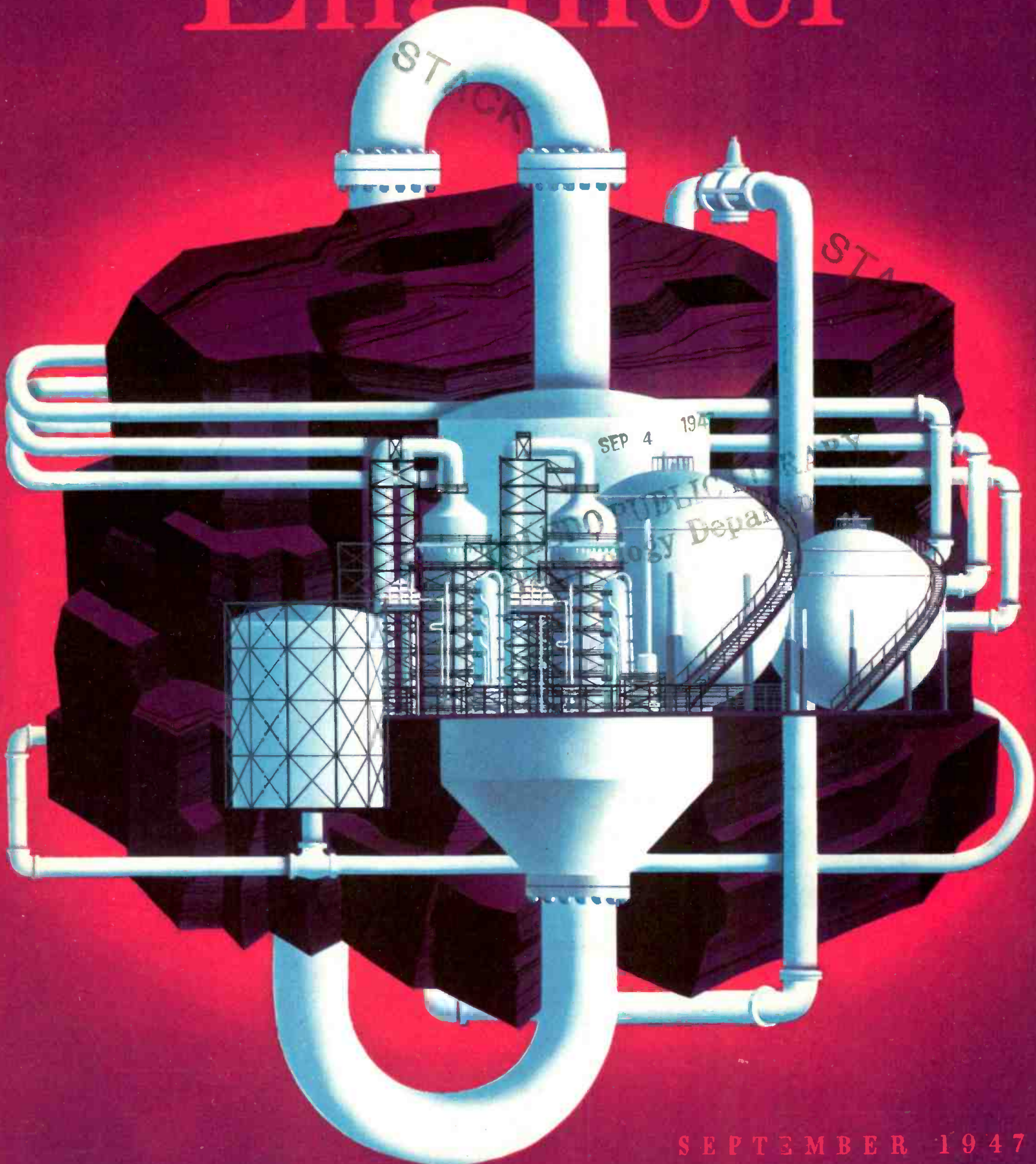
WESTINGHOUSE

Engineer



SEPTEMBER 1947

HYDROGEN—*Supreme Coolant*

Hydrogen is likely to remain unchallenged as a cooling gas for large high-speed rotating machines by virtue of not one but several qualities with which it was endowed when the universe was organized. Most important is its low density. It is the lightest of all substances, being only one fourteenth that of air, and half that of helium. Windage loss in large high-speed rotating machines is the greatest of the several losses, being about one half of the total. Because windage loss is nearly proportional to the density of the atmosphere in which the rotor turns, this loss for a given machine filled with hydrogen is reduced to seven percent of that obtained with cooling air of the same pressure.

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But the account for hydrogen adds up even better than that. Among potentially usable gases, hydrogen tops them all in ability to transmit heat. Its thermal conductivity is seven times superior to air. In this respect it is closely approached only by helium, with a conductivity six and a half times better than air.

The ability of hydrogen to conduct heat rapidly from hot surfaces of windings to the metal walls of the heat-exchange enclosure is obviously of great value to the machine designer. Also, this property means that heat passes more readily through the gas space between the coils and slots.

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Laminations of magnetic iron, no matter how tightly compressed, have thin layers of gas between them. These impede the flow of heat across the steel. Because of the superior conductivity of hydrogen the heat conductivity across a block of iron laminations runs about three times better in hydrogen than in air. Also the thermal drop at the surface of laminations surrounded by hydrogen is only one half the drop obtained if the gas were air.

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Aside from its advantageous thermal properties hydrogen helps thwart damage from corona. The deleterious effects are virtually eliminated because of the absence of oxygen. Additional advantages include reduced windage noise, increased life of insulation, and reduced maintenance because of the absence of dirt and moisture.

Hydrogen is now tacitly accepted as the superior cooling medium for large high-speed rotating machines. But this has not always been so. Hydrogen cooling had its beginnings in the middle twenties. In 1923 Max Schuler of Germany obtained American patent rights for a method of cooling rotating machines with hydrogen. Both Westinghouse and General Electric assumed licenses and began intensive development of hydrogen controls and of shaft seals.

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Hydrogen of commercial purity is used for generator cooling. This means that it contains a small percentage of oxygen and other gases. This, however, has only a small adverse effect on the cooling qualities of the gas and introduces no hazard as the oxygen content is well below the 30 percent allowable with safety. Experience bears this out.

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Hydrogen cooling was first applied to synchronous condensers because the problem of leakage prevention was simplified by the absence of protruding shafts. Westinghouse placed two 15 000-kva hydrogen-cooled synchronous condensers in service in 1930, one in Indiana and the other in California. Meanwhile intensive development of shaft seals had been prosecuted. A 7500-kva, 3600-rpm generator was tested at East Pittsburgh in 1928 and another of like rating in 1930. On the experience gained with these machines was laid the foundation for the Company's present hydrogen-cooling system. Extensive application of hydrogen cooling to generators did not begin until about 1936 because of almost complete absence of generator construction in the period from 1930 to 1936. Now all generators above about 15 000 kw are hydrogen cooled, the lower limits being not rigidly fixed.

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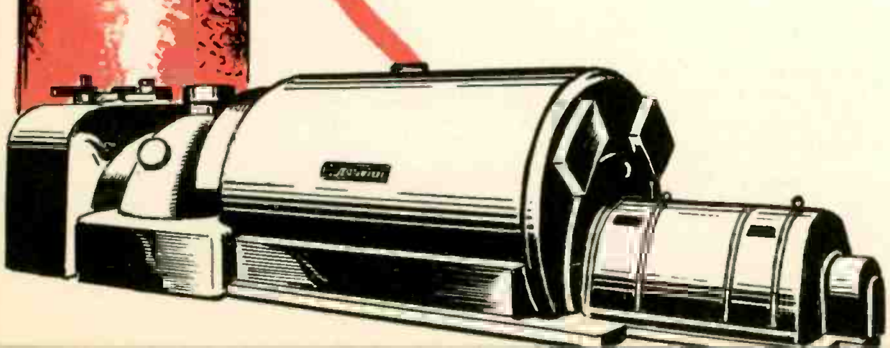
For two decades now the changes in hydrogen-cooling systems have mostly been in the interest of piping simplicity and ease of control. An additional development has been the raising of the hydrogen pressure from one-half pound gauge to 15 pounds gauge for emergency overload operation. This doubling of the gas density increases the windage loss but improves the heat transfer rate so that the net effect is an increase of approximately one sixth in load capacity of a given machine.



WESTINGHOUSE
Engineer

VOLUME SEVEN SEPTEMBER, 1947 NUMBER FIVE

On the Side

The Cover—A lump of coal is becoming less and less an end product and more and more the raw material for plants that convert it to better forms of solid, liquid, and gas fuels and to myriads of chemicals. This fact, discussed at length in this issue, is the theme of the artist, Richard Marsh.

• • •

Competition for the seventh annual Westinghouse-sponsored Science Talent Search has been announced. High-school seniors anywhere in continental United States who will graduate before October 1, 1948 are eligible. Each contestant must submit an essay on some personally explored science subject and compete in a nationally conducted examination on December 1, 1947.

The forty national winners receive a free trip to Washington, D. C., and will have an opportunity to compete for a total of $14 000 in scholarships. Equally important to all contestants is the attention focused on them by their standing in the contest. In six years, more than 1600 have received scholarship awards, in addition to the Westinghouse Science Scholarships themselves. The annual contests have proved increasingly popular.

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Add to the growing list of robots a new machine for automatically dispensing a freshly mixed drink of Coca-Cola. The machine on receiving a nickel, dime, or quarter, makes change and provides a paper cup, which is filled on the spot with accurately mixed, cold, charged water and sirup. The dispenser has cups, sirup, and refrigerated charged water for a thousand drinks without servicing.

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In This Issue

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Two and a half years ago these pages carried a story under the parallel title, "Why a Geared-Turbine Steam Locomotive." It was prophesied that the steam turbine would also appear in another locomotive form—as a turbine-electric drive. That promise has materialized. The first of three 6000-hp turbine-electric steam locomotives for the Chesapeake & Ohio Railroad was displayed in late June at Atlantic City and the second and third are being assembled.

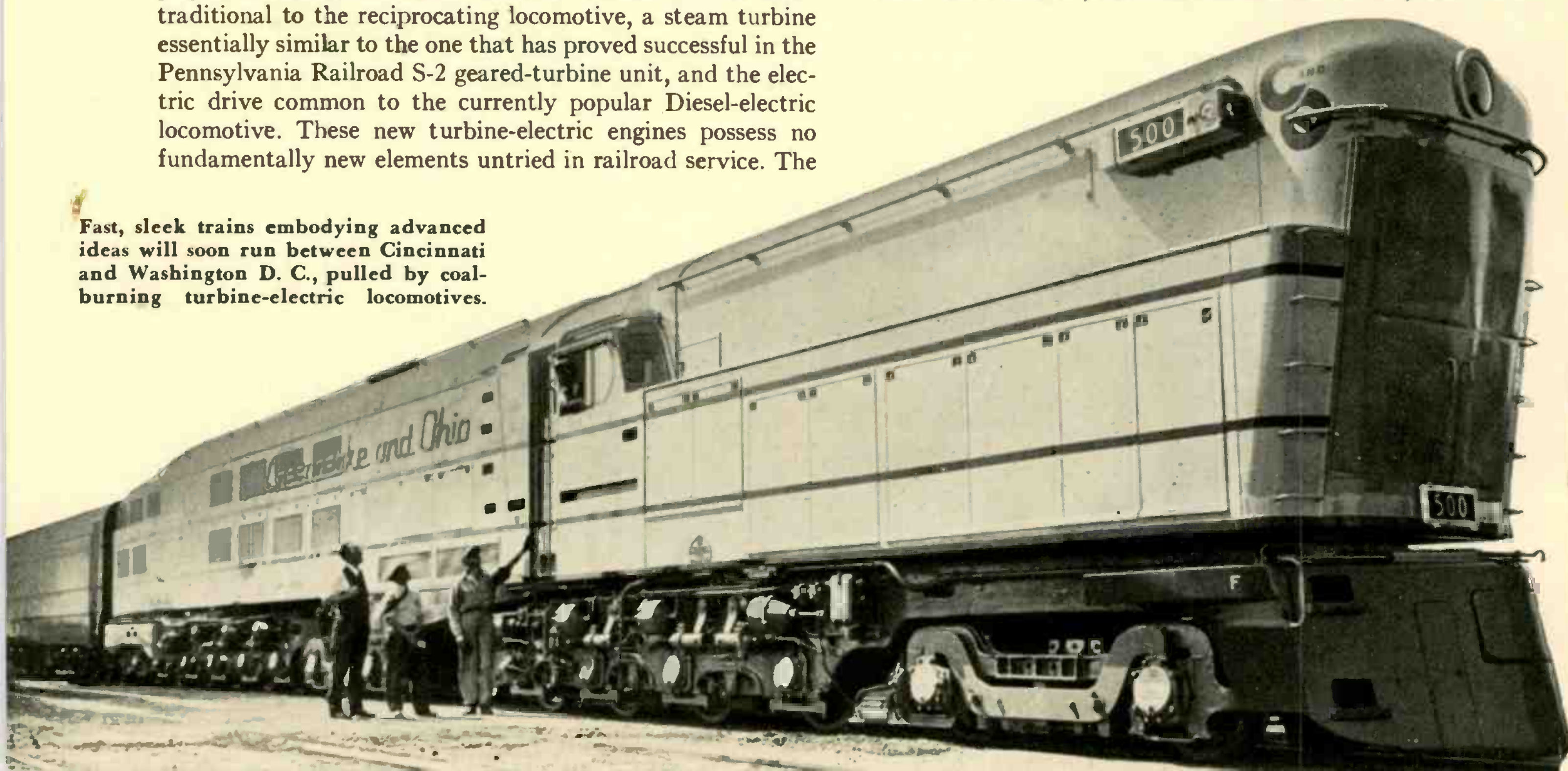
Why a Turbine-Electric Steam Locomotive

Charles Kerr, Jr. • *Consulting Transportation Engineer* • *Westinghouse Electric Corporation*

The family of practical types of main-line locomotives is growing. Until about the turn of the century the locomotive family consisted of a single member—the reciprocating steam engine, now well past being a centenarian. First there came the electric locomotive, followed a decade ago by the Diesel-electric, and three years ago by the geared-turbine steam unit. And now we have the coal-burning turbine-electric steam locomotive. On the horizon can be seen still another—the gas-turbine-electric locomotive. The situation in railroad motive power is by no means static.

These Chesapeake & Ohio locomotives are the first materialization of the country's coal-burning turbine-electric steam-type of motive power. They represent, in novel arrangement, a combination of elements all previously employed on locomotives. Each has the coal-fired steam boiler traditional to the reciprocating locomotive, a steam turbine essentially similar to the one that has proved successful in the Pennsylvania Railroad S-2 geared-turbine unit, and the electric drive common to the currently popular Diesel-electric locomotive. These new turbine-electric engines possess no fundamentally new elements untried in railroad service. The arrangement of these components, however, is unusual. At the front is the coal bunker, followed, in succession, by the operator's compartment, the boiler, and finally the turbine-generator power plant. Water is carried in a separate tender behind the locomotive.

The rightful place of the turbine-electric steam locomotive in the railroad scene will depend on its operating performance at different speeds and loads, efficiency, availability, maintenance requirements, first cost, and other factors important to railroad operators. Obviously some time must elapse before these can be set down with clarity. However, because this type of motive power represents a combination of basic proven locomotive elements, general appraisals can be made of the goals sought for it by the technical staffs of the Chesapeake and Ohio Railroad, Baldwin Locomotive Works, and West-



Fast, sleek trains embodying advanced ideas will soon run between Cincinnati and Washington D. C., pulled by coal-burning turbine-electric locomotives.

inghouse who conceived and executed it. Briefly the turbine-electric locomotive assumes some of the performance colorations of all types. Being a steam locomotive it can burn coal, which makes it attractive to railroads traversing coal regions. Its starting and high-speed tractive-effort characteristics are superb, and correspond to those of the Diesel-electric locomotive. With regard to thermal efficiency, simplicity of operation, and freedom from reciprocating forces it closely resembles the geared-turbine locomotive.

These locomotives will haul new ultra-modern high-speed passenger trains between Washington and Cincinnati on fast schedules. The territory traversed abounds in an excellent coal supply. It also embraces both long stretches of heavy mountain territory in the eastern portion and high-speed level track territory in the western end. The turbine-electric locomotive with coal as a fuel is an ideal combination to serve this region. Although the locomotives are intended for high-speed passenger service, the turbine-electric principle is extremely well suited to all types of freight operation.

The propulsion equipment was designed to operate with a conventional fire-tube boiler and at pressures and temperatures commonly used with such boilers. The turbine receives steam at 290 pounds pressure and 750 degrees F total temperature. The turbine develops its rated 6000 hp when supplied with 85 000 pounds of steam per hour, exhausting to atmosphere, and when operating at 6000 rpm. Geared to the main turbine are two double-armature, direct-current generators, operating at a maximum speed of 1000 rpm, which supply power to the eight axle-hung traction motors that furnish main propulsion power, two motors being permanently connected in parallel across each generator armature.

Speed of the locomotive is controlled by a variation of the generator excitation and the main turbine speed, the combination producing the maximum overall efficiency and simplification. The turbine and electrical equipments are described in greater detail in the accompanying discussion by Messrs. Putz and Baston.

The expected performance of the turbine-electric steam locomotive is compared in general terms with that of reciprocating engines, geared-turbine locomotives, and Diesel-electric locomotives of similar rating by the curves of Figs. 1 and 2.

The electric transmission of the Diesel and the turbine electric provides considerably better tractive-effort performance in the low-speed range at some sacrifice in output at the higher speeds. With the geared and electric types built for a maximum speed of 100 mph, the point at which the curves cross is between 40 and 45 mph. Fundamentally, the geared-turbine locomotive is better suited for territory where few severe grades are encountered and where high-speed operation predominates. With it, the losses incident to electric drive are avoided, but the absence of the torque-conversion characteristics of electric transmission handicaps both its starting and low-speed performance.

The turbine-electric and the mechanical-drive turbine systems each has its advantages and limitations. The turbine-electric drive is somewhat heavier, mainly because of the d-c generators. However, the electric-drive turbine runs continuously, in the same direction, never slower than 60 percent of rated speed. This means much reduced steam demand on starting. The mechanical drive requires a separate small turbine and clutch for reverse operation. As compared to the mechanical-drive Pennsylvania locomotive, which has all the power applied to four pairs of drivers, the C & O locomotives have power on eight axles.

Electric drive increases the overall flexibility of the locomotive. High starting power is provided for severe grades, ample tractive effort at the lower speeds is furnished for hauling heavy trains over these grades without helpers, and, in locomotives of this size, sufficient power still exists in the upper speed range to handle the desired tonnage at any permissible operating speed.

Many factors must be taken into consideration to determine the choice between the types of drive. Generalization may lead to incorrect conclusions. However, gear drives offer advantages for roads that normally encounter few severe grades and can be successfully operated by locomotives with relatively few driving axles. Turbine-electric drives, in turn, are attractive where operating conditions require locomotives with a multiplicity of driving axles and a considerable portion of the total locomotive weight on drivers. As a corollary to this line of reasoning, the turbine-electric locomotive also offers attractive possibilities as a heavy-duty freight unit where as many as sixteen driving axles can be provided in a single locomotive.

In all major respects, the operating performance of the turbine-electric should correspond exactly with that of a Diesel equipped with prime movers of identical capacity, the same number of driving axles, and geared for equivalent maximum speeds.

The Diesel and the turbine with electric drives have exactly the same tractive-effort curves, Fig. 2, if equipped with equivalent electric transmission. The maximum tractive effort of either is limited by motor and generator capacity and weight on drivers. Mechanical-drive locomotives are at a disadvantage at low speed, because of the absence of torque-converting drives, but are better at high speed as a result of superior drive efficiency. There is, thus, no single "best" type of locomotive.

The turbine-electric steam locomotive should introduce no new maintenance problem. The servicing required of conventional modern boilers is well known to railroad men. Maintenance of electrical equipment will correspond to that of the Diesel type. The turbine-electric has no slow-speed reciprocating parts. The turbine should add but little to the maintenance program. Industrial and central-station turbines are singularly free from maintenance difficulties. This seems likely to carry over to locomotive practice inasmuch as the Pennsylvania geared-turbine locomotive has operated for more than two and a half years with complete absence of turbine troubles.

With the turbine-electric locomotive, vibration and track-pounding forces will be absent, as with the geared-turbine unit. It should provide easy, smooth starts as does the Diesel-electric locomotive. Its operation will require no skills new to railroad practice.

The Chesapeake & Ohio locomotives are rated at 6000 hp, which meets the proposed high-speed passenger requirements

TABLE I—COMPARISON OF TURBINE AND DIESEL LOCOMOTIVE TYPES*

	Turbine Electric 6000 hp	Geared Turbine 6900 hp	Diesel Electric 6000 hp
Total weight loaded—lb	1 194 800	992 900	1 005 000
Weight or drivers—lb	508 000	260 000	696 000
Total wheelbase—feet	140	108	182
Starting tractive effort—lb	98 000	70 500	174 000
Continuous tractive effort—lb	48 000	—	79 200
Prime mover horsepower for traction	6 000	6 900	6 000
Maximum rail horsepower	5 100	6 550	5 100
Locomotive weight—lb per hp	199	143	168

*These figures are on the basis of eight powered axles for the turbine electric, four for the geared turbine, and three cabs with twelve powered axles for the Diesel electric.

of that system. Turbine-electric locomotives both larger and smaller could be built although it appears that the steam-turbine locomotive with either mechanical or electrical drive is best suited for large-capacity motive power. The smallest size that now seems likely to be feasible is 3000 to 4000 hp. The upper limit of horsepower is for all practical purposes set by the boiler, not by the propulsion equipment. Single steam turbines of considerably larger rating or two or more units of medium size could be employed to meet the requirements of a particular railroad.

For years, boiler designers have been studying the application of higher pressures and higher temperatures for locomotive use. A successful turbine drive should hasten their development because it can capitalize fully on the advantages of higher steam pressures, lower back pressures and higher temperatures. Locomotives of this type, when high-pressure boilers arrive, will provide motive power with still lower fuel expense and higher efficiency.

The operating characteristics of the turbine electric make it a worthy form of motive power for any type of service, passenger or freight, where locomotives of large capacity and high tractive efforts are required. The performance outlined herein is, it should be remembered, for the first of this locomotive type, hence does not represent the maximum that can be expected from future models. It is hoped and anticipated that the operating performance of these locomotives, soon to enter service following their initial test runs, will encourage far greater use in both freight and high-speed passenger duty in the years to come of the coal-fired, turbine-electric type. The steam turbine, both mechanical and electric drive, definitely deserves consideration in the railroad-locomotive picture.

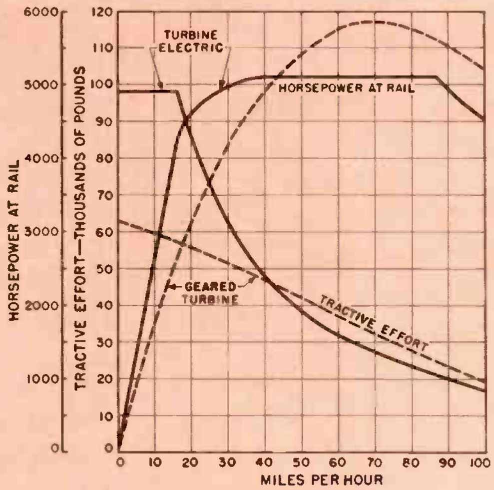


Fig. 1—Horsepower and tractive effort characteristics of steam-turbine locomotives (both the electric and mechanical drive) rated at 6000 hp and using identical boilers.

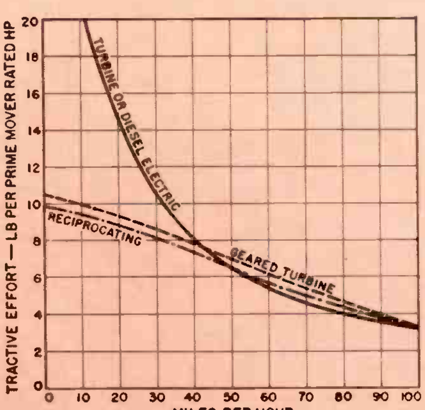


Fig. 2—Tractive efforts of four types of locomotives.

The coal-burning locomotive has powerful forces in its favor. This newest form, the turbine electric, combines several of the most desirable qualities of different locomotive types: it burns coal, it has the high starting tractive effort of the Diesel electric; it has the vibration-free performance of the geared-turbine locomotive; power is applied to several driving axles; its single cab is compact.

Power Plants for the

T. J. Putz
Manager, Gas-Turbine and Locomotive Engineering Steam Turbine Division

C. E. Baston
Locomotive Control Engineer Transportation & Generator Division

Westinghouse Electric Corporation

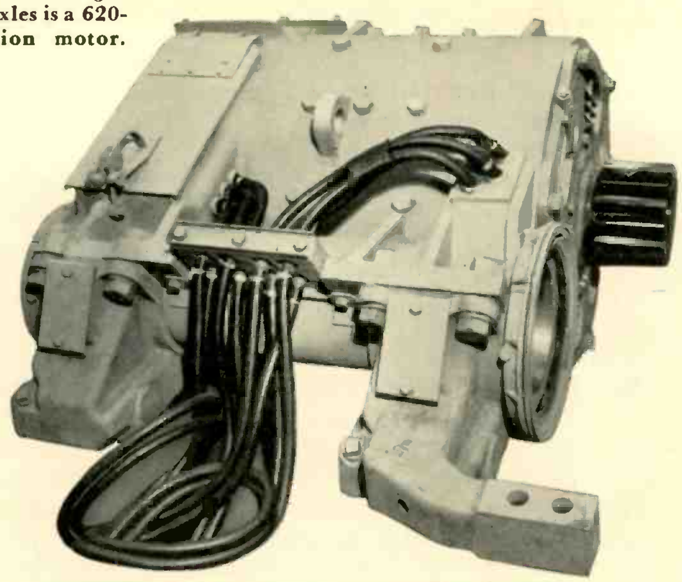
The main power plant of the C & O turbine locomotives is a single assembly consisting of the turbine, 6-to-1 reduction gear, and two double-armature generators. The turbine is coupled directly to a pinion that in turn drives two gear wheels each connected to a generator.

The single assembly for the power plant is at the same time an advantage and a necessity. Both space and weight were necessarily restricted. It was not practical to build the locomotive frame rigid enough to maintain satisfactory alignment of the rotating parts. This necessitated a self-contained assembly that is merely supported and restrained by the locomotive frame so no frame deflection is transmitted to it. The unit assembly is supported and restrained in the locomotive frame at three points, namely, two trunnions at the forward corners and a rubber supporting pad between the generators. This arrangement prevents stresses being transmitted to the units that might disturb the shaft alignments and also serves as support for all auxiliaries and the oil reservoir. Because of the complexity of the structure required, a one-quarter scale model was made and tested to prove the adequacy of the design for all possible inertia and torque conditions.

