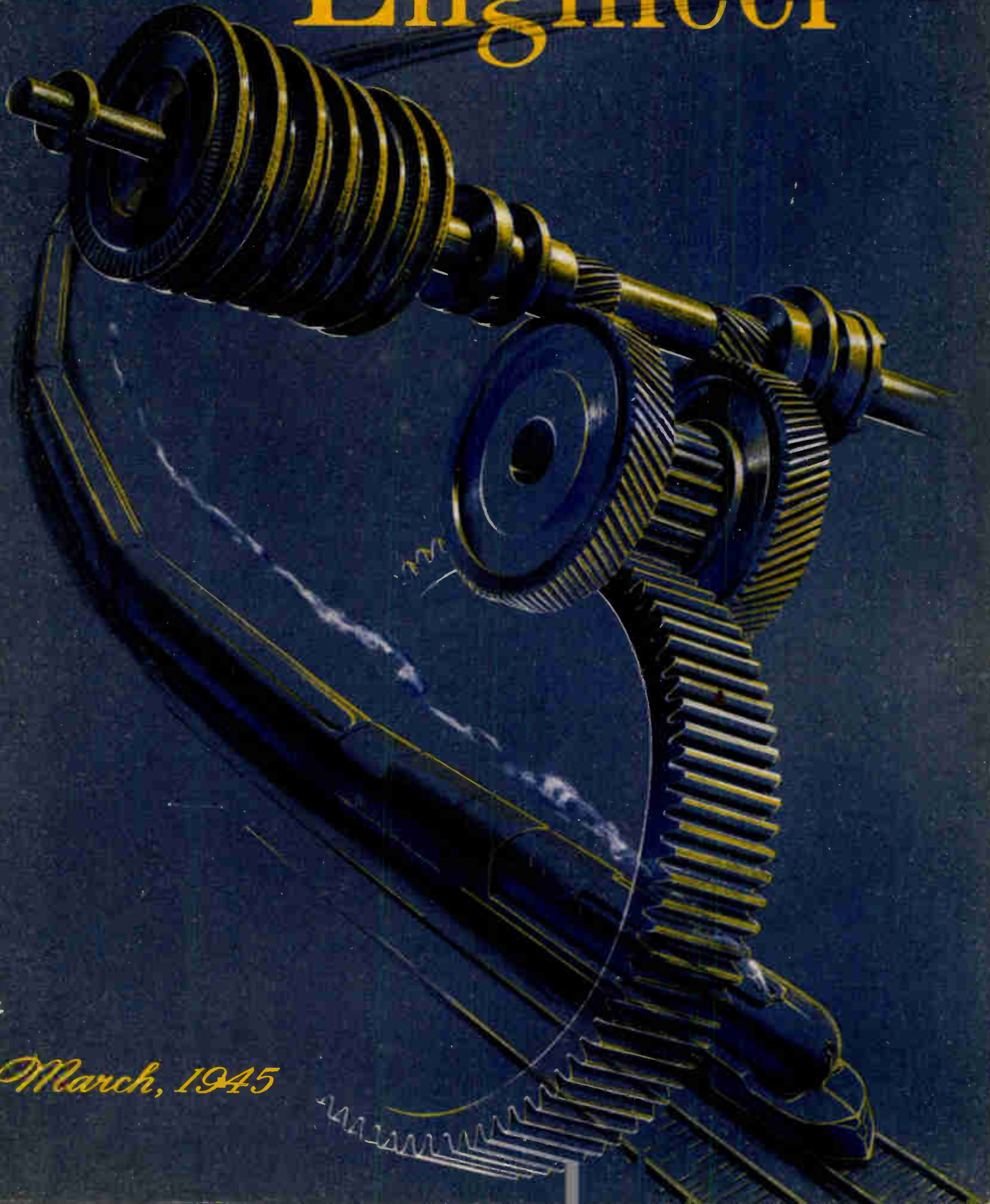
WESTINGHOUSE

# Engineer



*March, 1945*

# *Jet Propulsion*—That Third Law of Motion at Work

The great plague that swept London in 1665 and 1666 brought death to one third of its citizens. But because it forced Trinity College at Cambridge to close, sending Isaac Newton back to his boyhood home in the hamlet of Woolsthorpe, it gave time for reflection to the obscure young man of 23. The result was one of the all-time great contributions to mankind. Although Newton did not commit his famous three laws of motion to writing in the first book of the Principia until many years later, it is believed that he formulated them then—and at the same time produced his brilliant concepts of gravitation and developed the theory of fluxions, now called differential calculus. The three laws of motion, originally written in Latin, he stated as:

1—If no force acts on a body in motion, it continues to move uniformly in a straight line.

2—If force acts on a body, it produces a change of motion proportional to the force and in the same direction.

3—To every action there is always an equal and contrary reaction; the mutual actions of any two bodies are always equal and oppositely directed.

* * *

Many examples of the reaction principle fall within our common experience. Such is the rotating lawn sprinkler, propelled by its backward-directed jets of water. The squid unconsciously employs Newton's third law when it draws water in slowly through its mantle cavity and ejects it to the rear by a convulsive movement, causing the animal to advance by spurts. The child's toy balloon fully blown up and released with the stem open zips crazily through the air until its air is exhausted. This, too, is a manifestation of the self-same reaction effect. The blow torch pushes backward against the hand holding it. The operation of the airplane wing is based on the same principle. To support the aircraft above the ground an upward force is generated by propelling downward the mass of air handled by the airplane wings. The upward thrust, which in level flight just balances the weight of the airplane, is equal to the mass of the air handled multiplied by its downward velocity. In like manner the propeller-driven plane moves forward by giving a backward acceleration to a mass of air.

* * *

In the enactment of the third law of motion there are, obviously, two players: action and reaction. Within the field of common engineering experience it is the action that is usually wanted. The reaction is discarded, often at considerable expense. In artillery, for example, the end sought is the expulsion of a shell at high speed. The recoil is very much of a nuisance, requiring elaborate and troublesome engineering to absorb. When the reaction principle is used for producing flight, however, as in rockets, the bazooka, jet-assisted take-off and jet-propelled airplanes, the *reaction* is what is wanted: the *action*—as represented by the hot gases of combustion—is thrown away.

* * *

The wheel, its inventor now lost in antiquity, ranks among the half dozen discoveries most important to mankind. It freed men's backs from physical loads that would otherwise have kept them at the level of beasts of burden. It permitted transportation on the earth with greater and greater facility. All present engines are accordingly based on the principle of the wheel, for this is at present man's almost universal way of getting around. Even when the engine is used to drive an airplane, it is done with the aid of a kind of wheel, the propeller.

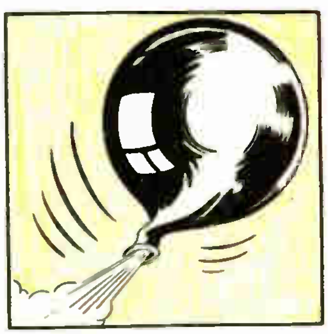
In the conventional propeller-driven airplane we have the problem of converting the mechanical energy first from reciprocating motion to rotating motion of a propeller, thence to the forward thrust. The cams, gears, pistons, crankshafts, connecting rods, and other complexities associated with reciprocating and rotating motions make large increases in engine sizes impractical. Propellers with their problems of rotation and their limits of tip speed at about sonic velocities cannot become appreciably larger.

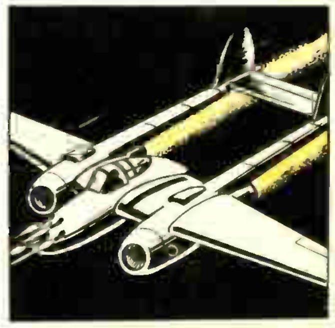
* * *

How the jet-propulsion engines will be put to work is not fully clear, although it has been the subject of much speculation, some wild, but much that is sane. Certainly meteorologists have a need for taking soundings of the atmosphere far above the shallow eight- or ten-mile layer they can now probe. The rocket offers that opportunity, making frequent and regular soundings to fifty and a hundred miles practical. Sometime, perhaps, deliveries of mail and express across oceans in an hour or so will be commonplace. Closer at hand are jet-propelled planes for high-speed flying. Jet-assisted take-offs will shorten the necessary take-off or increase the loads possible.

* * *

But the particular forms reaction-flight vehicles will take may not be nearly so important to the engineer at the moment as the fact that he has at his disposal a basic new type of engine. The various forms of jet-propulsion engines present problems galore. Gas turbines already are operating under heavy stresses at 1500 degrees F. Although ordinary steel melts at 2400 degrees F, engineers are hoping to achieve 2500-degree operation. This is mild compared to temperatures with which the rocket-motor engineer deals. He has already attained jet speeds of 6000 feet per second, which with presently used fuels correspond to 4700 degrees F. Several times that jet velocity are theoretically obtainable but the temperature of operation must be correspondingly increased. All this calls for research and development of high-temperature materials, heat exchangers, and cooling techniques—the results of which are applicable to gas turbines and other high-temperature machines not used in flight. Then there are problems of streamlining for supersonic velocities—a field of research on which only a bare start has been made. There are many, many more problems such as control of flight, of landing, of cabin pressurization, and those of high-speed rotating compressors. For many branches of engineering—chemical, mechanical, electrical, metallurgical, and others—Newton's third law of motion presents opportunities unlimited.





WESTINGHOUSE Engineer

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## On the Side

*The Cover*—The artist indicates the new steam-locomotive drive consisting of steam turbine and double-reduction gears, discussed in the first two feature articles of this issue.

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In a light breeze, fly ash from steam-plant stacks falls alike on the just and unjust over a radius of several miles. This deposition has caused intensive investigation into means of removing fly ash from the gases of combustion discharged from the stack. A combined mechanical and electrical dust-collector pilot installation, developed jointly by the Prat-Daniel Corporation and Westinghouse, has been incorporated in the Huntley Station of the Buffalo-Niagara Electric Corporation.

