a group of one or more shunting relays for each exciter. The exciters controlled by a common regulator must, however, have certain similar characteristics.

The advantage of a vibrating regulator is its accuracy and quick action (response). Its chief disadvantage is its moving and wearing parts with readjustment and maintenance required to keep the regulator performance good.

The *Silverstat direct-acting rheostatic-type regulator*, Fig. 5, has replaced the vibrating type for both a-c and d-c applications. This type of regulator has been applied in increasing numbers since about 1937. Its most significant features are its small number of moving parts and the long life with comparatively little attention.

The Silverstat regulator is self-contained, as it includes not only the regulator operating coil but also the regulating resistance. This differs from the vibrating voltage regulator where the regulating resistance, which the relays shunt, is separately mounted. The simple exciter field circuit for the Silverstat regulator includes the field of the exciter with a conventional field rheostat and the regulating resistance of the regulator, all connected in series. The silver-button assembly, Fig. 2, in the regulator is connected to taps on the regulating resistance. The regulator moving element controls the silver buttons, closing or opening steps in this assembly to remove or insert steps of the regulating resistance as required. All moving parts of this regulator are spring mounted, Fig. 4, thus eliminating shaft-and-sleeve or pivot-and-socket bearings, which wear and ultimately require readjustment or replacement. The steps in the silver-button assembly are worked at a low energy level to provide long life. Normally, no arcing or sparking occur.

Because the Silverstat regulator controls the exciter field current by directly cutting resistance in or out of the exciter field circuit, the characteristic operation of the regulator under steady-load conditions is without motion or vibration of the arm. The regulator arm moves only when a correction is required. When the correction has been completed, the arm remains in its new position with almost no movement or oscillation. This is in contrast to the vibrating voltage regulator wherein the regulator changes its rate of vibration to make a correction and then returns to a similar or new rate of vibration for a new steady-state load condition.

Typical circuit connections for the Silverstat regulator are shown in Fig. 6. Its voltage-measuring or voltage-responsive circuit is connected across one phase of the generator, the voltage of which is to be regulated. Its regulating resistance is connected in series with the exciter shunt field rheostat. The regulator is placed in control of the exciter by turning the exciter field rheostat to or near its limit in the "raise" direction.

Silverstat regulators are built in several sizes, the exact size depending on the kva rating and speed of the a-c generator. Silverstat regulators are available for d-c generators with exciters up to generator ratings of 3500 kw or more, at usual speeds, and for a-c generators with exciters up to about 25 000 kva at 1800 and 3600 rpm.

The *exciter-rheostatic regulator* (BJ-30) is used with large a-c generators driven by steam turbines or waterwheels, and with synchronous condensers. With this type of regulator, a voltage-sensitive element controls indirectly—by interposing means—a motor-operated exciter field rheostat and quick-acting field-forcing contactors. The regulating equipment consists of three main parts: (1) the electromechanical regulator control head, Fig. 8, mounted on the switchboard; (2) a contactor panel, which includes rheostat motor-control contactors and high-speed field-forcing contactors, this panel being mounted on the motor-operated rheostat; and (3) the motor-operated main-exciter field rheostat, Fig. 9, which is usually located separate from the switchboard. Its resistance is connected in series with the field of the main exciter. A pilot exciter is generally used to provide a separate constant-voltage source of excitation for the field circuit of the main exciter. The output of the main exciter is usually connected directly to the field of the a-c machine.

The exciter-rheostatic regulator has two sets of contacts in the regulator element. One set, for normal response, controls the rheostat motor through the interposing small contactors. The other set, called quick-response contacts, controls directly the high-speed contactors that remove or add blocks of resistance in series with the exciter field rheostat. Usually, the normal response contacts are set for a sensitivity of plus or minus one half of one percent to plus or minus one percent. The quick-response contacts can be set to any greater value between one percent and about ten percent, plus or minus three to five percent being usual. This type of exciter-rheostatic regulator has been applied since about 1935 and is still being used in many new central-station and public-utility generating plants. Typical circuit connections of the exciter-rheostatic regulator are shown in Fig. 10.

The voltage-regulating system employing a rotating amplifier is relatively new. Strictly speaking, the rotating amplifier is simply a special d-c generator (exciter). Such an exciter has a control field that requires a small amount of field energy, for example, a few watts instead of several hundred watts drawn by the field of a conventional exciter. It is this characteristic, as found in the Rototrol,* that makes it easily controllable by a voltage regulator, which can be of the direct-acting rheostatic type. The Rototrol is conveniently regulated also by an impedance-type voltage regulator or an electronic regulator.

In the *impedance-type regulator*, a self-contained reference is secured by utilizing the intersection of the characteristic curves of a non-linear impedance with a linear impedance, for example, a saturating reactor and a resistor. At the point of intersection of these curves, the two circuits draw equal current. Should the regulated a-c voltage increase or decrease from that indicated by the intersection of the non-linear and linear curves, one circuit requires more current than the other. The difference between these currents (rectified) is used to energize the Rototrol control field in a direction to raise or lower—as required—the excitation of the a-c generator and its voltage.

The connections to the regulator component parts are shown in Fig. 11. Alternating-current line voltage and current are combined in the potential unit to provide a positive-sequence component of voltage for the voltage-responsive circuits in the automatic control unit. A voltage-adjusting ele-

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

ment is connected between the potential unit and the voltage-regulator automatic control unit. This voltage-adjusting rheostat provides means for varying the resistance in series with the automatic control unit. This causes the regulator, by adding resistance to the circuit, to adjust for a higher voltage at the generator terminals and vice versa.

The automatic control element applies direct current to the Rototrol control field varying this current in magnitude and direction of flow as required to cause the Rototrol to increase or decrease its voltage, or maintain a constant voltage output.

Electronic regulators, Figs. 12 and 13, utilize electronic tubes and have no moving parts. Moreover, a relatively small amount of control energy is required to cause the electronic regulator to supply maximum output. The delay in the electrical circuit is slight. It can be made fast and extremely accurate. High amplification is readily obtainable if needed. Electronic tubes, however, require periodic test or replacement. The cost of tubes may be greater than that for the replacement of parts of electromechanical regulators.

In the electronic regulator a point or level of reference with which to compare the regulated quantity is required. The electromechanical regulator uses a spring as a reference. The impedance regulator uses intersecting impedances. The d-c reference for the electronic regulator can be supplied by batteries or by rectifiers. Other types of reference include a voltage-regulator tube, or an electronic tube having regulated and self-controlled voltages such that the output of this tube remains constant in spite of variations in the a-c supply voltage.

Sometimes a *static-type voltage regulator and Rototrol pilot exciter* are applied to a-c machines. In the usual excitation system for a large a-c generator the conventional pilot exciter is a constant-voltage generator. The Rototrol, however, is used in one arrangement as a variable-voltage pilot exciter. The method of operating the excitation system is essentially no different from the operation of a conventional exciter-rheostatic system, except that the Rototrol energizes directly the single field of the main exciter. No regulator-controlled, motor-operated rheostat for the exciter field is required. The Rototrol pilot exciter supplies an adjustable voltage to the main-exciter field, the Rototrol being controlled automatically by the voltage regulator or manually with a manual control unit. This unit consists of a bridge circuit excited by the voltage across the main exciter or generator field. It is a relatively small switchboard-mounted device.

The advantage of the Rototrol and static regulator, and its associated manual control unit, is the elimination of the rather more complicated exciter-rheostatic regulator with its moving parts, and the elimination of the motor-operated field rheostat for the main exciter. Mechanically and electrically, the Rototrol pilot exciter is as reliable as conventional pilot exciters. Standard parts are used throughout in both machines, the main difference being that the Rototrol has multiple fields. The main exciter is the same in the two types of excitation systems.

A somewhat different excitation system employs the same standard voltage-regulating equipment and a similar Rototrol exciter, but in this case the Rototrol operates as a buck-boost exciter. The main exciter is conventional except that it has either two or three shunt-field windings instead of the usual single shunt field, or two fields, that is, a main shunt field and a small differential field. One is a self-excited shunt field providing most of the main-exciter excitation and receiving its energy from the main-exciter armature circuit in the usual manner of a self-excited field. A small, separately excited shunt field is used if required for stabilizing purposes when the exciter is operating at low voltage on manual control. The Rototrol buck-boost exciter energizes directly a separate shunt field winding by means of which the exciter can be caused to raise or lower its voltage.

In operation with this excitation system, the main-field rheostat is set by the operator so that this field alone provides a base value of current; for example, that sufficient to maintain steady-state stability at full load on the a-c generator. The voltage regulator then controls the Rototrol buck-boost exciter output both as to polarity and magnitude, so that the excitation of the Rototrol-energized field either adds to or subtracts from the base excitation. With this arrangement, the regulator and the Rototrol can maintain a predeter-

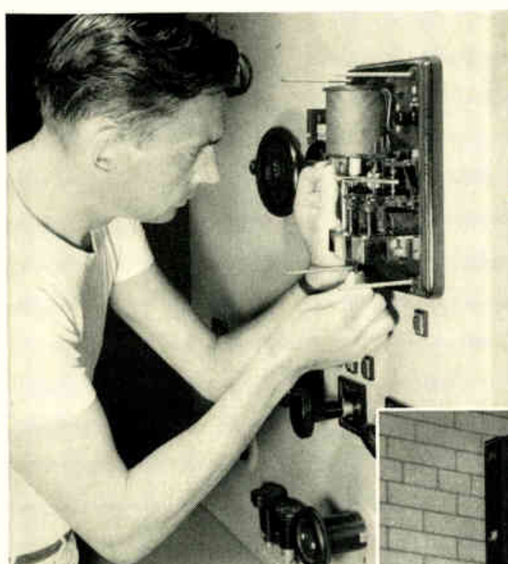


Fig. 8—The control element of an exciter-rheostatic regulator on a generator panel.

Fig. 9—The motor-operated rheostat controlled by the exciter-rheostatic regulator element is placed in a small cubicle. The contactor panel is located in the upper corner.

mined a-c voltage in spite of changing load on the a-c machine. Since the base excitation of the main exciter is supplied by the self-excited field, complete excitation is not lost, nor is the continuity of the load disturbed upon the occurrence of trouble in the Rototrol exciter circuits or the static voltage regulator elements such as to result in loss of output of these circuits. Should a regulator or Rototrol circuit failure occur at any time when the a-c generator is carrying a load, which requires the Rototrol to operate bucking or boosting, the a-c generator continues to carry its kilowatt load, but at a different power factor.

A simplified excitation system for large turbine-driven, a-c generators can be made by using a large main-exciter Rototrol* having the necessary stages of amplification. More than one stage of amplification makes possible a relatively large power-output capability, at the same time keeping the control-field energy requirements as small as in the Rototrol pilot or buck-boost exciter. This permits using the same static voltage regulator as is used with the small Rototrols.

In choosing suitable regulating equipment, the accuracy or sensitivity of the regulator should be considered. The sensitivity can be described as the minimum variation in the regulated voltage to which the regulator effectively responds. The rated sensitivity in published literature represents the band or zone of voltage, expressed in terms of percentage of the normal value of regulated voltage, within which the regulator normally held the voltage under steady loads. When the regulated voltage varies more than the percentage sensitivity from the regulator setting, due to changes in load or other conditions, the regulator immediately applies corrective action to restore the voltage to the sensitivity zone.

The sensitivity of the regulator should be suitable for the class of service to be supplied. For example, the lighting circuits of a hospital or laboratory require closer regulation of voltage than would be needed for power circuits on a construction job. The rated sensitivity of different regulators ranges from ± three percent for regulators used with small d-c or a-c generators, to ± one half of one percent for regulators used with large a-c generators or synchronous condensers.

One of the interesting features of the impedance and the electronic regulators is the continuity of their zones of sensitivity. In the older electromechanical regulators having contacts, the spacing between the raise and lower contacts—i.e., magnitude of the contact gap or "dead band"—determines the closeness with which the regulator attempts to regulate voltage. Static devices, however, are continuously sensitive, and are not subject to change in sensitivity due to mechanical wear as are electromechanical regulators.

The characteristics of the a-c or d-c generator must be taken into account as well as the characteristics of the regulator. When additional load is suddenly applied to a generator, particularly an a-c generator, a momentary dip in voltage is unavoidable. This is due to internal drop in the machine winding. In the case of a-c load at low power factor, there is also a demagnetizing effect on the generator field. These effects occur regardless of whether the machine voltage is under manual control or regulator control.

The regulator cannot be expected to anticipate a load change. The regulator can, however, respond quickly to correct the excitation for a changing or new load condition. Since generators and exciters vary considerably in size, rating, and speed, the field voltage, current, and inductive characteristics also vary considerably, depending on the purpose for which the machine was designed. To insure satisfactory performance, the regulating equipment should therefore be correlated to the machine characteristics.

The maintenance required by voltage-regulating equipment is an important consideration. On old electromechanical regulators, which have numerous moving and wearing parts, a schedule for periodic inspection or maintenance is just as essential as for the relay equipment that protects the generating apparatus. When regulator parts are replaced due to wear or deterioration, care should be taken to restore proper adjustment and alignment. In the replacement of resistors and coils, for example, exactly duplicate electrical characteristics with regard to resistance and current should be main-

*"Rototrol Provides Generator Excitation," by C. Lynn and C. E. Valentine, Westinghouse ENGINEER, March, 1948, p. 34.

Fig. 10—The exciter-rheostatic regulator controls the voltage of the a-c machine through a motor-operated rheostat and quick-acting contactors in the main-exciter field. A pilot exciter supplies energy at constant voltage to energize the field circuit of the main exciter.

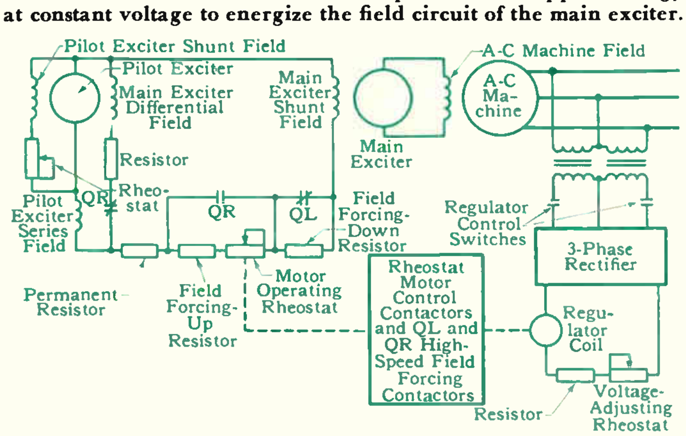
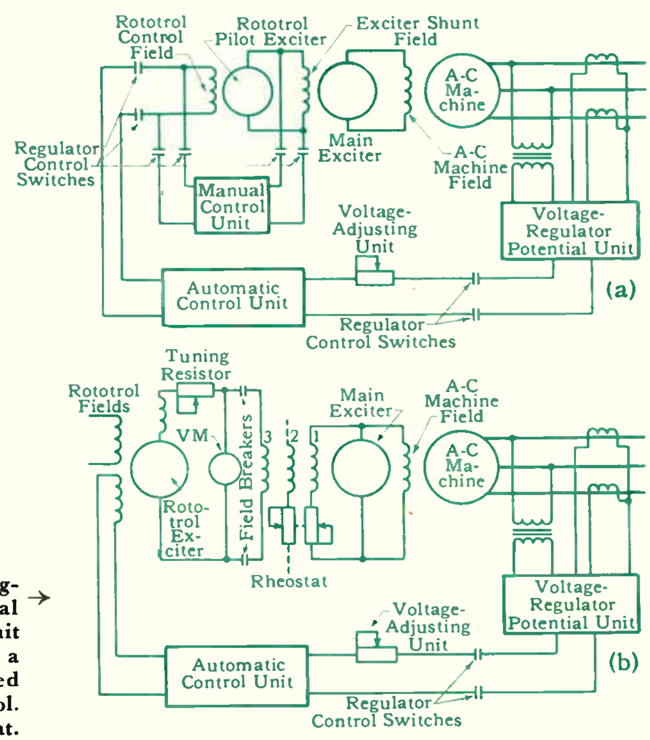
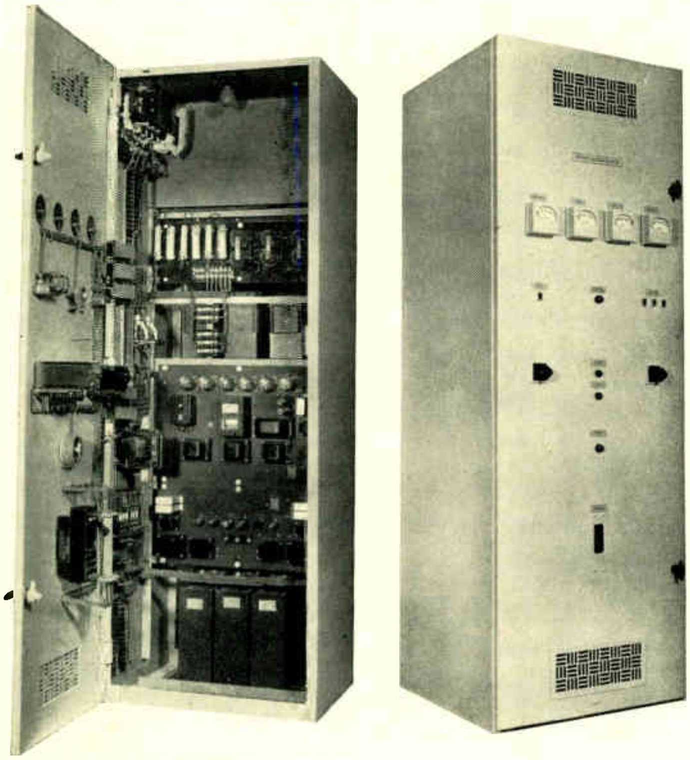


Fig. 11—Typical circuits showing impedance-type voltage regulator units and control of a Rototrol exciter: (a) a conventional main exciter is controlled by the regulator automatic control unit or by a small manual control unit; (b) the main exciter has a separate field energized by the Rototrol and a self-energized field that provides a base excitation with or without the Rototrol. Manual control is obtained by means of the exciter-field rheostat. →





Figs. 12 and 13—The electronic-voltage regulator.