The *steam turbine* is of the impulse type. It consists of a velocity-compounded impulse-control stage followed by four full-admission impulse stages. Steam flows to the turbine through a seven-valve steam chest cast integral with the turbine-cylinder cover. Each valve is connected by a cored passage to a nozzle group that admits steam to a portion of the control stage. The valves are of the single-seated diffuser type all connected to a common lift bar. The individual valve stems allow opening the valves in sequence, thus minimizing the throttling loss at any opening. The governor-operated hydraulic piston raises and lowers the valve lift bar through a yoke and link. A mechanical strap-type transformer governor, which is driven from one of the low-speed gear shafts, positions the hydraulic operating piston.

The eight-inch throttle-valve, located on the side of the

Geared to each of eight driving axles is a 620-hp traction motor.



C & O Locomotives

steam chest, closes automatically on turbine overspeed. Also, it is fitted with an emergency quick-closing control operated from the cab. The throttle valve is connected with a single supply pipe from the superheater header that is located in the smoke box.

The turbine and gear employ babbitted sleeve bearings. The turbine and pinion shaft is positioned by a segmental-type thrust bearing located at the exhaust end of the turbine. Each low-speed gear-wheel journal bearing has a thrust collar that positions the gear and generator shaft.

Built into the gear-case assembly is an oil reservoir of approximately 200 gallons capacity. A portion of the oil is required to operate the governor. The remainder is reduced in pressure through an orifice and is used to lubricate the journal bearings and gears. For starting, an oil pump driven by a separate steam turbine provides oil for governor operation, bearing lubrication, and gear sprays. When the main unit is brought to idling speed the oil-pump turbine is stopped and oil circulation is provided by a positive-displacement gear-type pump, connected by a quill to one of the low-speed gear shafts. The oil system contains a magnetic strainer and a shell and tube-type cooler, through which boiler feedwater is circulated. Automatic by-pass controls regulate the temperature of the oil leaving the cooler.

Generators—The generators and the motors are of the types that have accumulated much experience in Diesel-electric locomotive service. The armatures of the two generators are mounted on the gear shaft with the commutators facing outward. The outer end of each generator shaft carries a pulley that drives, through multiple vee belts, an auxiliary generator mounted on top of the main generator.

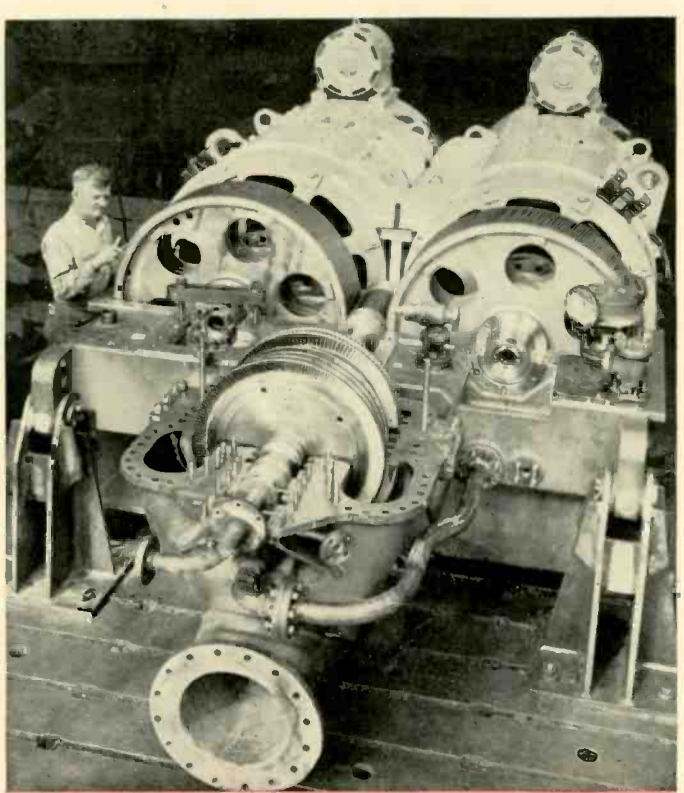
A turbine-driven vertical propeller-type fan mounted on one side of the main turbine supplies air to the space between the two stators of each double generator. From this point the air flows in both directions toward the commutators, thus carrying any carbon dust out of the machine. An auxiliary duct carries cold air directly to the generator commutators.

The main generators are eight-pole, multiple-wound, commutating-pole, direct-current machines provided with two windings on the main poles. The main exciting winding is connected to the armature through a regulating resistor. A field-discharge resistor is connected through a Rectox unit to prevent excessive voltages when opening the field circuit. The regulating resistor is adjustable in two steps. The first is sufficiently high to prevent uncontrolled build-up. The second permits maximum voltage to be obtained. The changeover from one winding to the other is under control of a voltage relay connected to the generator armature.

The separately excited field is controllable in 11 steps by the master controller, which obtains its power from the same generators that supply excitation.

Motors—Each of the four generator armatures supplies power to two 620-hp, 568-volt, 720-rpm (type 370-F) traction motors connected in parallel. These are six-pole, series-wound, axle-hung d-c motors geared with single-reduction spur gearing to the driving axles. They are force-ventilated by air from turbine-driven vertical propeller-type fans through ducts built into the locomotive under frame. On the front end, the fan is located in front of the coal bunker and supplies air for the three traction motors mounted on the front truck. The fan for the five motors on the rear truck is mounted on the opposite side of the main turbine from the generator blower. All of these fans are equipped with centrifugal-type air cleaners that remove a large portion of dirt and cinders drawn in with the ventilating air. Thus comparatively clean air is supplied to the electrical apparatus.

Because this is a coal-burning locomotive, it was desirable to take special measures to provide the electrical equipment with air free from smoke and steam. To do this, all air for the blowers is taken into the locomotive forward of the stack. A bulkhead separates the blowers in the rear compartment from the generators so recirculation of air is negligible. The electrical control equipment is separated by removable doors from the heated air discharged from the generators. This compartment is arranged for ventilation with outside air in summer and with heated air to prevent condensation in winter.



A single 6000-hp, 6000-rpm steam turbine drives, through a single gear reduction, two double-armature generators.

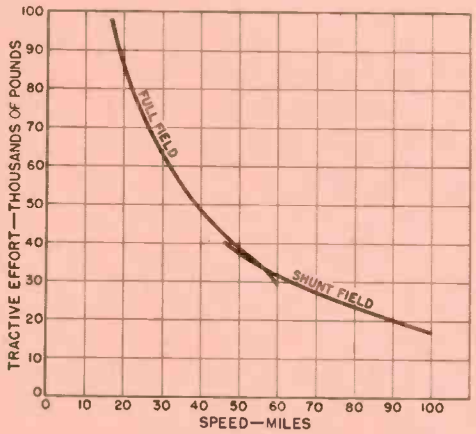


Fig. 1—Motor speed characteristics for different operating conditions and full throttle on the turbine.

The ducts discharging the dirty air from the cleaners to the outside cannot be made as short and straight as is desirable; consequently, a high-pressure air-scavenging system is provided that will be operated occasionally on each run.

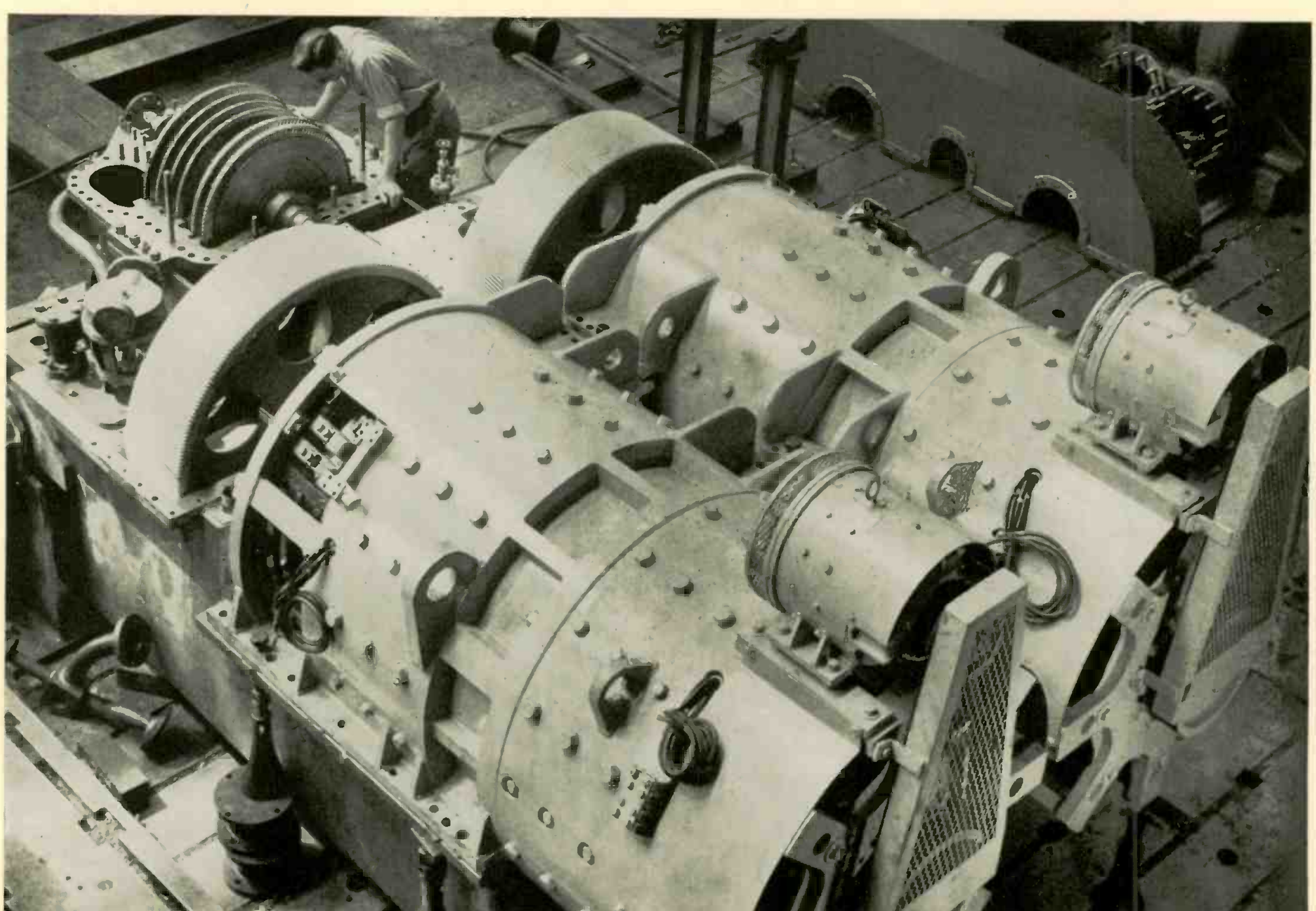
The electrical control differs from that used on Diesel-electric locomotives in that part of the acceleration is obtained by varying the strength of the separately excited fields of the main generators and part by speed control of the turbine. To obtain a satisfactory water rate, the speed of the turbine is not reduced below 60 percent of full speed in the idling position of the controller.

The control equipment for the main generators and the motors mounted on the rear truck is in a compartment behind the generators. The control equipment for the motors on the front truck is under the coal bunker.

The master controller, located at the engineman's position, has two handles, one to control speed and the other to control direction. When the speed handle is moved from *Off* to *Idle*, steam is admitted to the turbine, bringing it to the idling speed—about 3600 rpm. This is the condition employed when the locomotive is stopped for short periods, as at stations. Moving the controller to the first speed position applies excitation to the generator fields and power to the traction motors while movement successively through ten additional positions increases the power incrementally to the point that maximum separate excitation has been applied to the generators and the turbine speed is increased to 75 percent of full speed. The self-excited field is also connected to position one, but has little effect until the generator voltage increases. Further movement of the master controller increases the speed of the turbine to its full speed.

A meter panel is provided at the engineman's position to indicate the traction motor current and the turbine speed. These meters are lighted at night with ultraviolet or "black" light, which eliminates all glare and affords maximum eye comfort for the engineman. A buzzer is provided to indicate

This view from the electrical end of the main power plant shows the physical arrangement of double-armature generators, the two auxiliary generators above them, the 6-to-1 gear, and the turbine.



wheel slippage; and lights to indicate tripping of overload relays, operation of ground detector, functioning of blowers, temperature and pressure of lubricating oil.

The traction motors are connected to the generators by electro-pneumatic unit switches. The fields of the traction motors are connected to a drum-type reverser, which in turn is controlled by the reverse camshaft of the master controller.

One step of field shunting is provided by a non-inductive resistance connected across the motor fields by an electro-pneumatic switch. This switch is controlled by a voltage relay connected across the generator armature.

The slip relays are connected between the two traction motors supplied by one generator. The connection is made between the armature and field in each case. As long as the counter electromotive force and consequently the speeds of the two motors are equal no current passes through the relay. As soon as a wheel slips, the counter electromotive force of its motor increases, a current passes through the relay and it closes its contacts thus operating the warning buzzer. It does not shut off or reduce power.

Overload relays in each motor circuit are set to trip at the maximum accelerating tractive effort. If any of these overload relays operate, the emergency trip magnet valve is deenergized and the governor closes immediately, thus relieving the overload. Before load can be re-established the master controller must be moved to the *Off* position.

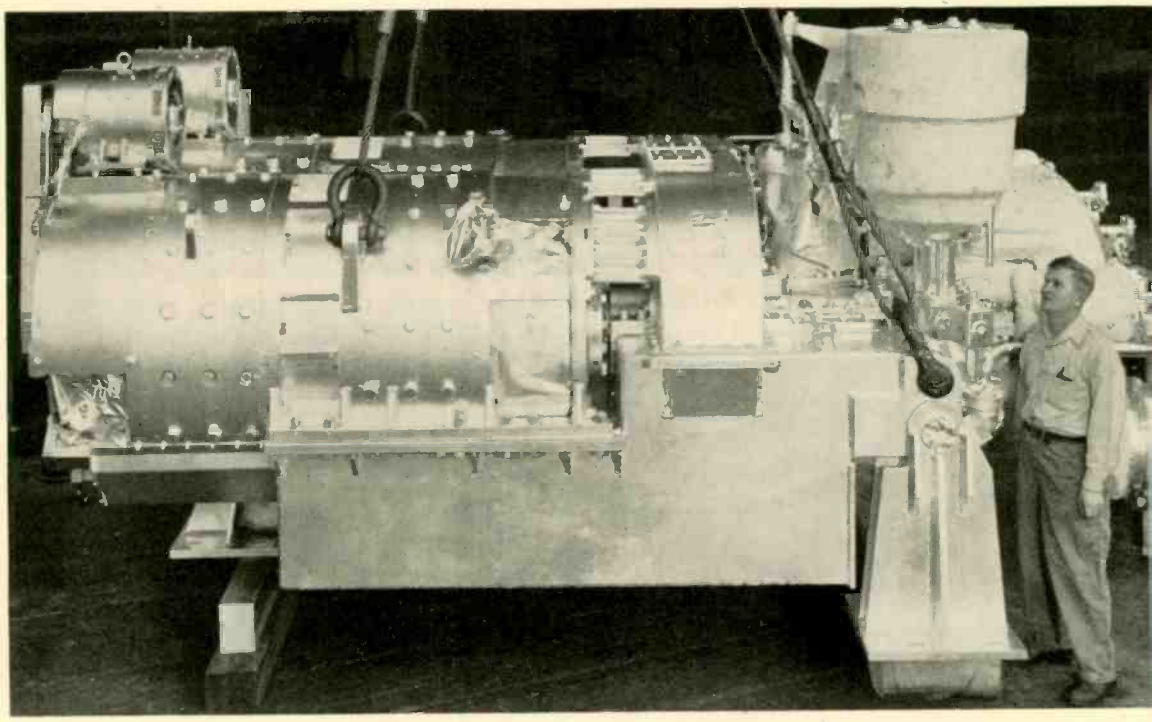
The master controller contacts are connected to a panel that consists of twelve contactors mounted on the front and the regulating resistors mounted on the rear.

Any generator armature and its affiliated traction motors can be disconnected should trouble occur in any of them. In that case three-quarters of capacity is available. Copper strap, mica and glass insulated, has been used for the main power-circuit wiring. Cable is used only where flexibility demands it.

Two 9-kw, 75-volt generators (type XG-51) supply auxiliary power although either one alone has sufficient capacity to supply the maximum load. This results in increased reliability. A single regulator controls both generators and they are paralleled through a balancing resistor. Either may be idle without in any way affecting the operation of the locomotive.

These auxiliary generators also supply power to the air-brake system and to the mechanical lubricator pump. This pump is also controlled by the master controller and is stopped when the locomotive is at rest, thus preventing waste of lubricating oil.

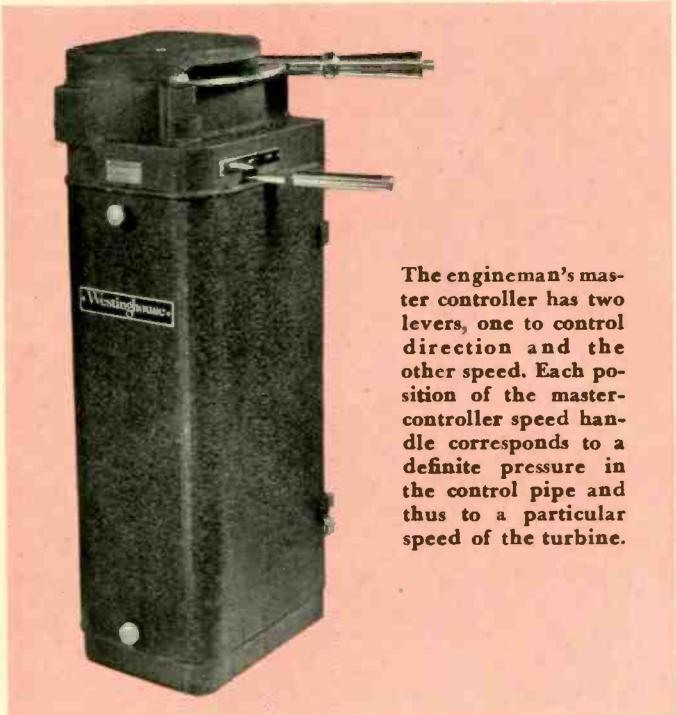
Considering the size of this locomotive, the control equipment is extremely simple while permitting operation at any point on the controller for any desired length of time.



Side view on the assembly floor of the 6000-hp turbine-generator unit.

TABLE I—PHYSICAL DATA RELATIVE TO THE TURBINE-ELECTRIC STEAM LOCOMOTIVE

Tractive effort—continuous	48 000 pounds
Speed at continuous tractive effort	40 mph
Starting tractive effort—maximum	98 000 pounds
Maximum speed	100 mph
Turbine rating	6000 hp, 290 pounds gauge 750 degrees F, 15 pounds back pressure
Turbine speed	6000 rpm
Generator speed	1000 rpm
Traction motor speed at 100 mph	720 rpm
Weight engine and tender, light	920 500 pounds
Weight engine and tender, loaded	1 194 800 pounds
Weight engine	750 000 pounds
Engine only, loaded	823 000 pounds
Weight on drivers	508 000 pounds
Weight of turbine generator unit	83 000 pounds
Driver diameter	40 inches
Wheel base, rigid	17 inches
Wheel base, total engine	90 feet, 7 inches
Wheel base, total engine and tender	130 feet, 7 inches



The engineman's master controller has two levers, one to control direction and the other speed. Each position of the master-controller speed handle corresponds to a definite pressure in the control pipe and thus to a particular speed of the turbine.

The High-Speed Radar Switch

"High-speed switching" has vastly different meanings to the power engineer and to the electronics engineer. The difference in speed is roughly 10 000 to one. An electronic switch, prosaically known as TR switch, can operate in a few millionths of a second and repeat that operation a thousand times each second continuously. Called into being by radar it stands beside the magnetron, klystron, synthetic crystal, and waveguide as a new electronics component, and like them is simple to comprehend.

S. Krasik, *Electronics Research Engineer,*
Westinghouse Electric Corporation

A TR switch (type 1B24) for use at about 10 000 megacycles. The adjustable gap is visible within the coupling windows.

The need in radar for an ultra-high-speed switch arises largely from the fact that the transmitter and receiver use the same antenna. In a microwave-radar system the transmitter emits a pulse of energy at high frequency for a period perhaps as brief as one millionth of a second. This is followed by a period of silence a thousand times longer than the pulse period during which the receiver "listens" for any echo that would indicate some reflective target. Joint use by transmitter and receiver of the same antenna represents an economy in size, weight, mechanical complexity, and cost but necessitates a means of isolating the receiver during the pulse period. Were the receiver to remain connected to the antenna during operation of the transmitter it would absorb an important portion of the pulse energy, which loss would be serious enough, but more important the receiver being sensitive to the small amount of energy in an echo, might be seriously damaged by the transmitted power. The means of doing this is the TR (transmit-receive) switch. Although it is a precision device the TR switch is essentially a needle gap in a gas closely controlled as to molecular density and ionization.

The TR switch protects the receiver from damage with an extremely small loss in both transmitted and received power. The receiver is protected automatically with an overall power loss of only one to two decibels.

The input element of a microwave radar receiver is generally a sensitive silicon-tungsten contact rectifier (crystal)* which acts as the frequency converter of the superheterodyne receiver. Under steady-state conditions this element can be permanently damaged by power levels ranging from a tenth of a watt to a few watts depending on the crystal type. The transmitted power in a radar pulse ranges from some tens of kilowatts to as much as a megawatt. The TR switch must limit the steady-state power level at the receiver to roughly one one-millionth of the transmitted power.

Under transient conditions—periods less than 10^{-8} seconds—crystal damage is determined by integrated energy. Typical limits for crystals range from a fraction of an erg to a few ergs, one erg equaling one ten-millionth of a watt second. This, together with the rate of rise of the transmitted power, determines the speed with which the TR switch must operate. The transmitted power rises to its full level in about 0.1 microsecond. Calculations based on various assumptions concerning the manner in which the transmitted pulse rises, indicates that the TR switch must operate within one thousandth and one hundredth of a microsecond after the onset of the transmitted pulse.

At the close of the transmitting period the time in which the TR switch must reconnect the receiver to the antenna is determined by the shortest range targets to be detected. For a minimum range of 500 yards, the necessary recovery time is approximately three microseconds. However, recovery specifications are related to the strength of the received echo because recovery of dielectric strength within the switch (i.e., switch opening) is gradual.

The Gas-Discharge Gap

The simplest TR switch is a discharge gap similar to a lightning arrester, bridged across the line leading to the receiver. As the transmitter power rises, the voltage on the receiver line goes up until the gap discharges. Further increase in transmitter power does not appreciably increase the voltage applied to the receiver because of the gas-discharge characteristic. The TR switch thus short circuits the receiver during pulsing. When transmission ceases, the discharge is extinguished and the system is prepared to receive echoes. A basic circuit arrangement employing such a simple point gap is shown in Fig. 1.

High-frequency gas discharges have certain features similar to the more common d-c discharges. The discharge voltage remains constant over a wide range of discharge current. Thus the gap voltage remains practically constant over the entire transmitted pulse. That the discharge voltage is not quite zero means the receiver is subject to certain leakage power during the transmitting period. For the simple gap this power is the square of the rms gap voltage divided by the receiver line surge impedance (the receiver is assumed matched to the line). One method of reducing the leakage power to the receiver is to reduce the discharge voltage.

As with d-c discharge, the discharge voltage is dependent on the gas pressure in the gap and is a minimum for a pressure considerably less than atmospheric. The pressure for minimum

*"Radar Receivers and Crystal Rectifiers," by Dr. S. J. Angello, *Westinghouse Engineer*, March, 1947, p. 54.

voltage depends on the gas used but, in general, is about 10 mm of mercury or 1/76 that of atmospheric pressure. Unlike d-c discharges, however, the discharge voltage decreases with gap spacing, because, over a large range of gap spacings, it is the electric field in the gap rather than the voltage that characterizes the discharge. At microwave frequencies this is true for any practical gap dimension. Thus for the lowest discharge voltage it is desirable to have a very closely spaced gap—of a few thousandths of an inch—in a sealed enclosure at low pressure.

However, such a simple discharge gap is inadequate for protecting the receiver. Effectively connecting the gap to the lines through transformers gives a large reduction in leakage power, although the relatively large lumped capacity of the gap requires that the circuit be tuned to resonance. An idealized lumped-constant circuit incorporating this idea is shown in Fig. 2. Losses in the resonant circuit result in a loss in received power, depending on the coupling between lines and resonant circuit.

An actual design of a basic resonant-cavity TR switch must incorporate many features. For example, the resonant cavity must be tunable over a wide band, accomplished by making one cylinder face in the form of a flexible diaphragm to permit one gap nose to be moved relative to the other. The resulting capacity change gives the desired tuning. Tube life is determined by the rate of disappearance of the gas; to extend it a fairly large reservoir is attached to the cavity in the form of a glass cylinder. To insure rapid striking of the high-frequency discharge an auxiliary d-c glow discharge is operated by means of an ignitor electrode.

There are two other sources of leakage power from the TR switch: (1) direct coupling, and (2) the leakage power associated with the initial formation of the discharge. Direct coupling is associated with the higher modes of oscillation of the electromagnetic field in the cavity, and is not concerned with the gas discharge; it exists even with the gap short-circuited. Direct coupling leakage is of importance primarily with high-power transmitters. The leakage power associated with formation of the discharge is commonly referred to as the "spike" because it is a high level pulse occurring at the very beginning of the transmission period; it is by far the most difficult leakage component to handle.

In high-frequency discharges free electrons provide the discharge with its conducting properties. The effect of positive gas ions, because of their large mass compared to that of the electron, is practically negligible; however, they do neutralize the electron space charge. In a given discharge the voltage is largely governed by gas type, pressure, and geometrical factors, while current and electron density are governed by circuit considerations. The electron density adjusts itself automatically to meet the current requirements imposed by the circuit and generator, with the particular discharge voltage. The discharge voltage is not zero because energy must be supplied to the electrons to make up that lost in collisions with gas molecules and to permit them to make up, by further ionization, the continual loss of electrons from the discharge. At the beginning of the transmitted pulse the electron density is relatively low. To form the discharge the electron density must be increased by many orders of magnitude. Even if this process of multiplication occurred slowly, the gap voltage would have to be appreciably greater than the steady-state discharge voltage. To provide additional ionization in a short time interval requires an even higher gap voltage, thus it is reasonable to expect that the initial formation of the discharge is accompanied by relatively high gap voltages for a short period; this is the reason for the existence of the spike. The duration of the spike and its magnitude are strongly influenced by the rate of build-up of transmitter power. It has been estimated that the discharge forms inabout 0.005 microsecond.

At the conclusion of the transmitted pulse the electron density in the gap must drop to a sufficiently small value so that transmission of received signals through the resonant cavity is unaffected by the electrons. The processes of diffusion of electrons to the walls of the cavity and their recombination with positive ions are much too slow to be satisfactory. Water vapor in the gas used, allows the electrons to attach themselves to it to form negative ions, which because of their large mass are as ineffective as the positive ions in the high-frequency field.