This marriage of convenience between the mechanical and electrical cleaners is blessed by the advantages of both without the shortcomings of either. The forte of the mechanical cleaner is the removal of large volumes of particles of substantial size. An electrostatic filter of any reasonable size would be overburdened by the tonnage of fly ash from a large power-plant stack. The fine particles, for the most part missed by mechanical filters, are, however, removed by the electrical filter with thoroughness.

The mechanical section of the duplex cleaner is a Thermix tubular collector that uses the "cyclone" principle. This removes over 82 percent by weight of the less numerous but bulkier particles (those more than 10 microns in size—one micron equals 1/25000 inch). Of the remaining fine particles (less than 10 microns) over 90 percent are removed by the Precipitron. This is an electrical device, operating on the electrostatic principle, which removes from the air impurities as small as 1/10 of a micron.



## In This Issue



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# Why a Geared-Turbine Steam Locomotive

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IN MOST new developments, it is customary to undertake initially the construction of a relatively small equipment and as experience is gained, expand in successive steps to larger size units. Not so with the class S-2 geared-turbine locomotive for the Pennsylvania Railroad. With a main turbine rating of 6900 hp, it is one of the most powerful, high-speed locomotives in the world. The experience gained in the design and operation of this locomotive indicates that the geared-turbine drive may go far towards revolutionizing the steam locomotive.

For stationary and marine uses, the turbine drive has substantially replaced the steam reciprocating engine. In such applications, the turbine drive has been developed and perfected to the point where it is a reliable and highly satisfactory prime mover. These advances in turbine development have been matched in the development of gearing and mechanical transmissions. The improvements in both fields have been translated to the requirements of the turbine prime mover and gearing for locomotive service.

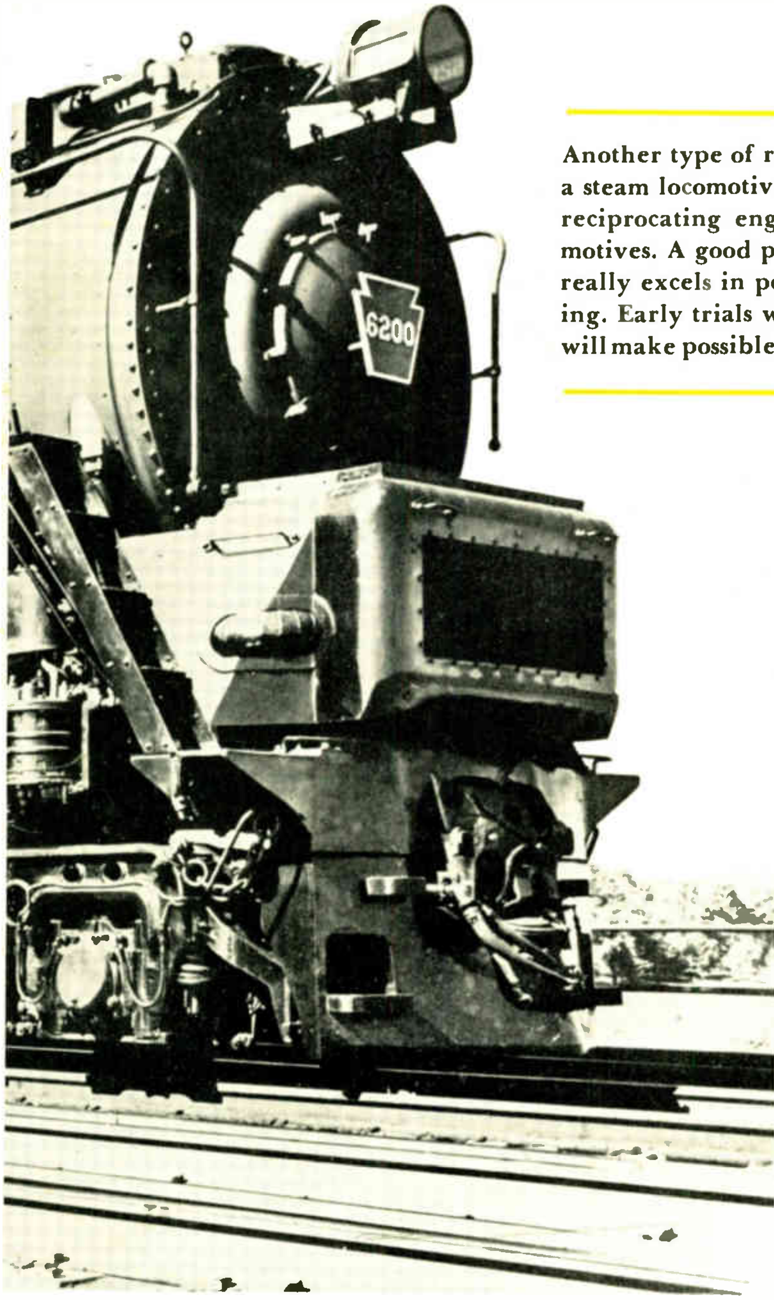
The propulsion equipment was designed specifically to operate with a conventional fire-tube boiler, and at pressures and temperatures commonly used with such boilers. Furthermore, it was designed for a locomotive for use primarily in high-speed passenger and freight service. The tractive effort of this locomotive is compared with that for a conventional two-cylinder reciprocating steam locomotive with the same weight on drivers and with a boiler designed for equal evaporation in Fig. 1. At standstill and at the slower speeds, the performance of the two locomotives is essentially the same. At the higher speeds, the tractive effort of the geared-turbine locomotive becomes considerably greater. Thus, it can handle a larger train at the same speed, or an equivalent train at a higher speed for the same steam consumption of the reciprocating engine.

The turbine locomotive produces a maximum of 6550 horsepower at the rail compared to 5630 horsepower for the reciprocating locomotive of equal boiler capacity, as indicated in Fig. 2. At 100 mph, the turbine horsepower is 5820 against 4750. Because railroad speeds are being continually raised, the larger horsepower outputs at the higher speeds become of increasing importance.

The largest Diesel-electric passenger locomotive built is a three-unit locomotive whose engines develop 6000 hp. The Diesel produces a high initial starting tractive effort through its electric transmission, but suffers in capacity at the higher speeds. Table I further compares a 6000-horsepower Diesel-electric with the class S-2 turbine locomotive.

With the tendency towards lightweight rolling stock, many

**Another type of railroad locomotive has appeared on the American scene. It is a steam locomotive powered by a single rotating engine instead of two or more reciprocating engines as required by the Diesel or conventional steam locomotives. A good performer at starting and at low speeds, the turbine locomotive really excels in power and tractive effort at high speed—with a large fuel saving. Early trials with the new locomotive give promise that the geared turbine will make possible more tractive effort from a locomotive of given boiler capacity.**




have questioned the wisdom of the large-capacity locomotives. Essential to high schedule speeds, both in freight and passenger service, is the ability of the locomotive to maintain these high speeds not only on level track, but also on adverse grades and to accelerate rapidly to these high speeds from station stops and slowdowns. The speeds possible with the three locomotives illustrated by Figs. 1 and 2 on grades ranging from level track to 1.0 percent are given in Fig. 3. These curves assume a 16-car, 1200-ton train where the power for air conditioning is supplied by the locomotive. Table II shows the time required by the three locomotives to accelerate this same 16-car passenger train from standstill to various speeds on level track.

Rapid acceleration of the train, when multiplied by numerous stops and slowdowns, results in a substantial overall increase in average speed, the net result of which is improved passenger appeal.

In the postwar period, high-speed freight service will receive equal rank with high-speed passenger service in the railroad's endeavor to keep the traffic on the rails. The locomotive rail horsepower required on the best roadbed to handle large freight trains at various speeds is given in table III. These requirements clearly show that the day of the large locomotive is far from being over, and that a development such as the turbine drive, which increases the capacity of the steam locomotive, will be most welcomed by the American railroads. As experience is gained with the geared-turbine locomotive, it seems highly probable that even larger turbine locomotives will be produced.

The geared-turbine locomotive is decidedly more efficient for high-speed main-line service. The steam consumptions of the turbine and conventional reciprocating locomotives are compared in Fig. 4. At low speeds, the turbine is at a disadvantage, but over its normal working range, the reverse is true. In a turbine drive designed for freight service, the turbine blading and the gear reduction would be made more favorable for low-speed operating efficiency, which would improve the starting efficiency compared with the performance shown by Fig. 4.

The ultimate limit in the capacity of the steam locomotive is the boiler. The turbine drive removes many of the limitations now imposed upon the boiler designers. With this type of locomotive they will enjoy a latitude previously denied them. Geared-turbine drive locomotives can be built with smaller wheels, the use of which permits boilers of larger diameter and also makes available many more combinations of wheel arrangements. The shorter wheelbase resulting from the smaller wheels allows a larger grate area under the boiler. Also, the turbine can utilize steam at temperatures prohibitive with reciprocating locomotives.

Besides having a better steam rate, the class S-2 locomotive also utilizes the coal burned in the boiler efficiently. Because of its small wheels and short driving wheelbase, it has been possible to equip this locomotive with a large boiler and a large grate. When developing full output, coal is burned at a low rate, which improves combustion efficiency and makes for easier draft conditions.

TABLE I—THE CLASS S 2 TURBINE LOCOMOTIVE AND 6000-HP DIESEL-ELECTRIC LOCOMOTIVE

| | Class S-2 | Diesel Electric |
|---|---|---|
| Total weight—lb | 992 900 | 1 039 000 |
| Weight on drivers—lb | 260 000 | 693 000 |
| Overall length | 122′7¼″ | 223′ |
| Starting tractive effort—lb | 70 500 | 173 000 |
| Prime mover horsepower for traction | 6 900 | 6 000 |
| Maximum rail horsepower | 6 550 | 5 200 |
| Locomotive weight—lb per rail hp | 152 | 200 |

TABLE II—TIME IN MINUTES TO ACCELERATE A 1200-TON TRAIN TO VARIOUS SPEEDS

| | Type of Locomotive | | |
|---|---|---|---|
| | Class S-2 | Reciprocating | Diesel |
| 70 mph | 5.12 | 5.81 | 5.63 |
| 80 mph | 6.80 | 8.18 | 8.50 |
| 90 mph | 9.46 | 13.26 | 14.26 |
| 100 mph | 16.00 | A* | A* |

*A—Maximum speed approximately 95 mph with a 1200-ton train.