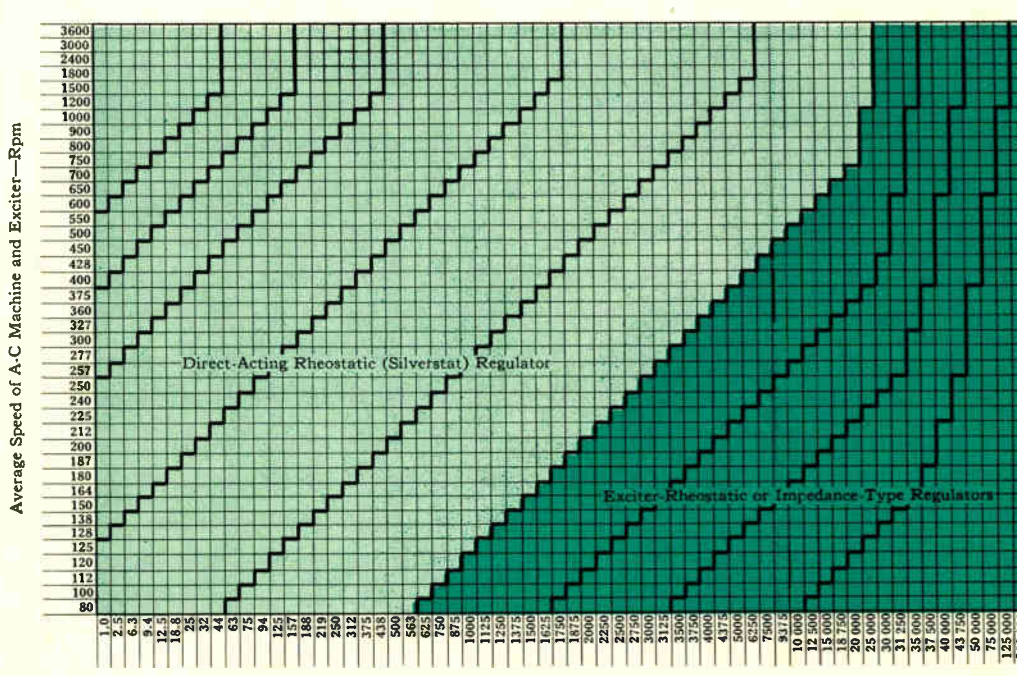
tained. In some cases resistors have been replaced by one of different size than was originally used. This results in different current, which can lead to erratic and relatively unsatisfactory performance of the regulating equipment.

Old voltage-regulating equipment can be maintained so that it will give excellent performance for many years provided a periodic schedule of inspection and maintenance is followed. It sometimes happens, however, that equipment is allowed to operate without inspection or attention until it fails completely. In such cases, a complete overhauling and replacement of parts become necessary. After many years—and depending on circumstances of operation—the condition of resistors, coils, wiring, and insulation in general may be so poor as to become hazardous instead of reliable. Under these circumstances, the cost of overhauling and adjustment can hardly be justified in view of the modern, simple, and reliable regulators available. A new regulator, possibly of a different type, engineered to suit the particular generator and the peculiarities of the load, may be more economical in first cost as well as in subsequent maintenance.

Troubles with the regulation of generator voltage are sometimes caused by conditions beyond the control of the regulator. Because the regulator is designed to correct errors in the regulated voltage, anything that affects voltage causes the regulator to act. Should an engine governor, for example, become erratic due to maladjustment or wear or for some other reason, the resulting changes in speed are reflected in voltage and require excessive corrective action of the voltage regulator. Voltage regulators have also been blamed for unsatisfactory performance when the trouble was due fundamentally to operation of the machines at other than normal rated speed. The voltage regulator cannot compensate for speed changes followed by voltage changes so rapid they cannot be corrected, nor does the regulator have the ability to retain control in the case of belted machines when the belt slips due to increase in electrical load. Under such conditions, the regulator, exciter, and generator may be unable to give satisfactory performance electrically no matter how good their design and coordination may be.

The direct-acting rheostatic type is the one now most commonly applied. The simplicity of the electrical circuit and the reliability of this type of regulator are its chief advantages. The trend of design is to improve reliability and freedom from maintenance and replacement. For public-utility and central-station applications the network-type regulator and rotary amplifier exciter (Rototrol) are being used more frequently. For waterwheel-driven generators, the exciter-rheostatic-type regulator is generally used. The Rototrol exciter, in public-utility and central-station applications is being used generally as a buck-boost pilot exciter although in some cases it is being used as a main exciter.

Fig. 14—The approximate ranges of applications of a-c generator voltage regulators. Within a given class one size and rating of regulator is used. Size and cost increases progressively from class O to class I. The regulators in the first three classes in the upper lefthand corner have sensitivities of plus or minus three percent to plus or minus 1½ percent. All the remaining classifications have sensitivities of plus or minus one-half percent. The exciter-rheostatic or impedance regulators are seldom applied to machines to the left of the boundary indicated. The electronic regulator in general is applicable to any class of machine but is usually not applied to the smaller machines unless the specific situation requires the special characteristics that the electronic regulator alone can provide.



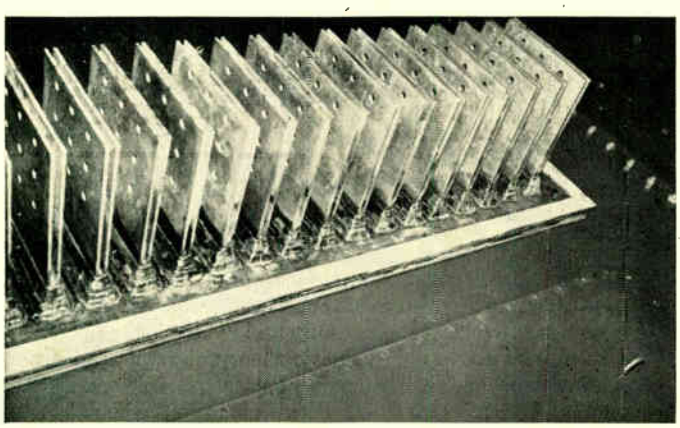
What's New!

Rubber Garters Seal Transformer Leads

ARC-FURNACE transformers must be built to take a beating, both inside and out. Internally they are subjected to heavy instantaneous surges of current which cause tremendous electrical and electromechanical stresses between the windings and the leads. Externally they are subjected to injurious gases, dust, and moisture, which cause havoc if they succeed in entering the windings.

The seals of the low-voltage leads of arc-furnace transformers are a particularly critical point as these leads must conduct currents sometimes as high as 200 000 amperes. These currents make it necessary to use a multitude of copper bars, which usually pass through the transformer cover. A satisfactory seal between the leads and the cover must be a good dielectric and must be sufficiently flexible to permit expansion of the bars with temperature changes, yet tight enough to prevent "breathing" of moisture or gas-laden air through the joint. Because a greater degree of flexibility is required (due to the larger currents) leads cannot be rigidly sealed, with insulating porcelain, for example, as is done with most transformers.

The completed seal for secondary busbars of arc-furnace transformers.



A new seal of synthetic rubber has all of these qualifications and in addition facilitates maintenance of the transformer. A neoprene mat extends over the entire cover opening. The joint between the mat and the transformer cover is made by clamping the rim of the mat all around between a boss on the cover and a metal frame. Thus the mat serves as its own gasket. The mat has slots through which the copper bars pass. A synthetic rubber garter of triangular cross section surrounds each bar and is cemented to it and to the neoprene mat. The cement forms a seal, but to be doubly sure, a special adhesive tape of unvulcanized synthetic rubber is placed over the joints at the edges of the garter. This arrangement securely seals the copper bars to the mat. Insulating blocks are located under the mat, between the bars, and are supported at their ends by the cover. These blocks space the bars and support the mat, relieving it of mechanical strain. The entire assembly is given a protective coat of varnish, which also adds a neat appearance. To remove the cover, the metal frame and insulating blocks are loosened, after which the cover is simply lifted away from the mat, which is manually held in place through the cover opening. Thus the seal to the bars need not be broken.

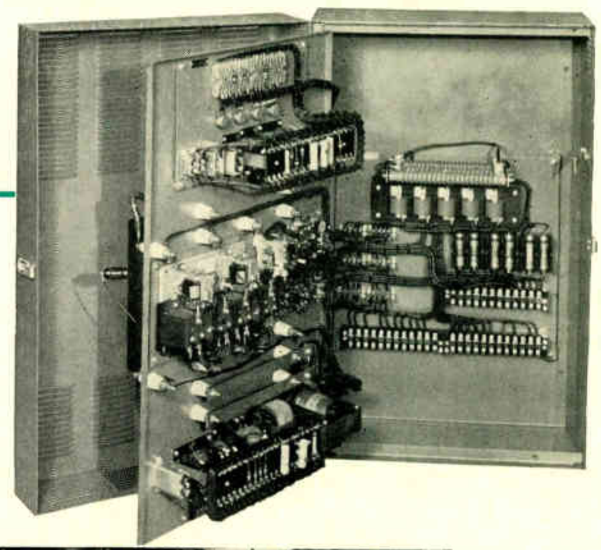
Transformers having this new seal can be equipped with suitable breathers and pressure-relief devices. Thus they function with the same degree of safety and oil preservation as power transformers not having the low-voltage, high-current problem of arc-furnace transformers.

Mototrol Becomes a Quick-Change Artist

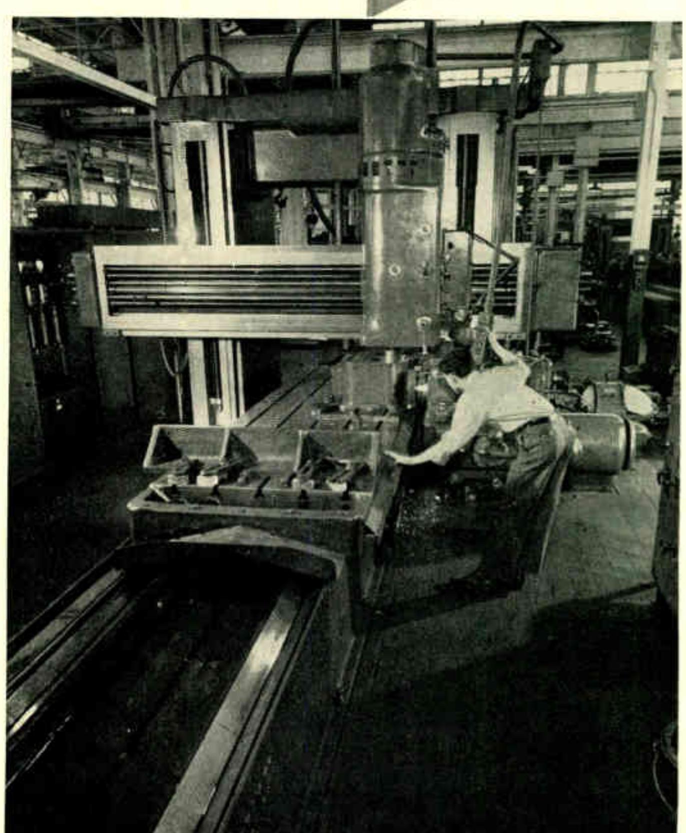
ONLY seven years ago, the Mototrol, the electronic adjustable-speed drive, was introduced to the industrial public. Now it is approaching maturity. Time was when each Mototrol was engineered and built for only one particular application. Now standard Mototrols in a wide range of sizes, speeds, and control operations are available for a variety of purposes.

The new Mototrol uses the building-block type of assembly, so that it can be changed from one standard form to another in a jiffy. The standard combinations provide reversing and non-reversing operation, with or without dynamic braking, jogging, and field control. The control equipment consists of five basic subassemblies so that a unit can be changed, for example, from non-

At right is the front view of a standard 15-hp Mototrol panel, cover open.



The drive for the table feed of this planer-type milling machine is a 5-hp Mototrol drive. The control cabinet can be seen to the left of the rail; the motor is on the floor to the right of rail (rear motor).



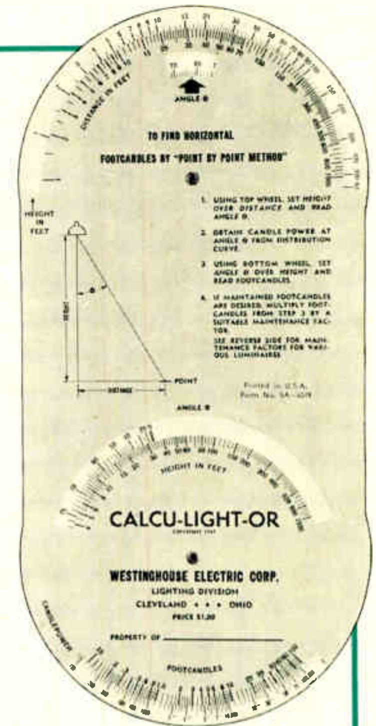
reversing to reversing operation, simply by substituting a different relay panel. The Mototrol drive is built in standard sizes from ½ to 25 hp (and others, if necessary) with motors of almost any base (full-voltage, full-field) speed. The standard speed ranges are 5, 10, or 20 to 1 with armature-voltage control only and 50 to 1 with both armature-voltage and field control. Even wider speed ranges are practical. Assemblies of somewhat off-standard characteristics can be arranged to suit even the most unusual industrial applications.

The Mototrol is a complete drive so that accessory equipment, such as a starter, is not required. All control (including speed changing) is accomplished from a single standard pushbutton station. The circuit has been simplified and the number of elements reduced. Components of the industrial type rather than of the radio type are employed. For example, Inerteen-impregnated condensers with porcelain bushings are used in place of paper-wound units. The transformer can be mounted in the cabinet with the other control equipment or separately. The transformer has class-B insulation and a Hipersil core to reduce size and weight. The Mototrol is also built in totally enclosed construction and in open-type panels for mounting in the base of a machine or with other controls as is often done with machine tools.

The Mototrol can be used for numerous adjustable-speed applications, such as machine-tool spindle, traverse and feed drives, warper drives for textile machines, conveyors, balancing machines, extruding and drawing machines, and many others.

Lighting Calculations Lightened

Illumination problems are simply and easily solved by the "Calcu-light-or," a slide-rule-type device that includes all information necessary for calculations involving either the lumen or the point-by-point methods. For the point-by-point calculation, a distribution curve of the particular luminaire is of course required. The Calcu-light-or is priced at one dollar.



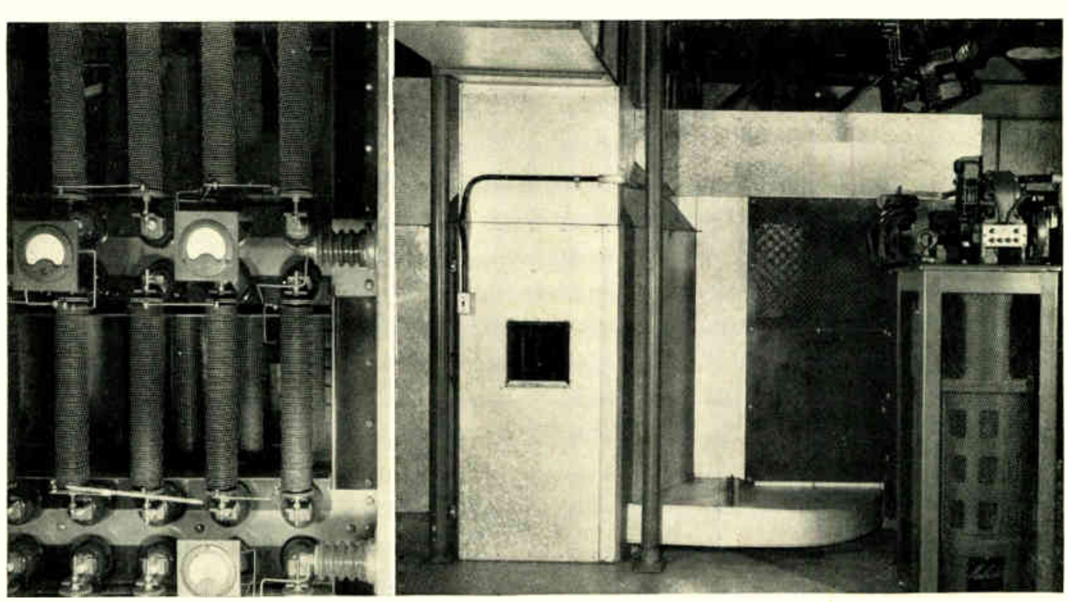
Selenium Disk Doubles Its Rating

The selenium rectifier disk has been taking vitamins. It must have been, for it has doubled its power output without visible change in size, shape, or other external characteristics.

A new rectifier disk, which is made by an entirely different process, looks just like the old but it has twice the voltage rating (24 volts instead of 12) with the same current capacity, hence doubling its power output. Furthermore, it is more efficient and has a better voltage regulation from no load to full load. The higher voltage rating cuts in half the number of disks required to obtain a specified voltage output. For example, to build a certain 240-volt d-c power supply requires a stack of 80 old disks but a stack of only 40 new. This reduction leads to a subsequent reduction in the size and weight of the complete power supply.

The high-voltage disks can be used in any power supply rated 12 volts (single-phase, full-wave) or higher; for example, in low-voltage applications such as plating, anodizing, and battery charging, and in industrial-voltage applications such as a-c to d-c motor drives for machine tools and business machines. The disks are particularly useful in extra-high-voltage (10 000 volts and up) power supplies for communications equipment and electrostatic dust precipitators.

The new disk has other features. It does not require a warm-up period; it is non-expendable; and it has a long, almost unlimited life. It has no moving parts, makes no noise, and requires little attention. In short, it is a maintenance man's delight.