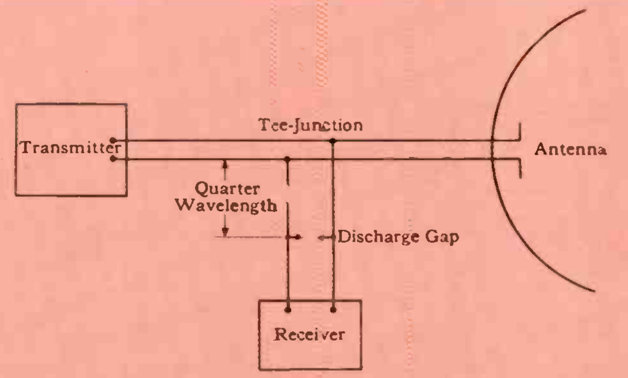


Fig. 1—Schematic circuit of an elementary form of spark-gap TR switch. The quarter wavelength spacing of the TR switch from the tee-junction insures delivery of practically all of the radar transmitter power to the antenna.

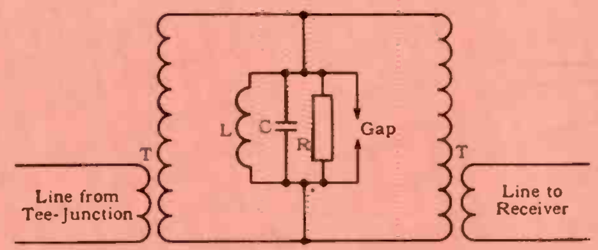


Fig. 2—Idealized lumped circuit for a resonant-cavity TR switch. Transformer *T* gives an impedance step-up from line to gap. *R*, *L* and *C* are equivalent lumped constants.

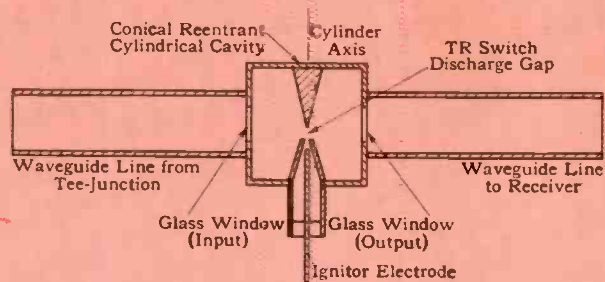
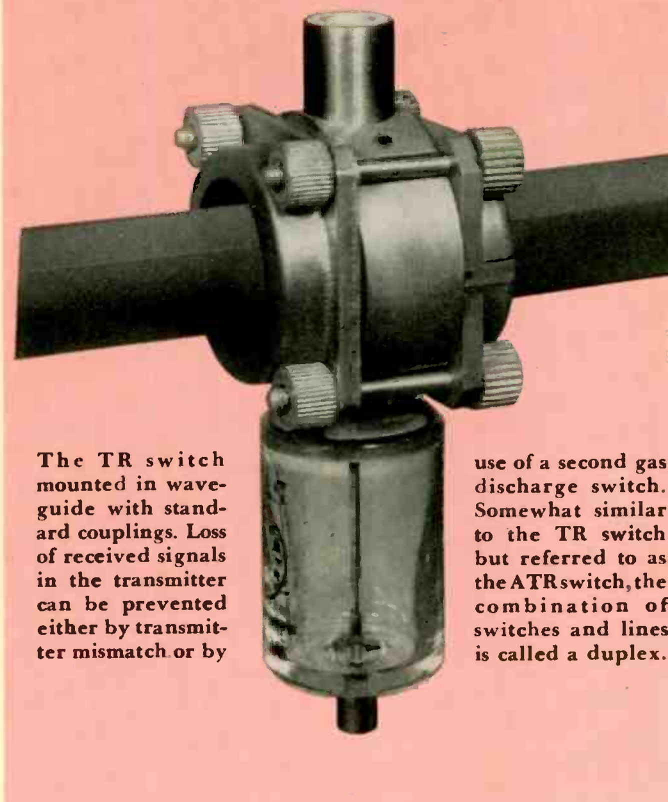


Fig. 3—The elements of a resonant-cavity TR switch. The coupling is adjusted by varying the size of the windows so that, with the cavity tuned to resonance at the radar frequency, there is only a small power loss for received signals. During transmission a gas discharge forms across the reentrant conical gap, limiting the power to the receiver.



The TR switch mounted in waveguide with standard couplings. Loss of received signals in the transmitter can be prevented either by transmitter mismatch or by use of a second gas discharge switch. Somewhat similar to the TR switch but referred to as the ATR switch, the combination of switches and lines is called a duplex.

Hydrogen Cooling for Turbine Generators

Hydrogen, the supreme coolant for large generators, demands as its price for the increase in capacity and reduction in losses, the addition of apparatus for its servicing and control. At the outset, a decade ago, the hydrogen piping resembled a plumber's delight. Apparatus evolution has simplified the functions of the hydrogen system and, by comparison, greatly reduced its complexity. Further simplifications are anticipated.

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A SYSTEM of hydrogen cooling of large a-c generators must comply with three essential requirements. It must be safe and reliable, and as simple as possible compatible with safety and reliability. That hydrogen-cooling systems have met these requirements is indicated by a trouble-free ten-year service record during which outages of generating capacity resulting from failure of the hydrogen apparatus have been essentially nil. Since the time of the early application of hydrogen systems to synchronous condensers the trend of development has been toward simplicity of controls from all points of view: installation space, operation, and maintenance.

The two better-known advantages of hydrogen cooling are: (1) lessened windage, friction, and ventilating losses, (2) increased output per unit volume of active material. A third is more and more assuming increasing importance—reduction of maintenance expense. This is made possible because the totally enclosed, hydrogen-cooled system can be kept free of dirt and moisture. Since it is also free of oxygen when operating, there are no harmful combinations to attack the insulation; an extended insulation life results.

Hydrogen-cooled generators are designed to be "explosion-safe", that is, all equipment is built to withstand internal combustion without causing damage external to the machine. Hydrogen does have explosive characteristics, but only when the proportions of oxygen and hydrogen lie within certain limits. Explosive mixtures of air and hydrogen contain from 5 to 70 percent of hydrogen by volume. With hydrogen cooling during normal operating procedure, it is impossible to have an explosive mixture of hydrogen and air in the generator; however, to anticipate faulty operation or unforeseen conditions, an adequate control and signal system warns of the approach of dangerous conditions. Controls insure that the purity of the hydrogen in the generator is maintained above 95 percent, which is far above the upper limit of the explosive range. Operating procedures along with the control system make the possibility of a hydrogen explosion extremely remote.

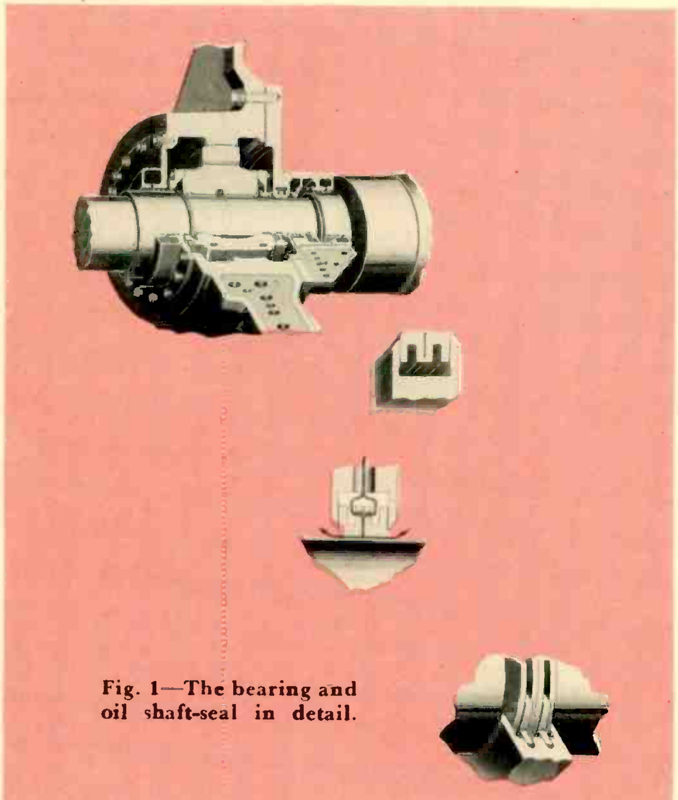


Fig. 1—The bearing and oil shaft-seal in detail.

Gas Coolers

The hydrogen ventilating circuit is shown on page 142. A propeller-type blower mounted on each end of the rotor circulates hydrogen through rotor and stator and then through coolers, where the accumulated heat is transferred to cooling water. The gas completes 30 to 40 such circuits a minute.

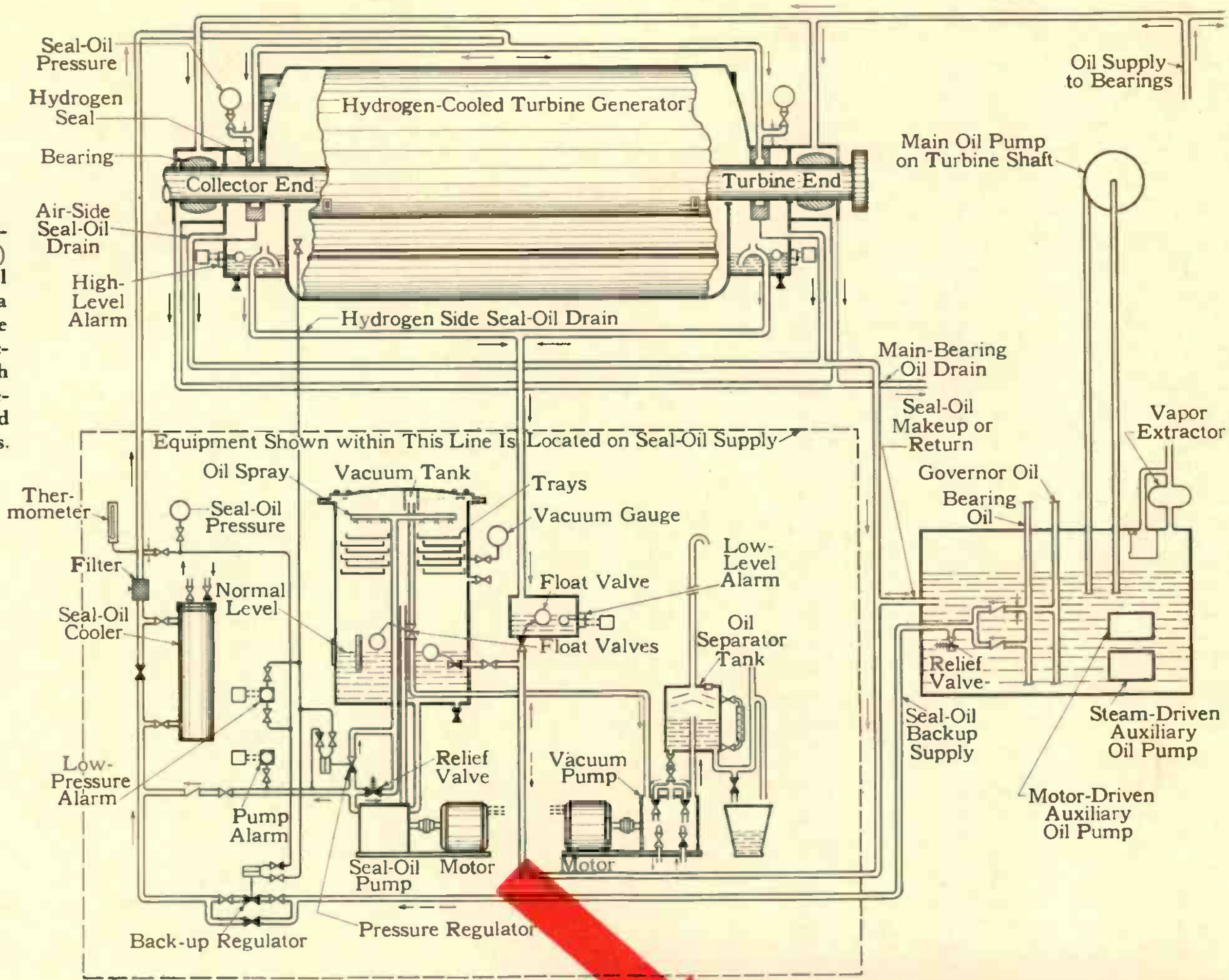
The hydrogen coolers are of the finned-tube type. The nozzle end is solidly bolted to the generator frame, while the rear end moves freely with temperature changes. The cooler tubes can be cleaned without losing gas from the generator. The cooler frame itself seals the nozzle end; a flexible rubber diaphragm between generator frame and cooler at the rear end serves to keep the gas in the generator.

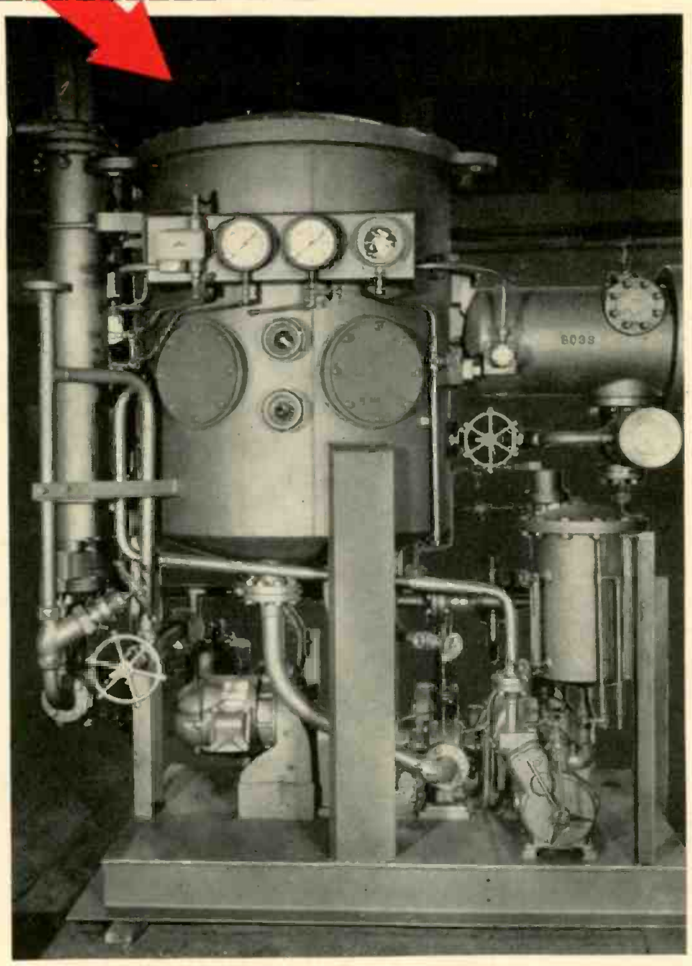
The Oil-Seal Rings

An important feature of a hydrogen-cooled generator is the seal at each end of the rotating shaft to keep hydrogen in and air out. These seals, developed in essentially their present form in 1926, are shown in detail in Fig. 1. The sealing member consists of two rings, free to move radially as they ride on the shaft but pinned so that they cannot rotate. Oil under pressure forms a seal to prohibit flow of air into or hydrogen out of the generator housing and to lubricate the sealing rings. Sealing-oil and bearing-oil systems, using identical oils, are completely separate, although there may be a slight interchange between the sealing oil of the air side of the seal and bearing oil because the drainage paths are in close proximity.

The operation of the sealing system and the paths taken by the sealing oil are shown in Figs. 2 and 3. A positive-displacement oil pump forces sealing oil at a pressure 10 psi above the hydrogen pressure through holes in the sealing rings into a groove in the shaft between them. The oil is forced in both directions along the shaft, some emerging on the air side of the seal and the remainder passing into the hydrogen side and dropping by gravity into a defoaming tank located in the bearing brackets. The resultant oil film between shaft and

Figs. 2 and 3—Schematic diagram (right) of the shaft-seal oil supply system and a view (below) of the large, cylindrical vacuum tank on which are mounted the required gauges and some of the controls.





rings prevents the passage of air in or hydrogen out along the shaft extension.

The hydrogen-side sealing oil overflows into a float chamber from the defoaming tanks, where the foam caused by shaft whipping and turbulence is dissipated. As the oil level rises above the center of this chamber a float-operated drain valve allows the excess to flow into a vacuum tank.

The hydrogen-side oil is joined at the vacuum tank by the sealing oil that has gone to the air side of the seals. Connected to the air-side drain line ahead of its entrance to the vacuum tank is a line to a reservoir of fresh sealing oil through which oil lost or gained through interchange at the shaft seals is drawn from or returned to the lubricating-oil system. This process is automatic, the oil level in the vacuum tank being governed by the float valve on its inlet.

From the vacuum tank, sealing oil is pumped to the seals, thus completing the sealing-oil circuit. However, only a small portion of the output of the seal-oil pump goes directly to the seals. The major portion of it is diverted to the top of the vacuum tank where it is discharged through a series of fine sprays. Because the pressure in the vacuum tank is held to one inch of mercury absolute or less, any water in the sealing oil flashes into steam and the gases trapped in the oil expand and bubble out. The steam and gases are continuously extracted by a vacuum pump. The gases are discharged through a vent, the condensed water settling on the bottom of the separator tank where it can be drawn off periodically. Recycling of the sealing oil through the vacuum tank in this fashion after its passage through the seals prevents contamination of the hydrogen by air and moisture. Operation of the vacuum-tank system, which can be by-passed for servicing, greatly reduces the amount of hydrogen that must be added to the cooling system to maintain the necessary purity.

The ratio of the sealing oil pumped directly to the seals and the amount sprayed back into the vacuum tank, is determined by a differential-pressure valve located in the by-pass return line to the tank. This valve maintains a constant seal-oil differential pressure 10 psi above the generator gas pressure by varying the flow of oil through this by-pass return. If the gas pressure in the generator is increased, the by-pass regulator starts to close, decreasing the amount of oil flowing through the line. Since the seal-oil pump is of a positive displacement type, the quantity of oil flowing through the line to the shaft seals will be increased, with a resultant increase in seal-oil pressure at the shaft. However, even when the flow to the shaft seal is greatest the amount by-passed for recirculation through the vacuum tank is several times greater, assuring adequate treatment of the oil.

Heat accumulated by the sealing oil is removed by a water-cooled heat exchanger located between the pump and the seals. A filter installed beyond the cooler traps any dirt in the oil. It is imperative that the oil be free of solid particles because the clearances between sealing rings and shaft are small.

To give absolute assurance that sealing-oil pressure will be maintained at all times even if trouble with the oil pump arises, a connection is made to the turbine lubricating-oil system. This line is normally closed but should sealing-oil pressure drop from its normal of 10 psi above hydrogen pressure to 7, a differential-pressure regulator opens it, connecting the sealing-oil system to the several, well-protected sources of bearing oil under pressure.

An important feature of the oil supply for both seals and main bearings is the vapor extractor mounted on the main-bearing oil reservoir to eliminate any possibility of hydrogen accumulation in either the pedestals, drain lines, or reservoir. This extractor creates a vacuum of about two inches of water in the main-oil reservoir, in the main-bearing drains, and in the bearing pedestals. All drain lines are constructed so as to flow only partially full of oil, leaving a ventilating passage above the surface of the oil. This permits a flow of ventilating air through the labyrinth oil-sealing strips at the bearing pedestals, through the partially full oil-drain lines to the main-oil reservoir, finally reaching the vapor extractor and vented.

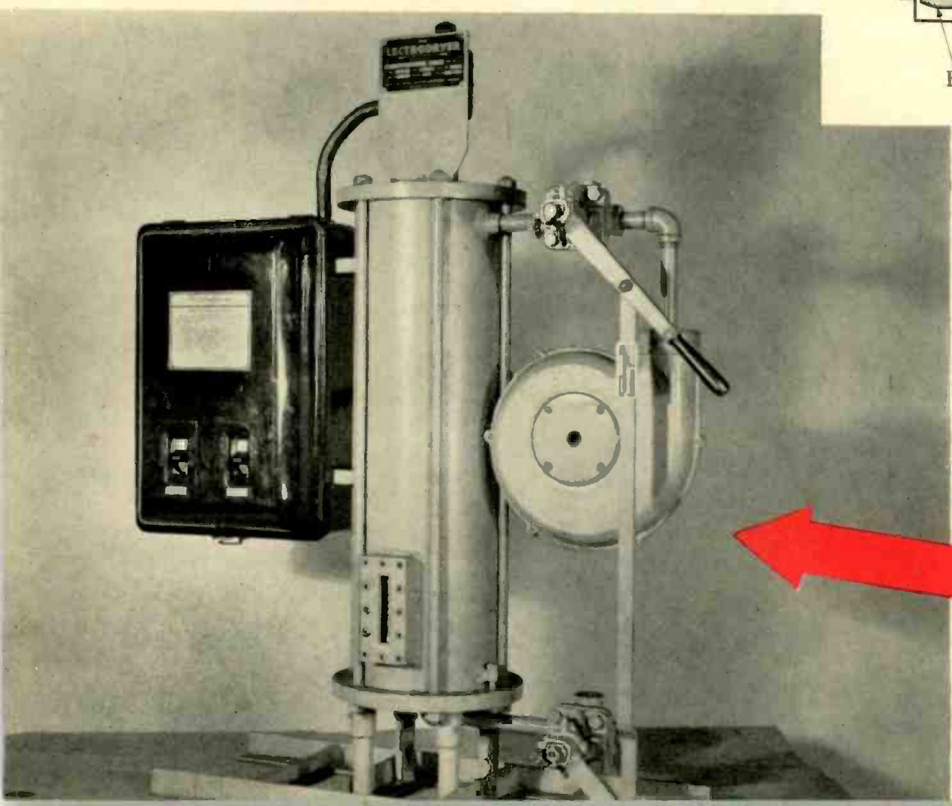
Gas Control

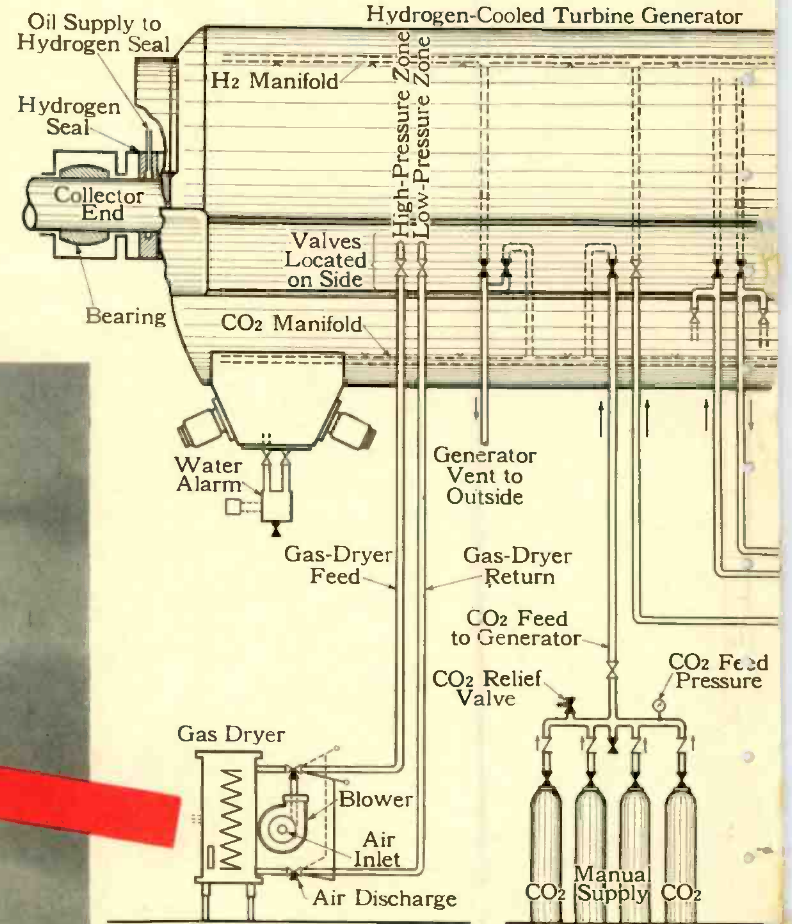
The gas-control system has several functions. It must maintain the purity, pressure, temperature, and moisture of the hydrogen within predetermined limits. It provides means for scavenging and filling the generator housing, and warning of improper operation of the hydrogen system. Also the gas-control equipment must take into consideration the conditions of running, standstill, gas-scavenging, and gas-filling.

The gas-control system when operations are normal is shown in Fig. 4. Hydrogen is maintained at a minimum gauge pressure of 0.5 psi to prevent air leakage into the generator. This is accomplished by an automatic pressure regulator on the hydrogen-bottle manifold. For generators operating with hydrogen above 0.5 psi a manual pressure regulator is provided on the hydrogen-bottle manifold in parallel with the automatic regulator. This regulator can be set to maintain hydrogen pressure at any value between 0.5 and 15 psi.

The manifold for the carbon dioxide used in the scavenging and filling operations contains in addition to a 100-pound pressure gauge, a relief valve set at 100 psi. The bottle valves must be opened wide while being discharged in order to avoid freezing. The relief valve protects the piping system against the application of full bottle pressure should all other valves

Figs. 4 and 5—The gas-control system, Fig. 4, is shown schematically. Valves not shaded are normally open; those in which both cones are shaded are normally closed; shading of one cone indicates normal throttling. A gas dryer, Fig. 5 below, removes moisture to maintain cooling-hydrogen dewpoint below that at which condensation takes place inside the generator. The active element is a chamber of activated alumina, capable of absorbing two pounds of water before reactivation is needed. Reactivation normally requires several hours, and is necessary about once a week.





in the system be unintentionally closed. A generator gas-pressure gauge is located adjacent to the gas bottles so that the operator can observe the generator gas pressure during the scavenging and filling operations.

The Density Meter

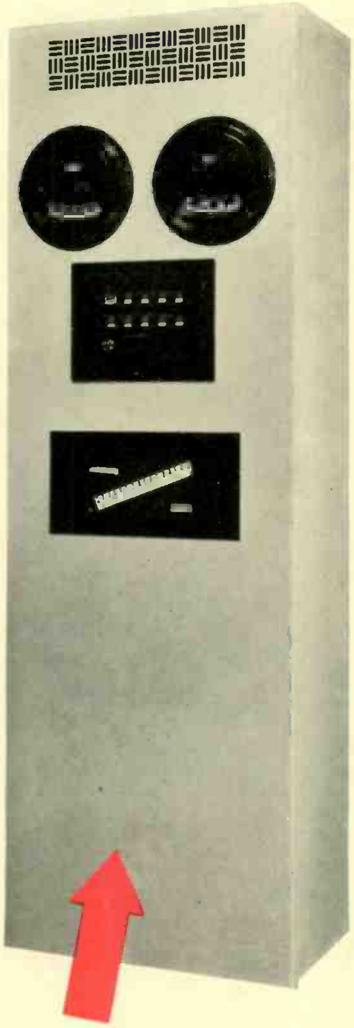
The purity of the hydrogen is indicated by a density meter on the hydrogen-control panel. This meter is actuated by a constant-speed blower. Variations in density are read as a reflection in any corresponding pressure change. It is graduated so that a reading of 150 indicates pure carbon dioxide; 100, air; and 7, signifies pure hydrogen.