TABLE III—HORSEPOWER REQUIRED TO HANDLE FREIGHT TRAINS AT VARIOUS SPEEDS ON LEVEL TRACK

| | 3750 Tons 75 Cars | 5000 Tons 100 Cars |
|---|---|---|
| 40 mph | 2370 | 3110 |
| 50 mph | 3610 | 4720 |
| 60 mph | 5270 | 6910 |
| 70 mph | 7370 | 9630 |

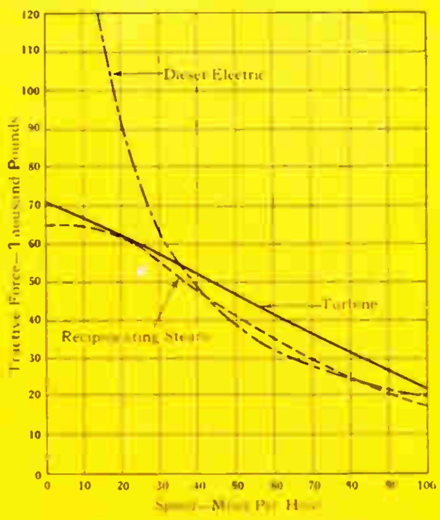



**Fig. 1—A comparison of tractive efforts developed at different speeds for the three types of locomotives under consideration.**

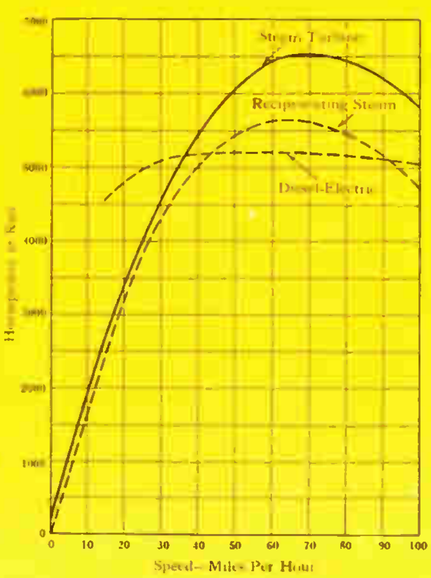



**Fig. 2—These curves compare the horsepower developed by the three types of locomotives, supplementing data of table I.**

**Fig. 3—The turbine locomotive is able to maintain its speed on grades better than either the other two types of locomotives. This comparison is based on a 1200-ton train.**

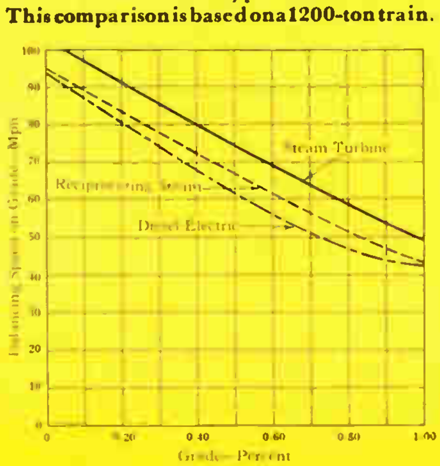



TABLE OF GENERAL DIMENSIONS AND WEIGHTS OF CLASS S-2 LOCOMOTIVE AND TENDER

LOCOMOTIVE

Drivers, 68″ diameter over tires

Wheelbase:

| | |
|---|---|
| Driving | 19′ 6″ |
| Rigid | 13′ 6″ |
| Total engine | 53′ 0″ |
| Total engine and tender | 108′ 0″ |

Boiler—Type, Modified Belpaire, 102″ diameter—largest course

Tubes—49—2¼″ diameter, 18′ 0″ long

Flues—235—3½″ diameter, 18′ 0″ long

Boiler Working Pressure—310 lb per sq in.

Grate Area—120 square feet

Superheating Surface—2050 square feet

| Heating Surface: | |
|---|---|
| Firebox | 340 sq ft |
| Combustion chamber | 190 " " |
| Circulators—(6 in firebox) | 84 " " |
| Tubes—2¼″ | 518 " " |
| Flues—3½″ | 3860 " " |
| Total | 4992 sq ft |
| Weight in Working Order (approximate) | |
| Front truck | 143 000 lb |
| Drivers | 260 000 " |
| Trailing truck | 177 000 " |
| Total engine | 580 000 " |
| Tender | 449 000 " |
| Total engine and tender | 1 029 400 lb |
| TENDER | |
| Water Capacity | 19 500 gal |
| Fuel Capacity | 85 000 lb |

For years, boiler designers have been studying the application of higher pressures and higher temperatures for locomotive use. Many problems still stand in the way, but such boilers will likely be perfected. 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.

The abundance of coal for fuel purposes in this country is leading to extensive research to find better ways for using it. Out of this development will eventually come a more efficient boiler. Hence, turbine locomotives with economies far better than those of the first turbine equipment can be expected. The curves in Fig. 5 show how total steam temperature, pressures, and exhaust pressures affect the efficiency of the turbine drive.

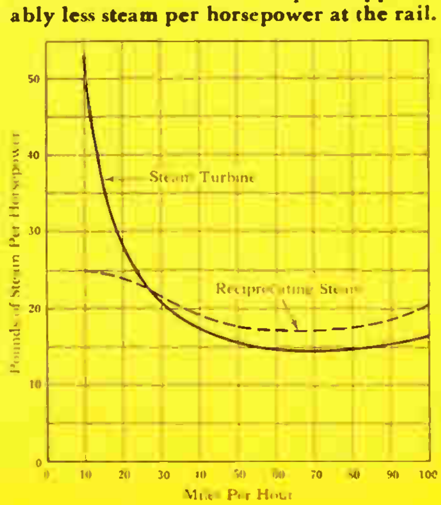
The geared-turbine locomotive substitutes a uniform torque for a pulsating torque, as Fig. 6 indicates. Having no reciprocating motion, the rotating elements of the turbine drive can be balanced, eliminating the undesirable features of unbalanced moving parts.

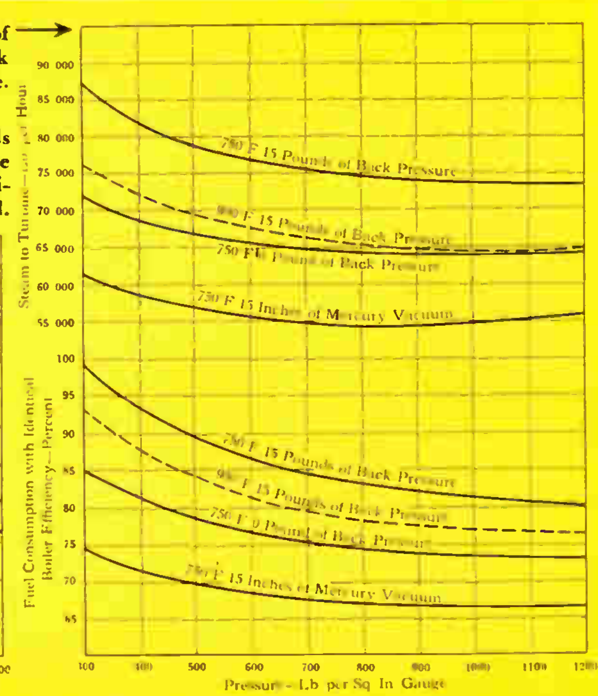
In various parts of the country, there are definite economic reasons dictating the use of either coal or oil as the preferred railroad fuel. The turbine locomotive will use either. The type S-2 geared-turbine locomotive can therefore be used by any railroad wherever located or whatever its source of fuel.

The operating-performance characteristics of the first geared-turbine locomotive built in the United States make it a worthy form of motive power for high-speed freight and passenger service where locomotives of large capacity are required. The operating results so far obtained from the class S-2 locomotive plus the advantages expected from the further developments that have been outlined, presage a promising future for this type of motive power. With future developments in the offing with this type of power, we believe that geared-turbine locomotives of 10 000 hp will eventually be available.

**Fig. 5—These curves show the effect of steam temperature and inlet and back pressure on efficiency of 6000-hp turbine.** →

**Fig. 4—Over the operating range of speeds of both freight and passenger trains the steam-turbine locomotive requires appreciably less steam per horsepower at the rail.**



# How the Geared-Turbine Locomotive Works

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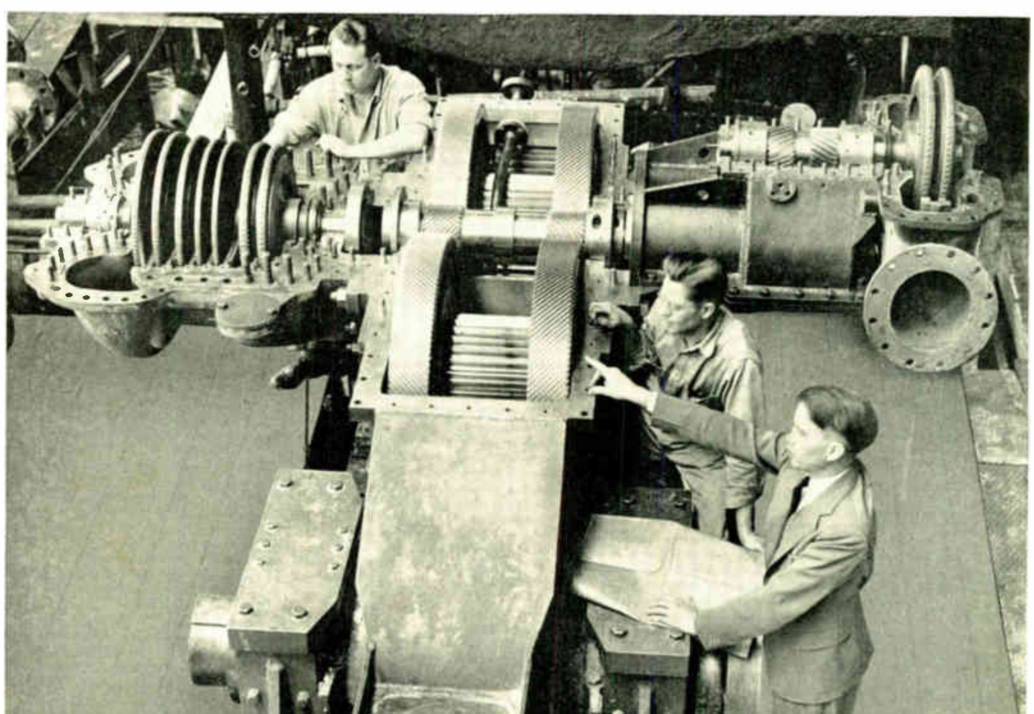
**The steam turbine and double-reduction gear, long acknowledged as the leader for ship drive, has taken to the rails. The first American-built geared-turbine locomotive is now undergoing trials. A giant among giants this locomotive is one fourth more powerful than its reciprocating-engine counterpart. To pack into a maximum width of ten and a half feet a 6900-hp turbine, gears, and a reversing turbine and clutch entailed not one but several unusual feats of engineering.**