These selenium disks, which form a 15 000-volt power supply for a radio transmitter, are housed in the metal-clad cabinet (right). At the far right is the voltage regulator that maintains constant output voltage as load varies.

Industrial Electronics Reference Book

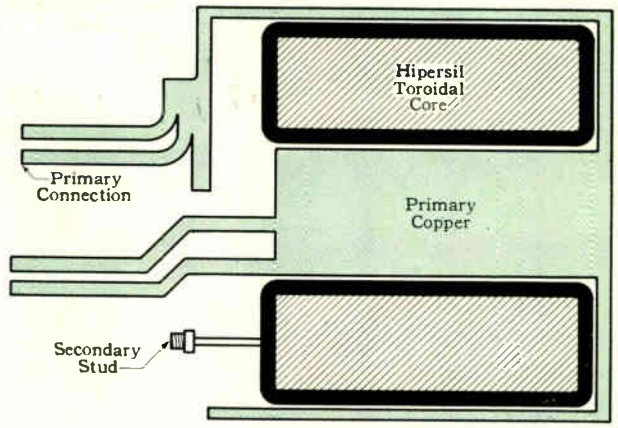
Electrical engineers who are having trouble catching up with fast-moving electronics developments will find the new "Industrial Electronics Reference Book" a big help. Prepared by an all-Westinghouse team of electronics and research engineers, this book contains information on basic theory, design, application, and maintenance of electronic equipment.

Running 36 chapters and 680 pages in length, the book has material by 36 different authors. Among these are Dr. W. E. Shoupp, Manager of Electronic Research and a co-discoverer of photo-fission of uranium atoms by gamma rays, and Dr. Harvey C. Rentschler, retired Director of Lamp and Electronic Tube Research, who developed the Sterilamp.

The first section of the book is devoted to basic electronic design, operation, and construction of equipment ranging from simple vacuum tubes to cathode-ray tubes and ultraviolet radiators. Electronic circuits are covered in the second section, and factors

Inside-Out Current Transformer

To hold a pair of socks together, the housewife folds the end of one back around the rolled-up pair to form an enclosing envelope. A similar operation is being performed on a new current transformer, but the purpose here is to shield the windings from stray magnetic fields. This shielding is accomplished by fanning out one of the primary leads into a copper cylinder turned back over the secondary windings so that they are almost completely encased in metal. The result is isolation of the secondary from magnetic fields except that of the current being measured, which increases accuracy. Accuracy is further improved by the use of Hipersil steel and a unique unbalanced winding that causes a continuously circulating magnetic field. This field keeps the magnetic particles in the steel in a state of agitation which facilitates their motion by load currents and thus reduces the effective reluctance to approximately 50 percent. The overall result of these new features is an accuracy of plus or minus 0.1 percent with a 5-minute phase angle over the range from 10 to 150 percent rated current at burdens up to 0.5 ohm.



This accuracy is better than that of any previous type of current transformer.

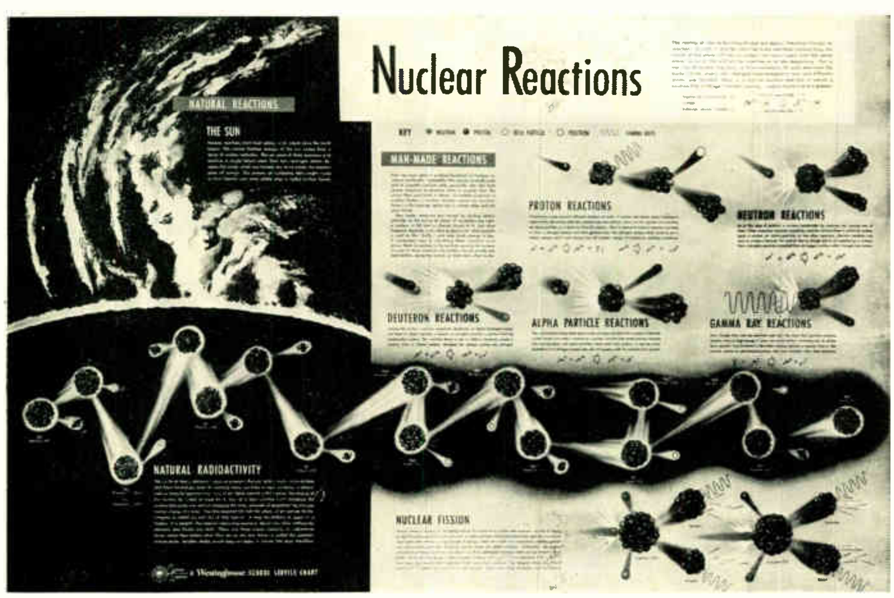
The new transformer weighs approximately 130 pounds and is provided with handles for carrying. Terminals for connection to either cables or busbars are available. The transformer has a tapped secondary, which gives eight ratings, ranging from 1000 to 4000 amperes primary current to 5 amperes secondary current.

concerning transmission lines and antennas in the third. The last two sections are devoted to different types of industrial electronic equipments, their advantages and limitations, and to the care and maintenance of electronic tubes and apparatus. Basically a reference book, it nevertheless contains up-to-date information on the latest electronic developments. The "Industrial Electronics Reference Book," published by John Wiley and Sons, New York City, sells for $7.50.

Nuclear Charts and Book

Published by Westinghouse for use by high schools, colleges, and interested industrial firms, is a set of large colored charts on nuclear physics (one of which is shown below) and an accompanying 32-page booklet. The complete set is sold for one dollar.

The contents of the book's six chapters parallel the charts. The first deals with the ten basic particles encountered in nuclear physics, including the neutrino and the meson. The second, which concerns the structure of the nucleus, depicts some 635 isotopes and 75 isomers and explains binding energy and Einstein's mass-energy formula. Natural and man-made nuclear reactions are explained in the third chart—solar energy, radio activity, nuclear fission, and spallation reactions. The fourth discusses tools of the nuclear physicist, the cyclotron, betatron, the atomic pile, Geiger counter, and others, and the fifth, applications of nuclear energy for power generation, the atom bomb, and isotopes. The history of nuclear physics is briefly discussed in the sixth chart and chapter of the booklet.



Krypton Improves Fluorescent Lamp Efficiency

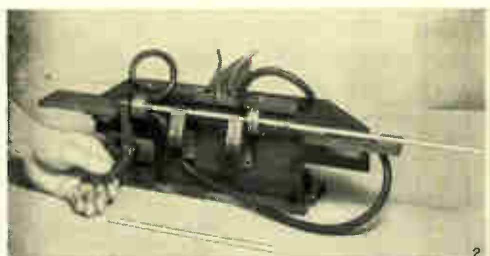
Krypton, one of nature's rarest elements, was discovered exactly fifty years ago to be present in air in the ratio of one part per million. Since then it has been used to give added light efficiency in special applications such as miners' cap-type incandescent lamps and more recently in the All-Weather Approach Landing System for airplanes, such as installed at Idlewild Airport. In 1939, the first experimental krypton-fluorescent lamps were produced, but their use was limited by insufficient quantity and high cost of the gas. Only recently have these factors been brought within the range of large-scale production.

Now, the ability of krypton to increase efficiency is being utilized in a new standard 85-watt fluorescent lamp, whose light output is equal to that of a similar 100-watt, non-krypton lamp. The rare gas produces, in essence, a 17-percent increase in efficiency from 42 to 49.5 lumens per watt. The rated life of the 85-watt lamp is equal to that of the 100-watt lamp and it has the same dimensions and uses the same fixtures and auxiliaries so that the two are completely interchangeable. Five lines of white light are available: Daylight, 4500 White, Standard White, Soft White, and the new Warm White.

Pictures of Industry

↑

DURING the war Navy men found that the shock caused by enemy bombs exploding in the water near a ship sometimes broke the frames of electrical devices, disrupting operation. To build equipment capable of withstanding such blows, resistors, circuit breakers, contactors, and other components are being subjected to a 1000-foot-pound shock test by the machine shown above. The effects are studied with the aid of high-speed motion pictures taken during the test.



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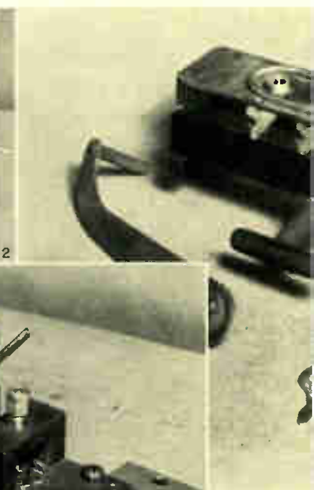
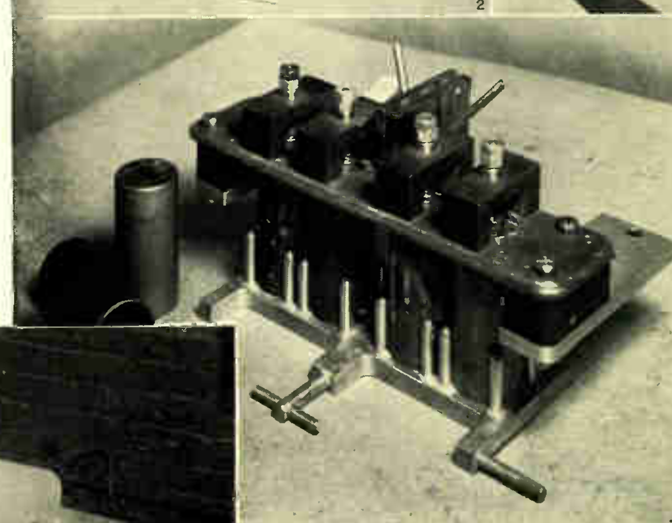
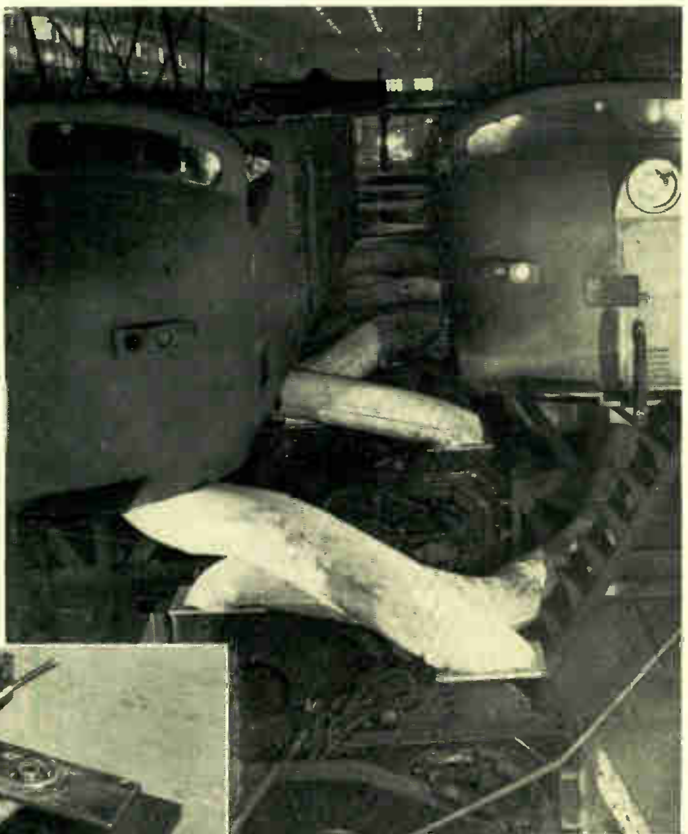




3

1

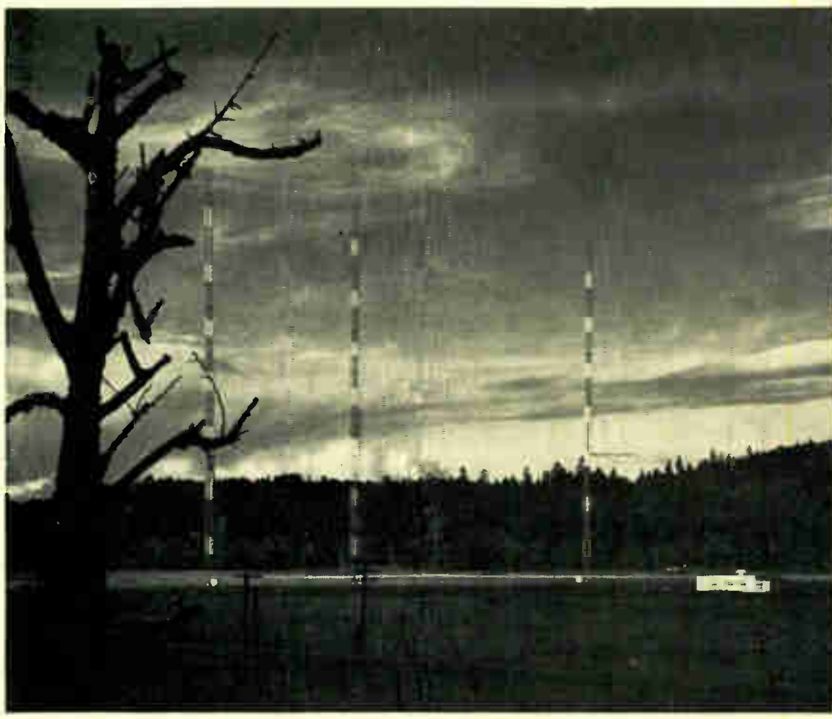
FOUR self-contained fixtures make it possible to braze or anneal fifteen different parts using only one five-kw radio-frequency generator. Changeover time from one fixture to the other is less than ten minutes. In 1, an arm is brazed to a hollow shaft without annealing a hardened key, which is kept cool in a "bathtub" fixture partially filled with water; in 2, hardened shafts are annealed selectively; in 3, a dashpot assembly, formerly made by deep-drawing, is brazed at one-fifth the cost; in 4, the fixture brazes bushings on any of the cam assemblies and crank arms shown in the picture.

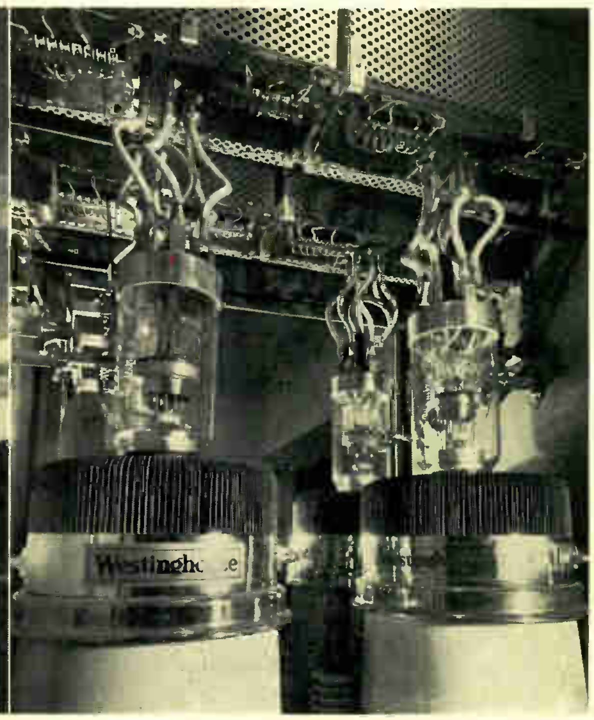


These electric locomotives are tested by having six traction motors of one drive six of the other through their gears. The tubes conduct cooling air to the motors.

Difficulty was encountered in moving this 35 000-kw, 114-ton generator to its final location. Because of a steep river bank on which its building is being constructed, the turbine could not be brought in directly. It had to be picked up on one side of the structure, transported over it, and then lowered into place.

In the striking photograph (below left) the 450-foot-high antenna towers for a new 50 000-watt transmitter for Station KEX, Portland, Oregon, stand out against the sky. At right are the transmitter modulator tubes.





Computer—Mathematical Merlin

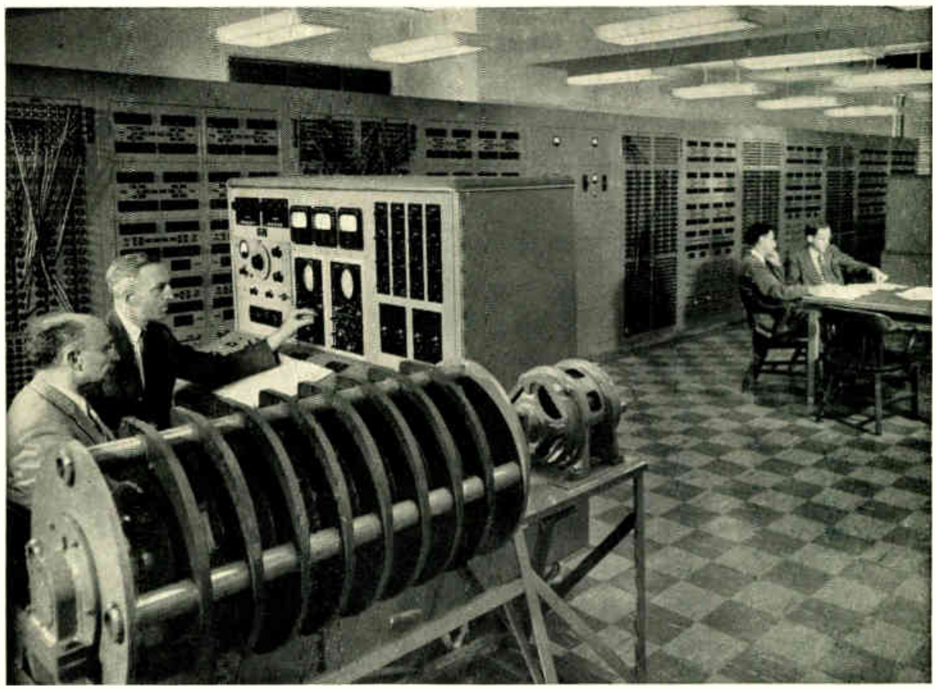


Fig. 1—The Anacom, the electrical-analog computer at the East Pittsburgh Works.