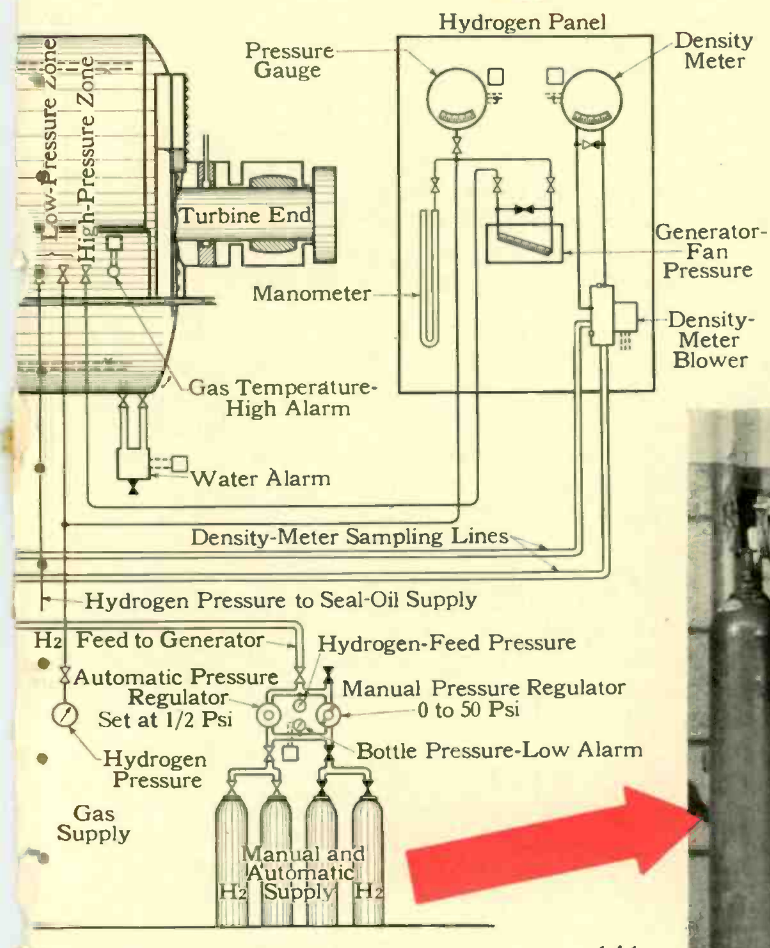
Gas Changing and Filling

Never—during gas-changing, filling, or normal operation—is a mixture of air and hydrogen permitted in the generator housing. In changing from hydrogen to air or air to hydrogen the generator housing is first scavenged with carbon dioxide. Gas changing can be performed with the generator rotor at standstill, while being rotated slowly by the turning gear, or at full speed. Generator load must be limited to 50 percent while gas is being changed or while operating on carbon dioxide or air. Likewise seal-oil pressure must be maintained while performing these operations.

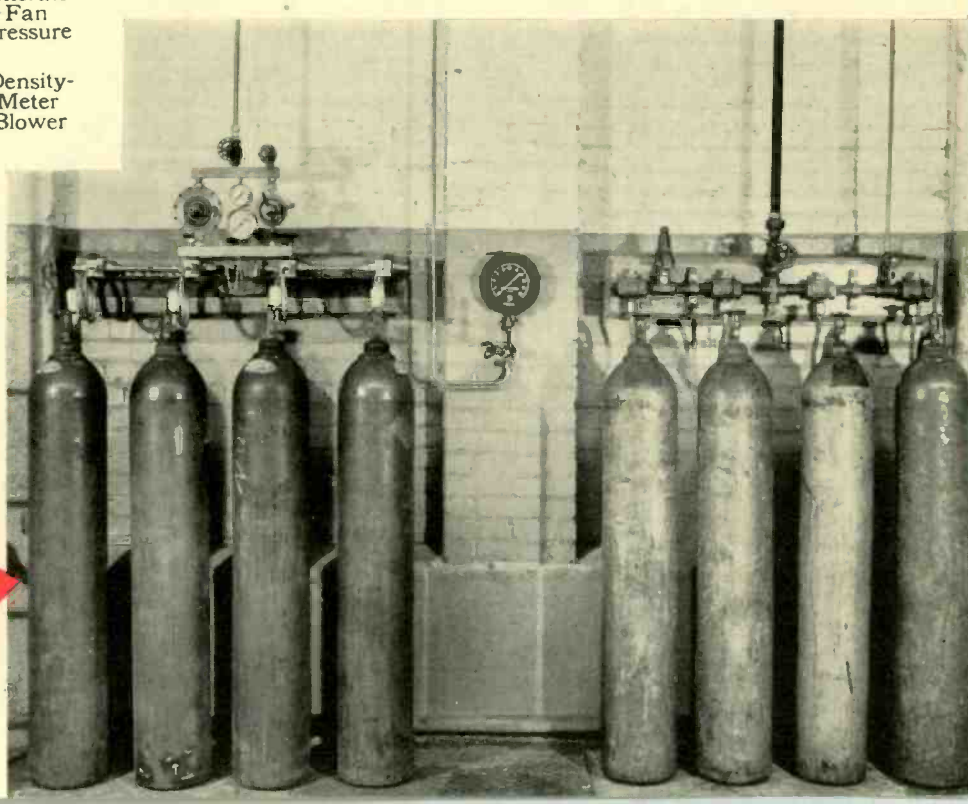
The amounts of gas required to perform the several steps in a gas change are specified in terms of generator volumes, which vary from 750 cubic feet for a 20 000-kw, 85-percent p-f, 3600-rpm generator to 3500 cubic feet for a 107 000-kw, 85-percent p-f, 1800-rpm generator. The amount of gas required depends upon whether the machine is running or stopped. (Turning-gear operation is considered equivalent to standstill.) Gas is admitted to the generator housing and exhausted from it through either of two manifolds, one located at the bottom of the housing, the other at the top. Less gas is required for a change when the generator is stopped than when running because, with the rotor motionless, the entering gas does not mix appreciably with the gas already in the generator, but gradually forces it out the vent manifold.

To displace air, carbon dioxide is admitted through the bottom manifold and air is vented through the top manifold. The carbon dioxide, 1.5 times as heavy as air, is put in at the bottom, assuring less turbulence and mixing than if admitted at the top. Approximately 1.5 volumes of carbon dioxide are required to displace all air in the housing at standstill and 2.0 volumes if the generator is running. Scavenging gas is admitted until the gauge, sampling from the top, indicates 150 percent density, thereby making certain that the entire housing is filled with carbon dioxide, and is ready with complete safety for admission of hydrogen.





Figs. 6 and 7—The hydrogen-control panel (Fig. 6 above) contains the automatically functioning controls, emergency back-up, and an adequate alarm system to give the operator a complete, compact indication of generator operating conditions. The inclined draft gauge measures fan pressure on the generator rotor. Since this varies with gas density, it can be used as a check on the density meter or as a hydrogen purity indicator should the meter be disconnected while the generator is running. An installation of hydrogen and carbon-dioxide bottles, Fig. 7, is shown below.



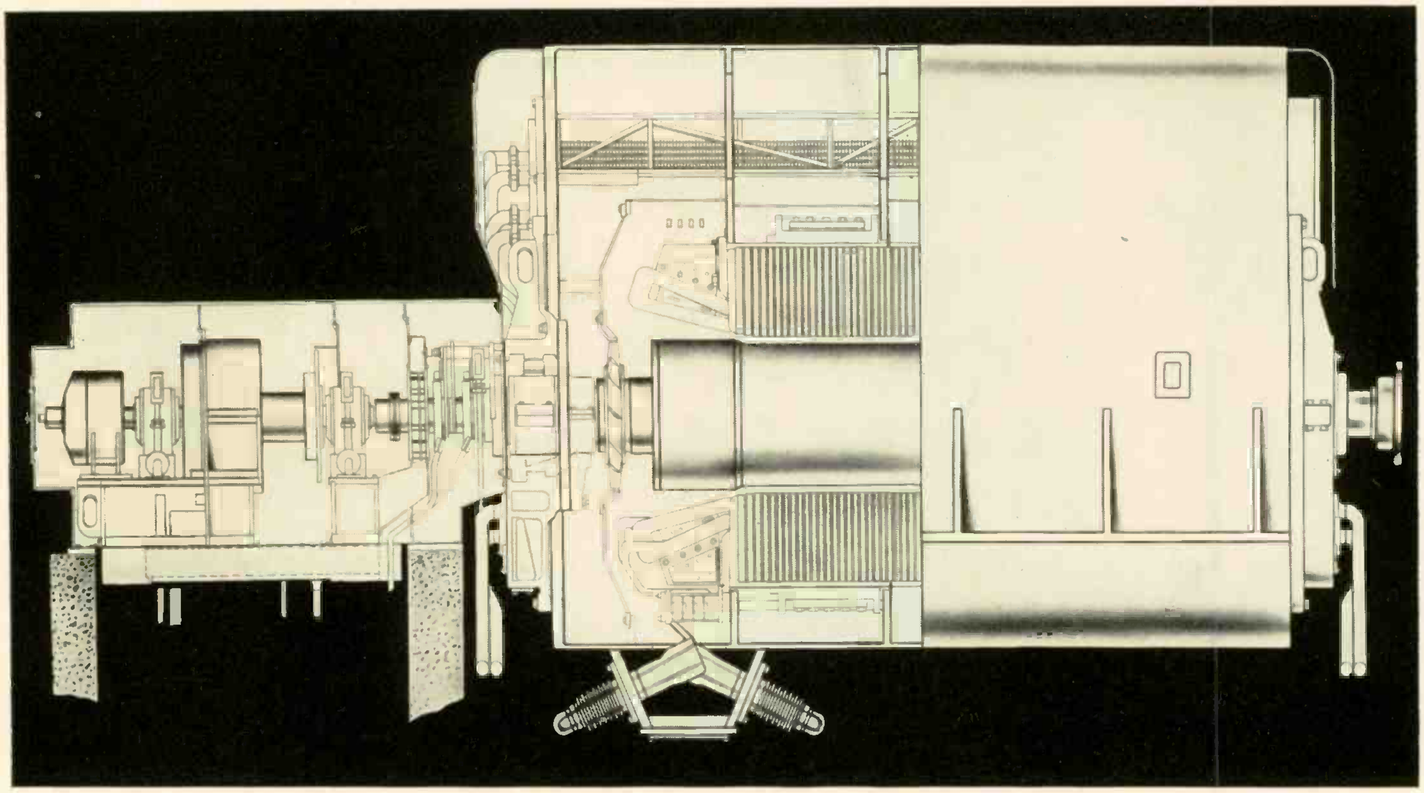


Fig. 8—Longitudinal section view of hydrogen-cooled generator with direct-connected exciter.

Hydrogen, being about one fifteenth as heavy as carbon dioxide, is admitted through the top manifold and the carbon dioxide is vented to atmosphere through the bottom. Two volumes of hydrogen are required for this operation at standstill and 3.5 volumes when the generator is running. At this time the density-meter blower sample is taken from the bottom of the generator. This part is the last to be filled with hydrogen; therefore, when the gauge indicates the desired purity at this point, the housing is known to contain at least this percentage of hydrogen.

To raise the generator-hydrogen pressure from 0.5 psi to 15 pounds either at standstill or running, one volume of hydrogen is required. During normal operation, the density-meter blower sample is taken from the bottom of the housing. If operating-hydrogen pressure is more than 0.5 psi, it is first reduced to this value by venting the excess to atmosphere before purging with carbon dioxide. Two volumes of carbon dioxide are required at standstill to purge hydrogen, and three volumes when the generator is running. Carbon dioxide is admitted through the bottom manifold and the hydrogen vented to atmosphere through the top manifold because of their relative densities. The density-meter sample meanwhile is taken from the top of the housing. If it is desired to remove the carbon dioxide rapidly, the manholes on the generator can be opened and air directed into the housing by fans.

Commercial hydrogen and carbon dioxide are of sufficient purity for use with hydrogen-cooled generators. The standard hydrogen bottle contains 190 cubic feet of gas and the standard 50-pound carbon-dioxide bottle contains 450 cubic feet of gas, of which only 400 cubic feet normally can be utilized because the remainder of the liquefied gas freezes.

Alarm System

An annunciator located above the inclined draft gauge is connected in parallel with an alarm horn to provide audible and visible indications of any of these conditions:

1—Hydrogen density—high or low
2—Hydrogen pressure—high or low
3—Hydrogen-bottle pressure—low
4—Water detector—high
5—Hydrogen temperature—high
6—Seal-oil pressure—low
7—Seal-oil pump—off
8—Defoaming-tank level—high
9—Hydrogen-side level—low

The alarms are activated by contacts on float valves, gauge dials, and Mercoid switches on the individual equipments involved. Their grouping in one central location provides a simplicity of operation at least equal to that of comparable air-cooled generators. In addition to a hydrogen-pressure gauge a 40-inch mercury manometer permits more accurate determination of the gas pressure.

The operating valves for the gas-control system are located at the turbine-room floor elevation inside access doors in the generator lagging. Simplification of controls and piping, along with improvements in generator frame design, has resulted in a marked decrease in hydrogen consumption of the present Westinghouse generators.

Conclusions

The auxiliary equipment described represents the result of a long evolution to achieve hydrogen controls of the greatest simplicity. Tests now are being conducted and designs investigated, which may indicate a practical method of maintaining hydrogen purity in the generator housing, without vacuum treating the shaft-seal oil. This would permit virtual elimination of the seal-oil system as the main-bearing oil system then would perform the functions of both lubrication and sealing. From this work and from tests now being conducted on a radically different type of shaft seal, still further simplification of the auxiliary equipment for hydrogen-cooled turbine generators can be hoped for.

The Bright New Future of Coal

"Most" is applicable to coal in more ways than to any other mineral. It is the most maligned, most misunderstood, most valuable, most complex, and most versatile. Its greatest disadvantage—that it is a solid—is being overcome. Tomorrow it will be the source not only of solid fuel, but also of gasoline and other liquid and gas fuels, lubricants, and innumerable chemicals. The trend is toward the day when consumption of a lump of coal just as nature made it may be outlawed.

COAL, petroleum, and natural gas are no longer the separate, unrelated industries once popularly believed. The close molecular kinship of these products is being more generally recognized by the managements and technical staffs of those industries as well as the lay engineer. Coal, oil, and gas companies are all in the business of selling Btu's, hydrocarbons, and chemicals. The raw material by which they arrive at these salables is ceasing to be a distinguishing feature.

No strain of the imagination is required to picture some strange situations developing in this country. Visualize, in a decade or two, liquid fuel for New York and adjoining populous centers originating in Wyoming, Colorado, Utah, and the Dakotas—and produced from huge coal-liquifaction plants. The far-western prairie and mountain states, now virtually without major industries but rich in low-rank coal, may be sites for enormous plants that convert sub-bituminous and lignite into gasoline, Diesel-fuel, lubricants, and a thousand and one chemicals. Gas for heating homes and factories along the Eastern seaboard may come via pipeline from coal-gasification plants located in the coal fields of Pennsylvania and West Virginia. The gasoline for tomorrow's automobiles may not have been made by nature as a liquid at all. It may originally have been natural gas reconstructed in huge liquifaction plants in the Southwest. Also, some, probably most, of tomorrow's gasoline will come, again, via the breaking up and rearrangement of the gigantic molecules containing carbon, hydrogen, and oxygen that comprise coal. Unless a successful coal-burning gas turbine materializes, trains some years hence may be pulled by gas-turbine locomotives requiring no coal, or water, or boilers, or ash-handling, but consuming liquid fuel synthesized from coal. Whether liquid fuel for tomorrow's locomotives comes from crude oil, natural gas, or coal will be inconsequential to the turbines.

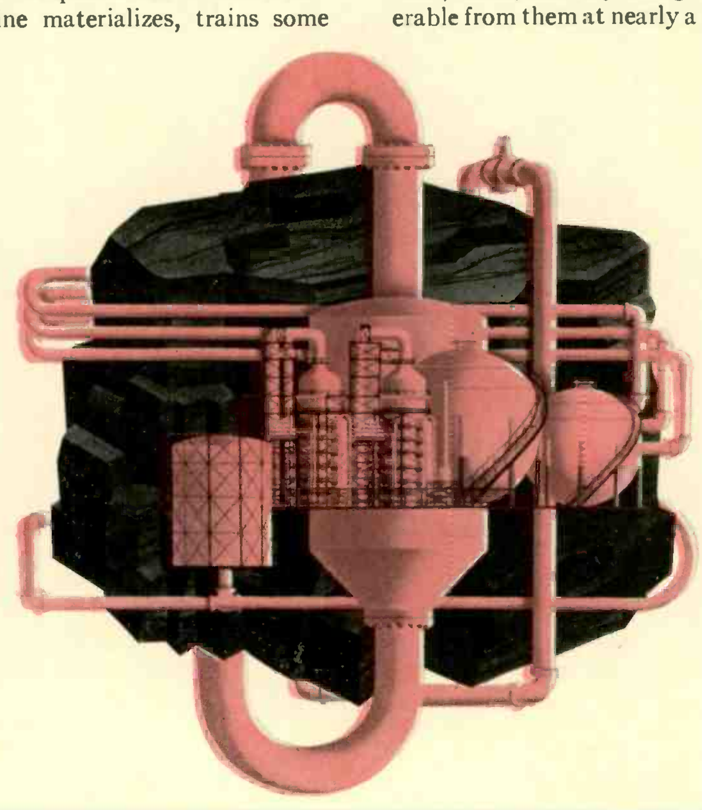
A rapid change in the use of fuels is at hand. Mostly it springs from the revolutionary new things being done with coal. This is inevitable. The United States has a superabundance of coal; the reserves of petroleum and natural gas are small by comparison. Whether the crude oil still underground is adequate for twenty years or twenty-five years is a matter of active discussion. But, even if the most enthusiastic guess be doubled—make it 50 years—the petroleum reserves are raised only from 0.2 percent to 0.4 percent of the national total of all fuel reserves. In the life of the nation the sometimes acrimonious debate as to the extent of petroleum crude reserves is unimportant.

The fuel-reserves picture is about like this.* The proved reserves of crude oil were estimated to be 24.2 billion barrels (of 42 gallons each) as of January, 1946. This is roughly one third the supposed world figure. Current annual production —which surprisingly to everyone has not declined from the war peak—is 1.85 billion barrels per year. More will undoubtedly be unearthed, literally, by future discoveries but the guess as to how much more depends in large degree on the optimism of the estimator, on tax considerations, and other intangibles. In any case, rate of discovery of new fields is now lagging far behind actual consumption.

The proven natural-gas reserves in January, 1947 were estimated at 160 trillion cubic feet. This is approximately equivalent in Btu's to the petroleum known to be underground. Present gas consumption is about 4.9 trillion cubic feet annually. Discovery of more gas pockets can be expected, but costs of recovery are bound to rise.

Oil-shale reserves are enormous. They lie mostly in Colorado, Utah, and Wyoming. Best guesses place the oil recoverable from them at nearly a hundred billion barrels or roughly four times the petroleum reserve. The only real obstacles to exploitation of the shales are the costs of mining, handling, and transportation, and the remoteness from consumption centers. Oil from shale is also higher in nitrogen and sulphur than refinery men relish.

Any attempt to arrive at the number of years we can live on our gas and petroleum reserves by dividing the estimated reserves by annual rate of consumption is both fallacious and unimportant. It is not as simple as that. The reserve figure will rise. Also gas and oil cannot be withdrawn from the earth at a constant rate



Prepared by C. A. Scarlott from information supplied by the technical staffs of the U. S. Bureau of Mines, Coal Research Laboratory of Carnegie Institute of Technology, Bituminous Coal Research, Koppers Company, Standard Oil Development Company, Pittsburgh Consolidation Coal Company, the Disco Company, and Westinghouse.

*"The National Fuel Reserves," by Arno C. Fieldner, *Mechanical Engineering*, March, 1947, p. 221.

until the fields are exhausted. The costs of both gas and oil will undoubtedly rise as depletion approaches. Other factors complicate estimation of what can be counted on as underground stocks.

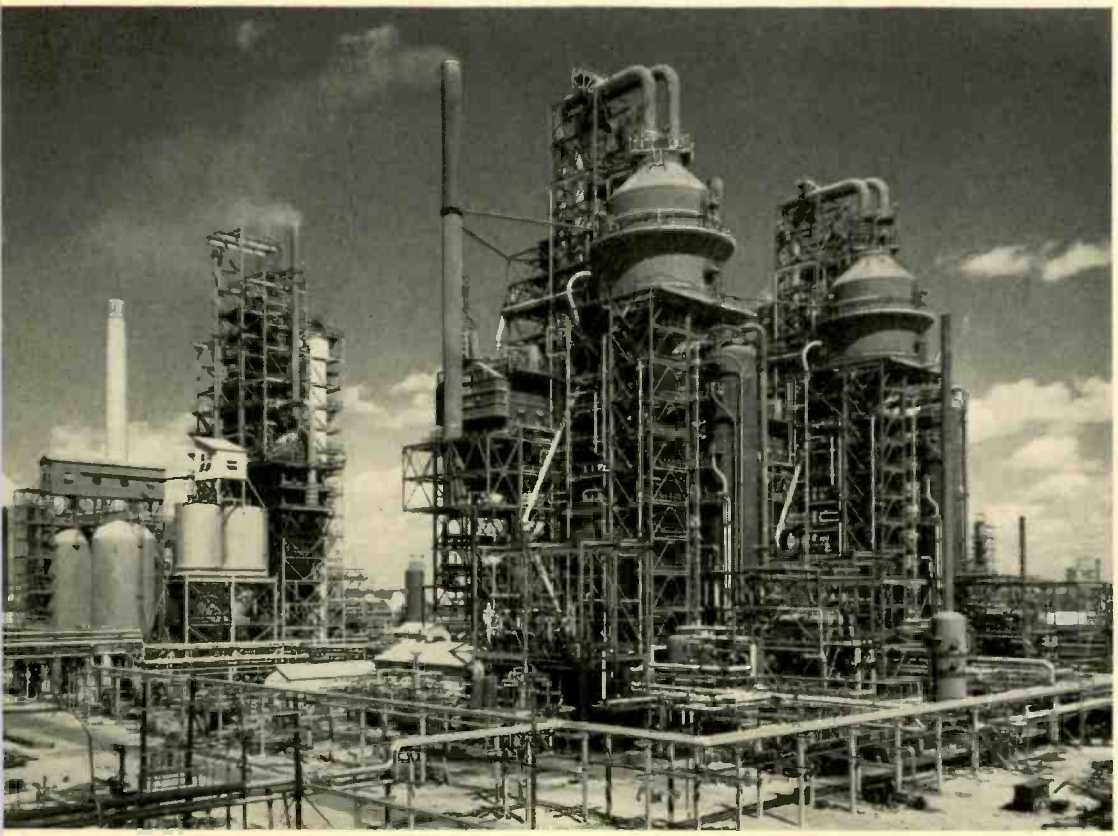
With coal the story is different. The total coal reserve figure is set at 3.2 trillion net tons or almost half of the world total. The beds of the five principal ranks of coal, reduced to 13 000-Btu per ton equivalent, total to 2556 billion tons in the United States and can be summarized thus: Anthracite, mostly in Eastern Pennsylvania, comes to about 15 billion tons, and is being withdrawn at about 0.06 billion tons per year. The low-volatile bituminous coal of the Pennsylvania and West Virginia regions totals some 56 billion tons, of which present annual use is 0.124 billion tons. The bulk of bituminous coal deposits is of the high-volatile variety. These, scattered throughout Pennsylvania, Ohio, West Virginia, Kentucky, Indiana, Illinois, Alabama, Iowa, Missouri, Kansas, Colorado, and Utah, are enormous in extent, perhaps 1403 billion tons. The use of these high-volatile coals runs to 0.485 billion tons per year. The sub-bituminous coals of Montana, Wyoming, Colorado, and New Mexico possibly amount to 598 billion tons, and the lignites of Montana and the Dakotas to 484 billion tons, of which only insignificant amounts are being mined.

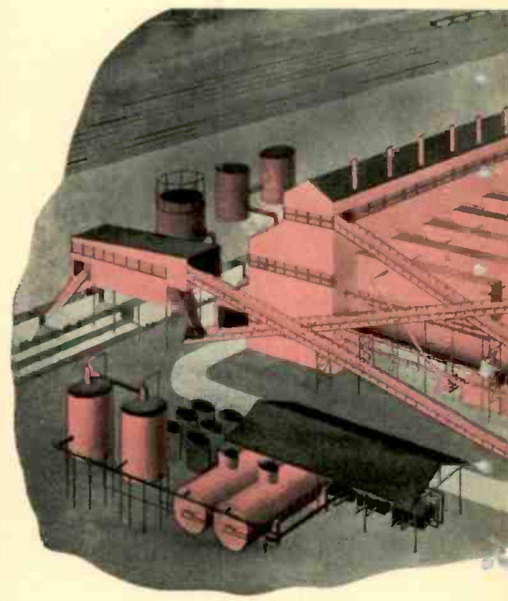
Converted to equivalent tonnages of 13 000-Btu coal, the reserves of the various carbonaceous fuels stack up in this fashion: coal, 2600 billion; proved petroleum, 4.8 billion; natural gas, 5.2 billion; oil shale, 21 billion. Percentagewise, oil shale amounts to 0.8 percent, petroleum to 0.2 percent, natural gas to 0.2 percent, with coal comprising the remaining 98.8 percent.

The essential, unescapable fact is this: the present long-range planning of this nation for fuel must inevitably be based on coal. The energy obtained from water power, while important, is comparatively small; what may develop from fissionable material is unknown. Placing our dependence on coal is both an absolute economic necessity and a very disturbing military one. It is no secret that the nation could not participate in another major war on fuel obtained from wells.

Coal and petroleum both contain hydrogen and carbon. The essential difference is in the ratio of carbon to hydrogen atoms (about 1.2 for bituminous coal and only 0.6 for petroleum), and the presence in coal of relatively much larger amounts of oxygen, nitrogen, sulphur, and some inert (ash) material. To convert coal to a petroleum-like liquid it is necessary to double the hydrogen atoms and to remove virtually all of the nitrogen, oxygen, sulphur, and ash. Also the heavy coal molecules must be "cracked" into the much lighter ones comprising petroleum.

Such manipulation of the molecules is not new. It has been done in various degrees for many years. In the long-familiar manufactured-gas process, while the emphasis is on the production of as much gas as possible, a small but valuable quantity of liquid hydrocarbons is made. The high-temperature coke process, usually integrated with steel-making, produces light and heavy oils and gases, as does the small but growing production of low-temperature coke for smokeless fuel. In all of these processes the production of liquid fuels and chemicals is secondary to the manufacture of coke and gas and is limited to the market for coke and gas.