The "iron horse" has been an exceedingly durable railroad motive-power unit. The reciprocating steam locomotive with Stevenson valve gear was introduced over a hundred years ago. Although it has been vastly improved in detail, its elements—fire-tube boiler, cylinders, slide-valve mechanism and linkages, and drive-rods—have suffered no essential change. Not that many have not been tried. Experimental locomotives have been built with water-tube boilers, compound engines, and poppet valves. While some innovations have been successful (and have been adopted), those that departed radically from the simple steam engine have not been adopted, either because they did not prove economical or because of mechanical inadequacy.

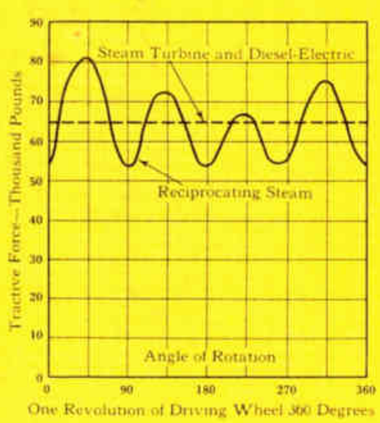
Turbines, too, have been applied abroad to steam locomotives. Some turbine locomotives have been successful and a few are still in service in Europe. Probably the most successful one is the 2000-horsepower noncondensing engine placed in service in 1933 on the London, Midland and Scottish Railway Company. Since then it has operated in express service between London and Glasgow over the same route as such famous locomotives as the "Coronation Scot." The performance of that geared-turbine locomotive has been creditable. However, its power is insufficient to make it economically competitive with the efficient compound reciprocating-engine locomotives used on the L. M. S. Locomotives for U. S. railroads are two or three times more powerful than those used in England, and American railroads use the less efficient but simpler and more reliable single-expansion engine. These factors make the turbine locomotive more attractive here than in England.

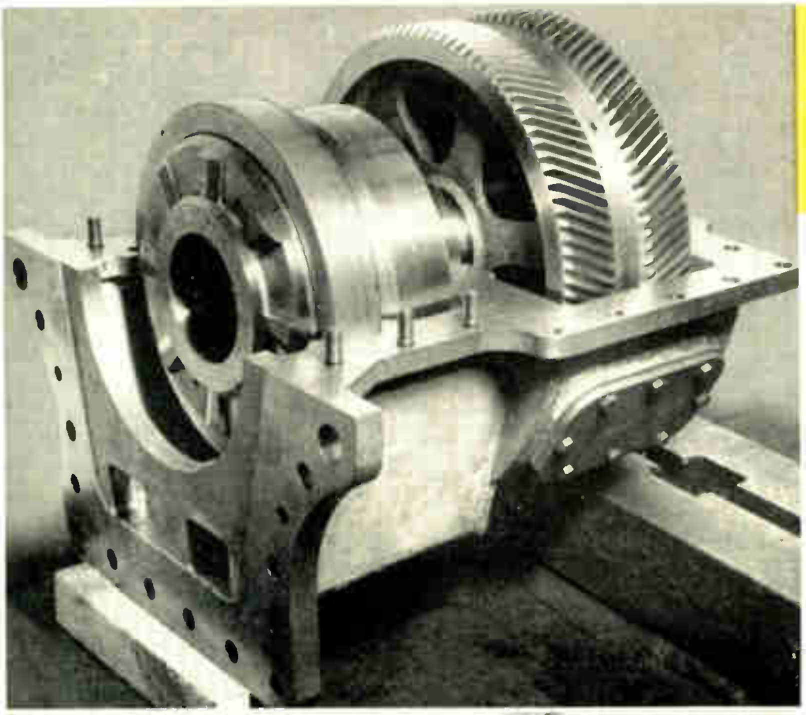
In 1937, the Pennsylvania Railroad became interested in the possibility of improving the performance of its standard passenger locomotive by replacing the single-expansion reciprocating engines with a geared turbine. An exhaustive study by Westinghouse and Pennsylvania engineers indicated the performance could be greatly improved, and that a good mechanical design would result, but the cost of making modifications to existing locomotives would be almost as much as the cost of a complete new engine. As a result designs for a

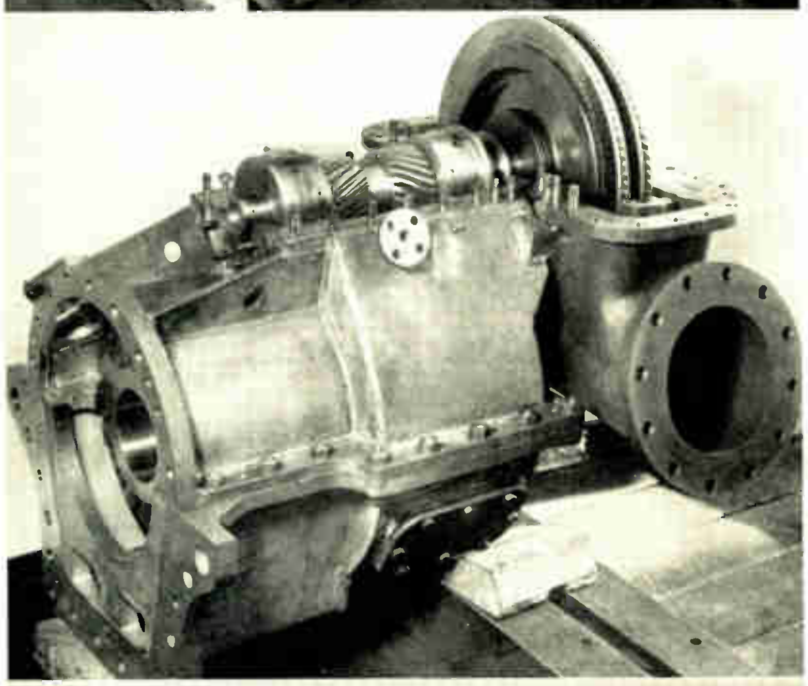


**The geared-turbine unit complete, except for the turbine cylinder and the gear case covers, as it looked from the front end on the turbine test floor. The ahead turbine is at the left, is above and between drivers two and three on the right side of the locomotive. The gear case, which rests between the rails, exposes the high-speed pinion, the two sets of first-reduction gears, and the low-speed pinions. The reverse turbine, at the extreme right, obtains a high torque by an additional gear reduction. The clutch for connecting the reverse turbine to the main gears is inside the gear box.**

**Fig. 6—The smooth application of power derived from a rotating prime mover is here compared with that of a reciprocating engine. The vibration inherent in the latter is obvious from the curves showing variation in torque applied throughout one complete driving-wheel revolution.**







**The gear case and four powered wheels as seen from the left side are shown in the lower view. The reverse turbine shown in the center view is mounted at about the position of the workman's head. The gear and one half of the toothed clutch through which the reverse turbine drives are pictured at the left.**

larger high-speed locomotive were prepared by engineers of the Pennsylvania, Baldwin Locomotive Works, and Westinghouse that culminated in the unit known as the S-2, which went into trial service last September.

The Pennsylvania class S-2 (6-8-6 wheel arrangement) is a geared-turbine, noncondensing steam locomotive. It has a conventional fire-tube boiler capable of supplying 95 000 lb of steam per hour at 310 pounds per square inch gauge boiler pressure or 285 pounds per square inch gauge and 750 degrees F total temperature to the high-speed noncondensing steam turbine. With this steam flow, the geared-turbine unit develops 6550 hp at the rail at 70 miles per hour; less at other speeds as shown in the curves of Fig. 1, in which calculated horsepower and tractive effort at the rail for both a conventional reciprocating engine and a turbine engine are related to speed.

The propulsion unit comprises a forward turbine, a double-reduction gear for each of the two middle driving axles, flexible cup-drive elements between the final drive gears and the two middle driving axles, a reverse turbine and gear unit clutched to the single high-speed pinion, a pneumatic steam-admission control with protection against overspeed, and low oil pressure and oil system auxiliaries including a cooler, magnetic and metal-edge strainers, two turbine-driven pumps, and control valves. Both forward and reverse turbines are supported from the gear case which, in turn, is supported from the main locomotive frame, making the power unit a complete assembly in itself. The gear case is supported from the locomotive frame at three points (two at one end of the case and one at the opposite end) so that distortion of the locomotive frame is not transmitted to the gear case and thence to the gears.

The forward turbine is of the impulse type and consists of a Curtiss stage followed by five full-admission Rateau stages. Although especially designed to meet the severe temperature and load changes found in railway practice, it is similar to the high-pressure units of cross-compound marine plants. At 100-mph locomotive speed the turbine turns at approximately 9000 rpm. It is connected to the high-speed pinion at the reverse-turbine side of the unit, a quill shaft extending through the pinion. Steam enters the turbine through 4 three-inch pipes, each pipe being connected to a nozzle group covering approximately 20 percent of the peripheral area of the Curtiss-stage blading. Each inlet pipe is connected to a throttle valve and steam header located at the top of the smokebox. Four cam-operated valves control the steam to the forward turbine, each valve controlling the flow of steam to one of the four inlet pipes. The cams are arranged to open the valves in sequence. Close regulation of locomotive power and speed are obtained by opening each valve successively in small increments.