DR. G. D. MCCANN
Professor of Electrical Engineering
California Institute of Technology

DR. E. L. HARDER
Consulting Transmission Engineer
Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania

Rivaling the performance of Merlin, King Arthur's magician, the modern computer performs mathematical miracles in much less time than the twinkling of an eye. By doing so, computers, now in several forms, are providing answers to hitherto insoluble problems, enlarging the engineer's and the scientist's knowledge and powers.

THIS is an age in which century-old dreams of mathematicians are rapidly materializing. Until but a few years ago, only the simplest mathematical operations could be performed by mechanical computing facilities. But recent advances have increased man's computing ability far beyond proportion to the time involved. In addition to enormous improvements in small computers and business machines, a number of large-scale machines have been built, each having a greater computing ability than its predecessors. Some indication of computer progress is given in table I.

TABLE I—TIME* REQUIRED TO PERFORM BASIC ARITHMETIC OPERATIONS AT DIFFERENT PERIODS IN THE AGE OF MAN

Year	Computer	Add Two 10-Digit Numbers (Seconds)	Multiply Two 10-Digit Numbers (Seconds)
5000 BC	Abacus or Longhand	10	120
1920 AD	Desk Calculator (Counting Wheel)	1	20
1944	Improved Counting Wheel (Electro-mechanical)	0.3	4
1944	Relay-type Computer	0.01	0.15
1945	Electronic Computer	0.0002	0.003

*The length of time is not exact, but indicates the order of magnitude.

The impetus for the development of large computers has come from many sources—the government, the military, and from scientific and industrial organizations. Each machine is best suited for one particular field. Yet, since mathematical principles remain unchanged, each machine is useful in other fields as well. Consequently, the more recent computers are designed for general-purpose computations, although each is particularly adapted to certain fields.

Principles of Computers

A computer is a device that performs one or more mathematical operations. Data is supplied to the machine, which provides the answer. The computer may add, subtract, multiply, divide, and take powers and square roots. It may integrate and differentiate. It may remember numbers and signs, refer to tables, interpolate, and produce functions of dependent or independent variables. It may discriminate relative magnitude of quantities, whether they are increasing or decreasing, etc.

Types of Computers

Computers can be classified into two types, the digital and the continuous (or analog). Digital computers operate only with whole discrete digits. Mathematical operations are performed by counting pulses on a counting wheel, electrical relays, or electronic tubes.

The basic principles of digital computers are utilized in the smallest types. The hand is a digital computer (digit means finger). It serves as a memory unit and an adding machine. It "remembers" numbers from zero to five, by the number of fingers raised. If the thumb is counted as five units and the other fingers as one each, the hand can remember numbers from zero to nine.

The abacus, also a digital computer, is an improvement on the hand as it remembers as many significant figures as there are strings of beads. On the Chinese abacus each string has two five's and five one's. Addition is much the same as with the hand, except that digits are added in any decimal place and the process of "carry" is introduced. The carry operation consists of adding one in the next higher place to account for ten in the lower. Multiplication requires adding a number to itself the required number of times; division is the reverse, a repeated process of subtraction.

The first mechanical calculating machine, a digital unit, was built by Pascal in the 17th century. Modern office machines, like their prototype, are digital computers. They are based on the counting wheel with ten positions corresponding to the ten digits from zero to nine. Digits can be added in any decimal place. When one wheel passes its tenth position, the wheels automatically carry by turning the next higher wheel one notch, as in the automobile mileage counter. Large complex digital calculators operate in similar fashion.

The analog or continuous computer, Fig. 1, compares the performance of one physical system with that of another having the same differential equations, which is a prerequisite for analogous systems although certain legitimate transformations can be made. Measurements are made on one physical system (known as the analog) to determine the behavior of the other system in which the problem exists. In general, the systems are entirely different; for example, the electrical analog of mechanical equipment.

Analog computers are of the continuous type, as distinct from the digital. As the analog medium is continuous (rather than separated into distinct digits) numbers between digits are represented as readily as digits themselves. Analog computers usually indicate the answers on meters and instruments.

The slide rule, which multiplies or divides by adding or subtracting the logarithms of numbers, is an analog computer. In this case, the numbers (or their logarithms) are not used as discrete digits but are represented by analogous distances. Other analog computers use shaft rotations or currents and voltages as analogs of numbers.

The analog computer can be used to solve abstract differential equations. In such cases, the analog parameters and variables (distances, rotations, voltages, etc.) are made analogous to corresponding terms and thus satisfy the equations.

Remembering and Handling Data

Remembering and handling data are functions vital to all types and sizes of computers, but particularly to larger machines. Without these functions computers would be very limited in calculating ability. Even the ordinary desk calculator has a "memory." The machine is based on a process of addition, which is repeated for multiplication. In multiplication, the machine carriage is shifted so that the multiplicand is added to itself the number of times called for by the value of each digit in the multiplier. Each position shift is equivalent to multiplication by 10, as in longhand multiplication. For example, in multiplying 4783 by 359, the machine first multiplies 4783 by 9, which equals 43 047. It then shifts one place, multiplies by 5 (equivalent to multiplying by 50) and adds this partial result to 43 047. Then it shifts two places, multiplies by 3 (equivalent to 300), and again adds the partial results. These operations require a finite period of time and hence the partial results must be remembered until added to obtain the final answer of 1 717 097. Therefore, the machine must have an "inner" memory for partial products of its own operations. Large business machines and computers likewise have an inner memory.

The desk calculator does not usually print or otherwise record partials as they serve no purpose to the user. However, in many cases the machine must record the multiplicand, multiplier, and product. Some recording facilities print numbers on sheets, others punch holes in cards or tapes. These mechanical "handling" facilities may be as important as the purely arithmetic function because they save money, time, and labor. Furthermore, mechanical handling makes it possible to record data permanently on cards and tapes (the "outer" memory). Such data can be reused many times without rereading and resetting, thereby reducing the likelihood of error. Business computations require the storage in the outer memory of immense amounts of information concerning bills, salary accounts, taxes, inventories, etc. Similarly, large-scale computers store logarithms, simple and complex functions of angles, and similar data.

Digital Computers

Business Machines

The types of digital computers vary from the simplest mechanical counting wheel to machines weighing many tons and containing thousands of vacuum tubes. The most common forms, however, are business machines, which include simple, hand-operated adding machines as well as units that approach large-scale calculators in complexity.

A typical large accounting office, Fig. 2, might include, among others, the following machines:

A *key punch*, on which an operator transfers written information to punched holes on a card for use by the machines.

A *reproducing summary punch*, which transfers data from one set of cards to another set or to several sets (by gang punching cards).

A *sorter*, which sorts cards into any sequence or classification. It can, for example, sort shuffled cards into numerical order or select all cards representing employes 45 years old.

A *collator*, a more elaborate sorting machine.

A *multiplying punch*, which takes two numbers from punch marks on a card and punches the sum, product, or both, in a third location.

These machines are extensively used for making large numbers of business calculations. They have also been applied to complex problems of science, engineering, and warfare; for example, the calculation of missile trajectories. The solu-

Fig. 2—A representative group of business machines.

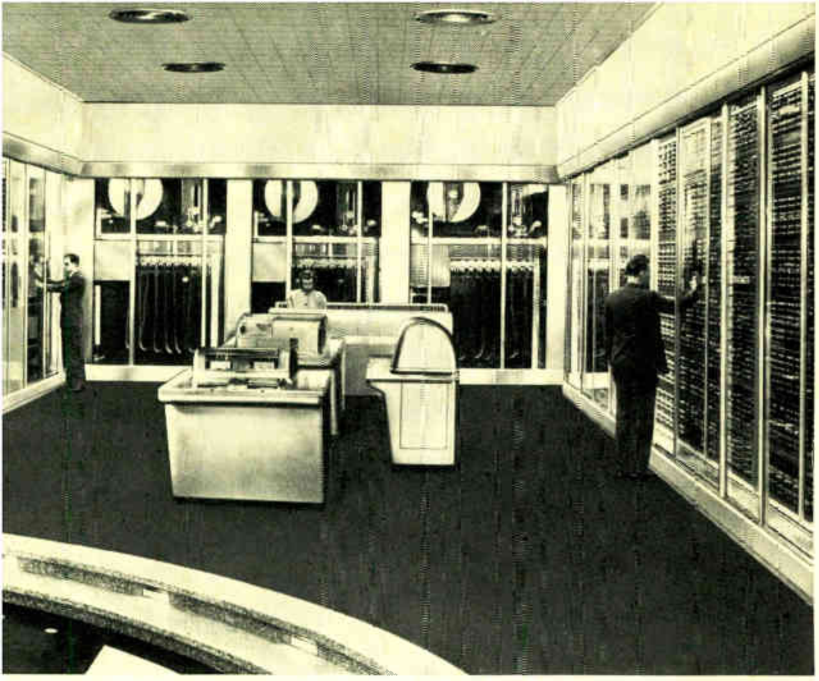
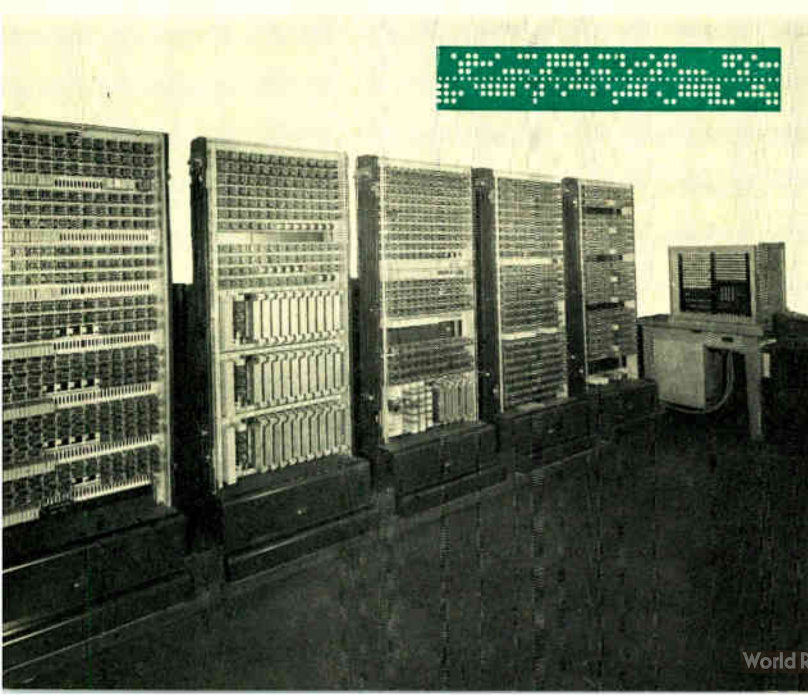


Fig. 3—The new Selective Sequence Electronic Calculator at IBM headquarters.

Fig. 4—Printers give a running account of results produced by the IBM calculator.

Fig. 5—The relay panel of a Bell digital calculator and a section of coding tape.



tion of such problems requires a succession of operations, rather than only a single operation. Repetitive, multi-sequence processes are employed, in which successively closer approximations are reinserted by the machine into the formulas to obtain the next. This is continued until a final approximation, accurate within the desired limits, is obtained.

The necessity of handling data manually between steps of such calculations limits the ability of desk computers and even business machines to solve more complex problems. This limitation has led to the development of large-scale computers in which this intermediate handling is also mechanized. The machines, directed beforehand as to what to do with intermediate results, proceed automatically until the final answer is obtained.

This function of mechanized intermediate handling has introduced new problems of planning ahead and coding into computers. But it also has improved immeasurably man's ability to calculate. Sequences of operations that would have required hundreds of man-years of desk-calculator or business-machine work are now accomplished in minutes. The limitation is no longer in the computing proper, but in preparing the data and coding the problem to go into the machine.

Large-Scale Digital Calculators

While large-scale digital computers have in common the characteristic of operating with discrete digits, they differ as to speed, capacity, and adaptability to certain problems. Punched cards or tapes and electrical connections are commonly used for inserting data and instructions and for extracting answers. These computers are employed principally on extremely complex problems requiring high accuracy and which can justify their high cost; for example, in calculating firing tables, trajectories of missiles, and astronomical data.

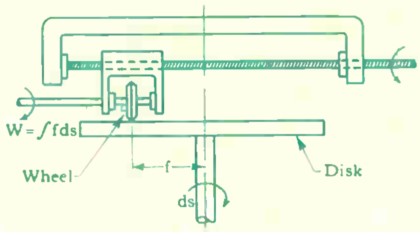
Early large-scale digital calculators employed the counting wheel as a basic unit. Later machines utilized the relay chain, which occupies more space but performs the same function at a much higher speed. Relay contacts are interlocked so that each new pulse picks up the next relay in the chain and drops the preceding one. The chain is closed (returning from nine to zero) and the carry operation consists of advancing the "ten" chain one step when the tenth relay in the "unit" chain operates. This assumes a decimal (or base ten) mathematical number system. However, the base can be less than ten, which requires a smaller number of relays. A base of two (binary system), for example, is used in some computers.

The latest and highest speed computers employ electronic tubes in a manner similar to relays. Each pair of tubes (called a "flip-flop") has two positions, "on" and "off." Only one flip-flop in a chain is "on" at one time. An incoming pulse energizes the next flip-flop, which locks in, de-energizing the preceding unit.

The arithmetic unit of a digital calculator, which performs the mathematical operations, contains the adders, multipliers, dividers, square rooters, etc., in the form of electronic tubes, relays, or wheels. The memory is usually divided into two parts; a high-speed inner memory and a slower speed outer. The high-speed memory, also tubes, relays, or wheels, stores and later transmits information obtained in intermediate steps and remembers instructions for later operations. In newer computers the elements of this memory may consist of mercury delay lines, electrostatic digit-storing tubes (the Selectron), or magnetic drums, wires, or tapes.

The slow-speed outer memory consists of punched cards or tapes, on reels of magnetic wire or tape. It stores mathematical tables or functions or instructions that must be

Fig. 6—The integrator is the basic unit of the differential analyzer.



referred to less frequently during the calculation. The outer memory is almost unlimited in extent. However, the time required by the machine to look up data depends on the method used for selecting the proper card or tape and finding the needed information.

The first large, general-purpose, digital calculator was built by International Business Machines Corporation and was presented to Harvard University in 1944 for scientific studies. It is known as the IBM Automatic Sequence-Controlled Calculator. It had, until recently, the largest internal memory and most complete sequencing or programming facilities of any calculator. It was the fastest, but the electronic ENIAC, installed in 1946, has set an entirely new record in speed. Recently IBM placed in service at its headquarters in New York City the latest Selective Sequence Electronic Calculator, Figs. 3 and 4. This calculator combines extensive memory and elaborate programming facilities with the high speed attainable only with electronic arithmetic units. It can print numerical results at the enormous rate of 24 000 digits per minute or punch cards at 16 000 digits per minute for use in subsequent calculations. It has an inner memory in electron tubes, relays, and tapes of over 400 000 digits, in addition to a practically limitless outer memory in the form of punched cards. This IBM machine has a basic adding (or subtracting) time for 19-digit numbers of one thirty-five hundredth of a second. It multiplies two 14-digit numbers in a fiftieth of a second and divides them in a thirtieth. A number of high-speed relay-type computers built by International Business Machines Corporation are in operation at Aberdeen Proving Ground, Dahlgren Naval Proving Ground, and the Watson Scientific Computing Laboratory.

Several relay-type digital computers have been built by the Bell System, one of which is shown in Fig. 5. This machine can operate for long periods without continuous attendance. All information, data and instructions, is coded on punched tape similar to that used in teletype machines. The code is checked for errors by running two tapes punched independently by different operators through a comparing device. Other self-checking devices immediately stop the machine and signal personnel when an error is made.

The ENIAC, Fig. 7, built by the University of Pennsylvania, is located in the Ballistics Research Laboratory at Aberdeen Proving Ground, Maryland. This machine, the first large-scale electronic computer, weighs 30 tons and contains nearly 18 000 electronic tubes. It has the amazingly high speed of 5000 ten-digit additions or 360 ten-digit multiplications per second. The high-speed memory can store 20 ten-digit numbers, sufficient for the missile-trajectory problems (the principal objective in its design) but insufficient for general-purpose computing. In addition, it has three tables, each of which can store up to 104 twelve-digit numbers before computation starts, for setting up arbitrary functions. These numbers can be referred to in one thousandth of a second. The ENIAC can calculate the trajectory of a shell in less time than the shell requires to reach its target. But several new digital calculators will be substantially faster than the ENIAC.

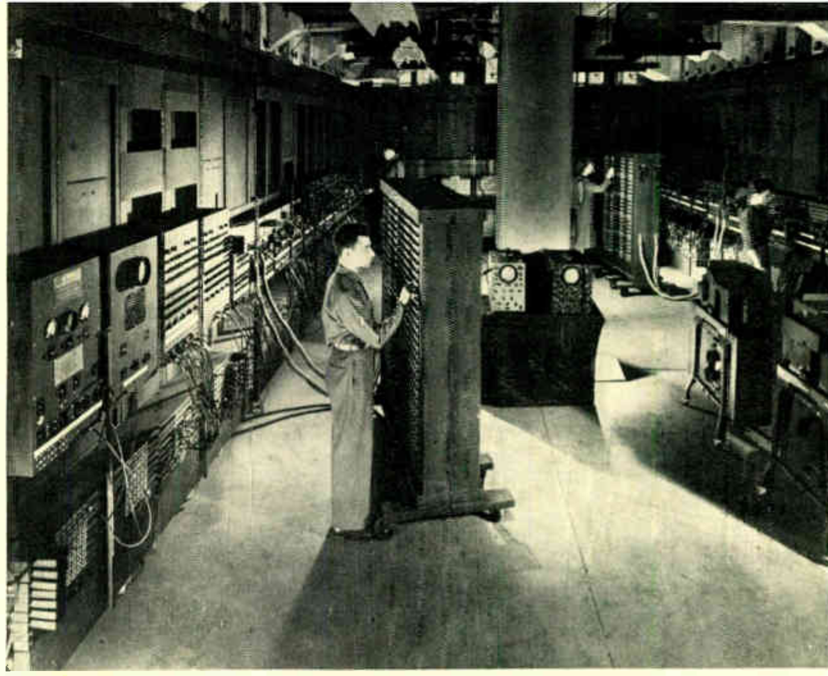


Fig. 7—The ENIAC is the highest speed computer.