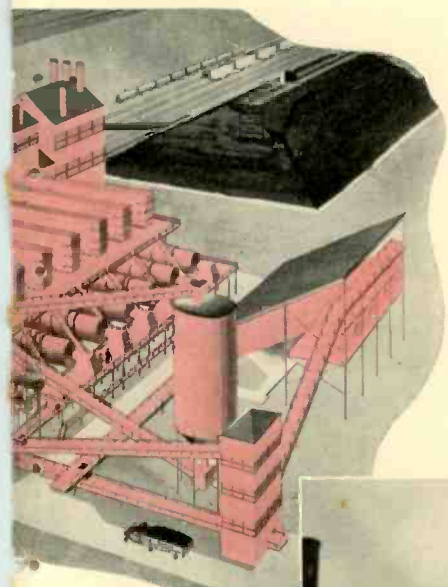
Of rapidly increasing interest and importance are other processes—two principally—for the complete transformation of coal to liquids and gases, fuels, lubricants, and chemicals. One is hydrogenation or the Bergius method developed and extensively employed in Germany and actively studied by the United States Bureau of Mines. The other is the gas-synthesis or Fischer-Tropsch process also originating and commercially used in Germany, and recently announced as the basic process for a large pilot plant to be constructed near Pittsburgh, Pennsylvania. Both hydrogenation and gas synthesis have liquid fuel as their primary product, with combustible gases, solid waxes, alcohols, and acids accompanied by literally hundreds of chemicals of great value.

Gas Synthesis (Fischer-Tropsch)

Arresting indication that a new era is opening in the utilization of coal was the announcement in March by Pittsburgh Consolidation Coal Company and the development subsidiary of the Standard Oil Company of New Jersey of plans to erect a coal-gasification pilot plant based on the Fischer-Tropsch principle for processing 50 tons of coal daily. If this experimental plant is successful it will be followed by two and possibly three enormous commercial plants in the Pittsburgh area. Linkage of the two largest firms in the petroleum and the coal business is itself significant. While this project of Standard Oil and Pittsburgh Consolidation Coal is the only one formally announced other oil companies are known to be aggressively investigating the matter.

The Nazis began development of the synthesis step or Fischer-Tropsch process in 1933 and in World War II had nine plants in operation employing it. The production from them reached a peak annual rate of 640 000 tons (four million barrels) or about four percent of the total German oil consumption. These plants were of astonishing size and bewildering complexity and were the target of many a costly but successful Allied air raid. Japan and France also had Fischer-Tropsch plants in operation.

Gas-synthesis is, in principle, a two-stage reaction. First a gas of hydrogen and carbon monoxide (modified water gas) is produced from coal, coke, natural gas, or any other hydrocarbon available in quantity. This synthesis gas can then be converted into the desired solid, liquid, and gaseous hydrocarbon molecules.

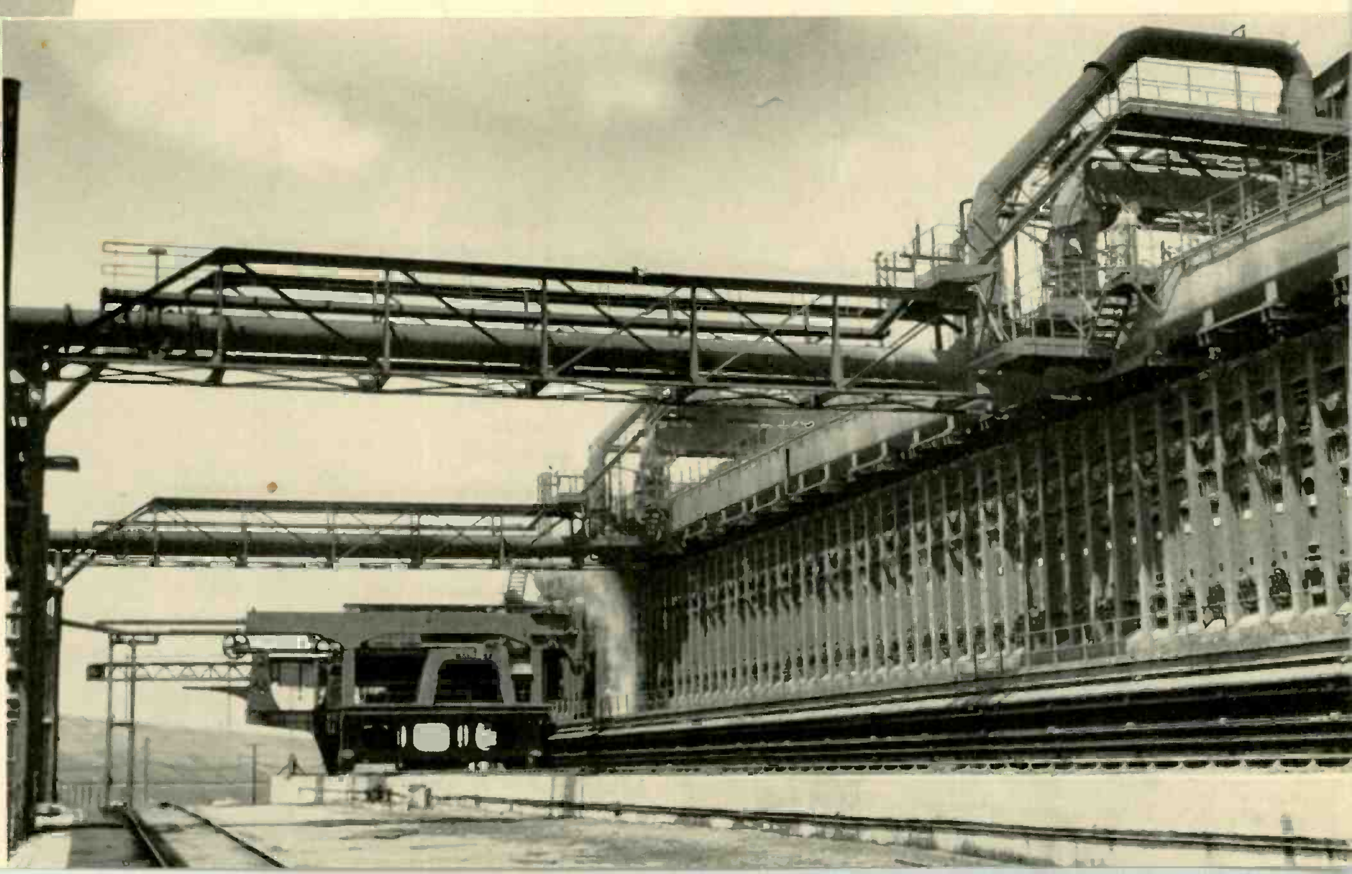


As planned for application in the United States, coal, steam, and oxygen will be fed together and continuously to a synthesis-gas generator. Here the mixture at high temperatures and moderate pressures (1800 degrees F and 0 to 300 psi) will react to produce a gas of hydrogen, carbon monoxide, carbon dioxide, and flyash. This synthesis gas will be drawn off through dust separators to remove the solid particles, purified to remove carbon dioxide and sulphur compounds. If necessary, another conversion step is added to obtain the correct ratio of carbon monoxide and hydrogen. The product of these steps then enters a hydrocarbon-synthesis reactor where it meets a boiling mass of catalyst. The powdered catalyst suspended in the synthesis gas behaves like a fluid, giving the most intimate contact with the synthesis gas. Pressure and temperature are stepped up to 150 psi and 300 to 400 degrees F. Under these conditions the hydrogen reacts with the carbon monoxide to form hydrocarbons in the gas and liquid range, carbon dioxide and water. The lighter molecules are separated from the heavy ones in a recovery column as gases and liquids. The gas, after being stripped of some carbon dioxide, may be a fuel gas of 500 to 1000 Btu per cubic foot depending on the extent to which the light hydrocarbons are removed. The gas thus is similar chemically to high-Btu city gas and could be used as such.

The liquid from the recovery tower can be considered a synthetic crude oil. It can then be processed by essentially conventional oil-refinery techniques into gasoline, alcohols, Diesel and light oils, and heavy tarry residues.

In the gas-synthesis process the coal, except for the inert ash, is completely converted to liquids and gases. The process offers considerable control over relative quantities of the various products obtained. In fact one avowed objective of the announced Pittsburgh-area plants is the production in winter of a high proportion of fuel gas to supplement natural gas for domestic and factory use. In summer the emphasis will be on the production of synthetic crude oil.

The gasoline resulting from this technique in Germany was



ump of coal can less and be considered the end luct of the coal industry as its raw material from ch will be coke, gas, line, oil, lubricants, and lmost infinite number of nicals. Plants such as e will increasingly charrize the industry. At the is a cracking plant of the ıdard Oil Company of Jersey which is now ed with natural crude, is of the type that will ear as part of future -to-gasoline plants. In center is depicted the low-temperature carization plant of the Disco ıpany of Pittsburgh now er construction. At right battery of modern Kop- Company coke ovens.

only about 45 in octane rating, not high enough to be used as motor fuel without further refining or the addition of tetraethyl lead or both. The German Diesel fuel produced, however, was of excellent quality. The process improved and applied in this country may provide a gasoline of better octane rating, and, if so, a Diesel fuel of somewhat lower quality.

A large measure of the great improvement of the Americanized version of the Fischer-Tropsch process over that applied in Germany stems from the catalyst, both as to kind and its use in fluid form. The fluidized-catalyst principle, developed in America, was of vast importance in the phenomenally successful wartime high-octane aviation-gasoline program. The kind of catalyst and its fluidized form greatly accelerates the reaction. Also its use as a fluid permits building within the reacting chamber the necessary heat exchanger in the form of a boiler by which the great quantities of heat of reaction can be rapidly removed and utilized. The enormously practical result of this improvement is the reduction of the size of the reactors by 95 percent as compared with the German plants employing static catalysts. In German plants these reactors covered literally acres of ground; a 10 000-barrel per day plant required 130 acres of cooling surface. The consequent reduction in capital investment is large and vital to the success of the proposition.

The second step of the Fischer-Tropsch process is similar to that to be employed in two plants now being erected in Texas and Kansas to convert natural gas to gasoline. The Carthage Hydrocol plant at Brownsville, Texas, is intended to produce 7000 barrels of gasoline and Diesel oil daily from low-cost natural gas. The cost of synthetic gasoline made from natural gas will be less than from coal; it is expected to be fully competitive with gasoline obtained from petroleum.

Coal Hydrogenation

An older process for converting coal to gas and oil is hydrogenation. It too was first introduced in Germany and is generally credited to Friedrich Bergius. Although it was announced in 1913, its development was slow. Not until the early twenties did the process reach the pilot-plant stage. However, by the outbreak of the war 18 plants were producing at the maximum yearly rate of four million tons or about 28 million barrels of high-octane synthetic gasoline and other synthetic products from coal and tar. This was about six times that produced synthetically in Germany by the Fischer-Tropsch process and one fourth Germany's total oil supply. England too had a coal-hydrogenation plant at Billingham, erected in 1935, with a capacity of about a million barrels of motor fuel annually.

TABLE I—COMPARISON OF COAL-CONVERSION PROCESSES

	Reaction Pressure and Temp.	Raw Materials	Products per Ton of Coal*	Rank of Coal Suitable				
				Anthracite	Low-Volatile Bituminous	High-Volatile Bituminous	Sub-Bituminous	Lignite
Blue Water gas	Atmos. 2800° F	Coal Steam Air	55000 cu ft 290-Btu gas per ton of coke	Yes	Yes	Yes	No	No
High-Temp. Carbonization	Atmos. 1500 to 2000 (1700° F average)	Coal Heat	1400 lb coke 11 000 cu ft gas 13 gal tar and light oil 28 lb chemicals	No	Yes	Yes	No	No
Low-Temp. Carbonization	Atmos. 1000° F	Coal Heat	1440 lb coke 15 gal tar 3700 cu ft gas	No	Yes	Yes	No	No
Hydrogenation (Bergius)	800-900° F 3000 to 10 000 psi	Coal Hydrogen Catalyst	80 gal gasoline 20 gal liquified gases 425 cu ft 535-Btu gas	No	No	Yes	Yes	Yes
Gas Synthesis (Fischer-Tropsch)	(1) 2800° F 30–150 psi; (2) 300-400° F 0–150 psi	Coal Oxygen Steam Catalyst	8000 cu ft 350-Btu gas 20 gas. gasoline, propane, etc. 15 gal Diesel oil 125 lb wax	Yes	Yes	Yes	Yes	Yes

*Results for hydrogenation and gas synthesis are based on German experience which should be considerably bettered in American plants. Water-gas products are based on one ton of coke and hence require coking coals.

Coal hydrogenation essentially follows the direct procedure of making up coal's deficit of hydrogen by breaking down the complex coal structure and adding hydrogen before the fragments can reform. Pulverized coal is mixed with equal parts of a heavy oil obtained from the process to form a paste. The paste, to which is added a small amount of catalyst, is pumped along with hydrogen to a high-pressure reactor or converter. The process is characterized by the pressure and temperature reached in the cycle: 800 to 900 degrees F and 3000 to 10 000 psi, the pressure depending on the kind of coal used and the cost and availability of catalyst. The light and middle oils formed in the converter are separated from the heavy oil by distillation and are carried, along with the excess hydrogen and hydrocarbon gases formed in the reaction, into a heat exchange and condenser system. Subsequently the oils are separated from the gases. The gases are scrubbed with oil under pressure to remove the bulk of the hydrocarbons, and the residual hydrogen is recycled to the preheater.

The heavy oil contains in suspension the ash-forming constituents and unreacted coal particles. About two thirds of this slurry is directly recycled to the paste-preparation system, whereas the remaining third is centrifuged to remove a portion of its solids. The centrifuge oil and the oil recovered by a coking distillation of the centrifuge solids are recycled to the paste-preparation system.

The light and middle oils are separated into three fractions: gasoline, middle oil, and heavy oil. The last is recycled to paste preparation. The gasoline fraction obtained in this first stage or liquid-phase constitutes about 27 percent of the total gasoline yield and is of about 72 octane number before the addition of tetraethyl lead.

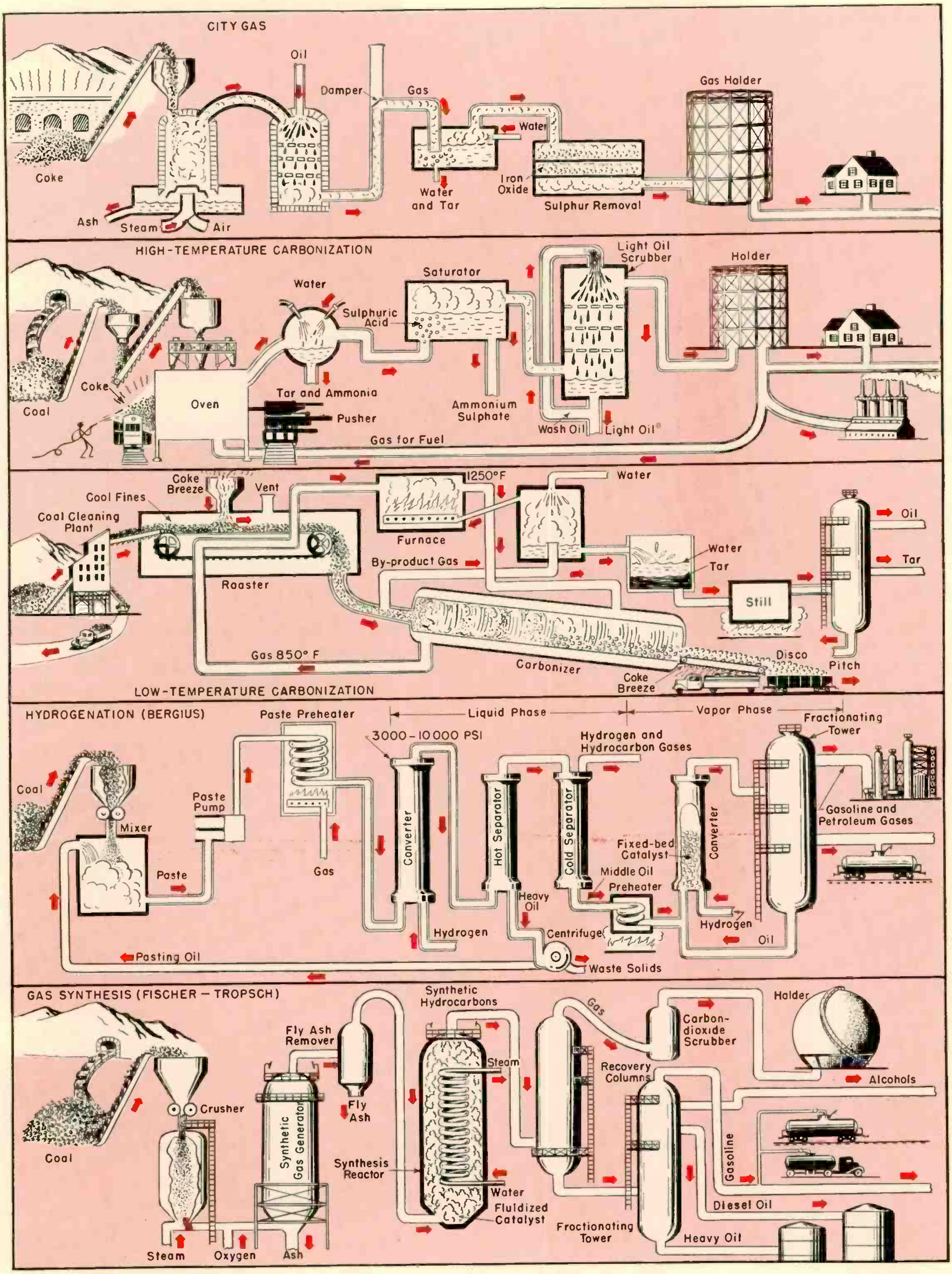
The middle oil from the liquid-phase is pumped with hydrogen at 3000 pounds per square inch, through a preheater into the vapor-phase converters filled with catalyst pellets. In passage over these catalysts the middle oil reacts with hydrogen to form water, ammonia, gasoline, and lower boiling hydrocarbons, such as butane, propane, ethane, and methane. The gasoline thus obtained has a high-octane rating.

The proportion of solid residues, oils, and gaseous hydrocarbons resulting from the hydrogenation is controllable over a wide range by the temperatures at which the reaction is allowed to occur and its duration. The overall thermal efficiency of the coal-hydrogenation process for gasoline production in Germany was about 28 percent but the Bureau of Mines estimates this can be substantially increased, perhaps as much as doubled.

Unlike gas-synthesis on which Standard Oil and Pittsburgh Consolidation Coal plan to stack a high pile of blue chips, hydrogenation has not been chosen for a commercial plant in the United States as yet. However, it has been under extensive study by the Bureau of Mines for nearly ten years and the research is being actively continued.

Manufactured Gas

The synthesis gas of the Fischer-Tropsch process consists of hydrogen and carbon monoxide. This is essentially the


CITY GAS
Oil
Damper
Gas
Gas Holder
Water
Coke
Iron Oxide
Water and Tar
Sulphur Removal
Ash
Steam
Air
HIGH-TEMPERATURE CARBONIZATION
Light Oil Scrubber
Holder
Saturator
Water
Sulphuric Acid
Coke
Coal
Oven
Tar and Ammonia
Pusher
Ammonium Sulphate
Wash Oil
Light Oil
Gas for Fuel
Coke Breeze
Vent
1250°F
Water
Coal Fines
Coal Cleaning Plant
Oil
Furnace
Water
Tar
By-product Gas
Tar
Roaster
Still
Gas 850° F
Disco
Carbonizer
Pitch
Coke Breeze
LOW-TEMPERATURE CARBONIZATION
HYDROGENATION (BERGIUS)
Paste Preheater
Liquid Phase
Vapor Phase
Fractionating Tower
3000-10000 PSI
Hydrogen and Hydrocarbon Gases
Coal
Paste Pump
Mixer
Converter
Hot Separator
Cold Separator
Converter
Gasoline and Petroleum Gases
Fixed-bed Catalyst
Paste
Gas
Middle Oil Preheater
Heavy Oil
Hydrogen
Centrifuge
Hydrogen
Oil
Pasting Oil
Waste Solids
GAS SYNTHESIS (FISCHER - TROPSCH)
Synthetic Hydrocarbons
Gas
Holder
Fly Ash Remover
Carbon-dioxide Scrubber
Steam
Recovery Columns
Alcohols
Crusher
Fly Ash
Synthetic Gas Generator
Gasoline
Coal
Synthesis Reactor
Water
Fluidized Catalyst
Fractionating Tower
Diesel Oil
Heavy Oil
Steam
Oxygen
Ash

same as water gas, the manufacture of which came into vogue about 1873. To make water-gas, coke or anthracite is brought to incandescence by blasting with air. Then, with the air shut off, the hot coals are blasted with steam to produce hydrogen and carbon monoxide. The heat content of this gas is about 300 Btu per cubic foot. By adding gases from the cracking of heavy oils, the gas is enriched to 500 Btu or more per cubic foot, the resulting product being called city gas. This is the gas produced in the plants traditionally always on the "wrong side of the tracks." A large amount of by-product coke-oven gas, described below, is also used for house heating.

A glance at the nation's energy picture leaves several unescapable conclusions: the cost of energy from any fuel source is bound to rise; long-range energy planning rests squarely on coal; liquid and gas fuels of the future will be made from coal regardless of costs, which probably will be only slightly higher than present costs; conversion of coal to liquid and gas will mean the founding of giant industries supported by vast research, and marked by increased employment directly and indirectly; technically trained men will be needed in large numbers. The picture is breathtaking.

The "gas" works produce in addition to gas for fuel a small amount of petroleum-like chemicals. The process cannot be a major factor in the production of liquid fuels from coal but is important as a measure of producing hydrogen.

High-Temperature Coke Making

Ever since the by-product coke oven superseded the distressingly wasteful beehive ovens, the manufacture of metallurgical coke has been an important contributor of fuel gas and valuable chemicals such as benzene, toluene, phenols, ammonia, creosote, and tars. The typical modern coke battery consists of a series of ovens 40 feet long by 12 feet high and 18 inches wide slightly tapering from one end to the other. Between each pair of ovens is a wall with built-in flues through which pass hot furnace gases. Each oven is filled with crushed coal, air excluded, and heated by conduction from the flue walls on either side. The volatile components driven off are cooled, precipitating some liquids as tars and ammonia liquor from the gas, which, after scrubbing for removal of ammonia and light oil, is used as fuel in steel making for heating the ovens, and for domestic heating. After about 16 hours the red-hot coke is pushed out one end of the narrow vertical oven into a car and quenched in a tower with water.

Low-Temperature Coke Making

Metallurgical-coke manufacture involves temperatures of about 1700 degrees F. Coke can also be made at lower temperatures, around 800 to 1000 degrees F. The idea is not new; many processes have been proposed but their application in this country has been small. The largest plant, with a daily capacity of 225 tons of product called Disco, has been in operation near Pittsburgh, Pennsylvania, for about 15 years. That it is considered successful is indicated by the present construction adjacent to the existing one of a new $3 000 000 plant three times larger.

The solid fuels that result from high-temperature and low-temperature carbonization have quite different burning characteristics. The low-temperature product burns smokelessly, but, because the distillation is less complete, it ignites more readily and holds the fire better in domestic furnaces, and is well adapted for compliance with anti-smoke programs.

The raw material for low-temperature coke manufacture is coal fines obtained from coal cleaning. This coal dust is roasted on continuous conveyors at 600 degrees F and mixed with a certain and important proportion of the coke fines (called coke breeze) obtained later in the process. The hot, dry mixture flows continuously into a carbonizer. This is a cylindrical revolving drum 9 feet in diameter and 125 feet long, closely resembling a cement or lime kiln except that it is not lined and is externally heated. The dust and breeze slowly start by gravity toward the lower end. Meanwhile combustion gases from a furnace flow in the opposite direction around the carbonizer. As the mixture progresses it accumulates heat, softens as volatile gases are distilled, and then forms into balls that spill out at the lower end of the carbonizer onto a conveyor for cooling and discharge ready for use.

The coal gases driven off in the carbonizer are collected, passed through condensers to recover the liquids, tar, and water. The remaining gas is used as fuel to heat the carbonizer or for other heating purposes.

Factors Affecting Coal Conversion

Unquestionably the means are at hand for the production of liquid and gas fuels and the recovery of valuable chemicals from coal. Both hydrogenation and gasification were successful, large-scale operations in Germany where petroleum was scant and the military need commanding. Coal gasification by gas-synthesis is soon to be given proof-of-the-pudding trial on a sizable scale in the United States. The technology of hydrogenation is being thoroughly explored and eventual application seems likely.

The cost of liquid fuels from coal? It is too early to say. Various estimates, differing widely, have been made. Some authorities believe that gasoline can be made by gas-synthesis from high-volatile bituminous coal for about 10 to 15 cents per gallon, which must be compared with present-day selling price along the Eastern seaboard of about 7 to 8 cents per gallon at the refinery (i.e., without taxes and transportation). Present estimates place the cost of gasoline via hydrogenation at perhaps 15 to 18 cents per gallon. Expected production costs of gasoline from natural gas at the Texas plant have been given at 5 to 6 cents per gallon. These costs can only be approximations because the developments are not far enough along for plant investment, overhead, and production figures to be known. Research and development can be counted on to bring the costs of synthetic gasoline down. Meanwhile the cost of underground crude will rise, diminishing the disparity between the cost of engine fuels made by nature and by man.

One fact concerning cost is conspicuous: the cost of gasoline made synthetically from coal or natural gas will not be exorbitant by present standards. Even if production costs of synthetic gasoline are double that of petroleum gasoline, which seems pessimistic, the cost at the pump should not increase by more than a fourth to a third. Petroleum-produced gasoline is likely to increase some in price anyway.

The cost of gasoline from coal, while important and not to be ignored, does not in the long run have much bearing on whether or not coal becomes the source of liquid fuel. The fact is, it is inevitable. Liquid fuel is a matter of absolute national necessity as well as convenience. Present-known large reserves underground of crude oil and gas can be looked upon as only giving time in which we must learn how to support ourselves on the vastly greater supplies of coal.

In evaluating coal conversion another factor is important: which process can use what kinds of coal. Fortunately both hydrogenation and gas-synthesis are even better adapted to the more abundant lower rank coals and lignites than are the high-rank bituminous coals. This fact is doubly important. Coal conversion brings into practical use the vast stores of lower rank coals not now utilized because of their low grade and remote location. Also these low-rank coals are not suitable for the making of coke, which is an absolute requirement in the production of steel. It is fortunate for our national economy that the relatively smaller amount of bituminous coals does not have to carry the burden of both steel making and synthetic-fuel production.

An attempt to weigh hydrogenation against gas-synthesis methods now is fruitless. There are far too many unexplored variables in each to judge the place of either in the national energy economy. The experience in Germany is not too indicative, as the situation there was confused by political and military decisions, by the need for integrating coal conversion with a quite different steel, power, and chemical industry setup, and by different raw materials. Gas synthesis appears in general to be the more versatile. By it virtually any organic material available in quantity can be converted into almost any desired liquid or gas fuel or lubricant and the proportions of those products varied to suit the current need. Wood, cornstalks, cane, natural gas, hard or soft coal, or even the sub-bituminous coals and lignites are eligible. Coal hydrogenation also works well on the high-volatile bituminous, sub-bituminous, and lignites. Anthracites do not respond well to hydrogenation. A hydrogenation plant with its high-pressure vessels probably entails higher initial investment and some operating difficulties connected with paste pumping. However, experience thus far indicates hydrogenation conversion efficiency is somewhat higher and the gasoline is of superior quality to those that have been produced by gas synthesis. But there are unknown factors such as the adaptability of the processes or modifications of them to the specific fuels in this country, the effect of improvements in techniques now known as possible, the bearing of new, better catalysts. Quite possibly the two processes, or major variations of them, may be complementary not competitive. Only one thing right now is sure: by either process coal can be converted to fuels and chemicals at reasonable cost.