The reverse turbine is a single Curtiss stage, overhung on an extension of the reverse-gear pinion shaft. Steam is admitted to nozzles in both the base and cover of the reverse-turbine cylinder through a single inlet pipe, connected to the reverse throttle valve (also cam-operated) and located adjacent to the forward turbine valves. The maximum locomotive speed in reverse is 22 mph, at which speed the turbine develops 1500 hp at approximately 8300 rpm.

The maximum starting tractive effort in reverse is 65 000 pounds at 25 percent adhesion. This is made possible with the small reverse turbine and only a third of the steam flow of the forward turbine by the addition of the reverse gear, which multiplies the torque of the reverse turbine by four at the high-speed pinion.

Power in reverse is transmitted to the high-speed pinion through an hydraulically actuated, positive-engagement clutch. The forward turbine is solidly connected to the high-speed pinion at all times, but the reverse turbine is engaged with this pinion only during operation in reverse. Engagement or disengagement of the clutch when the locomotive is moving is prevented by a "zero speed" interlock in the pneumatic control circuit.

Speed as well as direction of the locomotive is controlled by a single small lever at the engineman's position. The complete motion of the lever is the same as that in shifting an automobile engine from "low" gear to "intermediate." The neutral position of the gear shift is the *off* position for the locomotive; moving into "intermediate" position controls the flow of steam to the *forward* turbine; moving into "low gear" engages the clutch and controls the flow of steam to the *reverse* turbine. The control, built by Westinghouse Air Brake Company, consists of a forward "pneudyne" (a cylinder controlled by an air relay) located on the engineman's side of the locomotive, a reverse pneudyne on the fireman's side of the locomotive, overspeed and low oil pressure protection valves and a zero-speed interlock. The pneudynes, through a rack and pinion forward and a lever in reverse rotate the throttle valve cam shafts and thereby control steam flow to the turbines. If either turbine overspeeds (110 mph forward, 25 mph reverse) or if the lubricating oil pressure falls below 5 lb per sq in., the protection valve operates to close either throttle by exhausting the control air to atmosphere.

The main gear is a double-reduction unit designed to transmit power to the second and third driving axles from a single high-speed pinion. Transmission of equal torques to each of

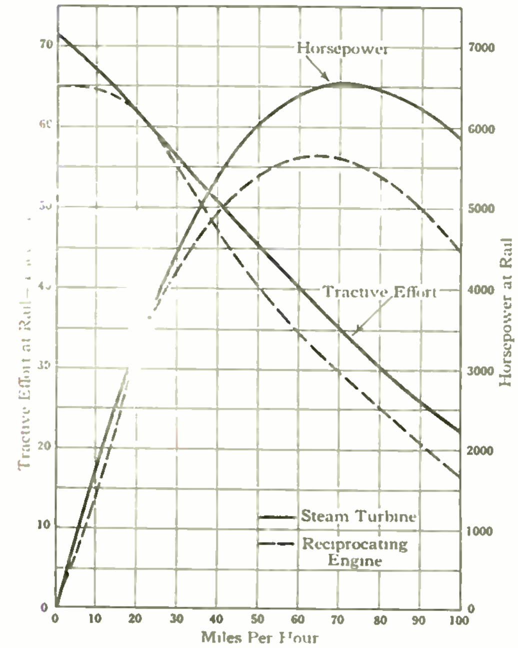



**Fig. 1—The calculated curves of performance indicate that as speeds increase above about 30 mph the geared-turbine locomotive provides more horsepower and greater tractive effort than is obtainable with the familiar form of locomotive.**

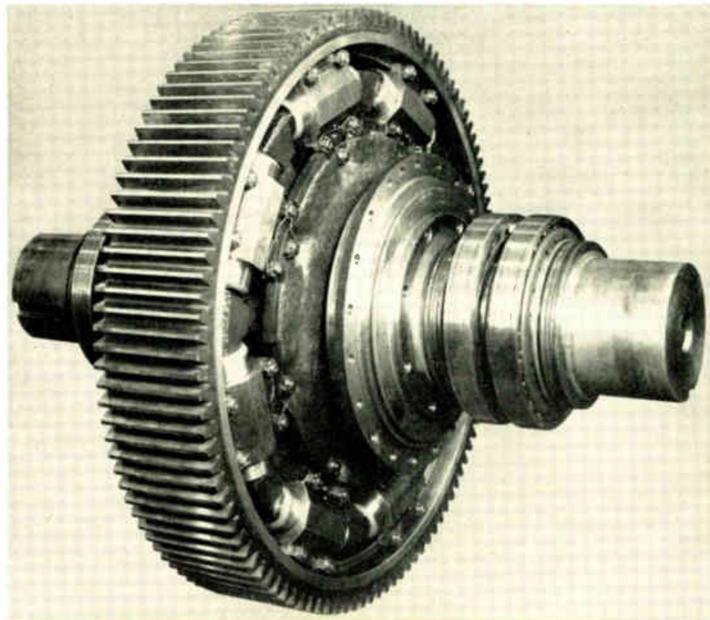
the driving wheels is assured by side rods connecting the four driving wheels on each side. The gear is of the nested type with two double-helical high-speed gears, two low-speed spur pinions, two low-speed spur gears, and two cup-drive elements all housed in an enclosed, fabricated-steel gear case. The high-speed pinion and the second-reduction gearing is hardened and ground. This is the first commercial application of hardened and ground double-helical gearing. The tooth loading and contact hardness (450 Brinnell) of the high-speed pinion are more than twice the values commonly used. The first-reduction gears are hobbed from material also of nearly twice the hardness commonly used.

The development of a method of grinding double-helical gearing with the extreme accuracy required is the first major advance in this type of gearing since the first gear was built by George Westinghouse in 1909. Grinding is effected with a flat wheel in combination with a novel grinding rig. Although materials of the usual hardness might operate satisfactorily


**A locomotive without reciprocating drive. The reverse geared turbine is the round structure above the second and third drive wheels.**

in this application, an additional factor of safety is introduced by the use of the harder, stronger gear-tooth material. Further development and use of this new grinding technique may make possible real savings in the weight and space of double-helical gearing for high-speed, high-power turbine drives used in other applications.

Bearings for the high-speed pinion and the high-speed gears are tin-base babbitt lined. Clearances greater than usual are required for the high-speed pinion bearings because of their high rubbing velocity. The high-speed gear bearings are novel in that they rotate with the pinion and gear, being fitted into the hollow-bored low-speed pinions on which the first-reduction gear wheels are shrunk. The bearings rotate upon trunnions that center the second-reduction pinions. The low-speed gear bearings are of the anti-friction type, duplicates of those furnished as quill bearings for electric locomotives.



Torque is transmitted to each of the two axles by one of these cup-drive units, which allows the necessary motion of the drivers with respect to the gears, solidly mounted to the locomotive frame. In each cup is a spring that gives that flexibility.

The gear case is split into four separate pieces. The center section is the principal structural member to which both the forward turbine and the reverse turbine and gear assembly are bolted. The upper section forms a cover for the high-speed gearing and contributes to the crosswise stiffness of the case. The two lower sections, removable to permit dropping the axles, are lubricating oil sumps as well as enclosures for the low-speed gearing and the cup-drive assemblies.

The complete propulsion unit is supported from the locomotive frame, which is spring borne. Thus the second and third driving axles must be permitted to move up and down with respect to the low-speed gears surrounding them as the locomotive moves over the rails. This vertical motion of each driven axle must take place while it is turned by its gear. The "cup drive" which permits this motion is really a misalignment coupling between the low-speed gear and the locomotive axle. It is used on most main-line electric locomotives, having been developed by Westinghouse for that purpose. While the cup drive on the S-2 is the same in principle as the drives used on electric locomotives, it bears little resemblance physically to its predecessors.

On electric locomotives, the traction motors occupy almost the entire space between the wheels, the main locomotive frames and journal bearings being outside the wheels. The cup-drive assemblies are usually mounted in the plane of the driving wheels. The side rods on steam-turbine locomotives prevent this. It is necessary that the axle journal boxes and the cup drive be between the wheels.

The cup drives occupy the centers of the low-speed gears and are on the axial centerline of the locomotive. The "quill" becomes two short seats on the gear center for roller bearings, which are carried in the main gear case. There are two rows of cup assemblies with eight in each row. Because the quill cannot extend to the driving wheels, as in the case of the electric locomotive, a drive spider is pressed on the locomotive axle, at its center, and the gear torque is transmitted by springs within the cup assemblies to the arms of this spider.

Two major departures were made from conventional cup-drive design to enable the drives to withstand the heavy duty imposed on them by having to transmit power to all four axles. The cups are made in two pieces, with self-aligning inserts which distribute the spring loads over relatively large areas of contact with the drive spider arms. Also, the whole drive is enclosed by oil-tight cover plates so that the entire mechanism is kept clean and well lubricated with a bath of heavy, extreme-pressure lubricant.

The cup drives, in addition to permitting the up and down motion of the driving axles, are torsionally flexible. This protects the gearing and turbine from shock loads. It would also mean that, if the driving wheels on one of the two geared axles were larger than those on the other, one axle would tend to "hog" the load and the springs of its cup drive would "wind up." To prevent this, and to force an equal division of power flow to each of the geared axles, the wheels on these two axles have also been provided with side rods which are fully balanced, so that the dynamic unbalance is eliminated.

All turbine and gear bearings and the gear teeth are lubricated with the same oil, a high-grade turbine oil. The system contains approximately 150 gallons, and the entire quantity is recirculated by one of two small turbine-driven centrifugal pumps. One pump is for normal duty and the second one is an emergency standby. Oil is pumped from the gear case through a magnetic strainer and oil filter to a surface-type oil cooler, cooled by boiler feedwater, and then to a distributing manifold equipped with a steam-heating coil before being piped to the bearings and gear sprays.

A regulator maintains a constant oil pressure of 15 lb per sq in. on the bearings and sprays. The pump-discharge pressure is 60 lb per sq in. high-pressure oil being required for the hydraulic cylinder, which is used to engage the clutch when operating in reverse.