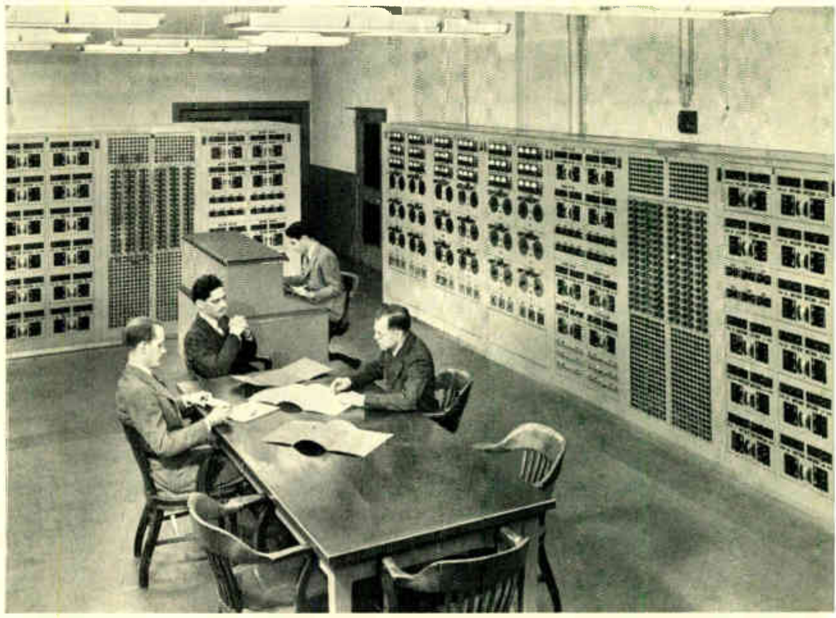
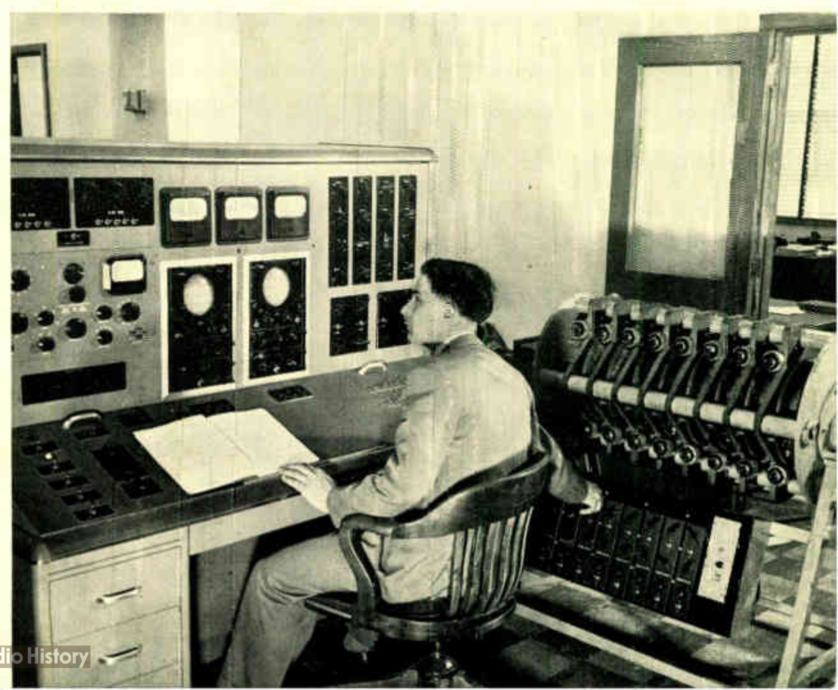
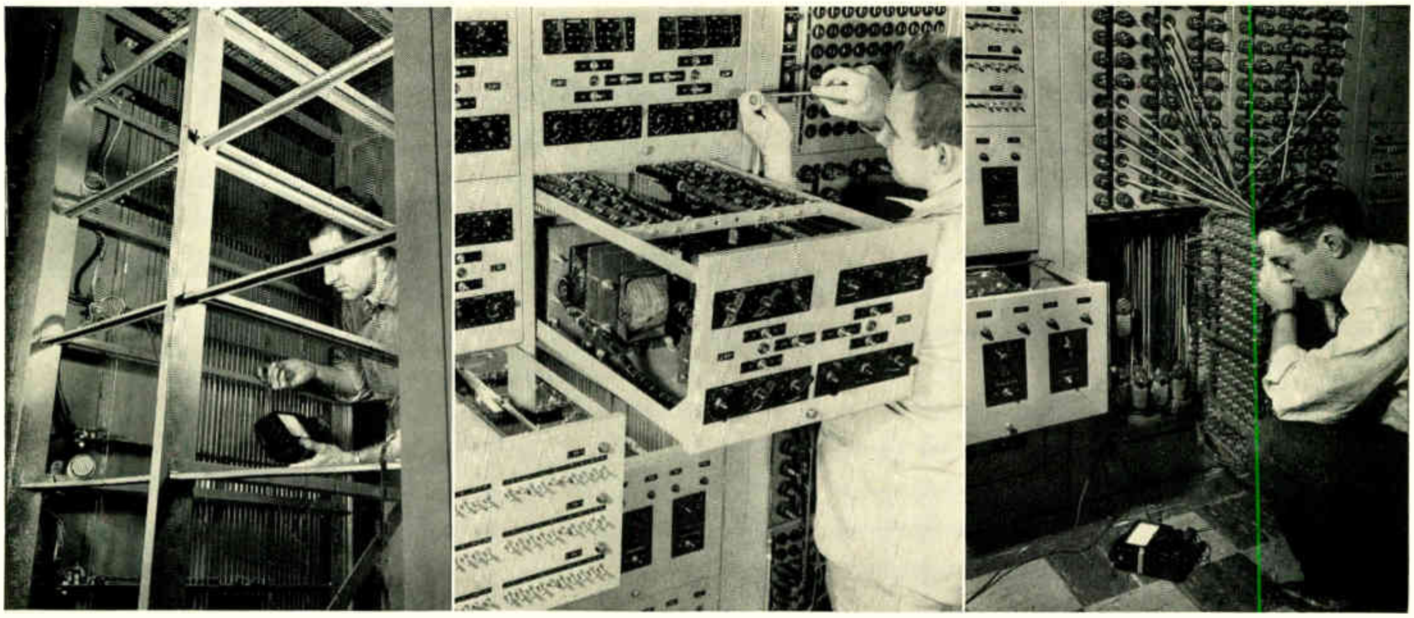


Fig. 8—The a-c network calculator is used for many problems other than analysis of networks.

Fig. 9—This rotating synchronous switch is used on the Anacom to repeat transients, to build special forcing functions, and for other analytic purposes.





Figs. 10, 11, and 12—The Anacom's spaced busbars and special plugs (left), adjustable condenser and transformer assemblies (center), and pulley-type connectors for setting up a problem (right).

Analog Computers

The Differential Analyzer

The differential analyzer, first placed in service in 1930, is an analog-type calculator for solving integro-differential equations. It uses shaft rotations as analogs of numbers and integrates in the manner of a planimeter. The computer is an assemblage of integrators, shafts, gears, plotting tables, and equipment for connections and control.

The differential analyzer makes use of the fact that a differential equation can be reduced to an integral equation. Hence the machine need only integrate. The basic unit is the integrator, Fig. 6, which consists of a disk and wheel. To integrate a *work* problem, for example, the radius at which the wheel runs on the disk is equivalent to force (f) and the disk rotation to ds (derivative of distance). Thus wheel rotation equals the *work* or $\int f ds$. The integrator is made practically frictionless by a polarized-light servomechanism linking the wheel to a driven member. Addition or subtraction of rotations by differential gears is equivalent to adding or subtracting integrals and variables.

The differential analyzer has been improved considerably in recent years. Early machines were set up manually by changing plotting tables, integrators, and gears. However, in 1942, Massachusetts Institute of Technology placed in service a completely redesigned and expanded version, in which set-up time has been greatly reduced by arranging the elements as separate units connected electrically through servomechanisms. Differential analyzers have been used on problems involving ballistics, voltage regulators, servomechanisms, nonlinear electrical and mechanical systems, and others.

Network Calculators

One of the first large-scale analog computers, the d-c network calculator, was developed about thirty years ago. Its purpose was to reduce the time, labor, and engineering skill required to solve problems of electric-power networks. Without the board, such problems would be solved "manually." If a network contained fifty loops, which is not uncommon, fifty simultaneous equations would be solved—by no means a small task. Using the calculating board, the problem is set up in miniature with line resistances, generators, and loads represented by analogous components. The answers, current flow and voltage at different points in the network, are read on built-in instruments.

The d-c board was limited to in-phase problems or those that could be approximated as such. To circumvent this limitation, the a-c board, Fig. 8, on which phase angles as well as magnitudes are represented, was built in 1929. The electric-power industry now has about 18 such computers.

Electrical-Analog Computers

In addition to solving network problems, the a-c network calculator is used in solving mechanical problems; for example, to determine resonant frequencies and steady-state torque amplifications in multi-mass systems. Also, its circuits are used in the electrical-transients analyzer, together with oscillographic recording equipment for the computation of electrical transients and synchronous switching equipment for studying complex phenomena by a repetitive technique.

Since the completion of the a-c board, the electrical-analog method has been increasingly applied to the solution of problems in many varied fields such as hydraulics and applied mechanics. Much heat-flow work has been done by Columbia University and others. The mechanical-transients analyzer extended the transient computing technique to mechanical systems. A servo-analyzer, employing amplifiers and time-delay circuits, is employed to study regulating systems and servomechanisms.

In 1946, Westinghouse and the California Institute of Technology jointly embarked on the development of two large-scale, general-purpose electrical-analog computers of substantially identical components. The Westinghouse unit (Fig. 9 through Fig. 12), is known as the Anacom and is located in the East Pittsburgh Works; the other is in Pasadena. The computers can handle a wide range of problems in electrical—and mechanical—engineering and allied fields. An analogous electrical circuit can be devised for almost any physical system for which differential equations can be written. Linear systems (systems whose differential equations are linear expressions with constant coefficients) are most readily studied by the computers. However, elements are provided to extend the units into the more general field of non-linear systems. The elements of the Westinghouse-Cal Tech computers are capable of performing all the operations involved in differential equations.

The computers represent variables in terms of voltages or currents. Variables can be added or subtracted by connecting equivalent voltages in series. A variable can be integrated or differentiated by passing an analogous current through a capacitance or inductance respectively (since $e_C = 1/C\int i dt$ and $e_L = L di/dt$). The result is equivalent to the voltage across the corresponding circuit element. Multiplication or division of variables is accomplished by a multiplier, an electronic circuit. Arbitrary functions (functions of any shape) of dependent and independent variables are provided by the computers for simulating complicated variables. Time scale and power level can be changed to suit the best range of operation of the circuit elements provided. Measurements are related by known multipliers to corresponding quantities in the actual system.

The block-diagram of the computer, Fig. 13(a), for solving any problem consists of three elements. First is the forcing function, which generates electrical voltages equivalent to the forces applied to the actual physical system. Second is the electrical analog of the system being studied; many analogs of different problems are already known and methods are developed for systematically determining new ones. Last is the measuring equipment, which usually includes oscillographic apparatus for transient problems. The exact type of measuring equipment may vary with each individual analysis.

Application of the electric-analog computer in solving two typical mechanical problems of a three-mass rotating system is illustrated in Fig. 13 (b), (c), and (d). One is a steady-state vibration problem and the other a transient-torque problem. The analog of the system consists of three inductances proportional to the three masses and two capacitances proportional to the reciprocals of the shaft spring constants. To obtain the correct overall analog, the equation of each analog element is simply made identical to that of the corresponding part of the mechanical system. A single overall differential equation for the entire system need not be determined.

The steady-state problem requires the determination of natural frequencies and the ratios of shaft torques to applied torque as a function of frequency. The forcing function is an adjustable-frequency power supply. The voltage ratios, e_{12}/e, and e_{23}/e, are equal to the analogous torque ratios T_{12}/T, and T_{23}/T, and can be plotted as a function of frequency. Peaks of current and torque come at the natural frequencies of the systems, which are identical.

Transient problems, such as indicated in Fig. 13 (d), must be solved to design turbine-generator shafts and couplings to withstand the torques imposed upon them during short circuits. The forcing function required is complex but it can be simulated accurately by the electrical components of the computer. The forcing function contains three terms generated separately by three resistance-inductance-capacitance circuits. These circuits are initially charged and are discharged simultaneously through a slide-wire resistor producing a voltage drop, e, analogous to the actual torque applied during a short circuit. When this voltage is applied to the analog circuit, the oscillograph reads the applied torque, T, the generator-shaft torque, T_{12}, or the turbine-shaft torque, T_{23}. The phenomenon is repeated ten times per second by means of a synchronous switch; the time scale is made to suit this frequency. De-energizing circuits restore a condition of rest during the "off" periods between transients. The result is a continuous record on the oscillograph, which is observed or photographed and then analyzed to determine the effect of short-circuit torques on the mechanical system.

This problem is simply illustrative. Others are solved in similar fashion. Different forcing functions, analog elements, and measuring devices are provided in the computer, making it suitable to all types of problems.

The advantages of the electrical-analog computer lie in its flexibility, which makes it adaptable to a wide variety of engineering problems involved in the design of equipment and systems in many fields. It is suitable only where the usual engineering accuracy is sufficient. In general, the accuracy is limited by the initial data, rather than by the computer, and the answers are as accurate as can be justified.

The rapid development of both digital and analog computers is noticeably affecting technological progress. Many problems that have been economically insoluble until recently are rapidly being brought under control. In the military field, new weapons of amazing accuracy and power are being investigated. In meteorology, computers are making it possible to utilize accumulated data more completely, thus improving the accuracy and the advance time of weather forecasting. In engineering, more accurate predictions of stresses and performance improve safety, and may reduce safety factors and costs. In science, the computer is being used to explain the complex relations of nature, including the behavior of the atom and its components.

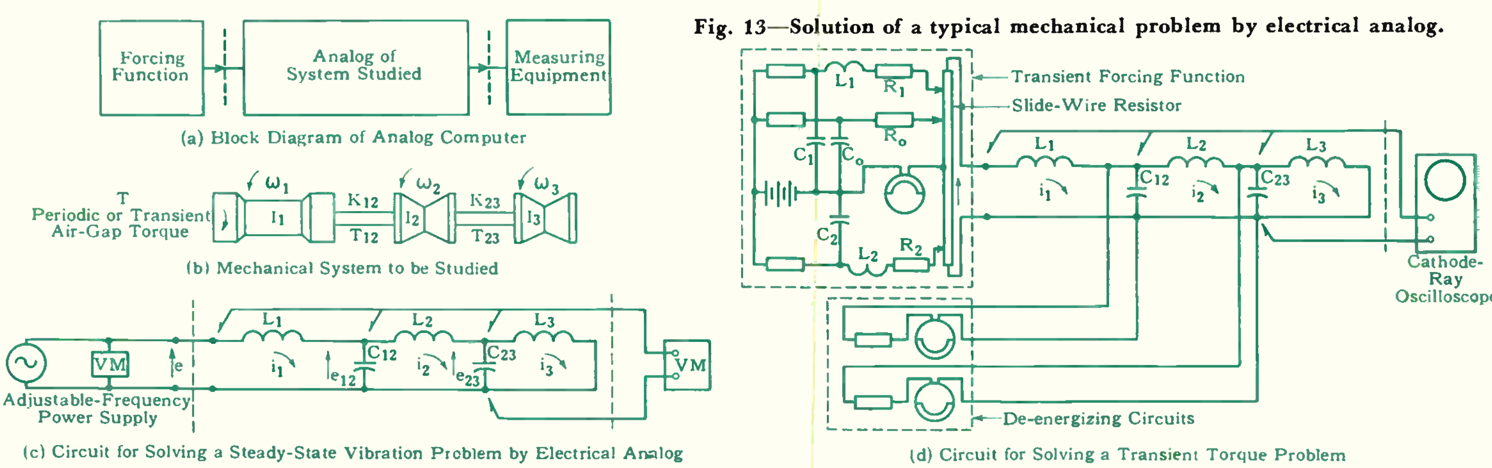


Fig. 13—Solution of a typical mechanical problem by electrical analog.

Stories of Research

Cathodes That Stay Put

A PROBLEM as old as the electronic tube itself is the need for a cathode that won't expand when it becomes hot during operation. Because the distance between cathode and grid plays a vital role in the performance of the thermionic tube, a change in this dimension while the tube is in use is highly undesirable.

This problem is especially critical in very-high-power (1000-watts output or more) tubes in the FM-television frequency (50 to 200 megacycles) range. Here the distance between cathode and grid may be only about 0.002 inch and even the minutest variation in this dimension causes serious fluctuations in power amplification and power-input requirements. Further, the range of cathode temperatures (up to 3300 degrees F) makes expansion effects of major concern.

Recently, Ralph O. McIntosh and Glenn E. Sheppard of Westinghouse Research Laboratories came up with what they believe is the answer. Working on the theory that if you can't prevent thermal effects in metal you may be able to control them, the two men have designed a cathode assembly in which all the expansion effects cancel out, so that the net movement of the cathode with respect to the grid is virtually zero.