Complete conversion of coal to liquid and gas fuels and to chemicals means the establishment of whole new major industries. It will, clearly, have direct bearing on the nation's future energy supply, on employment, on transportation, and on the centers of gravity of industries. It will have bearing less direct but no less noticeable on established business.

For one thing, these plants will be all king-size. Small-scale operations are not practical. Each commercial plant proposed by Standard Oil and Pittsburgh Consolidation Coal Company, if the pilot-plant at Library is successful, it is estimated, will cost in the neighborhood of a hundred million dollars, will employ directly 2000 men and twice that many indirectly, will consume 20 000 tons of coal daily, and will require at least a 30-year supply of coal. Nothing less seems feasible.

Just to supply the liquid fuel annually consumed in the United States from coal instead of from petroleum would require the mining of an additional 420 000 000 tons of coal or 65 percent more than is being mined now.

One of these 20 000-ton per day gas-synthesis plants, which will produce some 14 000 barrels of motor fuel and 200 million cubic feet of gas fuel, will probably have a total connected electrical load of about 25 000 hp, mostly in motors and gearing to drive conveyors, pumps, fans, and crushers. Hydrogenation plants, with their high pressures, will also require large amounts of electrical apparatus. The quantities of steel required, not only for the plants themselves but also for pipelines, will be enormous. The project will require vast sums for research and development and many technically trained men.

Large-scale supplemental plants will be required. Both the coal-gasification and hydrogenation systems call for volumes of hydrogen that stagger the imagination. The water-gas plants to produce these will be sizable. The fractional-distillation oxygen plant for a single 20 000-ton coal-gasifying plant as visualized by Pittsburgh Consolidation Coal Company will require 5000 tons of oxygen daily.

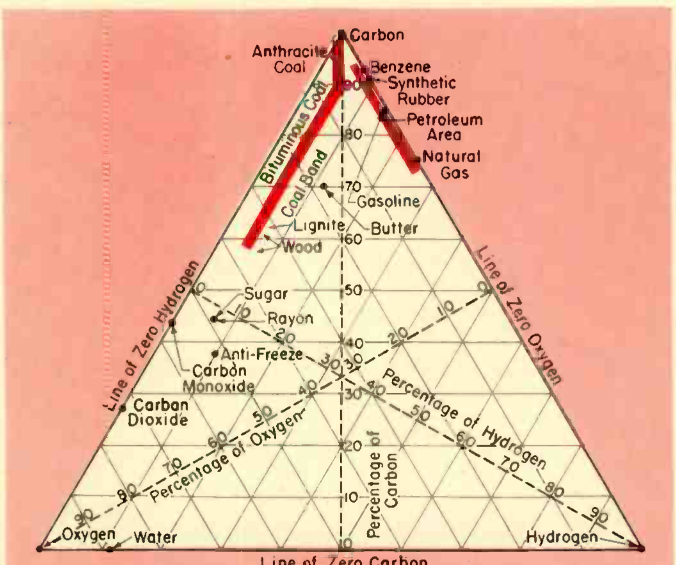
Gasifying Coal Underground

Prominent in the news is the gasification of coal without mining it. Russia has experimented extensively with the controlled burning of coal *in situ*, the gases, mostly carbon monoxide being led off for fuel. Underground burning is likely to be tried extensively also in Belgium and Holland.

One experiment is under way in the United States. The Alabama Power Company in cooperation with the United States Bureau of Mines and Southern Research Institute have attempted this at the Gorgas mine near Birmingham. For purposes of experimentation and safety, a peninsula of thin-seam coal was selected and entirely isolated from the main bed. A U-shaped duct was cut around it. The fire was set and air and steam pumped in one leg of the U. The escaping gases were removed at the other end of the U.

Only a preliminary and inconclusive report has yet been made. The heat value of the gases ran 50 to 80 Btu per cubic foot, which is too low to make transportation economical. Underground gasification may have some application. But it is likely to be limited. It appears most suitable for coal beds of small area or thin seams more common in Europe than in America. Experience thus far does not indicate that burning coal underground will figure strongly in the energy picture.

Coal is one of the most complex substances in all nature. One nationally known coal-research director puts it this way: "Although we have been mining and burning coal for centuries, and in spite of years of research and vast sums spent in the study of coal, we still know relatively little about coal. We understand only faintly what coal is and what can be done with it." Certainly we are beginning to respect a lump of coal as more than something to burn—and dirty in the bargain.



The eternal triangle of carbon, oxygen, and hydrogen compounds shows the close molecular relationship of coal and petroleum and gives a partial idea of what must be done to convert coal to liquid and gas hydrocarbons. Essentially, the heavy coal molecules must be broken up and rearranged to contain more hydrogen and less oxygen and sulphur.

STORIES OF RESEARCH

Tagged Atoms Invade Metals

Radioactive tracers are rapidly coming of age. In the decade since the Curie-Joliots discovered they could be produced artificially, "tagged" atoms have been used to study cancer and goiter, to investigate the role of carbon in photosynthesis, to learn how chicken embryos grow, and for a host of other problems in biology, medicine, and chemistry.

Now they are being applied to the solution of some fundamental problems in metallurgy. Mr. J. K. Stanley of the Westinghouse Research Laboratories is using radioactive carbon—the so-called heavy carbon 14—to study its migration in irons and alloy steels. From this investigation he hopes to get answers to such questions as why certain steels are hard and others brittle, what happens to metals during aging, and the effect of carbides.

Carbon is an old and familiar friend of the metallurgist. By careful control of the amount he puts in iron, he can produce steels with the highest hardness and wearability. But the same element can and does yield a crop of headaches. In aging, for example, where the metal is subject to elevated temperatures over a period of time (from minutes to days), the carbon atoms may take up positions in the steel that give excellent tensile strength, but are dangerously brittle. A certain specimen of low-carbon steel with an impact resistance of 35 foot-pounds before aging may snap under 15-foot-pounds impact after aging.

Although metallurgists have known the effects for a long time, the underlying causes are still somewhat of a mystery. Stanley believes that the "tracer" method, enabling scientists to plot the course of carbon atoms as they migrate through the metal during heat treatment, aging, and other processes, may turn up some long sought for clues.

The Westinghouse scientist is using the radiographic technique to gather his evidence. A minute amount of radioactive carbon—a few milligrams—is injected into the metal under study. After heat treatment to disperse the carbon uniformly throughout the metal, a fine-grain photographic film is exposed to the betaradiation from the tagged carbon. This produces a uniform fogging of the film at those points bombarded by the high-speed particles. When the iron is aged—for 500 hours at 212 degrees C, for example—the carbon unites with the iron atoms to form carbides in separated "clusters." This produces a spottiness on the film indicating the position of the carbide clusters in the metal. The intensity of the spots is correlated with time at a given temperature or with temperature for a constant time.

James K. Stanley, Westinghouse Research engineer, inserts a sample of radioactive material into a counter. The sound of particles flying off the carbon is amplified and fed to a loud-speaker.

Plastics That Stick Like Glue

Ever since primitive man found that melted animal hide was good for sticking things together, the quest for better and better glues has gone on. Thus far the record looks excellent, thanks largely to plastic adhesives produced synthetically in the laboratory. But many problems remain to be solved.

Fritz J. Nagel and Elisabeth M. Ackermann of the Westinghouse Research Laboratories have been attacking some of them in the field of resorcinol resins. These are first cousins to the familiar Bakelite plastics, the main chemical difference being the addition of a group of hydrogen and oxygen atoms to the molecular chain. By a new technique, the two chemists have been able to produce a glue with 10 to 15 percent more strength than the best resorcinol resins now available.

The new glue maintains maximum bond strength in temperatures from 60 degrees below zero F, to 300 degrees above, and for short periods even up to 400 degrees. It has been immersed in boiling water for three hours and cold water for 24 without signs of weakening; in fact, the strength of the bond showed some improvement. Its shear strength is slightly over 3200 psi.

The addition of a group of hydrogen-oxygen atoms to the molecular chain gives it the unique quality of hardening at room temperature and at pressures low enough to give intimate surface contact. Its Bakelite cousin, on the other hand, requires high-temperature baking up to 24 hours, and at pressures from 25 to 250 psi. In some way, not yet clearly understood, the additional group of hydroxl radicals hastens the reaction by 1000 to 1500 times over that of Bakelite resins. The result is quick hardening at ordinary temperatures and low pressures.

The glue is of great practical value to the large-scale user of bonding materials, since it eliminates the need for ovens or large presses. For bulky or curved shapes, such as building arches or beams, where presses are impractical, the low-pressure hardening effect is of special advantage. While it does harden at room temperatures, the application of heat can reduce the curing time greatly, a temperature of 210 degrees F producing a permanent set in two minutes. Where quick setting is used, unit production time can be decreased and output raised appreciably.

The glue can be used to bond wood, rubber, leather, paper, cloth, cardboard, china, and plastics. Only metals and glass are excluded. This makes it applicable for boat and furniture construction, shoe manufacture, rubber processes, plastic bonding, electrical equipment manufacture, and a host of other uses where strong, weatherproof and waterproof bonding is required.

The two chemists aren't resting on their laurels with development of this tough new glue. They are seeking still other modifications of the resin that will bring about hitherto unrealized qualities. One of these is flexibility. While the resorcinol resins show excellent tensile and shear strength, they have poor bending moment. A glue that combines tensility, shear strength and bending qualities with its other advantages is the next objective.

Power-Line Carrier Communication

Power-line carrier communication systems have steadily climbed in favor with major electrical utility companies. New equipment, new ways of using the old, innovations in the whole field of communications, have brought the systems to a high degree of dependability. It seems a far cry now to the days of 1917–1918 when the first recorded message, likely an emergency order, went over a power line in war-torn France.

R. C. Cheek • *Central Station Engineer* • *Westinghouse Electric Corporation*

PRESENT-DAY power-line carrier equipment can provide a communication system that practically duplicates the service obtained from a private automatic-telephone exchange. Its reliability, economy and speed of carrier communication have been of immense value to the power-generating industry, which is clearly indicated from the large number of terminals now in use and under construction.

Power-line carrier communication systems comprise, in essence, receivers and transmitters with their calling devices, and apparatus to couple transmitter and receiver to the power transmission lines. The lines themselves compose the voice-carrying medium. Capacitors of the type shown in Fig. 1, couple the equipment to the power line, as indicated in Fig. 2, generally using a single conductor with ground return. This arrangement offers maximum economy in coupling and in use of by-passing or trap units shown in Fig. 3. For lowest attenuation and noise level, a second conductor of the three-phase line sometimes is employed as a return circuit.

The power-line carrier frequency band, 50 to 150 kc, is dictated by the characteristics of power-transmission lines when they are used as carrier mediums. Short branches along the lines sometimes cause losses because they may approximate an odd quarter wavelength that represents a low impedance at carrier frequency. A line trap inserted in series at the tap point can prevent this. The trap consists of a coil of heavy cable, capable of carrying the full power current of the line tuned to parallel resonance at the carrier frequency. Representative power-line carrier transmitters and receivers are shown in Figs. 4 and 5.

System Combinations

Power-line carrier communication systems can differ in the method of calling, the power supply, or in the modulation system, but any given assembly can be classified as simplex or duplex, depending upon its operation.

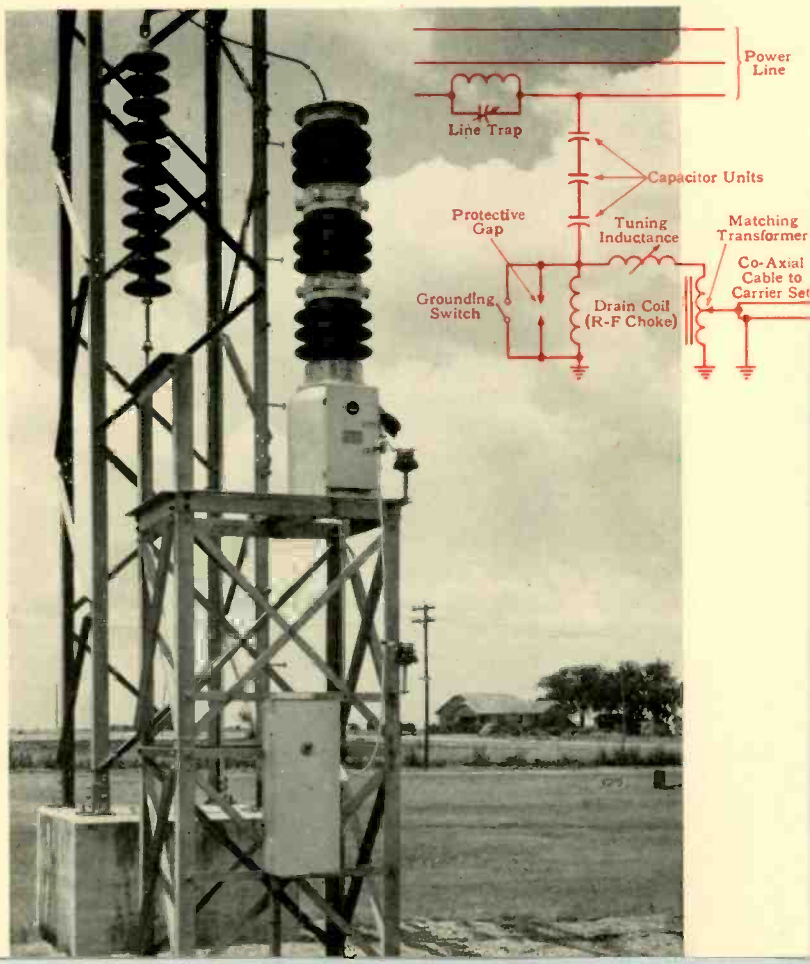
A *simplex* system is one in which transmission can proceed from one station only at any given instant. In simplex communication all stations on a channel operate on a single frequency. Transmission and reception cannot take place simultaneously on the same frequency at one station, because the transmitter in operation blocks the local receiver and may even damage it permanently unless the receiver is de-energized. The simplex system requires means for turning off the receiver during transmission.

Requiring only a single carrier frequency, simplex lends itself readily to applications in extensive carrier-communications involving more than two terminals. It is more economical of space in the carrier-frequency spectrum since the same frequency is used at all transmitting points. Because crowding of the spectrum is a serious problem on many power systems today, this factor alone is often sufficient to justify its application.

A *duplex* system is one in which transmission can take place simultaneously from both stations as in ordinary telephone service. In the usual duplex system, at one station the first of two frequencies is used for transmission, the second for reception. At the other station, the first frequency is used for reception, the second for transmission. The difference between the transmitting and receiving frequencies is held to a minimum of 20 percent of the higher of the two frequencies. This prevents local transmitter-receiver interference.

Duplex operation normally is limited to two terminals per channel, unless communication is desired between a central office and several other stations not requiring intercommunication. Its major advantage, and one that in the minds of some users outweighs any disadvantages, is its ability to

Fig. 1 (photo)—The carrier wave, containing the voice signals, is applied to the power line for transmission through a coupling capacitor of which this one on the system of the Texas Power & Light Company is representative. The connections to the power transmission line, simplified, are shown in the diagram, Fig. 2.



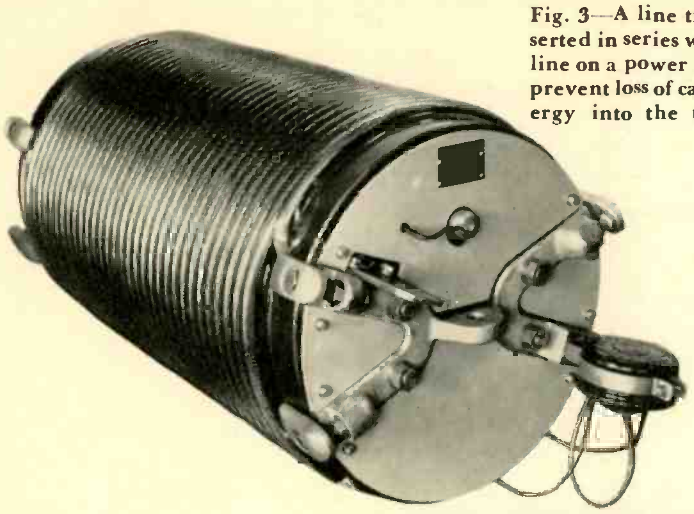


Fig. 3—A line trap is inserted in series with a tap line on a power circuit to prevent loss of carrier energy into the tap line.

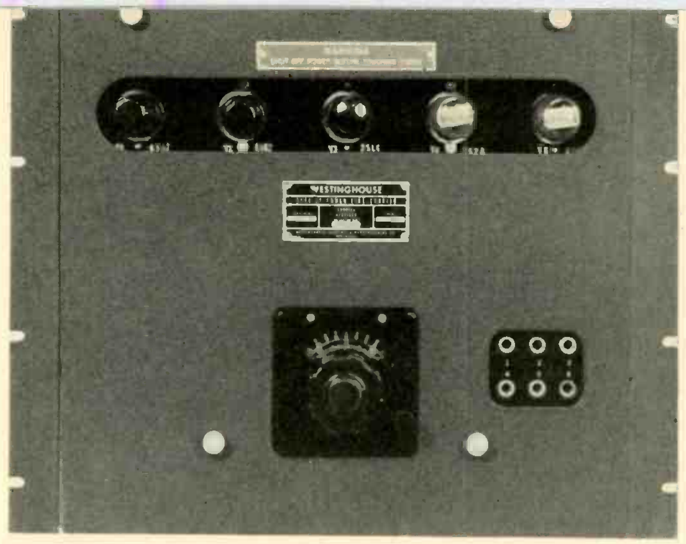


Fig. 5—In this superheterodyne receiver, a band pass filter feeds into a mixer and a two-stage i-f amplifier. Two full-wave rectifiers are used, one for detection, and one for automatic volume control to minimize variations in signal strength caused by changes in channel attenuation, sleet forming on lines, and as compensation for the varying distances separating stations using a single channel.

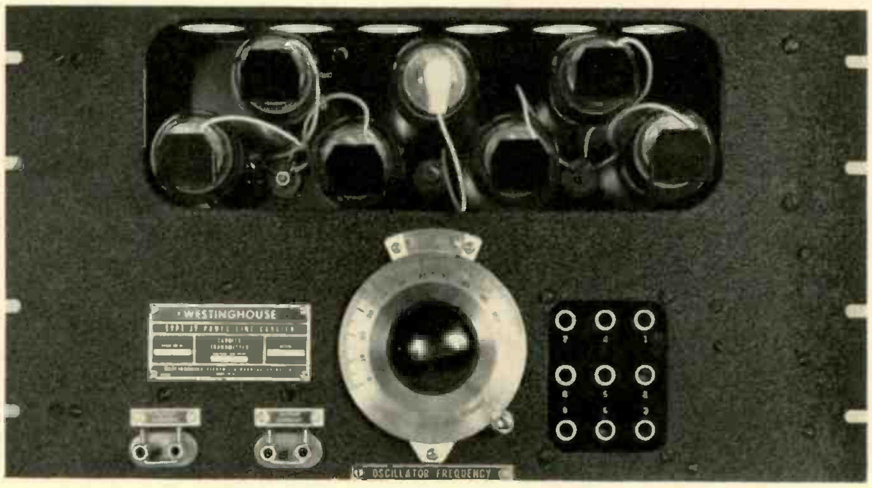


Fig. 4—Carrier communication transmitter. A beam-type oscillator tube in a Colpitts circuit is used to excite six similar tubes in push-pull-parallels. Grid-bias modulation is employed with a carrier output of 25 watts, adequate for all the usual power-line carrier applications. Low-powered transmitters, designed to operate from the 125- or 250-volt batteries provided in power stations are often used.

provide two-way conversation without the switching operations required by the manual-simplex system.

The Single-Frequency Manual-Simplex System

In the single-frequency manual-simplex system, shown diagrammatically in Fig. 6, "send-receive" switching operations are performed by the speaker using a pushbutton on the telephone handset. Although provision can be made for complete operation over a two-wire extension, a control circuit separate from the speech circuits generally is required. The need for d-c control circuits, and the fact that a special telephone instrument with a "push-to-talk" button is necessary, precludes any simple method of extending a manual-simplex telephone channel through a conventional private-branch exchange type of board.

The system is used where a simple point-to-point communication channel is needed and where telephone extensions from the carrier equipment are short and few. For routine or emergency communication between system operators accustomed to handling the equipment, the manual-simplex system often is entirely adequate.

The Two-Frequency Duplex System

The basic units of a two-frequency duplex assembly are shown in Fig. 7. Transmitter and receiver operate through the audio-hybrid unit, marking the difference between this system and that of the single-frequency, manual-simplex. The audio-hybrid unit allows transmitter and receiver to operate continuously without switching and using only a conventional two-wire telephone extension.

The assembly shown in Fig. 8 is used with telephone extensions that provide d-c paths between carrier equipment and telephone. The hook switch energizes the transmitter through a d-c control circuit when the telephone receiver is lifted. If the extension does not provide a d-c path, the same equipment can be used with the transmitter energized continuously, whether or not conversation is in progress. This may be objectionable because of the possibility of continuous interference with other carrier channels. Alternatively, the assembly can include an element called an audio-relay unit, which functions automatically to energize the transmitter when an audio signal, either voice or ringing tone, reaches the equipment from the telephone line. Time-delay circuits keep the transmitter energized continuously during conversation; they turn off the power at some predetermined time after the conversation has been completed.

The Multi-Station Duplex System

The multi-station duplex system provides the advantages of duplex communication between any two of a number of stations on a channel. The basic units are shown in Fig. 9.

The transmitter and receiver to be used at a given station, during a conversation, depend upon the point of origin of the call. Designating the two frequencies as F_1 and F_2, all stations would normally receive on F_1. A station originating a call would transmit on F_1. The F_1 transmitter is selected by the calling party by picking up the telephone handset. The closing of the d-c circuit through the hook switch operates a relay, causing the contactor unit to apply audio-amplifier output to the audio terminals of transmitter F_1. Simultaneously the contactor unit energizes the transmitter and applies the output of receiver F_2 to the audio-hybrid unit. At the called station, reception of the carrier signal from the calling station on receiver F_1 operates a relay whose contacts open to prevent a transfer (transmitter F_2 to transmitter F_1) being made by the contactor unit when the called party replies.

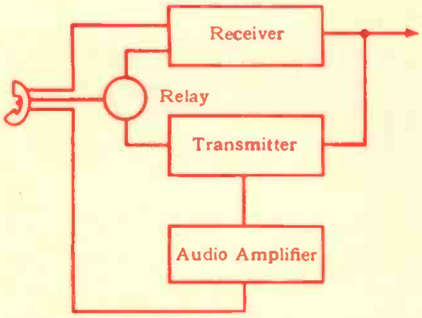


Fig. 6—The basic units of a manual-simplex carrier communication assembly. The relay removes power from the receiver and applies it to the transmitter when the control button on the handset is operated. The audio amplifier can be omitted.

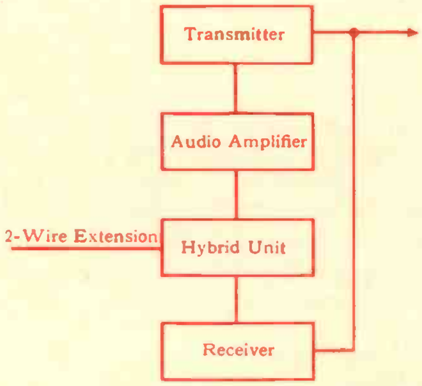


Fig. 7—The basic units of the two-frequency duplex communication assembly. The hybrid unit directs outgoing speech into the transmitter and incoming speech to the telephone circuits.

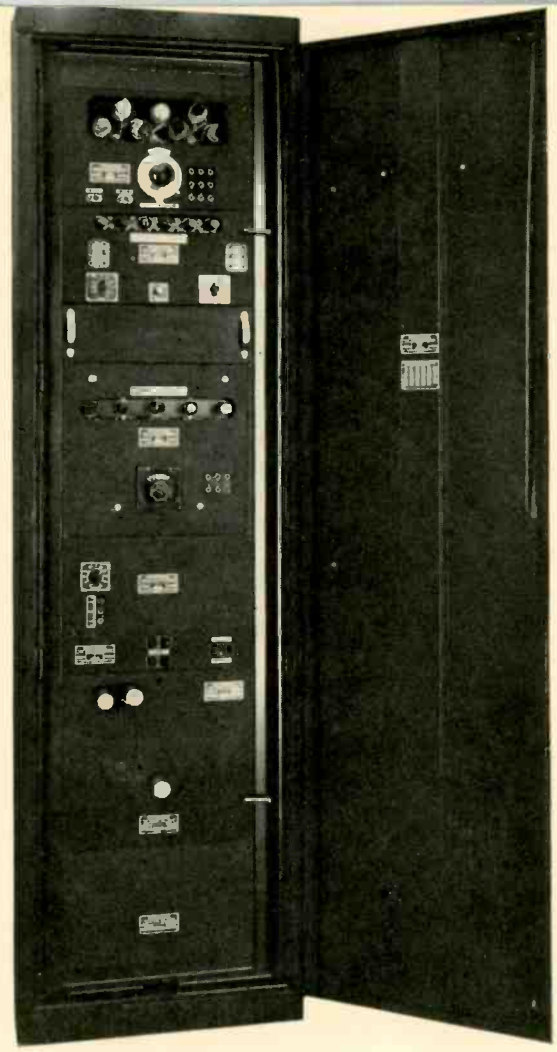


Fig. 8—Typical two-frequency duplex power-line carrier communication assembly. Units, from top to bottom are transmitter, audio amplifier, panel for test meter unit, superheterodyne receiver, audio hybrid unit, switch and fuse panel, 640-volt rectifier, and 120-volt rectifier. →

Transmitter F_1 and receiver F_2 at the calling station and transmitter F_2 and receiver F_1 at the called station remain energized throughout. The conversation completed, replacing the receiver at both stations returns conditions to normal, with all stations receiving on F_1.

The Single-Frequency, Automatic-Simplex System

Single-frequency, automatic-simplex is the most versatile of all the power-line carrier-communication systems. The number of stations on a given channel is not limited to two, as is the case with the usual two-frequency duplex system; it permits a single conversation among several stations on the channel, and it permits operation with two-wire telephone extensions and through PBX boards without requiring balance of a hybrid unit.

Modern automatic-simplex equipment eliminates objections to "send-receive" switching because this function, accomplished automatically, is so rapid and quiet that the user often is unable to detect its occurrence. In up-to-date automatic-simplex equipment, the transfer is made so rapidly that after every slight pause, or even between words, a party speaking can be interrupted.