The S-2 locomotive has been undergoing tests on the railroad in both passenger and freight service on the Pennsylvania system. Continued operation in revenue service is contemplated to prove the mechanical adequacy of the design.

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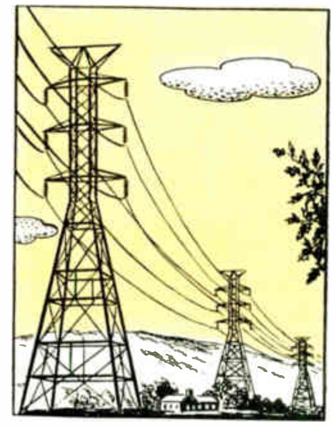
Editor's Note: *At the time of going to press the geared-turbine locomotive has been in revenue and test service between Harrisburg and Altoona, and has now been returned to the shop for minor adjustments. The total mileage chalked up is yet too small to provide conclusive evidence of performance, but nothing has developed that indicates any fundamental defect in this revolutionary type of drive.*

# Power-Line Carrier Modulation Systems

**The Cheshire cat in Alice in Wonderland disappeared entirely except for its grin. Engineers have managed to do something like that with power-line carrier by eliminating the carrier wave and one of the side bands, and transmitting only the remaining side band over the line. At the receiving end the side band is mixed with a carrier wave identical to that from which it was divorced at the sending end. The result is that more intelligence can be transmitted more clearly over a given band width of frequencies.**



R. C. CHEEK
*Central Station Engineer*
*Westinghouse Electric & Mfg. Company*

IN THE application of power-line carrier equipment, the most important problem confronting the power-system communication engineer today is the crowded condition of the carrier frequency spectrum. The carrier spectrum normally includes the frequencies from 50 to 150 kilocycles. Among the factors that dictate the use of this range of frequencies are the increase in undesired radiation that occurs as frequencies are extended above 150 kc and the possibility that frequencies lower than 50 kc may interfere with telephone-line carrier systems. Radiation and resulting interference with radio services are particularly serious because important radio-beacon and direction-finding frequencies lie just above the 150-kc limit of the carrier band. The problem of spectrum crowding exists not only on large power systems that have extensive carrier systems of their own, but also on smaller systems interconnected into large groups in which the total number of carrier installations is large. The postwar plans of many utilities include extensive additions to their carrier systems, and the spectrum-crowding problem will become even more serious after the war.

Other important problems in the application of carrier equipment are the high attenuation encountered on long-haul communication and telemetering circuits and the high noise and interference levels that exist on some lines. In general, increasing the power of A-M equipment is not a satisfactory solution to these problems. Noise and attenuation levels are measured in decibels, a logarithmic unit. An increase in the power of a 25-watt A-M carrier transmitter to 50 watts provides a gain of three decibels, but the power must be doubled again, i.e., increased to 100 watts for an additional three-decibel gain. A further three-decibel gain requires another doubling of power, to 200 watts, and so on. Appreciable gains in signal strength in terms of decibels therefore require inordinately large amounts of power.

These problems have led to the consideration for power-line carrier work of two systems of transmission fundamentally different from the conventional A-M system. They are the frequency modulation or F-M system and the single-side-band system for transmitting intelligence over power lines.

### Amplitude Modulation or A-M

In the left-hand portion of Fig. 1, conditions are shown for an A-M carrier without modulation. During periods of no modulation, i.e., no conversation or telemetering impulse on the channel, the only quantity transmitted is the unmodulated carrier, a constant amplitude, single-frequency sine wave, which can be represented in vector form as a single vector of constant length, rotating at carrier frequency.

The right-hand portion of Fig. 1 shows conditions for 100-percent amplitude modulation of the carrier wave by a sinusoidal audio tone. Two additional waves are introduced, one of frequency equal to carrier frequency plus modulating frequency, and one of frequency equal to carrier frequency minus modulating frequency. The amplitude (voltage) of each of these additional components, which are called the side-band components, is 50 percent of the carrier amplitude. The power in each side band is therefore 25 percent of the carrier power. This gives a total average power under complete modulation of 1.5 times the unmodulated carrier power. This power is the average of the variations in total transmitted power as the carrier and side-band components combine to give a wave whose power varies between the limits of zero and four times the unmodulated power during an audio cycle.

The variation in *amplitude* of the transmitted signal from zero to twice normal value is caused by the presence of the two side-band components. These components, being of different frequencies, alternately augment and oppose each other to produce a resultant that is of their average frequency, that is, the carrier frequency, with an amplitude that varies from plus 100 percent to minus 100 percent of carrier amplitude. This resultant, added to the carrier, causes its amplitude to vary at the audio frequency between the limits of zero and twice its normal value.

The vector representation of this action is shown in Fig. 1 for successive intervals of time during the audio cycle. The vector representing the carrier remains unchanged during modulation. The vectors representing the upper and lower side-band components revolve about the carrier vector in opposite directions at audio frequency, because their frequencies are carrier plus audio and carrier minus audio, respectively. The two side-band vectors are of just the proper phase to produce a resultant that is always directly aiding or opposing the carrier vector.

In the A-M system, the carrier and all side-band components are transmitted, and an A-M receiver must accept a frequency band sufficiently wide to accommodate the highest and lowest side-band frequencies produced. This means that the channel width required is twice the frequency of the highest frequency audio component to be transmitted. For speech, a band width of six kilocycles is required to accommodate the

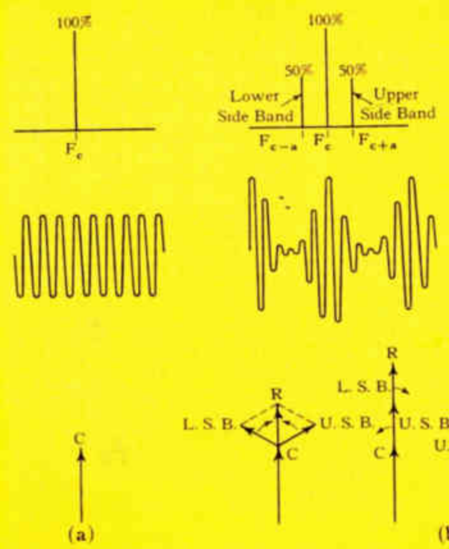
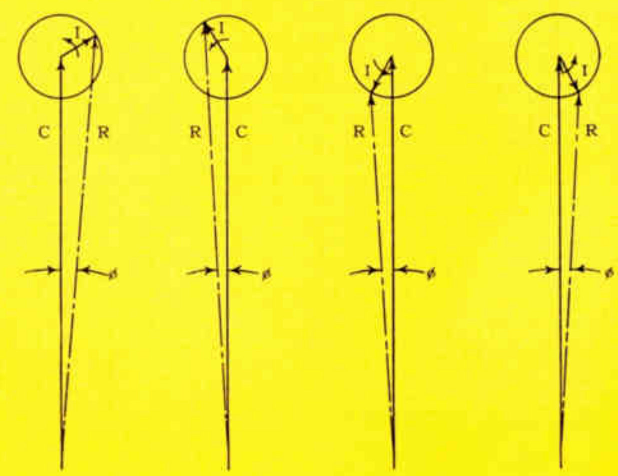



**Fig. 1**—In (a) an unmodulated carrier is shown with its vector equivalent. One hundred percent amplitude modulation of a carrier by a sinusoidal audio-frequency wave is shown in (b). In this and succeeding figures, *C* represents carrier; *R*, resultant; *L.S.B.*, the lower side band; *U.S.B.*, the upper side band.

**Fig. 2**—The effect of interference on an A-M carrier is here shown vectorially.




upper speech frequencies in the vicinity of three kilocycles.

#### How Interference and Noise Affect an A-M Signal

In the A-M system, the receiver responds only to changes in the amplitude of the carrier; changes in the phase or slight changes in the frequency of the carrier produce no audible output from the receiver. Interference with an A-M signal occurs when an undesired wave is passed by the tuned circuits of the receiver (which must accept all frequencies in a six-kilocycle band in the system under discussion) and adds to the desired carrier wave in much the same manner as the desired side bands add to it, producing variations in its amplitude. If the undesired signal is another carrier wave, the familiar beat-note type of interference is the result. The frequency of the audio output of the receiver for this type of interference is the difference between the frequencies of the carrier and the interfering wave. The amplitude of the audio output is the same for all interfering waves of equal amplitude applied to the detector, whether their frequency is close to the desired carrier or close to the edge of the band accepted by the receiver.

Vector diagrams showing the effect of interference on an A-M carrier are given in Fig. 2. Assuming that no side-band waves are present, i.e., that the carrier is not intentionally being modulated, the carrier vector *C* is again a single vector of constant length. Assume that the interfering wave *I* has an amplitude of 10 percent of the carrier amplitude. The vector representing it adds to the carrier vector, and revolves about it as shown at a frequency equal to the difference in frequency between the two. The resultant vector varies in amplitude and phase at this difference frequency. The amplitude variations are equivalent to 10 percent modulation of the carrier amplitude and the receiver detects them as such.

The preceding discussion was based upon interference from a single-frequency wave. Random noise consists of a large number of such waves, each of small amplitude, distributed throughout the frequency band accepted by the receiver. The effects of such waves are similar, except that the audio output of the receiver is simply noise, of no definite frequency, instead of an audio tone.

### Frequency Modulation or F-M

In any discussion of F-M, the important distinction between narrow-band and wide-band F-M must be kept clearly in mind. Narrow-band F-M, in which modulation causes the frequency of the transmitted signal to swing over a limited range, was investigated nearly 25 years ago by J. R. Carson and others, but was abandoned. It was found that, limited to the channel width of the A-M system, narrow band F-M offered no material advantages in performance. Wide-band F-M, introduced by Armstrong in 1936, is employed in ultra-high-frequency F-M broadcasting and is the type around which publicity has centered in recent years.