In appearance, the cathode is a rigid sheet of tantalum, folded down at the sides to form a channel-shaped piece with the flat top facing the grid. Struts of tantalum, held in place by water-cooled copper blocks, give vertical support to the cathode. By careful calculation and experiment, McIntosh and Sheppard have determined the ideal shape and dimensions of a cathode assembly, in which all the forces tending to move it out of position cancel. Upward and outward expansions of vertical struts are "absorbed" by corresponding expansions of the cathode top. Any tendency of the top to buckle in the middle is prevented by the channel-shaped construction. The result is a cathode that can be heated uniformly and yet presents a completely flat, relatively motionless surface to the grid. This permits greater precision in control of the input power and amplification of the tube.

While on the one hand the tube engineer wants the closest possible spacing of cathode and grid for maximum amplification, on the other hand he is limited by undesirable capacitance effects that become more serious as this spacing is decreased. The new cathode assembly enables him to maintain the balance with a greater degree of accuracy and marks a noteworthy advance in the design of high-power television and FM tubes.

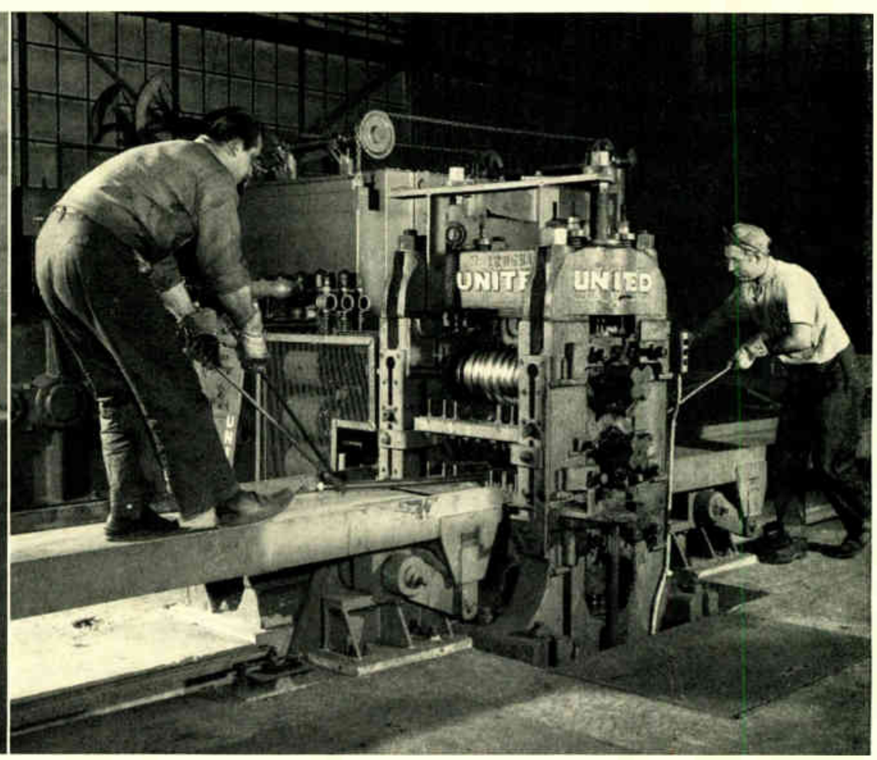
Super-Alloy Rolling Mill

IT IS recognized by metallurgists that as the high-temperature strength of heat-resistant alloys is raised, it becomes increasingly difficult to hot form them. While this problem can be alleviated somewhat by careful alloying, the fact remains that making an alloy more resistant to high-temperature stresses is almost synonymous with making it more resistant to deformation at forging and rolling temperatures. Consequently, the development of forgeable alloys for jet engines and gas turbines, where temperature and stress requirements are unusually high, has been severely limited by the facilities available for hot forming.

Metallurgists at Westinghouse Research Laboratories, where development of the so-called "super" alloys has been a major project, have rounded off several years of experimentation in the art of hot rolling with the design and installation of a mill that overcomes most previous limitations. It is a single-stand, three-high mill with 10-inch by 24-inch rolls that can produce hot-rolled rounds (from 1¼ to 2 inches in diameter) from 2¾-inch square billets. The rolls need be changed only once.

Research engineer Ralph O. McIntosh inspects the cathode assembly designed for high-power, high-frequency tubes.

The new rolling mill is a valuable tool in the further development of special high-temperature alloys.



Because of the careful design of roll passes and lifting tables and the application of lessons learned in experimental rolling, the new mill can roll alloys formerly classed as "unforgeable." Finished rounds require only a minimum of straightening.

Detection by Fission

The neutron is not only one of the most important nuclear particles, it is also one of the most elusive. Because of its neutral, uncharged nature, it defies detection by counters or recorders employing direct electrical means. Consequently, efforts to track it down have been aimed at recording it indirectly.

Doctors W. E. Shoupp and Kuan-Han Sun of the Westinghouse Research Laboratories have developed a detector that combines the fissionable qualities of uranium 235 with the simplicity and speed of the scintillation counter designed earlier by Westinghouse physicists. While the scintillation counter detects beta, gamma, alpha, and x-radiations, the Shoupp-Sun version, by the addition of uranium, has proved to be an excellent neutron detector as well.

The uranium is mixed with a transparent phosphor and coated on the surface of a phototube. Neutrons striking the film cause fission in the uranium, throwing out nuclear fragments. These collide with the phosphor, releasing a flood of light rays, which are collected by a mirror system and focussed on a photocathode. From here electrons are emitted, amplified in nine successive stages by the familiar photomultiplier process, and collected. Total amplification is about a million. The neutron fission pulses register as individual counts on an oscilloscope or on a counter, or as an integral reading on a meter.

The fission scintillator is an excellent neutron detector particularly because of its copious yield of signals and extremely high pulses. Neutrons detected near a cyclotron, for example, yield pulses 10 to 15 times higher than alpha pulses, which are themselves 10 to 15 times higher than beta pulses. These powerful neutron pulses are easily distinguished, which is particularly advantageous when other radiations are present in strength.

Although only U^{235} is used, the counter should work equally well with other fissionable materials, such as U^{233} or plutonium. The counter is designed primarily for slow neutrons. For fast neutrons, materials such as U^{238} or thorium can be used. Instead of using fissionable materials, common neutron-detecting agents such as boron were also tested with success. The pulses, however, were much smaller, similar to those of alpha particles.

Mapping Voltage Contours by Pantograph

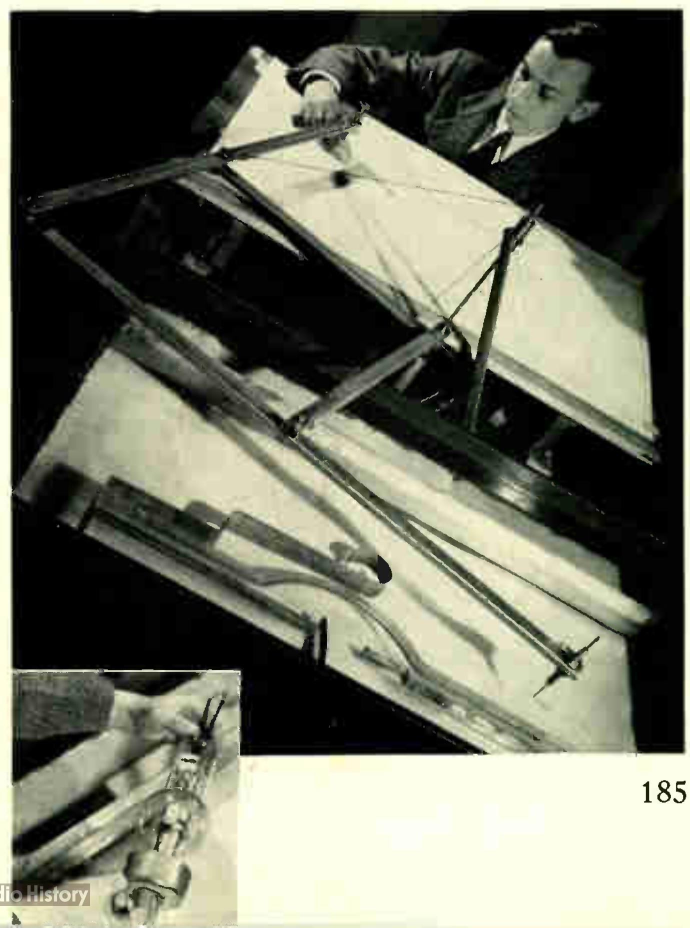
A pantograph system helps Dr. John W. Coltman of Westinghouse Research Laboratories to determine the ideal shape of the external shield for an x-ray rectifier tube. The apparatus gives a graphic picture of the voltage gradient and equal-voltage contours surrounding the tube. Thus, it tells where protection against breakdown must be strongest and establishes the shape of the tube shield.

The equipment consists of a pantograph, a drawing of the tube under investigation, metal electrodes (which follow the configurations of the tube), two conducting solutions (in which the electrodes are immersed), and an electrical circuit. Two solutions of different conductivities represent the different dielectric constants inside and outside the tube, which is oil immersed in actual service. The barrier conforming to the shape of the glass envelope separates the two solutions physically but permits proper electrical contact between them.

Voltages corresponding to the operating potentials of the tube are placed on the metal electrodes. The scientist, in searching for the contour of a particular voltage, moves the tracing point of the pantograph about the area surrounding the drawing. The conducting needle follows his movements through the solution. This needle is connected to an electrical detector circuit, which measures the difference in potential between the needle probe and a calibrated potentiometer set to read zero for the voltage sought. When the probe reaches a point in the solution at which the potentiometer reads zero, the potential at that point is equal to the voltage desired. This point is then marked on the drawing. The scientist then probes for another point and the process is repeated until the complete contour for that voltage is traced. The potentiometer circuit is reset and the contour of another voltage is plotted on the drawing in like fashion.

Dr. Kuan-Han Sun inspects the neutron detector. The white coating on the phototube is the uranium phosphor.

Dr. Coltman is using the pantograph system to trace voltage contours. Rectifier tube, minus shield, is shown in inset.



Locomotives

Reciprocating steam locomotives still predominate on American railroads in all types of service.

At the end of the first hundred years of railroading only two types of locomotives had been developed—the reciprocating steam and the electric. Now, two decades later, we have several—Diesel-electric, geared steam-turbine, and steam-turbine-electric. The near future promises the gas-turbine-electric; eventually utilization of atomic energy may be possible. The reasons for each type of locomotive, and the merits of each, make a fascinating story of a progressive transportation industry that results from a vigorous imaginative technology.

H. E. Dralle, *Manager,*
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Westinghouse Electric Corporation
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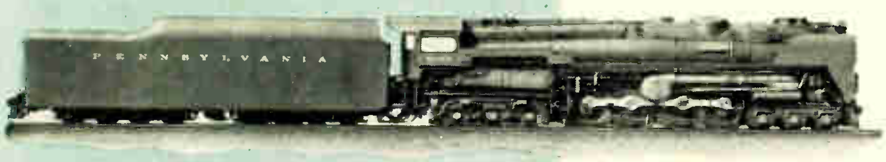


The S-2 geared locomotive proves the practicability of steam turbines for locomotives.

One of the C & O's three 6000-hp steam-turbine-electric locomotives for fast service between Washington and Cincinnati.

A 6000-hp (three 2000-hp units) Baldwin-Westinghouse diesel-electric locomotive for passenger and freight service.

A 4620-hp GG-1 electric locomotive on the PRR, for use in freight and passenger service.

For more than a century railroads have been the main arteries of American industry and commerce. Today they are carrying over three quarters of the nation's goods and passenger traffic, and for a long time to come will remain our chief means of transportation. There is a wealth of evidence that over the years the railroads have been progressive in thought and action, but nowhere is this more striking than in the field of motive power. The railroads and manufacturers together have undertaken numerous locomotive developments, involving long periods of time and large sums of money. Not only have they sought entirely new types of motive power, but also they have waged an aggressive campaign to improve the steam locomotive.

Although the reciprocating steam locomotive has undergone so many improvements and radical changes that it bears but small resemblance to its ancestors, it has remained the same in its fundamental principles of operation. It is today a highly reliable machine, equally at home in passenger, freight, or switching service.

The most distinctive feature of the modern reciprocating steam locomotive is its high-capacity boiler. The largest passenger locomotives develop from 6500 to 7000 cylinder horsepower while freight locomotives develop nearly 8000. Operating efficiencies, however, are low—between seven and nine percent.

Today, reciprocating steam locomotives frequently make runs of 1000 miles and they show high availability with monthly mileages averaging from 15 000 to 28 000. When supplied with good coal and water, and given the benefit of high-quality servicing and maintenance, they are establishing enviable operating records. As a matter of fact, such records are not possible without them.

Economics dictate a gradual decline in use of the reciprocating locomotive, despite the fact that it provides the most horsepower per dollar of initial investment. Competitive forms of motive power are challenging the supremacy of the reciprocating steam locomotive, but the day is still distant when it will cease to be a major factor in rail traffic. Whether or not it will ever completely disappear is debatable.

Other Developments in Coal-Burning Locomotives

To satisfy a continuing high level of interest in coal-burning locomotives, efforts are under way to develop new forms of steam motive power. Two of these, the geared steam-turbine and the steam-turbine-electric, are already in existence and others are in prospect.

The geared steam-turbine locomotive, which eliminates many of the disadvantages of the reciprocating type while retaining its desirable features, was first introduced in 1944. It was designed for high-speed passenger or freight service. A geared drive allows small driving wheels, provides greater space for the boiler, offers flexibility in the selection of the wheel arrangements, operates with reduced steam consumption and higher efficiency, and, as it utilizes rotating rather than reciprocating parts, assures a minimum of mechanical trouble and low maintenance.

The geared-turbine locomotive, which is classified as the S-2, has a conventional boiler that supplies power to the 6900-hp "forward" and a smaller "reverse" steam turbine geared direct to the driving axles. The reverse turbine, de-clutched when the locomotive is operating in a forward direction, can supply the necessary torque for backing at low speeds any train the locomotive can haul forward. The turbine and gear power plant, easy to operate and control, converts heat energy to pulling power efficiently and, above all, is thoroughly dependable.

The S-2 is a milestone in locomotive design. It adequately demonstrates that the steam turbine is a practical and desirable form of prime mover for locomotives, thus making possible a new, more flexible form of steam locomotive—the steam-turbine-electric.

The steam-turbine-electric locomotive, of which three are in high-speed passenger service on the C & O Railroad between Washington and Cincinnati, employs a conventional coal-fired steam boiler, a steam turbine, and an electric transmission. All have accumulated extensive operating experience. The arrangement of these components is quite unusual. The coal bunker is located at the head end, followed by the operator's compartment, the boiler, and finally the turbine-generator power plant. Water is carried in a separate tender behind the locomotive.

Each giant locomotive, with tender, weighs slightly less than 600 tons when carrying 30 tons of coal and 100 tons of water, and is 153 feet long and 15½ feet high. Full horsepower over a wide speed range, small driving wheels that permit flexibility of arrangement and construction to give space and weight efficiency, and the ability to use coal as a fuel, are some of its many advantages.

At full load the single 6000-hp, 6000-rpm turbine of the power-generating unit uses 85 000 pounds of steam per hour at 290 pounds inlet pressure, 750 degrees F temperature, exhausting to air. The turbine is geared to two 2-unit, 580-volt, d-c generators supplying power to eight 620-hp traction motors on separate driving axles. These traction motors are the largest built for self-powered locomotives.

The overall efficiency of the steam-turbine-electric is not much greater than that of the reciprocating steam locomotive due, mainly, to losses in the several power transmission steps between boiler and wheels. However, thermal efficiency is only one of the factors entering into the appraisal of the real worth of a locomotive. Others include initial cost, direct operating expense, maintenance cost, developed power per ton, speed-tractive effort relationship, fuel cost, flexibility in handling traffic, and availability.

A steam-turbine-electric locomotive brings to steam motive-power practice those advantages of electric transmission that have contributed so much to the popularity of the diesel-electric. The power plant can be located in the main locomotive cab, free of restrictions encountered in direct mechanical connections to the drivers, and free of vibration and impact stresses common to reciprocating motions. Many axles can be drivers; a locomotive can have as many as 16. With the locomotive weight distributed over many wheels, starting tractive effort and running drawbar pull are high. Electric transmission enables constant horsepower to be delivered to the drivers over a wide range of locomotive speed.

Even with all of these advantages and features, the steam-turbine-electric locomotive as it stands is not the ultimate in steam motive power. Operating efficiency must be almost doubled to make it strictly competitive with other locomotive types. Little can be done to increase the efficiency of the traction motors, the generator, or the turbine prime mover. The answer seems to lie in having a more efficient boiler. Theoretically this can be accomplished in a design employing much higher temperatures and pressures (in the neighborhood of 900 degrees F, 600 pounds pressure) and larger grate area, resulting in a 30- to 50-percent fuel saving per horsepower. Development of such a unit is now under way and indications are that it can be made practical.

Steam at these pressures and temperatures is not practical with reciprocating locomotives, principally because of lubrication and packing problems. It can, however, be utilized advantageously by a turbine.

A steam turbine offers the only means of utilizing high temperatures and pressures. A locomotive equipped with an efficient, reliable, compact, high-temperature, high-pressure boiler should have a high availability and should be competitive in operating economy and performance with other modern types of locomotives. Although eventual success in obtaining such a locomotive seems likely, the development will be evolutionary rather than the result of a single effort.

Electric Locomotives

The electric locomotive was the first to offer real competition to the reciprocating steam type over 40 years ago. The operating performance of the electric locomotive leaves little to be desired, particularly on roads of heavy traffic density. It is unmatched in several respects.

1. High intermittent overload capacity (making possible high schedule speeds in heavy traffic density).
2. Elimination of shock and vibration incident to reciprocating motions (thus lowering track, roadbed, and motive-power maintenance).
3. Cleanliness and quietness of operation.
4. Minimum direct operating expenses.