A typical assembly for automatic-simplex communication is shown in Fig. 10. In addition to the units used in the two-frequency duplex assembly, automatic-simplex operation requires an electronic-transfer unit and a bias-controlled audio-amplifier unit. The latter provides a convenient place to block receiver audio output without disabling the radio-frequency portion. It consists of a single-stage class-A amplifier, with transformer-coupled input and output. Leads are brought out from the grid circuit to a terminal strip so that an external negative blocking bias can be applied.

The transmitting audio amplifier in the stand-by condition is unblocked and ready to amplify voice signals from the telephone line. Reception of a carrier signal blocks the amplifier, so that once reception has started, no transmission can occur until the equipment returns to the stand-by condition. On the other hand, if an outgoing voice signal reaches the amplifier from the telephone line with the stand-by condition in effect, it causes the entire receiver to be blocked so that no signal can be received until conditions return to stand-by. The switch from transmit to receive and vice versa requires that the equipment pass through the stand-by condition in each direction.

The electronic-transfer instrument is the key unit in the automatic-simplex assembly. It switches automatically from stand-by to transmit or receive as required. The unit is normally in the stand-by condition, that is, with no signal being received or transmitted. The transmitter is blocked by voltage 1 (Fig. 11), and the r-f circuits of the receiver are energized to detect the presence of an incoming signal. The bias-controlled amplifier is blocked in the stand-by condition by voltage 2, so that no audio output from the receiver reaches the telephone line. When no carrier signal is being received, the automatic-volume-control circuits of the receiver increase the gain to such an extent that noise on the channel might become annoying if operation of the bias-controlled amplifier were not blocked.

The operation of the transfer unit when changing from stand-by to transmit or receive is as follows:

Transmit—An audio signal (voltage 3 in Fig. 11) from the telephone line passes through the transmitting audio-frequency amplifier and is applied simultaneously to transmitter and transfer unit. In the latter it is further amplified and then rectified by a diode detector. The positive bias so produced is applied to the grid of a small thyratron, which breaks down and begins to rectify a ten-kilocycle internally generated voltage. The negative voltage then appearing across the thyratron load resistor is used to block the radio-frequency circuits of the receiver (voltage 4), and, simultaneously, to stop a second thyratron from rectifying the ten-kilocycle voltage. Extinguishing this second thyratron removes blocking voltage 1 from the transmitter, allowing the audio signal initiating the switching to be transmitted. The entire sequence occurs in 2.5 milliseconds or less, so that not even the first syllable of the outgoing speech is lost.

The disappearance of the audio signal from the telephone line does not instantly return the equipment to stand-by. Resistance-capacitance time-delay circuits with adjustable constants provided in the diode rectifier circuit prevent the actuating bias from disappearing immediately speech ceases. This delay can be adjusted to allow return to stand-by at the end of words, phrases, or sentences, depending upon the preference of the user.

Receive—The incoming carrier signal (voltage 5 in Fig. 11) is taken from the i-f output stage and applied to an amplifier in the electronic-transfer unit. The amplified signal is rectified by a diode detector, and the resulting bias causes a thyratron to break down and start rectifying a ten-kilocycle voltage supplied by the transfer-unit oscillator. Current through the load resistor in the thyratron plate circuit produces a negative bias voltage 6, which blocks the transmitting audio amplifier, extinguishes a second thyratron, and removes blocking-bias voltage 2 from the receiving audio amplifier, thus permitting the incoming signal to reach the telephone line. This operation occurs in 2 milliseconds or less. Disappearance of the carrier signal removes the actuating bias furnished by the diode rectifier and causes the opposite sequence of events, returning the equipment to the stand-by condition.

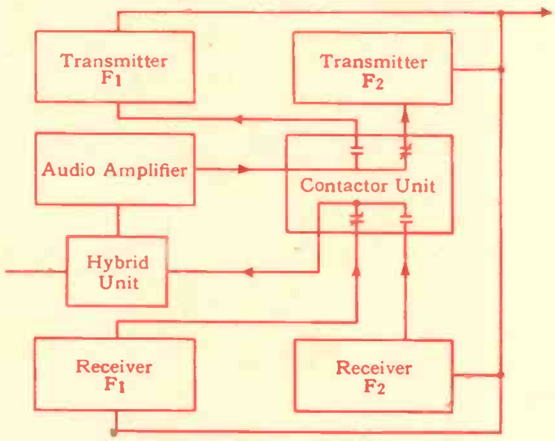
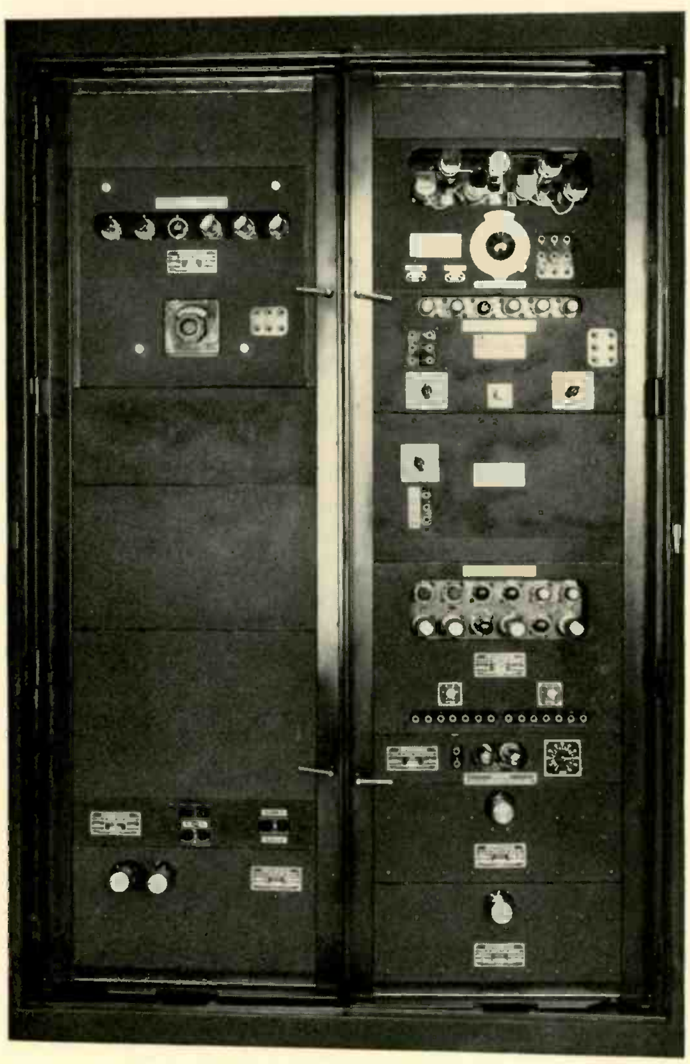


Fig. 9 (above)—Basic units of multi-station duplex communication assembly. Fig. 10 (below)—A representative assembly of automatic-simplex power-line carrier-communication equipment.



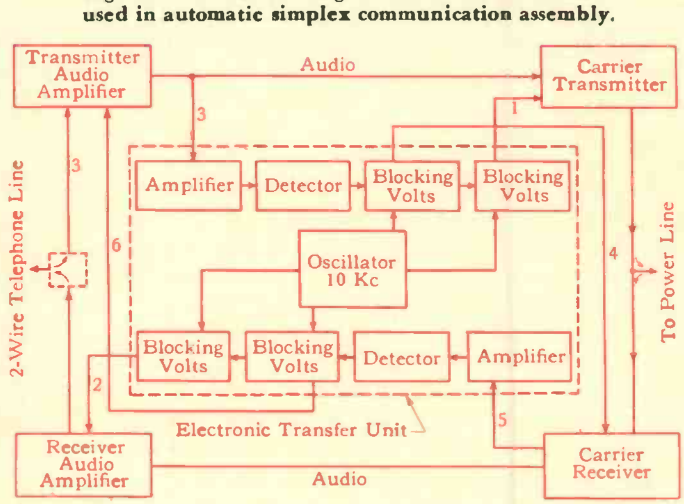
Calling Systems

Several systems to establish a call over a carrier channel are in general use. Among the more important are: code-bell, voice, automatic bell, and dial selective.

Code-bell calling is a system often used on rural telephone party lines, in which all telephones on a given circuit ring. The desired party is indicated by a code of long and short rings. In power-line carrier communications the calling party transmits the code by turning a hand generator, or applies a 60-cycle voltage to the line by means of a pushbutton on his telephone. A relay in the carrier equipment, actuated by calling voltages between 16 and 60 cycles, operates in accordance with the coded signal to apply 60-cycle modulation to the transmitter. At the other terminal or terminals of the channel, the receiver output energizes a circuit selective to 60-cycle modulation. This circuit operates a relay that applies ringing voltage (either 20 or 60 cycles) to the telephone extensions, causing all telephones to ring in accordance with the coded signal. Code-bell calling can be used with either a-c or d-c telephone extensions, and is the most popular system used in power-line carrier work.

In the *voice-calling system*, the call is placed by speaking the desired party's name into the telephone transmitter. Loud-

Fig. 11—Functional diagram of electronic transfer used in automatic simplex communication assembly.



speakers with individual amplifiers at all telephone extensions are disconnected when the receiver is lifted. Where ambient noise level is high, voice calling can be supplemented by a high-frequency tone, transmitted at the option of the calling party by a pushbutton or key switch. Voice calling can be used with either a-c or d-c lines.

In the *automatic bell-calling system*, the telephones at the opposite terminal are rung automatically when the calling party lifts the handset. The ringing continues for a few seconds and then is cut off. To repeat the ring the calling party must hang up the telephone handset and remove it again, or close the hook switch manually and then release it. Automatic bell-calling systems require d-c telephone extensions, because closure of the d-c circuit through the telephone transmitter initiates application of calling voltage to the carrier equipment. Since this system provides no means of indicating which telephone on an extension should be answered, in general it is used only on point-to-point systems where only one extension is operating at each end of the channel. A carrier channel linking two PBX boards provides an ideal application for the automatic bell-calling system.

In *dial selection*, the desired number is dialed in the conventional dial-telephone manner. Each carrier set includes its own line-selector unit, which receives incoming dial pulses and applies ringing voltage to the wanted extension. Each of these selector units is in itself a complete private automatic-telephone exchange. The automatic-simplex carrier system with selective calling provides nearly every operating feature found on modern dial-telephone systems, such as a busy signal, a revertive or ring-back signal, local intercommunication, executive right-of-way or preferential service, and a disconnect signal.

Any one of ten separate extensions at as many different terminals can be chosen by the selector unit. It provides for selection of one line by another at the same station, independent of the carrier channel.

Alternating current at 120 or 240 volts generally has been used for carrier-communication equipment. At locations remote from generating sources, automatically starting motor-generator sets or converters have been used to provide power for the carrier set during emergencies or upon loss of normal d-c supply. This practice still is followed on long-haul channels using relatively high-powered equipment. Equipment capable of operating directly from 125- or 250-volt station batteries has made it possible to provide uninterrupted communication more economically, and without the maintenance problems associated with rotating equipment and accompanying control devices.

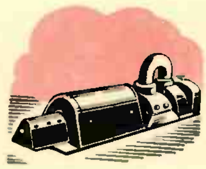
The Single-Sideband System

Although the carrier-communication assemblies described use the conventional amplitude-modulation system, they can be supplied with the single-sideband system of modulation for channels with high noise level or high attenuation. The single-sideband system offers an advantage in reduced band width, making it possible to operate more channels in a given band of frequencies.

Power-line carrier-communication equipment has progressed rapidly since first developed and offered commercially in 1923. Today it is firmly established as the prime means of communication for the remote and often isolated areas through which many power-transmission lines are carried. An assured future is indicated for the various systems; their stable reliability in a field where this is all-important will do much to make acceptance general throughout the industry.

ENGINEERING TRENDS

Among the unprecedented number of new central-station turbines now beginning construction are several of unusual engineering interest. One is a 65 000-kw triple cylinder for Boston Edison Company. The steam conditions, while high, are not unusual, but the unit will employ steam reheating to an uncommon degree. Steam is to be supplied at 1450 psig and 1000 degrees F. Steam enters the high-pressure turbine at 1450 psig and is exhausted at approximately 365 psig. The steam then returns to the reheat boiler and re-enters the intermediate-pressure element at 1000 degrees. The low-pressure turbine has an inlet pressure at approximately 40 psig and is of the conventional double-flow construction.



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A 30 000-kw turbine for Dow Chemical Company represents, without question, the most complicated automatic extraction application of its size ever contemplated. The unit is designed to operate with 1250 psig, 825 degrees F at the throttle. Steam is extracted at 425 psig and again at 165 psig. The unit exhausts at 25 psig. A hydraulic governing system makes possible the controls for this unit in a relatively simple manner considering the duty to be performed.

• • •

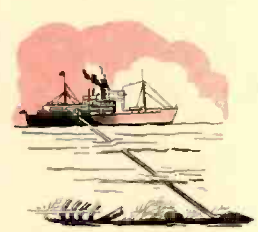
Indication that the package-power-plant idea is taking hold is given by the recent announcement that ten 5000-kw units are simultaneously undergoing manufacture, the first four to be installed in Mexico next year. These are compact and standardized units consisting of a steam turbine, generator, and auxiliaries mounted on the condenser as a foundation.

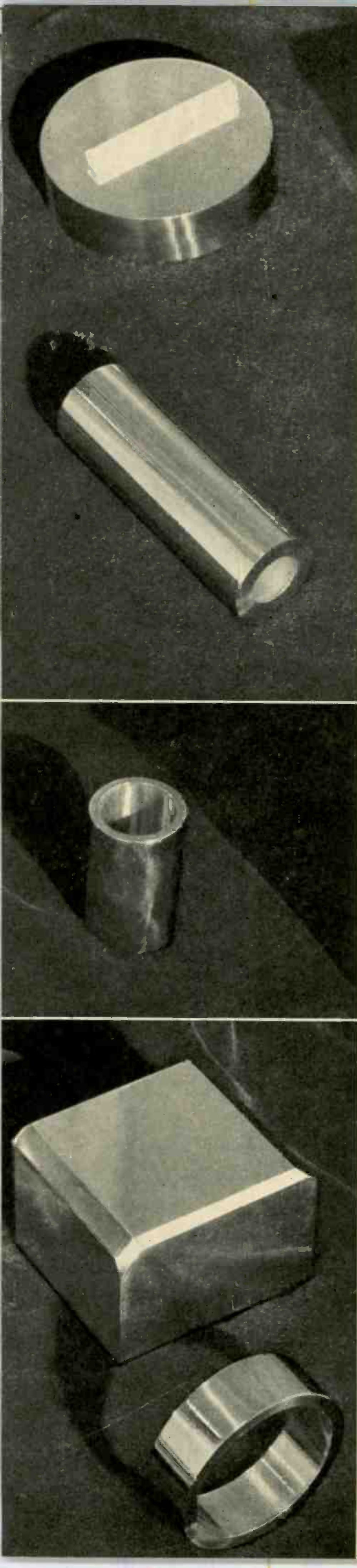
• • •

Ignitron rectifiers have been used to provide direct current for steel-mill main drives in the United States, but on a comparatively small scale. A steel mill being built in France will use them in a big way. Ignitrons totaling 15 000 kilowatts will be installed to furnish power for the finishing end of a hot-strip mill. The slabbing mill will be driven by twin motors of 7000-hp capacity. Each of the four motors driving the three stands and the reel of the tandem cold mill will have its own generator, which calls for extremely close speed matching. This practice, comparatively new, eliminates the IR booster generators. The 66-inch hot-strip mill is powered by 39 600 hp in motors.

• • •

A colossus of sea-going vacuum cleaners is being built to keep busy harbors open. It is a hopper dredge able to suck up 8000 cubic yards of harbor muck and haul it to sea in one trip. (Eight thousand cubic yards is equivalent to a six-foot square column slightly over a mile high). The dredge will be entirely electrically operated, has twin screws, and is 525 feet long. Each of its two 5500-hp steam turbines will drive three direct-current generators in tandem: a 3300-kw propulsion generator; a 1600-kw pump generator; and a 500-kw auxiliary-power generator. Two 1850-hp pumps will draw up debris through a 36-inch suction head closely sweeping the harbor floor. Direct-current power will be used throughout to obtain the ultimate in speed control of the propulsion drive which must move slowly while pumping and faster while traveling to and from the sea. Use of Rototrol controls makes full power available at all speeds regardless of pumping depth, and the kind of material being pumped.





MOLYBDENUM—
Practical Structural Material

One quality of molybdenum that appeals to designers has been the one to prevent its wide usage as a structural material. Its melting point is so high it cannot be produced like the common metals, necessitating resort to powder-metallurgy techniques. War-born improvements, however, have eliminated the limitations of size and shape of molybdenum structures and have considerably lowered the cost.

John Gelok
Manager, Lamp and Tube Parts, Westinghouse Electric Corporation

Molybdenum, with its attractive physical properties particularly at high temperature, is now available to designers as a structural material. The limitations on size and shape of molybdenum parts have been effectually eliminated by new manufacturing methods and techniques. Ingots weighing 250 pounds are currently being produced. For many years the largest ingots used commercially were ¼ inch square and 10 inches long, weighing about 1½ pounds. Even at the beginning of World War II, maximum-size ingots were 1⅛ inches square and 20 inches long with a weight of eight to ten pounds. The largest molybdenum piece that can be made is naturally limited to the weight of the starting ingot.

The restrictions on shape, too, have been lifted. Whereas previously only simple shapes, such as wire or rectangular pieces were practical, solid cylinders, tubes, discs, squares, and numerous other shapes are possible in diameters up to 7 inches and in lengths up to 30 inches. These larger ingots permit the manufacture of molybdenum sheets 20 inches in width and 36 inches long. Sheets even wider and longer can be produced with the installation of larger rolling and fabricating equipment. The new process does not have inherent limitations as to size as did the old. Furthermore, the cost of producing molybdenum ingots has been significantly reduced.

The Background of Molybdenum

Molybdenum is not strictly a new material; it can't be, because it is one of nature's 92 elements. Its physical, chemical, electrical, and metallurgical properties have been catalogued for years and have appeal for many applications. Its metallurgical uses were the first to develop and have been the best known.

When this country entered World War I, metallurgists were faced with the urgent need to create or find a substitute for tungsten, then used as an alloy for high-speed tool steel. Scarcely known molybdenum proved to be the answer, and from the large deposits, chiefly molybdenite (MoS_2) in the United States, came the first molybdenum used in the manufacture of high-grade steel, a use that remained molybdenum's chief and outstanding metallurgical contribution for the next 22 years. The United States has continued to lead the world in production of this metal and now supplies 90 percent of world molybdenum requirements.

Molybdenum had long been of interest to lamp designers. For years considerable quantities of molybdenum wire have been used in incandescent lamps as supports for the filaments, lead-in wires and mandrel wire on which the tungsten filament is wound. For these lamp uses the total amount of molybdenum required was small and the individual pieces, too, were small. Hence the old manufacturing tech-

←
Molybdenum can be made in a wide variety of shapes and sizes. The high polish obtainable in the finishing of molybdenum pieces is illustrated here. The cigarette on the highly polished block at the top reflects its image to give the appearance of two cigarettes.

Material	Specific Gravity	Specific Heat (c. / gm x °C
Molybdenum	10.3	0.065
Tungsten	19.3	0.034
Tantalum	16.6	0.036
Platinum	21.4	0.032
Aluminum	2.71	0.[illegible]
Copper	8.9	0.092
Silver	10.5	0.056
Iron	7.9	0.107
Chromium	7.1	0.12
Nickel	8.9	0.[illegible]
Westinghouse "K-42-B"	8.2	
Westinghouse "Kovar A"	8.2	
Westinghouse "Cupaloy"	8.9	0.[illegible]

niques were adequate. However, World War II, with its unprecedented demand for electronic tubes for radio and radar equipment necessitated not only a multifold increase in the production of high-purity molybdenum, but also larger pieces and of more complex shapes. Large quantities of pure molybdenum wire, rod and sheet were required for grids, supports, plates, and other parts in each electronic tube.

This demand, coupled with the urgent need for a source of molybdenum to supply our future Allies, led the Westinghouse Lamp Division to expand its production facilities and to search for ways of removing restrictions on size and shape of molybdenum structures. Both were achieved. The production rate in 1945 had reached approximately fifteen hundred percent of the prewar figure. Today the plant is one of the largest producers of the pure metal and is the only known source for many items fabricated from molybdenum.

How Molybdenum Ingots Are Made

Molybdenum is one of the heavy metals of the class of tungsten and tantalum, characterized by high melting points. The pure metal is silvery white in color, has a specific gravity of 10.3 and a melting point of 2620 degrees C (4750 degrees F). The high melting point of molybdenum makes it impossible to use ordinary methods of reduction, melting, casting, and working; it is necessary to employ powder-metallurgy technique. Powder metallurgy was first used commercially about forty years ago to process tungsten for lamp filaments. The process has since been extended to include many of the more common metals and alloys.

In the case of molybdenum the traditional method, and the one still employed, is to press the metal powder in steel dies at a pressure of approximately 40 000 psi. The resulting bars are sintered in a hydrogen atmosphere at high temperatures by passing electric current through them, after which they are broken down at high temperatures by rolling, forging, or swaging. Finally they are worked to the required size and shape at lower temperatures.

The molybdenum must be of the highest purity—better than 99.9 percent—as even tiny amounts of impurities seriously affect the operation of an electronic tube or incandescent lamp. The powder is formed by the reduction of pure molybdenum oxide or ammonium molybdate in hydrogen gas. The grains are microscopic in size, the average diameter of the individual particles being approximately one to two microns, (0.00004 to 0.00008 inch).

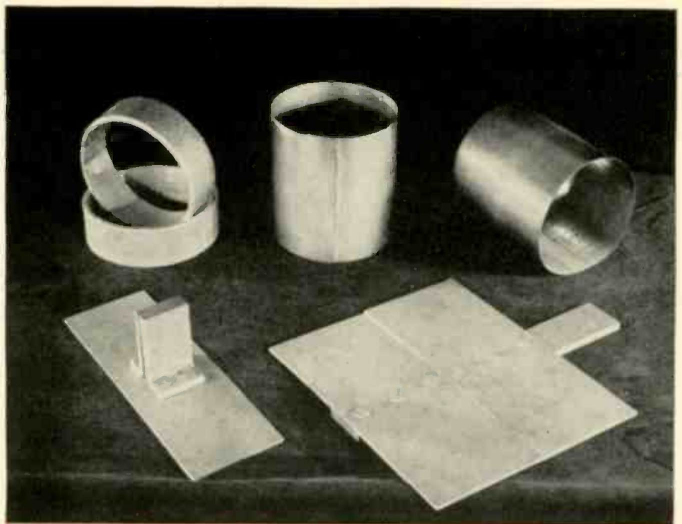
Properties

Molybdenum has an imposing list of physical and electrical properties, of which some comparisons are made with other metals in table I. Its melting point, modulus of elasticity, strength at elevated temperature, and thermal conductivity, to mention only a few are generally higher than even the best-quality steel. Specific heat and coefficient of expansion are less than those of steel, while corrosion resistance in many media compares favorably with tantalum, palladium, and platinum, each considerably more expensive than molybdenum. Tungsten is slightly superior in some respects, but it costs more, is twice as heavy, and is limited in the sizes and forms obtainable, much as molybdenum has been heretofore.

The *melting point* of molybdenum is exceeded among the

TABLE I—MOLYBDENUM COMPARED WITH OTHER METALS AND ALLOYS

Average Physical Constants							Typical Physical Properties at 20° C					High-Temp. Properties—Short-Time Tests			
Melting Point (°C)	Mean Linear Coefficient of Expansion ($\frac{10^{-6}cm}{°C \times cm}$)	Thermal Conductivity ($\frac{cal \times cm}{cm^2 \times sec \times °C}$)	Electrical Resistivity ($\frac{microhms \times cm^2}{cm}$)	Electrical Conductivty (Percent of Copper)	Tensile Modulus of Elasticity (10^6 psi)	Magnetic Properties	Form and Condition	Tensile Strength (10^3 psi)	Yield Strength (10^3 psi)	Elongation (Percent)	Brinell Hardness Number	Temperature (°C)	Tensile Strength (10^3 psi)	Elongation (Percent)	Brinell Hardness Number
2620	5.4	0.346	5.7	29	42	Paramag.	Unworked	60		up to 25	150	20	150		
							Sheet	70–140	70–90% of T.S.	up to 25	175–250	600	110		
							Wire	up to 350		up to 25		700	107		
												900	94		
3370	4.4	0.476	5.5	30	53	Paramag.	Unworked				285	20	400	Drawn Wire	
							Sheet	up to 400	ap. 90% of T.S.		up to 450	500	260		
							Wire	up to 500				900	85		
												1300	70		
2850	6.5	0.130	15.5	11	27	Paramag.	Sheet and Wire	50–170		25–45	60–120				
1775	8.7	0.165	10.6	16	24	Paramag.	Annealed	24	10	24	40				
							Cold-Rolled	36	27	2	100				
657	24.6	0.54	2.9	58	10	Paramag.	Annealed	13	5	35	25	20	13	45	
							Cold-Worked	25	21	5	45	260	3.5	85	
												370	1.5	95	
1080	17.4	0.923	1.724	100	16	Diamag.	Annealed	30	10	45	30	Not used above 200°C			
							Cold-Worked Full Hard	53	48	5	125				
960	19.0	0.974	1.5	112	10	Diamag.	Annealed	23	8	50	30				
							Cold-Worked	54	40	5	90				
1535	11.7	0.17	9.7	17	30	Ferromag. u Max. = 9000	Annealed	35	20	45	70	20	40		120
							Hot-Rolled	45	30	25	100	500	20		110
												700	7		90
1830	8.1	0.165	13.1	13		Paramag.	Electrolytic				570–1250				
							Cast Oxygen-free				130				
1450	13.7	0.190	6.9	24	30	Ferromag. below 360°C u Max. = 550	Annealed	48	9	26	115				
							Cold-Worked	to 175							
1400	15.0	0.027	108	1.6	30	Non-mag.	Precipitation Hardened	150	90	30	270–300	20	160		
												650	120		
												760	70		
1450	4.5–5.1 (30–400°C)	0.046	49	3	25	Ferromag. below 400°C	Annealed Sheet	75	55	35	140–160				
[illegible]	16.5	0.78	2	84		Diamag.	Worked	65–75	60–65	17	150	100			165
							Sand Cast	47–50	35	25–30	100–125	400			140



Molybdenum's workability is shown in these pieces fabricated by welding and riveting. Produced from sheet 0.010 to 0.375 inch thick, the top rings and cylinders are for high-frequency sets; glass-furnace electrodes are shown at bottom.

elements only by those of carbon, tungsten, osmium, rhenium, and tantalum. This permits its use at temperatures far above the softening point of common metals or refractories.

Molybdenum has a low *specific heat*—about half that of nickel or steel. This is of advantage where rapid temperature changes are desired or for the reduction of temperature gradients in a heated body.

Its high *thermal conductivity*—about three times that of steel—is an advantage for heat-transfer purposes. Because of this and its low specific heat, molybdenum can be rapidly heated and cooled with much lower thermal gradients than obtained with steel. Molybdenum when used for welding tips takes advantage of this property together with excellent hardness when hot and with good contact properties.