In the wide-band system used in F-M broadcasting the frequency of the transmitted signal is swung over a band of 150 kc, and large gains in signal-to-noise ratio over A-M are obtained as a result. It is because F-M broadcast stations require so much channel space that they are forced to use the ultra-high frequencies, the only place in the radio spectrum where sufficient space is available. No such wide channels are available in the power-line carrier band, because the entire band is only 100 kilocycles in width. Any F-M system used for power-line carrier work must therefore be of the narrow-band type, which offers no advantages over A-M with respect to noise and attenuation for the same channel width, or some compromise between narrow-band and wide-band F-M must be employed to obtain gains in signal-to-noise ratio at the expense of space in the frequency spectrum.

In the F-M system a carrier signal, identical in every respect to the A-M carrier, is transmitted during periods when modulation is absent. These conditions are shown in the left-hand portion of Fig. 3, where we again have a constant-amplitude, single-frequency sine wave represented by a single vector of constant length proportional to carrier amplitude.

When modulation is present, we have instead of the sine-wave carrier a wave of the same amplitude whose frequency varies above and below the original carrier frequency. This variation in frequency of the transmitted signal takes place at the audio or modulating frequency. It is caused by the presence of side-band components, as in the A-M system. However, an important difference exists. Instead of a single pair of side-band components for a single modulating frequency, an infinite number of side-band pairs is produced in F-M. These side-band pairs are spaced above and below carrier frequency at multiples of the audio frequency. Thus, the first side-band pair occurs at carrier plus audio frequency and carrier minus audio frequency, as in A-M. The second pair occurs at carrier plus and minus *twice* audio frequency, the third at carrier plus and minus *three times* audio frequency, and so on.

Another important difference is that in F-M the amplitude of the carrier-frequency component is reduced during modulation. However, the resultant obtained by adding the new carrier vector and the side-band vectors in F-M is always a vector of amplitude equal to the original unmodulated carrier amplitude. The intelligence is transmitted, not by a change in the amplitude of the resultant vector, but by a continuous oscillation in its phase position with respect to the position of the unmodulated carrier vector as a reference. In other words, the resultant vector, instead of remaining stationary in phase and varying in amplitude, is unchanged in amplitude but oscillates in phase ahead of and behind the reference position. The oscillation in the phase position of this vector introduces a modulation of the frequency of the transmitted signal, because during the process of a change in phase, a change takes place in the speed of rotation of the vector, which, of course, means a change in frequency. The frequency deviation from normal at any instant is proportional to the rate at which the phase is changing at that instant.

The vector diagrams of Fig. 3 show for a particular F-M system how the resultants of each pair of important side-band vectors add to the carrier vector to maintain the same total resultant amplitude but to produce a change in phase. The vector diagrams are drawn for different instants during an audio cycle. The total effect of all the vectors, carrier vector plus all side-band vectors, is to produce a total resultant vector whose length is always that of the *original unmodulated carrier vector* but whose phase oscillates at the audio frequency or frequencies being transmitted.

The frequency swing above and below normal frequency depends upon the loudness of the modulating signal and the design of the system. The frequency swing in a given F-M system is the same for any audio frequency of a given loudness. This means that the phase swing must be inversely proportional to the modulating frequency. If the lower modulating frequencies are to produce the same frequency change as the higher modulating frequencies, the resultant vector must travel through a greater phase change during a low-frequency audio cycle than during a higher frequency audio cycle. In other words, the speed of swing of the resultant vector is the same at a given point on the cycle, whether the audio frequency is high or low. Because the resultant vector has a longer time to change in phase during a low-frequency audio cycle, the actual phase swing is greater than for a higher frequency audio cycle. This fact is important to an understanding of the way in which F-M provides gains in signal-to-noise ratio over A-M.

Although an F-M signal contains an infinite number of side-band pairs, the magnitude of each pair is different. At a certain frequency in each direction from carrier frequency the higher and lower frequency side band components become negligible. The channel width occupied by an F-M signal is the band required to transmit all significant side-band components, because if they are not transmitted, audio distortion is introduced.

The ratio of the maximum carrier-frequency deviation from normal to the highest audio frequency to be transmitted is called the deviation ratio. If the carrier-frequency swing is three kilocycles and the highest audio frequency to be transmitted is three kilocycles, a deviation ratio of unity is obtained. These conditions are the ones that have been illustrated in Fig. 3, which shows that while the frequency swing may be only three kilocycles above and below carrier frequency, the side-band components that must be transmitted in order to obtain this frequency swing actually occupy a band width much greater than six kilocycles. These side-band components are not brought within a narrower band with a lower modulating frequency, because although they are closer together, the number of significant side-band components becomes greater, with the result that the band width required is about the same. According to one authority, the channel width required for reasonably distortion-free reproduction is one and one half times the total band over which the frequency of the transmitted signal is swung.

#### How Interference and Noise Affect an F-M Signal

The deviation ratio in F-M is also the maximum phase swing in radians when the signal is modulated by a tone of maximum loudness and of the highest audio frequency to be transmitted by the system. This phase swing must be twice as great for a modulating tone of the same loudness but of half the frequency, and for very low audio frequencies the phase swing becomes enormous. In all cases, however, the *frequency* swing is the same and the receiver reproduces each tone with the same loudness.

Consider now the effect of adding to an F-M carrier the same interfering signal assumed in the discussion of A-M. Refer again to Fig. 2. If the interfering wave has 10 percent of the amplitude of the desired carrier and has a frequency three kilocycles away from the carrier, the vector representing it will revolve around the carrier vector, producing a resultant vector that undergoes a phase oscillation of 5.7 degrees (0.1 radian) at a frequency of three kilocycles. This is one tenth of the swing produced when an F-M system with a deviation ratio of unity is modulated by a three-kilocycle tone of maximum loudness; therefore, the interfering signal causes exactly the same amount of interference it would have caused to an A-M carrier, that is, ten percent.

If the interfering signal is removed only 1.5 kc in frequency from the carrier, however, conditions are somewhat different. Assuming the same amplitude for the interfering wave, the same 0.1 radian phase oscillation occurs, this time at a frequency of 1.5 kc. This is only one twentieth the phase swing for a desired 1.5 kc modulation of maximum loudness. Hence,

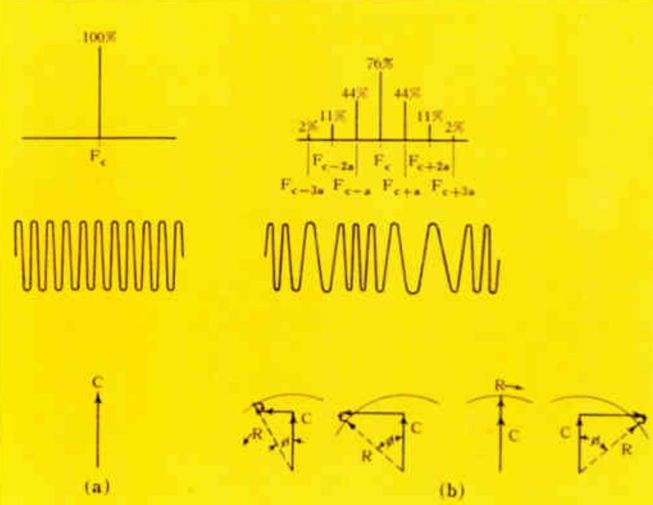



**Fig. 3—The unmodulated carrier wave in an F-M system shown in (a) is identical with the unmodulated A-M carrier wave shown in Fig. 1 (a). The F-M carrier wave, modulated with a sinusoidal audio tone, together with the vectorial representation of this modulation is shown in (b).**

although the amplitude of the interfering wave is the same as before, the audio output it causes is only half as much. As the interfering signal gets closer and closer in frequency to the carrier, the audio output it produces becomes less and less, falling to zero at carrier frequency.

In Fig. 4 an F-M system with unity deviation ratio is compared with the A-M system from the standpoint of the effects of interference. Random noise is made up of components of all frequencies, and assuming that both the A-M and F-M receivers considered for Fig. 4 accept the same band of frequencies, the relative effect of random noise power on the two systems can be found by comparing the areas under the power-output curves for the A-M and F-M systems. These areas give the total integrated noise power for each system. The area under the F-M power-output curve is exactly one third of that under the power-output curve for the A-M system, a gain in signal-to-noise ratio for the F-M system of 4.8 decibels.

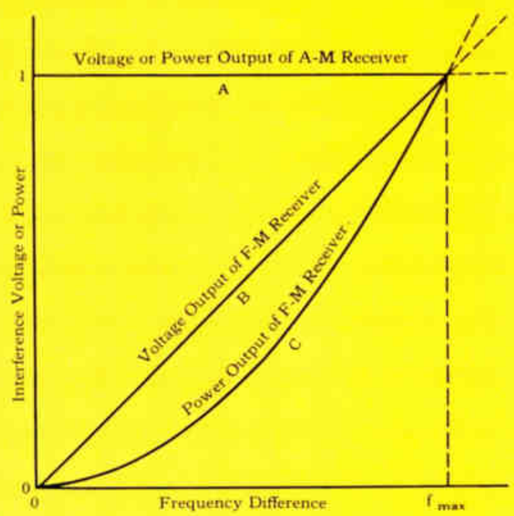



**Fig. 4—A comparison of the effects of interference on an F-M system with unity deviation ratio and an A-M system.**

## The Single-Side-Band System

In the A-M system the carrier-frequency component of the signal is unchanged during modulation. Modulation merely introduces additional components that act upon the carrier-frequency component to vary its amplitude. Suppose that the lower side-band component were suppressed, and only the carrier and the upper side-band component were transmitted. The amplitude of the resultant signal would still vary at the audio frequency, and intelligence could be transmitted in this manner in half the frequency band width required for A-M.

It is possible to go a step further and suppress the carrier itself in a low-power stage at the transmitting end and amplify and transmit the components of *only one side band.* The carrier-frequency wave, upon which the side-band waves act to reproduce amplitude variations at audio frequency, can be generated by a small oscillator at the receiving end of the channel. Thus, instead of consuming power to generate a constant-frequency, constant-amplitude sine wave, which is subjected to all the attenuation and losses involved in transmitting it to the receiving end of the channel, we can use a small local oscillator to produce this wave at the receiving end. The power, which was originally used in amplifying and transmitting the carrier, can then be used to transmit intelligence-bearing side-band components.