Two systems of electrification are in common use—the a-c system, usually with a 12 000-volt trolley, and the d-c, with trolley potentials between 600 and 3000 volts. The relative merits of these two systems have been the subject of much discussion, but neither system has such outstanding advantage over the other than it can be unqualifiedly recommended for all electrifications. Actually, either provides excellent operation and each has ample background to assure its success for any installation; consequently, the choice between the two is largely controlled by local conditions and personal preferences.

The a-c system has the great advantage of a high-voltage trolley, which makes it economical to supply large blocks of power over long distances for heavy concentrations of traffic.

For a-c systems three types of locomotives have been built, the series-motor type, the motor-generator type, and the split-phase type. The a-c series-motor locomotive is well adapted to any application while the others are primarily best suited to slow-speed, heavy-grade service.

The best examples of the a-c series-motor locomotive are the Pennsylvania class GG1 and the New Haven class EF3. Nominally rated at 4800 horsepower continuously, these locomotives can deliver up to 9000 horsepower for short periods when necessary. An intermittent output in excess of the nominal rating can be delivered at the rail over the entire speed range of the locomotive. Coupled with this high output is a flexibility of control unmatched by any other locomotive type. The PRR class GG1 locomotive, in particular, has become a synonym for the best in high-speed passenger power.

Good examples of a-c split-phase locomotives are those on the Norfolk and Western and the Virginian Railways. The Virginian also uses motor-generator locomotives as does the Great Northern Railroad.

Progress is continuing on the development of locomotives for electrified roads. A new and larger 3-unit electric locomotive having a continuous rating of slightly more than 8400 horsepower is being planned. It will be fully 25 percent larger than the present largest electric locomotive in continuous rating and should be ideal for heavy freight traffic. All weight will be evenly distributed on 18 separately powered axles, giving this new giant great pulling power without wheel slippage, thus making it possible to maintain or improve present schedules without a second locomotive. For this new locomotive, new motors—smaller, better insulated and more efficient—will be used. Electric braking is employed to hold back trains on descending grades and to effect quicker stops with minimum mechanical brake wear. This locomotive, which can be built in standardized units, embodies almost a half century of experience and development.

The service records of electric locomotives in peace and in war have never been excelled. That they are not used more widely in this country is traceable to economics rather than to locomotive performance. High initial capital expenditure for a complete electrification is the main drawback to its immediate extension. In spite of this handicap, the important and interrelated problems of fuel cost and fuel reserves, coupled with demands for operating requirements that can be met only by electrification, may combine to accelerate its return to American railroads. Increasing availability of low-cost electric energy from water power and from highly efficient central-station generating plants using coal or even atomic energy as fuel are long-term favorable factors.

Diesel-Electric Locomotives

The diesel-electric locomotive, possessing many of the advantages of the straight electric, is currently the most popular of all types on American railways. It represents 95 percent of all current purchases of locomotives. The diesel-electric eliminates problems incident to water and coal, provides a smooth flow of power with simple control, is capable of long sustained runs without refueling, and has a high-efficiency prime mover. The diesel engine has the highest thermal efficiency of any existing power unit. This characteristic contributes to economy of operation and permits carrying fuel supply adequate for long-distance runs. Water-treatment problems are eliminated as water is used only for cooling purposes. Also, the idling and standby losses are low, compared to coal-burning locomotives that must maintain steam.

The electric transmission is really the heart of the locomotive. It has the inherent characteristic of a smooth, continuous and non-pulsating flow of power to the drawbar, eliminating starting shocks and track pounding. With simple control, the full horsepower of the engine can be utilized over the entire speed range of the locomotive. Like the electric, the locomotive weight can be used for adhesive purposes since the entire weight is distributed over a large number of wheels, any or all of which may be powered with electric driving motors.

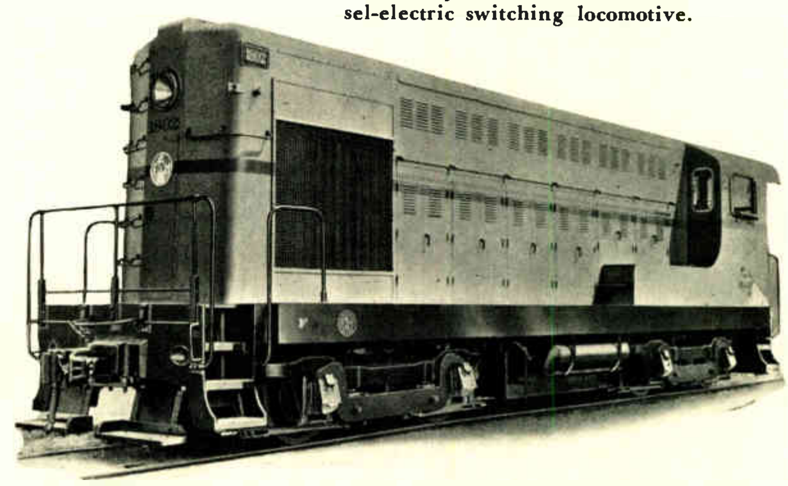
The diesel has found its widest usage and has gained its earliest popularity in switching service, where it has no equal from the standpoint of either performance or economy. Diesel engines of moderate capacity can be employed on switchers because the torque-amplification feature of the electric transmission permits using full engine horsepower at low speeds. High availability reduces the number of locomotives necessary. In addition, few facilities for servicing are required, so that initial investment is relatively low. Repair and fuel costs are also relatively low.

Manufacturers have standardized the design of switching locomotives to the point where three sizes satisfy practically all requirements of the railroads. The principal characteristics of these three standard units are as shown in table I.

For economy of manufacture and to provide maximum flexibility of application, diesel-electric road locomotives are made up of standardized power cabs or units of 900-, 1350-, 1500-, 2000-, or 3000-hp rating. A recent survey showed that these units are combined to form road locomotives approxi-

A 2000-hp double-end Baldwin-Westinghouse diesel-electric locomotive for suburban service.

A 1000-hp Fairbanks-Morse diesel-electric switching locomotive.



mately as shown in table II. Generally speaking, locomotives of 5400 to 6000 hp are used where grades are severe.

Locomotives made up of 2000-hp diesels are generally used in passenger service. Those using 1500-hp engines are more popular for freight service because greater motor capacity is provided in proportion to the diesel engine horsepower.

The demand has continually grown for increased horsepower in a single engine ever since the introduction of diesel road locomotives. Today locomotives employ engines having a maximum rating of 2000 horsepower, and more is desired. Unquestionably, this trend towards a greater concentration of power in a single engine will continue and with it will come higher engine speeds, decreased weight in engines and generators, and improved weight efficiency. This trend may well represent the most striking change in diesel-electric locomotives of the future.

Progressive development of designs and the efficient uses of new materials have permitted increasing the capacity of electrical equipment to the point where diesel locomotives are more nearly self-protecting against overloading. Efforts are continually directed toward producing the ideal locomotive—one in which there is a practical and economic balance between the factors of self-protection and excess motor capacity. This involves close coordination of the engine and electrical parts to permit working all equipment to maximum capacity. Continuing improvement in apparatus details are not in themselves particularly spectacular but are extremely important in locomotive work where they directly affect availability and maintenance.

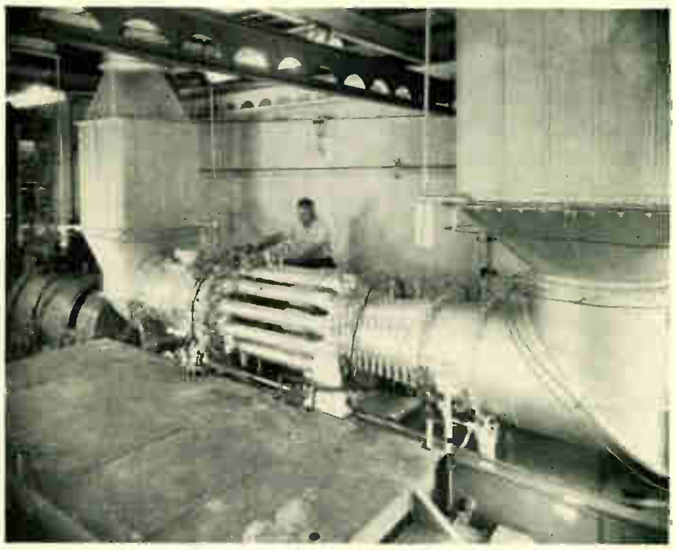
Gas-Turbine Locomotives

One might infer from the records of good performance of the electric, steam, and diesel locomotives, that there is no field for other types of motive power. Such is not the case.The search continues for something better, and the gas-turbine-electric locomotive now being energetically developed by many builders has exciting possibilities, particularly in the larger sizes of road locomotives. Several companies are actively engaged in the development of such locomotives, with some efforts being directed toward a coal-burning type and others toward a liquid-fuel type.

The gas-turbine locomotive has conspicuous merits. Larger horsepower can be concentrated in small space. There are no reciprocating parts and no troublesome shock and vibration problems of the type that reciprocating motion imposes. The amount of lubricating oil is materially reduced. The gas turbine can burn any kind of liquid fuel, although not with uniform efficiency. The unit requires no water and has no ash problem. The gas turbine is the essence of simplicity and compactness and offers unequaled accessibility for service. While the fuel economy of the present type is not as good as for diesel engines, the difference in fuel consumption is offset by its many advantages. The gas-turbine-electric makes possible the construction of locomotives with two thirds the weight and one half the length of present diesel electrics of similar horsepower rating.

A surprising characteristic of the gas turbine is that it de-

Artist's conception of a proposed steam-turbine-electric locomotive utilizing a high-temperature, high-pressure boiler.



The experimental 2000-hp gas turbine arranged for tests. Inlet and outlet are upward through the roof. Control and temperature-measuring leads extend to the instrument panel out of range at left.

TABLE I—CHARACTERISTICS OF STANDARD DIESEL-ELECTRIC SWITCHING LOCOMOTIVES

Engine horsepower	660	1000	1500
Total locomotive weight—tons	100	160	125
Overall length—feet	46	46	58
Weight per driving axle—pounds	50 000	50 000	62 500
Starting tractive effort—pounds—33 1/3 percent adhesion	66 700	80 000	83 300
Continuous tractive effort—pounds	34 000	34 000	42 800
Continuous speed—mph	5.3	9.0	10.5

TABLE II—POPULARITY OF DIESEL-ELECTRIC LOCOMOTIVE BY SIZES

Number Units or Cabs	Locomotive Horsepower	Percent Total Locomotives
1	1350–1500	8
1	1800–2000	10
2	2700–3000	19
2	3600–4000	14
3	4050–4500	20
3 or 4	5400–6000	29

**TABLE III—GENERAL COMPARISON OF ROAD LOCOMOTIVES

Factor	Reciprocating Steam	Geared Steam Turbine	Steam-Turbine-Electric	Diesel Electric	Gas-Turbine-Electric	Electric
First cost	1	2	4–5	4–5	3	6*
Direct operating expense	6	4–5	4–5	3	2	1
Probability of increase in direct operating expense	5–6	5–6	3	4	2	1
Overall efficiency (fuel to rail)	6	4	5	1	3	2
Probable long range fuel availability	2–4	2–4	2–4	6	5	1
Effect in changing the volume of freight traffic in coal	1–3	1–3	1–3	6	5	4
Output as affected by mechanical condition or fuel	6	4–5	4–5	2–3	2–3	1
Ability to handle increased traffic	6	4–5	4–5	2–3	2–3	1
Freedom from road failure	4–6	4–6	4–6	2	3	1
Length	4	3	5	6	2	1
Weight per hp	4	3	6	5	2	1
Maintenance	6	3–5	3–5	3–5	2	1
Time required for servicing at terminals	6	4–5	4–5	2–3	2–3	1
Availability	6	4–5	4–5	3	2	1
Flexibility for use in various localities	1–5	1–5	1–5	1–5	1–5	6

*Includes electric transmission system.

**All factors in this table do not have equal weight. Care should be exercised in referring to this table as the classifications given are general. For a specific railroad, the weighting of these factors could be materially different than shown. Also in generalizing, there are sufficient supporting data for only three of the locomotives listed (reciprocating steam, diesel, and electric). The remainder are based on judgment and predictions hinging upon performance of similar apparatus for other applications. More accurate comparisons must wait for further operational tests.

velops considerably more power in cold weather than in hot weather, because the air is of greater density. For example, a gas turbine that develops 2000 horsepower when the air is 80 degrees F, develops 2500 horsepower when the temperature falls to 10 degrees above zero. This characteristic makes this form of locomotive particularly suitable for operation in regions of cold climates.

The fundamental theory of the gas turbine was developed in the late 1800's. It was not applied more quickly simply because materials have not been available to withstand the high temperatures necessary to make the unit practicable. At 800 degrees F, the gas turbine develops only enough power to drive itself. Useful work is performed only to the extent that higher temperatures are used.

In the gas turbine the products of combustion are used directly in the turbine at temperatures well above 800 degrees F—the higher the temperature, the more efficient the operation. Complete fuel combustion must be obtained in the burners because a carry-over of liquid or solid matter rapidly erodes the turbine blades at these temperatures. The life of blading material is also affected by high temperatures. Of course, the higher the temperature, the shorter the life of the material. If the gas-turbine locomotive is to be successful these problems must be overcome, so that the life of the blading must be measured in years, not in hours.

The size of a turbine for a given output is intriguing. A 2000-hp power plant now on test and suitable for locomotive use is only 26¼ feet long, 3½ feet wide and 6 feet high. Two such units might be placed side by side in a locomotive, with a center aisle, permitting 4000 horsepower of prime mover capacity in approximately 26 feet of locomotive cab length. Each unit consists of a compressor, combustor, turbine, gear unit, and generator, assembled in that order from the compressor end. The overall weight is 39 000 pounds for a single gas-turbine power unit.

The gas turbine when used to drive its own compressor has no starting torque. Like the diesel engine, it must be started by auxiliary means. This characteristic compels the use of electric transmission, or two turbines, one to be used for traction. The first gas-turbine locomotive will employ the d-c system of electric transmission which is already proven by its performance in millions of miles of operation in diesel-locomotive service.

To be entirely practicable for locomotives, the service life of a gas turbine must approach that of the steam turbine, which has been perfected to the point of running for long periods without shutdown. When such gas turbines are produced, we can expect them to be a part of locomotives having high availability and low maintenance expense.

The 2000-hp gas turbine is easily adaptable for high-speed, heavy-duty passenger service. In a single cab weighing 225 tons, two such turbine-generator sets can be installed. These sets, placed side by side, consume less than 60 percent of the total cab length, leaving the remainder of the cab for other necessary apparatus. Two such cabs could be connected together to form an 8000-hp gas-turbine locomotive for heavy freight service. Gearing naturally can be applied to provide the proper speeds for the service required. Speeds up to 120 miles per hour for passenger service and 70 miles per hour for freight service are easily possible. With this type of locomotive, the weight per horsepower developed would be considerably less than that of other self-propelled locomotives.

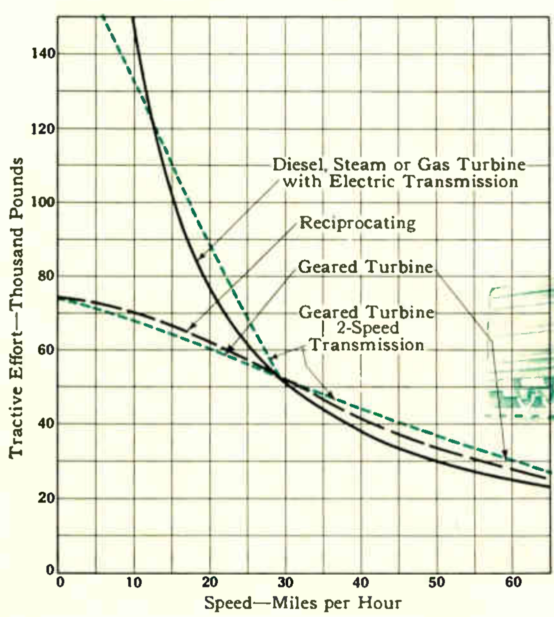
If coal can be used as a fuel, the gas turbine may become a serious contender to all other types of motive power. The burning of coal satisfactorily in a gas turbine is no easy problem and the solution is somewhere in the future. In the meantime oil will be used as fuel.

The gas-turbine locomotive will not be exceptionally low in cost. It will definitely be more expensive than steam power; probably more nearly that of diesel power. The prime mover is constructed from about the highest priced structural material known. Precision manufacture of all parts is required.

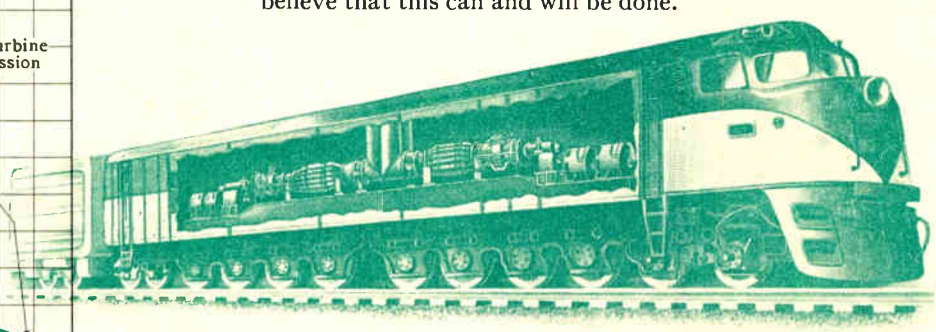
Activity on the gas-turbine locomotives is not limited to the type described. Two other forms are in prospect. One being developed by Bituminous Coal Research Corporation will use coal as a fuel and the other being developed by Lima-Hamilton Corporation will utilize a novel type of gas generator which will replace the conventional compressor and combustor and is expected to improve thermal efficiency.