The *electrical conductivity* of molybdenum is about one-third that of copper and silver. It is excelled in this property only by aluminum, copper, gold, magnesium, and silver. This is most important where mechanical parts carry current.

The low *coefficient of thermal expansion* of molybdenum (half that of steel) is advantageous where elevated temperature is involved. This is true for non-uniform temperatures involving intermittent heating and cooling; it means greater dimensional stability and less danger from thermally induced stresses. Special glasses are available for sealing to molybdenum, whose low coefficient of expansion is about the same as that of Kovar.[1] The high thermal and good electrical conductivities of molybdenum are distinct advantages in some sealing applications, making possible the use of a smaller wire.

Molybdenum sheet has *tensile strength* at room temperature of from 70 000 to 140 000 pounds per square inch depending upon the amount of cold rolling used in fabrication. In wire form, tensile strength varies from 100 000 to 150 000 psi but values as high as 350 000 psi have been obtained with cold-drawn wire. Tensile properties in cold-worked sheet and plate material can be appreciably different in the direction of rolling as compared to that obtained in a transverse rolling direction.

The *strength of molybdenum at very high temperature* (over 900 degrees C or 1650 degrees F) far exceeds that of any other commercial metal or alloy with the exception of tungsten.

Molybdenum is *paramagnetic* at room temperature. For practical purposes, it is "non-magnetic" and magnetically similar to 18-8 stainless steel and aluminum.

Its high *modulus of elasticity* is exceeded only by those of sintered carbides, iridium, and tungsten, and is, therefore, well suited to applications requiring high rigidity. A combination of high modulus and high tensile and yield strengths means that a part can be made smaller and still react the same to a particular stress. However, the high modulus of elasticity partially offsets the beneficial effect of a low coefficient of expansion on stress resulting from thermal gradients. In cold-worked sheet or plate material, modulus of elasticity varies with the direction and amount of "cold" work.

The *corrosion resistance* of molybdenum is high, showing no reaction with cold or warm hydrofluoric acid, dilute sulphuric acid, cold potassium hydroxide, phosphorous, or sulphur and its compounds. Reaction is slow with concentrated hydrochloric acid and concentrated nitric acid, and rapid in hot dilute hydrochloric acid, dilute nitric acid and in hot concentrated sulphuric acid. In molten oxidizing salts the reaction is violent.

The metal oxidizes slowly at about 400 degrees C (750 degrees F) but more rapidly with rising temperature. At 700 degrees C (1292 degrees F) a dense white smoke forms. Its high-temperature use therefore depends on the application of vacuum, protective coatings, or a protective atmosphere. Molybdenum has two oxides, MoO_2 and MoO_3, the latter predominating and controlling the rate of oxidation. MoO_3 is volatile and melts at 795 degrees C (1463 degrees F); thus it affords no protection at higher temperatures.

Molybdenum has a *room-temperature hardness* of approximately 85 to 90 Rockwell "B" or 150 kg per mm^2. Hardness of molybdenum increases sharply as the temperatures are lowered. At minus 180 degrees C (minus 292 degrees F) the hardness is approximately 400 kg per mm^2. As the temperature is increased the hardness shows a continuous decrease to approximately 20 kg per mm^2 at 1900 degrees C (3450 degrees F).

Machinability—Molybdenum produced by the new methods does not offer the machining difficulties and the need for special tools and extraordinary care formerly met when working molybdenum. Now ordinary high-speed steel tools are used in conjunction with lubricants such as carbon tetrachloride or white lead. Although molybdenum is not a hard metal, it is tough and abrasive. On all machining, tools must be kept sharp, clean and cool, especially in drilling, where the difference in expansions of tool and molybdenum may cause sticking. The cut must be deep enough to pierce the skin in order to prevent "glazing" of the surface and dulling of the tool. A highly polished surface similar to the best chromium plate can be obtained by using standard buffing wheels; the finish has reasonable permanence.

Spinning or forming—The metal sheet can be spun or formed by deep-drawing. In spinning thicknesses of metal up to 0.032 inch, a small gas flame is played on the material to raise the temperature to between 100 and 300 degrees C, depending on its thickness and shape. Molybdenum thinner than 0.032 can be drawn and formed cold; some heat is desirable on heavier material, the amount necessary depending on the thickness of the molybdenum as well as the type of forming.

Welding—Molybdenum can be successfully welded to itself or to numerous other materials. Certain precautions to obtain a ductile weld are necessary. Short heating times prevent grain growth and consequent brittle welds. In welding thin sheets or wires a condenser-discharge type of welder, or ignitron type with ½-cycle timer is satisfactory; molybdenum

[1]See "Kovar, An Alloy That Seals Metal to Glass," by W. H. Brandt and E. S. Latimore, *Westinghouse* ENGINEER, Vol. 5, July, 1945, p. 117.

or molybdenum-alloy tips are preferable, while at least one surface should be sand-blasted or dimpled. For heavy sheets and rods a most satisfactory weld can be made using atomic-hydrogen or helium-shielded arcs.

Riveting—It is possible to join molybdenum with rivets made from molybdenum wire or rod. Small rivets having a shank diameter of about 0.0625 inch can be made by the standard rivet process from annealed molybdenum obtainable in coil form. Large rivets are turned in a lathe from rod stock; a head can be formed by heating the rivet end and peening.

Applications

Pure molybdenum continues to find extensive use in the incandescent lamp industry for which it was first developed. The wire is used to support the tungsten filament because of its high melting point and relative economy and ease of working as compared to tungsten. The modern "coiled-coil" tungsten filament as used in incandescent and fluorescent lamps is wound on a molybdenum mandrel which is later removed. The electronic-tube industry, its demands pyramided from war needs, uses large quantities of molybdenum wire rod and sheet. Parts subject to high temperatures are made from the wire; plates, channels, caps, and other special shapes are formed from the sheet or machined from slab material.

The glass industry is one of the largest users of heavy molybdenum sheet or plates, a use that is continually expanding as more and more electric glass-melting furnaces for special glasses are installed or converted from carbon electrodes to molybdenum. These are built from several pieces of heavy molybdenum plates that conduct the current through the molten glass. Much higher and more uniform temperatures can be obtained by this method. The glass from furnaces using molybdenum electrodes is reported to be of better quality than that previously obtained.

In the form of wire rods or strip, molybdenum can be used for heating elements in the construction of furnaces capable of operating at temperatures of 1650 degrees C (3000 degrees F) in vacuum or protective atmospheres. Furnaces of this construction are economical and have long life. Spot-welder tips made from molybdenum take advantage of its good electrical and its high thermal conductivity as well as its high hardness when hot and good contact properties. It has also been used to advantage in the manufacture of bimetals, thermocouples, stirring devices, and thermocouple protection tubes—all for applications where the temperatures are above the melting point of common metals.

Molybdenum alloys with superior oxidation resistance, higher strength, and other desirable properties have been made, and, although many are still classified as secret, at least one has found wide acceptance in the industrial field. This alloy, known as "M2A," has advantages over standard molybdenum, such as greater strength and ductility, and an increased resistance to heat checking.

Another advantage of this alloy is its better resistance to shock, both hot and cold, as compared to molybdenum. Using the Charpy impact test at room temperature, results have indicated the new alloy to be about 825 percent stronger. It has slightly lower electrical and heat conductivity and requires higher annealing temperatures. Test results show that it is far superior to pure molybdenum as a spot-welding tip, particularly as to the number of welds that can be made between tip dressings.

Molybdenum alloys with a hardness of 60 to 65 Rockwell "C" have been tested for applications where high hardness is essential. These are as hard at high temperatures as many of the common so-called hard alloys at room temperatures. Combinations such as molybdenum-silver and molybdenum-copper find wide use as electrical contacts. They are not true alloys, the combination merely aligning the high-temperature resistance of the molybdenum with the high current-carrying capacity of the silver or copper to produce a superior contact.

Conclusions and Future Possibilities

The properties of molybdenum and its alloys are outstanding. Because only a few of its conceivable uses have been explored, it is too early to do more than list a few of the applications for which molybdenum may prove practical. However, even this brief list is impressive:

(a) As heating elements for ultra-high-temperature electric furnaces without element protection.

(b) Used in the construction of blades, nozzles, and firing chambers for gas turbines and rockets.

(c) Formed into dies for die-casting brass or other alloys, melting at relatively high temperatures.

(d) Formed into hot and cold metal-working tools.

(e) Used as liners for tanks, vessels and pipes where non-corrosion properties are needed.

(f) In seamless tubing and valve construction for the petroleum and chemical industry.

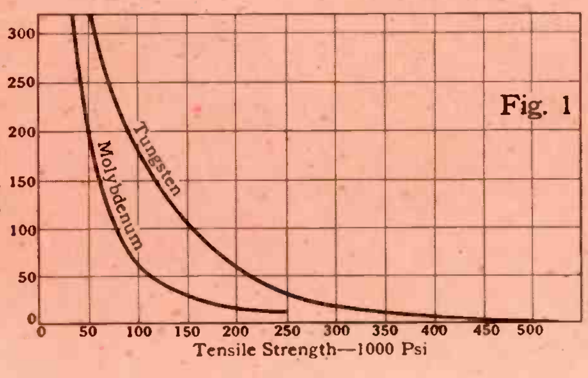
(g) Used in the making of crucibles for melting materials of very high melting points.

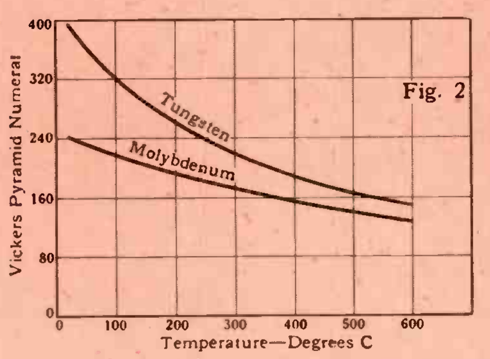
(h) As high-temperature resisting barriers.

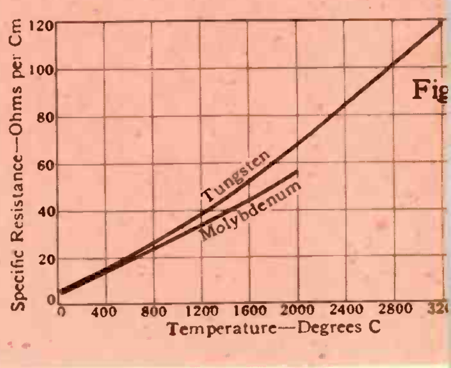
(i) Used in construction of high-temperature materials.

(j) Dies for hot pressing, drawing, and extrusion.

Fig. 1—These curves show tensile strengths of molybdenum and tungsten wire. Fig. 2—A comparison of molybdenum and tungsten hardness variation with temperature. Fig. 3—A measure of the resistance of molybdenum and tungsten with temperature.

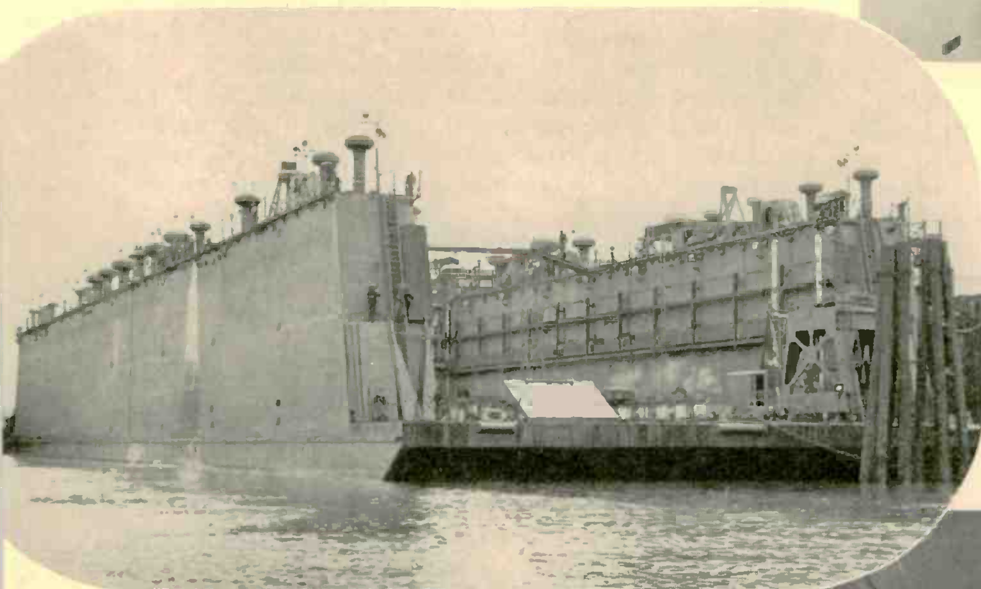




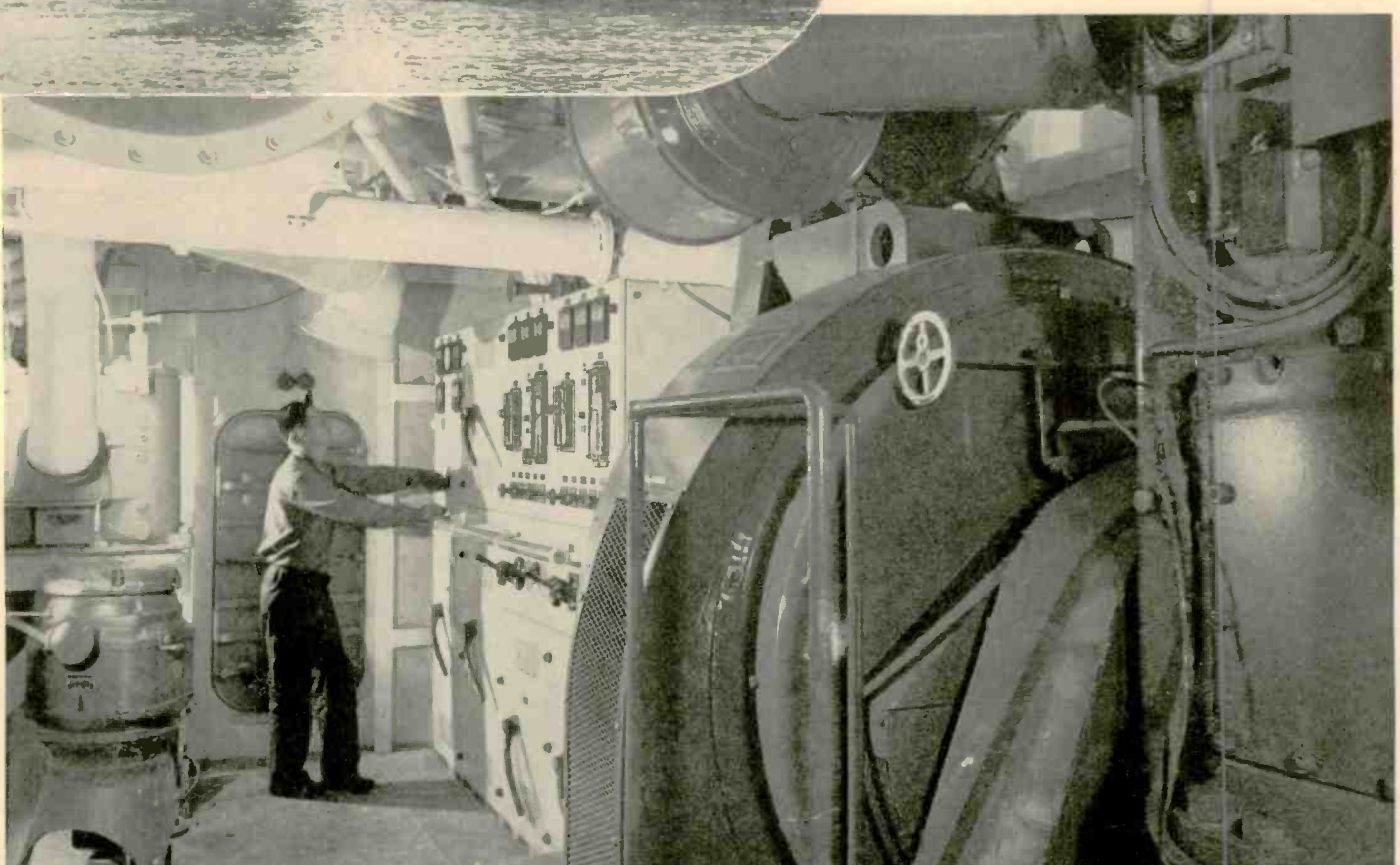


Floating Drydock Has 1350-Kw Power Plant

The largest vessel ever launched on an inland waterway is not a ship at all but a floating drydock. It is a sizable craft 448 feet long and 97 feet wide, which, even with sidewise launching, presented unusual problems in easing it into the Ohio River, from the ways of the Neville Island Yard of the Dravo Corporation, near Pittsburgh. This drydock, of the AFDL class, for the Navy's smaller craft, supplements the Navy's more spectacular sectionalized drydocks, of the ABSD variety, which can accommodate vessels as large as battleships. Neither type is self-propelled.



This mobile 6000-ton drydock, built at Pittsburgh and floated down the Ohio and Mississippi rivers to the sea will permit servicing of such vessels as mine layers and sweepers, fleet tugs, tenders, fueling ships, and others of the Navy's indispensable fleet auxiliaries. The main power plant consists of three 400-kw, 450-volt, 3-phase, 60-cycle Diesel-driven generators of which one and its switchboard is shown above. Most of this power is used by the 40 motor-operated valves and 16 pumps driven by 50-hp motors to pump water to and from the ballast tanks. Direct current for ship's services is provided by two 75-kw, 125-volt generators driven by a 250-hp squirrel-cage motor placed between them as shown below.



PERSONALITY PROFILES

Robert C. Cheek's extensive amateur radio set-up licensed under the call of W3LOE and operating on the 10-20-40 meter bands, takes up much of his available spare time. In addition to his own activities on the air, he has just been appointed chairman and trustee for the Westinghouse Educational Center amateur radio club.

In 1946 Cheek invented an electronic multiplier, which is a device used to give the instantaneous product of two rapidly varying voltages. The multiplier is an important component of the transient analyzer, the electro-mechanical brain that solves little things like differential equations by the operation of a few switches.

Cheek's first contacts with Westinghouse occurred in 1939, as a cooperative student. He came with the Company finally in 1941, with a B. S. in electrical engineering from Georgia Tech. He obtained his Master's degree from University of Pittsburgh two years later. Cheek functions as a headquarters central-station application engineer and regularly visits the southeastern states assisting power companies with their engineering problems. This is Cheek's third appearance in these pages, having written on transformer overloads and power-line carrier.

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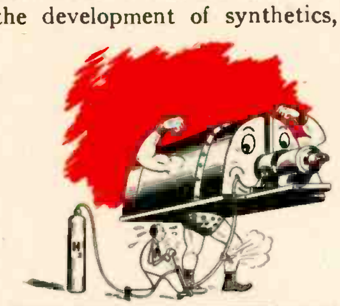
A native of Johnstown, Pennsylvania, *R. B. Roberts* joined Westinghouse in 1945. His alma mater is Carnegie Institute of Technology from which he obtained his degree of B. S. in chemical engineering in 1935. In the interim he was employed by the B. F. Goodrich Company, working on the early design and application of equipment in which rubber was used to combat corrosion, vibration, and abrasion. Japanese control of practically the entire raw rubber output of the Orient during the black days of 1942 and 1943 forced a transfer of much of this activity to the development of synthetics, and



Roberts remained to assist in this search for a satisfactory rubber substitute until 1943 when he moved over to Crosley. Here his work was of the top-secret variety concerned with the design of anti-aircraft gunsights and the production of gyroscopic fire-control instruments.

Roberts joined Westinghouse when plans for postwar turbine-generator redesign were taking shape. He has had the opportunity of following this redesign through all the stages from the drafting board to the installed generator in the purchaser's plant.

• • •

T. J. Putz is parading through these pages with fair regularity. This is his fourth appearance within less than two years. In May of 1946 he discussed the geared-steam locomotive; two months later a new method of grinding pinions of super-hard steel; and last spring the experimental locomotive-type gas turbine; and now the steam portion of the turbine-electric locomotives. Putz is manager of the engineering section at Westinghouse having to do with locomotives and gas turbines. Just 10 years ago this spring Putz graduated from the University of Illinois as a mechanical engineer. He has been active on various phases of turbine research and design ever since.

• • •

If you ride on an electrified railroad, almost anywhere in the world, the chances are good that *C. E. Baston* had a hand in engineering the electrical control equipment. Control for the New York, New Haven and Hartford locomotives was his first concern in 1922 after completing the graduate-student training course at East Pittsburgh. This was followed by sessions on locomotives for the Detroit, Toledo, and Ironton, the motor-generator locomotives of the Great Northern and the single-phase Pennsylvania locomotives. In 1936, after he had spent more than two years on the Great Northern system after its new-type locomotives had been commissioned, Baston went to England to assist the English Electric Company in designing similar motor-generator locomotives for the Southern Railway. He liked that England sojourn because it was his birthplace, although not his home for long; his family emigrated to California, where he grew up and received his schooling, graduating from the University of California in 1921 (B. S. in E. E.).

Upon returning from England, Baston helped engineer various major railroad equipments, including the locomotives for the Sorocabana Railway in Brazil and for the Chilean State Railways. For a year, beginning in the summer of 1944, he went to South America to help get these locomotives running smoothly.

Baston is in an excellent position to make miniature railroading his hobby. Instead, it is flying; he has 35 hours solo time to his credit.

• • •

This year *Charles Kerr, Jr.*, celebrates the accumulation of 25 years' experience with the locomotive power equipments for railroads. He has been at it ever since 1922 when he came to Westinghouse, having obtained his degree in electrical engineering from the Massachusetts Institute of Technology. In that time he has been prominently connected with most of the major railroad electrifications in this country and several abroad. About two years ago he was made consulting engineer of the Transportation Engineering Department so that his wide experience with locomotives could be used to best advantage. Kerr first appeared in these pages, in March, 1945 when he discussed the mechanical-drive type of turbine locomotive.

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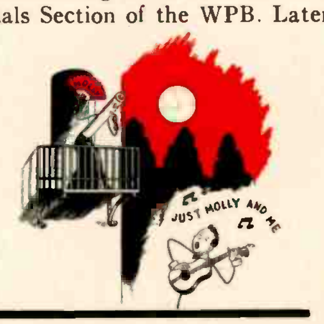
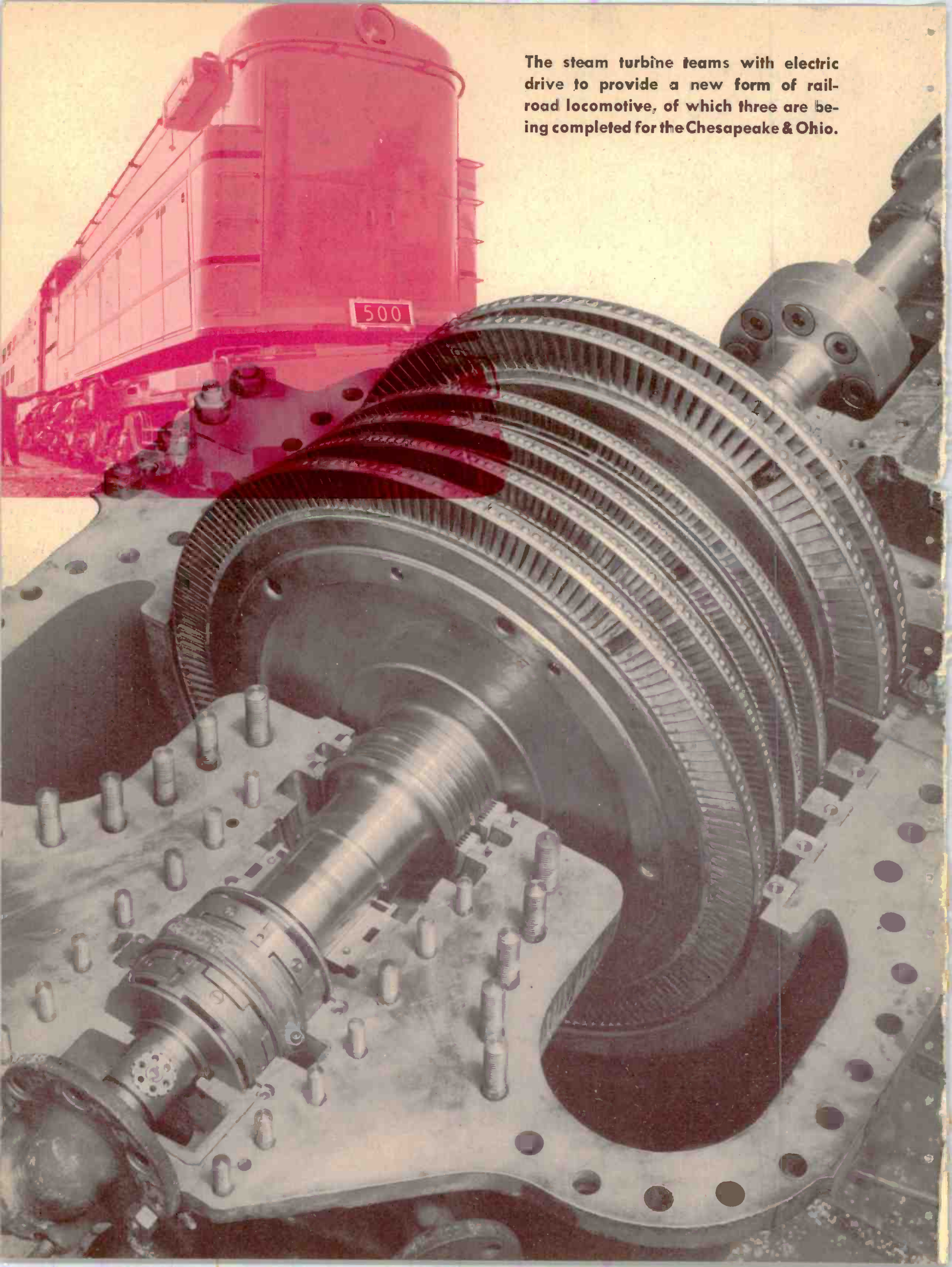
John Gelok has an important managerial position with the Lamp Division of Westinghouse, yet he has nothing to do with lamps, their design, manufacture, or sale. His activities are concerned with what might be called by-products of lamp manufacture—such as molybdenum.

Gelok sampled the insurance business for four years before coming to Westinghouse in 1928. Since then his progression in the Company has been steadily consistent and rewarding. He started as a "server," toting material to the lamp-making machines at Bloomfield. Later he moved to the parts division, advanced through the various steps to become foreman in the molybdenum manufacturing department and then office manager of the parts division, a position he attained in 1942. He was loaned to the United States government from 1942 through 1943, functioning as Chief of the Critical Materials Section of the WPB. Later he



acted as special consultant to the government on critical materials problems. In 1944 he was appointed Assistant Industrial Sales Manager of the Lamp Division and finally Manager of Lamp and Tube Parts Sales, which position he now holds.



The steam turbine teams with electric drive to provide a new form of railroad locomotive, of which three are being completed for the Chesapeake & Ohio.