The railroads, by meeting the five basic requirements of modern transportation—cost, speed, convenience, safety, and dependability will continue for a long time to come to be our chief means of transport. Existing motive power of all types will continue to serve the railroads and will undergo improvements and modifications. New forms may appear to meet changing times and conditions.

Costs, both initial and operating, thermal efficiency, horsepower per ton, speed, availability, overload capacity, fuel cost, and maintenance, are some of the more important standards by which locomotives are judged. Improvement of existing locomotives and design of new ones will be based on improving one or all of these factors. There is every reason to believe that this can and will be done.



Characteristic relationship between tractive effort and speed for various types of locomotives.



An 8000-hp locomotive could employ four gas-turbine power plants similar to the 2000-hp experimental unit, thus materially decreasing the length.

A Turbine for All Industry

Equipment is best when it can be installed and then forgotten. This is the objective of a new general-purpose turbine intended for use indoors or outdoors. Weather-protected construction and other features help make this possible.

W. Schmid, *Manager, General Purpose Turbine Engineering, Westinghouse Electric Corp., South Philadelphia, Pa.*

The principal actors in the drama of industry are the big machines. It is at these that the visiting layman and engineer stand and gape—at the smooth appearance and quiet efficiency of the turbine generator, at the tremendous raw power demonstrated by the steel rolling mill, at the wonder of the Fourdrinier that transforms a sludge of water and cellulose fibers into clean, smooth paper.

Behind the scenes are the stage hands—the auxiliary equipment—less spectacular but no less vital. And all important to the auxiliaries are their drives. One kind of drive is the general-purpose turbine, of which a new member (the type E) has recently been developed. It is suitable for almost every industry—power, steel, paper, chemical, petroleum, sugar, and many others.

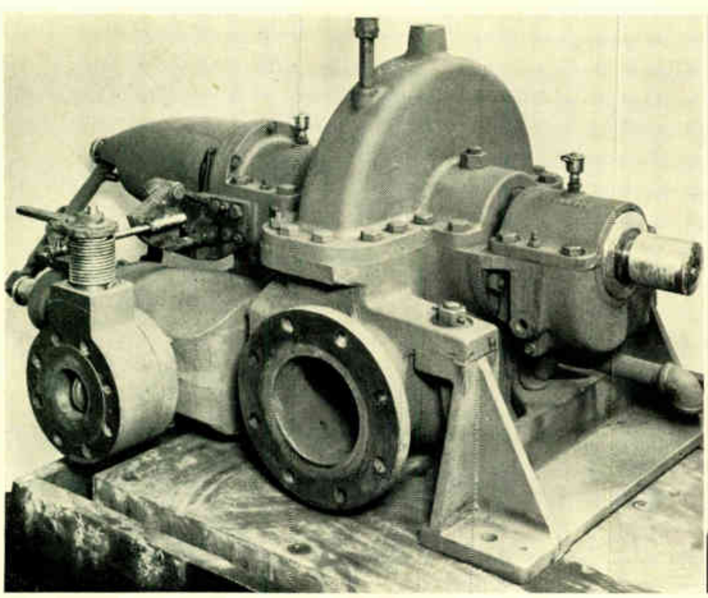
The requirements of the modern general-purpose turbines depend on the industry served. Operating environment is often far from ideal, varying from clean air, as found in power plants, to atmospheres laden with dirt, dust, moisture, and corrosive gases, as in paper mills, steel mills, and chemical plants. Outdoor operation, quite common in some industries, has imposed the additional ravages of sand, extreme heat or cold, rain, snow, and ice. The turbine must operate under such conditions for long periods of time without excessive maintenance or repair.

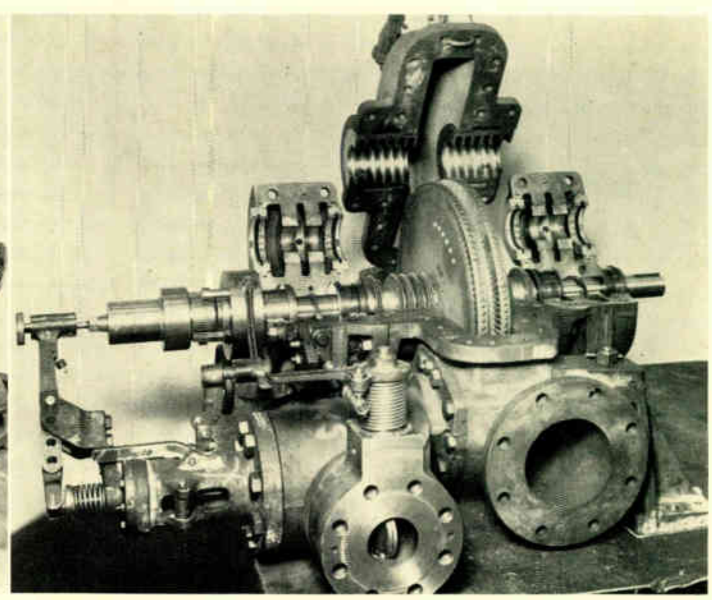
The design of the new general-purpose turbine is based on extensive research, field experience, trends in application, and the suggestions of operators. The type-E turbine is sturdily built and weather protected to withstand physical abuse and exposure to abnormal conditions sometimes encountered in industry. It is suitable for either indoor or outdoor operation. It replaces the type-C turbine.

The turbine is built in three different frame sizes and is available in ratings up to 1500 hp at speeds up to 7000 rpm. Maximum steam conditions are: inlet pressure, 1500 pounds per square inch; temperature, 950 degrees F; and exhaust pressure, 300 pounds.

The principle of center-line support employed for central-station turbines has been adapted for the type-E family. Two supports are used, a rigid one at the coupling end, which anchors the unit and permits radial expansion of the casing, and another at the governor end, which flexes readily in an axial direction only. Alignment to driven apparatus is maintained regardless of change of operating temperature because the supports are not a part of but are some distance from the turbine cylinder. Consequently, the temperature of these supports, and hence their dimensions, is substantially constant, and as a result alignment is maintained. This feature is important as even with constant initial steam temperature, each change in load or speed affects the exhaust temperature. In addition thrust from the piping is transmitted to the foundation with a minimum of casing distortion. This method of supporting the unit is an improvement over the center-line support systems generally used with auxiliary turbines. It combines complete freedom of casing expansion, the rigidity required to transmit piping loads efficiently to the foundation, and ability to maintain shaft alignment with driven apparatus.

The smallest turbine frame is shown in the external and cutaway views below. Cylinder glands, bearing seals, shaft governors, trip linkages, and other parts of the type-E family are interchangeable for all three frames.





General-purpose turbines are often used for standby or intermittent service. For such duty it is very important that the casing glands do not deteriorate, which causes excessive steam leakage and maintenance. Full protection against such a condition has been provided for by the use of corrosion-resisting materials for all the component parts.

However perfect the design of a gland may be, the sliding action of the shaft on the ring eventually causes it to wear and, as a consequence, the leakage through the gland increases. In many cases the additional loss of steam itself is not serious, but because the bearing housing is of necessity close to the gland, the possibility that condensed steam may enter the bearing is increased. To help prevent such an occurrence, the leakage across the outermost ring is minimized. This is accomplished by keeping the pressure drop across this ring to a very low value by the use of extra-generous leak-off spaces within the gland itself and large connections that safely conduct the leakage steam away from the gland housing. To assure proper piping and to facilitate installation, pipe connections from the two glands are brought out to a common, conveniently located point.

It is general practice in this kind of turbine to provide a valve, other than that under the control of the governor, that is closed automatically whenever the speed reaches a predetermined amount in excess of normal. Experience has indicated, however, that under adverse conditions such a valve is often not free to close.

As an additional safeguard against excessive overspeeding under such conditions, "dual overspeed protection" was developed. It consists of a simple mechanism whereby both the valve generally used for this service and that normally under the control of the governor are closed automatically, but independently of each other. This exclusive Westinghouse feature was first used on the type-C turbine and has been retained for this new unit. It has been improved to assure greater protection even under the most adverse conditions.

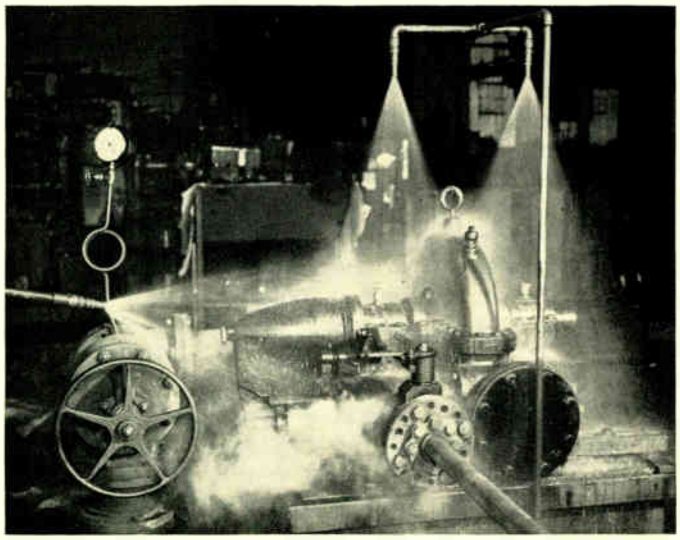
The expanding use of turbines outdoors has greatly increased the need for better bearing-housing seals and better drainage of the pockets between glands and bearing housings. The seals are made to exclude water and dust. To test the seals, a turbine was subjected to an artificial rainfall of 158 inches per hour for 24-hour periods. Afterward, jets of air, heavily laden with cement dust, were directed against the seals. The tests indicated that only the slightest traces of water passed the seals under these severe conditions and that dust was completely excluded.

After completion of these tests the turbine was left outdoors in an exposed location for nine months, from October until the following July, during which an unusually severe winter and exceptionally heavy driving rains were encountered. At the end of this period, the oil in one bearing housing was found to contain no water while the oil in the other analyzed only two percent, which was due to a damaged fitting. After the tests the overspeed trip linkage functioned properly.

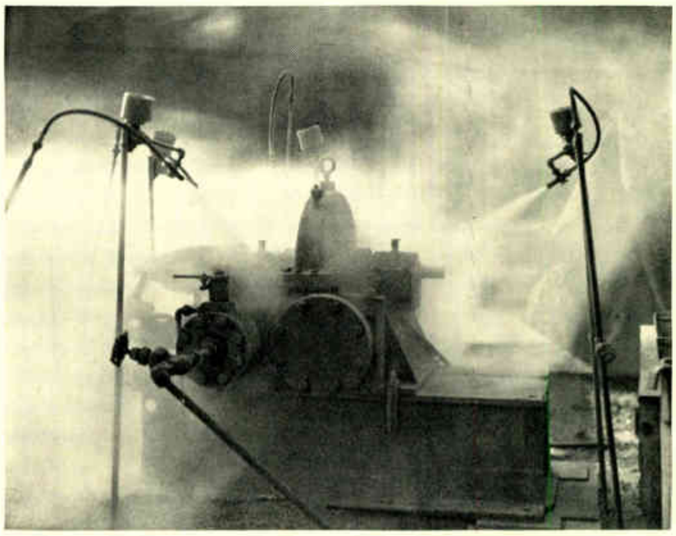
Studies and tests indicated that the method of supplying oil to bearings and distributing it over the journal surface could be further improved, in spite of superb past performance. Bearings for the new turbine are, therefore, quite different from those used previously. Casual observation will not reveal a noticeable difference in performance but tests have shown that local high temperatures have been reduced so that the bearing has a greater margin of safety. To obtain sufficiently high critical speeds (the critical speed must be greater than rated to prevent the possibility of vibration build up) the bearings must necessarily be close to the casing glands (in this case, the distance is about three inches). These glands attain a temperature almost that of the exhaust steam, which is sometimes as high as 600 degrees F or more. Considering their location (which is accepted as general practice) the bearings cannot be expected to be cool. Relatively, however, they are reasonably cool.

The use of high steam pressures and the extremely wide range of operating conditions encountered in industry today create a governing problem vastly more complex than that of a decade ago because they result in a wide spread of steam flow to be controlled by the governor. Years ago, when the operating and capacity ranges were much narrower, a shaft governor could control the steam valve through a lever having a fixed fulcrum point, i.e., one ratio of governor travel to valve travel was sufficient. Twelve years ago, when the type-C turbines were designed, two such ratios were found to be necessary. Later, provision was made for three. Now, to accommodate present and future needs, the type-E turbine is provided with a governor lever that can be adjusted for any one of four fulcrum points. The result is an increased flexibility in application of the general-purpose turbine.

The ability of the type-E turbine to resist the elements was proved by these water . . . .



. . . . . . and dust tests. Analysis indicated little water and no dust in the bearings.



Personality Profiles

No one would ever accuse *C. E. Peck* of being the gabby sort. But in almost exactly 20 years with Westinghouse he has accumulated a fund of information about electric heat that equips him to answer questions in that field so easily that the questioner is prone to wonder why he didn't know the answer himself. Peck, a native of Pittsburgh, attended Carnegie Tech, where he obtained his degree as mechanical engineer in 1927. In 1928 he joined

Westinghouse, going first to the East Pittsburgh Works, where he took the mechanical-engineering design course. Peck joined the Power Engineering Department, working on heat-flow and ventilation problems of large a-c and d-c generators, working at the direction of such renowned engineers as Soderberg, Fechheimer, and McCarty. In 1935, soon after the controlled-atmosphere electric furnaces began to be an important tool, the Industrial Heating Section was formed—with Peck in the middle of it. In 1936 he became its manager. Peck's career spans almost the entire development and growth of controlled-furnace atmospheres. Two of the basic gases, Monogas and Endogas, developed under his aegis.

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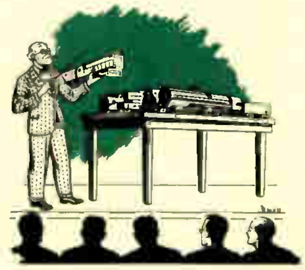
As far as engineering experience is concerned, *H.E. Dralle* has now "completed the cycle." Following graduation from the University of Illinois in 1916 (B.S. in E. E.) he dealt with electric mining locomotives. Now he is Manager of the Transportation Application Section, in which locomotives play a major part. In between, however, lies a career full of varied engineering and selling experiences.

After his early locomotive experience, he turned to arc welding (then in its first stages) and electrification of machine tools. During the first World War he was a member of the staff of the late Dr. Frank Conrad, Westinghouse Chief Engineer, and worked on such problems as the development of meters, hand grenades, and the first spark radio transmitter for planes. Petroleum engineering next became his work and in 1926 he toured the European and East Indian oil fields to assist in their electrification. By the end of his trip Dralle had studied, firsthand, petroleum production and refining problems.

His original interests found application when he became Manager of the Transportation Application Section in 1945. Dralle's varied but thorough experience has still left him time to acquire the knack of swinging a mean golf club.



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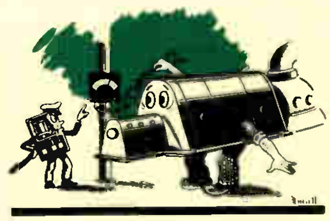
Making his second appearance this year, *C.E. Valentine* has come up with another article on his favorite subject—regulators. Small controls have always fascinated him, from the time of his undergraduate days in Lowell Institute, M.I.T., right up to the present. One of his first jobs after joining Westinghouse in 1923 was to help with the controls for the famous mechanical man, Televox. Valentine worked in the Automatic Substation Equipment Section until 1928 when he was placed in charge of the development of switchboard devices. In 1935 he became manager of a newly formed department handling voltage regulators. Under his able direction, such things as the Silverstat and the Rototrol (for excitation control) have been developed.



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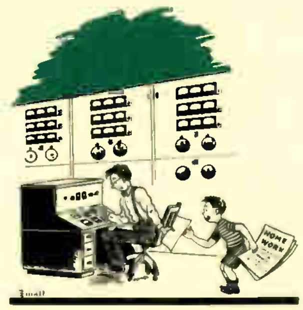
The complexities of large-scale calculators are boiled down to simple engineering terms by Doctors *G. D. McCann* and *E. L. Harder*. Dr. McCann left Westinghouse in 1946 to return as Professor of Electrical Engineering to California Institute of Technology, from which he received his master's degree in 1935 and his doctorate in 1939. While at Westinghouse, McCann, who helped devise the mechanical-transients analyzer, spent much of his time investigating lightning. To study this phenomenon, McCann and his associates created several special devices: the automatic cathode-ray oscillograph and the photographic surge recorder. Armed with these, he climbed skyscrapers and transmission towers to collect a mass of valuable information that helped to make him an internationally recognized authority on lightning and its effects.



Dr. Harder is unusual among engineers in that he can visualize physical significance in an abstract mathematical equation and then convert it into something practical. His vision, in one case, resulted in the transformation of a set of equations involving symmetrical components into a simplified pilot-wire system (the HCB) that appeared about ten years ago; in other cases, in some 40-odd patents. Harder joined Westinghouse in 1926 after graduating from Cornell and has since been engaged in problems concerning railroad-electrification networks, regulator design, and systems of relaying. Dr. Harder had a banner year in 1946. He received his Ph. D. from the University of Pittsburgh, was made Consulting Transmission Engineer, and was placed in charge of the Anacom and other research.

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When *W. Schmid* completed his mechanical-engineering training at Cornell the first World War was about over. He first worked with a shipbuilding company but it soon became evident that the prospects in this field were not too rosy at the time. Schmid cast about for something more stable. He selected steam turbines. Now, 30 years later, he is still with them and going strong. He first learned about turbines from the service viewpoint. Six months he spent installing and servicing turbines for Westinghouse, then moved, in 1920, to the manufacturing plant in South Philadelphia, still on service. After three years, Schmid changed to design and has continued in this activity becoming head of his group in 1930.

Destined to increase production of steel, this double helical gear (being hobbed) will serve as the pinion of a rolling-mill drive.