The single-side-band suppressed-carrier system is illustrated in Fig. 5. The conditions for no modulation are shown again in the left-hand portion of the figure. The frequency spectrum contains no components when modulation is absent. The constant-frequency, constant-amplitude, sine-wave carrier, common to the A-M and F-M systems, is absent.

When modulation occurs (again assuming modulation by a single audio frequency) a single component appears in the frequency spectrum. This quantity is a pure sine wave, of constant amplitude, and of frequency equal to nominal carrier frequency plus audio frequency. The assumption is made here that only the upper side-band component is being transmitted, the lower side-band component being suppressed. Actually, either one could be used.

The vector diagram shows the locally generated carrier as a dotted line, to which the incoming side-band vector, shown as a solid line, is added. The frequency of the side-band wave differs by audio frequency from the locally generated carrier frequency; so the vector representing it revolves about the carrier vector at audio frequency. The amplitude of the resultant vector therefore varies at audio frequency. The resultant wave, produced by adding the local carrier and the received side band, is a wave similar to that which would have been obtained had the carrier and lower side-band components been transmitted from the sending end. This resultant wave can be applied to an ordinary A-M detector and rectified in the usual manner.

### Gains in Signal-to-Noise Ratio with the Single-Side-Band System

As indicated in the description of the A-M system, the average power transmitted during complete modulation is 1.5 times the unmodulated carrier power. The extra power required during modulation can be supplied in several different ways. In one A-M system, the output stage of the transmitter operates at a relatively low efficiency during periods of no modulation. The modulator supplies no power but changes the efficiency of the transmitter during modulation, increasing the average output by 50 percent. The 1.5 times normal power produced during modulation is the average power transmitted as the instantaneous power varies between the limits of zero and four times normal during the audio cycle, and an A-M transmitter of the efficiency-modulated type must be able to produce this four times normal power at its peak efficiency, which it reaches for an instant during each audio cycle.

When such an A-M transmitter is used to amplify a single-side-band signal, it can operate at peak efficiency throughout the audio cycle, because the signal is a constant-amplitude radio-frequency wave, without the peaks and "troughs" of the modulated A-M carrier. The power in the single-side-band signal transmitted is then four times the normal A-M carrier power, and the signal received at the receiving point is four times as strong. Halving the band-width of the receiver removes half of the accepted noise power, an additional gain of two to one in signal-to-noise ratio. The total gain over A-M with the single-side-band system is, therefore, eight times or nine decibels with the same transmitter and the same peak power. This gain is accomplished with a signal which uses only half the channel width of an A-M signal.

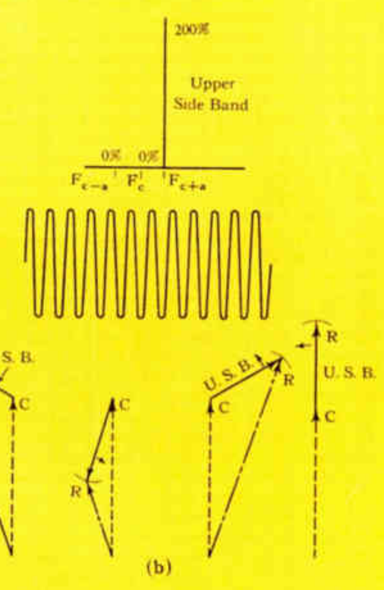



**Fig. 5—These graphical and vectorial presentations of single-side-band, suppressed-carrier system show (a) conditions for no modulation and (b) modulation by a single audio frequency.**

**Other Advantages of the Single-Side-Band System**

Reduction in channel width and gains in signal-to-noise ratio in the presence of random noise are not the only advantages offered by the single-side-band system. A type of interference sometimes encountered on power systems is that known as corona modulation, a phenomenon in which the amplitude and phase of an A-M or an F-M carrier are varied at a sixty-cycle rate by the presence of corona on a transmission line. Increasing the power of the carrier does not help the problem, because the relative amount of modulation remains the same as power is increased. The single-side-band system offers the only real solution to the problem, because no carrier is transmitted and there can, therefore, be no such modulation of the carrier wave.

One of the most important characteristics of the single-side-band system is the absence of the carrier wave. This permits many applications that are impossible with the A-M and F-M systems, in which a continuous carrier is transmitted. Elimination of the carrier permits a single receiver to receive signals from several different transmitting points simultaneously. For example, different telemetering tones can be used to modulate single-side-band transmitters at each of several locations, all operating on the same nominal carrier frequency.

Elimination of the carrier also permits repetition of frequencies for tone telemetering and load-control channels. All that is required is that a different set of tones be used in each channel on the same frequency. The carrier frequencies can be the same.

Perhaps the most important feature of the single-side-band system is one that results from its basic similarity to the A-M system. Because of this similarity, existing and future installations of rack-and-panel mounted A-M equipment of suitable design can be converted to single-side-band operation. This conversion can be accomplished in the field. This makes it possible for users of carrier equipment to purchase ordinary A-M apparatus of proper design now, with the assurance that it will not have to be replaced if they should later adopt the single-side-band system.

Transmission of intelligence with single-side-band system is not a new concept. The question naturally arises as to why it has not been used extensively for power-line carrier. The answer is simple. Heretofore, single-side-band signals were generated as double-side-band signals and passed through filters to eliminate the unwanted side band. At power-line carrier frequencies it is difficult to build filters with sufficiently sharp cut-off characteristics for this purpose. Such a filter would be quite complicated. Until now the only alternative means of utilizing single-side-band signals has been to use equally complicated double modulation schemes. Under these conditions single-side-band equipment could not be offered on an economically competitive basis with the A-M system. The development of a simpler system of single-side-band generation that requires no filters or double modulation schemes removes the principal deterrents to the adoption of single-side-band transmission of intelligence for carrier service.

The single-side-band system cannot be expected to replace A-M completely in the power-line carrier field. The latter system is still the proper one to use for the majority of applications because it is simpler, better known, and entirely satisfactory for many purposes. Where special problems arise, the relatively more complicated single-side-band system should be considered. The same considerations apply to F-M because it, too, is more complicated than A-M and has the additional disadvantage of requiring larger band widths for appreciable gains in signal-to-noise ratio. On the whole, the single-side-band system is fundamentally a more sound approach to these problems because the gains in signal-to-noise ratio it provides can be obtained simultaneously with gains in carrier channel space. These and the other advantages assure it a place in the postwar power-line carrier picture.

# Ceramic Dashpots*

**Engineering ingenuity is, as often as not, a matter of developing new uses for old machines or materials. The ceramic dashpot is a case in point. Some of the oldest artifacts that have come down to us from prehistoric times are ceramics. Yet few know that modern ceramics can be made to tolerances measured in thousandths of an inch.**

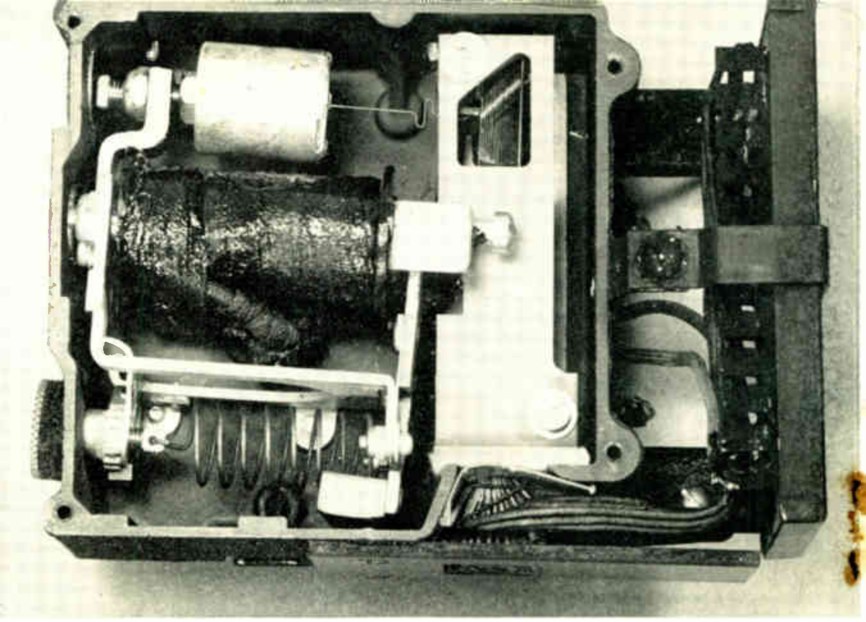


**Fig. 1—The ceramic dashpot is in the upper left of this Silverstat control assembly. It insures that the contacts on the numerous leaves to which the piston is connected cannot open and close at a rate greater or less than that preset by means of the needle valve.**

The value of a snubbing action in controlling energy probably has been known since wild horses were tamed by throwing a loop of a woven-vine lasso about a stump. Many modern equipments need a mechanical damping device to control the rate of operation. Such a damping mechanism is the dashpot, frequently used in motors, controls, switchgears, scales, and other places where damping of mechanical motion is essential to the proper operation of the apparatus. A dashpot consists of a cylinder in which moves a closely fitted piston. The cushioning or slowing medium can be air or a liquid. The rate of motion or the extent of damping action is governed by the rate of flow of the air or liquid into or out of the piston chamber. This is determined by varying the size of an orifice that bleeds the cushioning medium into or out of the cylinder.

Dashpot damping has been used for many years. The dashpots have been built of many different materials including metals, alloys, and plastics. Metals and alloys, even the best stainless steels, corrode or tarnish sufficiently to cause difficulties in the proper operation of the dashpot. This is particularly true where the damping must be constant under all operating conditions.

Plastics do not always hold their shape with sufficient accuracy for close fitting dashpots. Plastics also are unsuited generally for close grinding and polishing for securing a low coefficient of friction.

For applications where the accuracy of damping is not important, metal and plastic dashpots are generally satisfactory. Where the dashpots are fluid filled, the use of ones of metal or plastic construction can be extended although the operation of fluid-filled dashpots is affected by changes of fluid viscosity because of temperature changes.

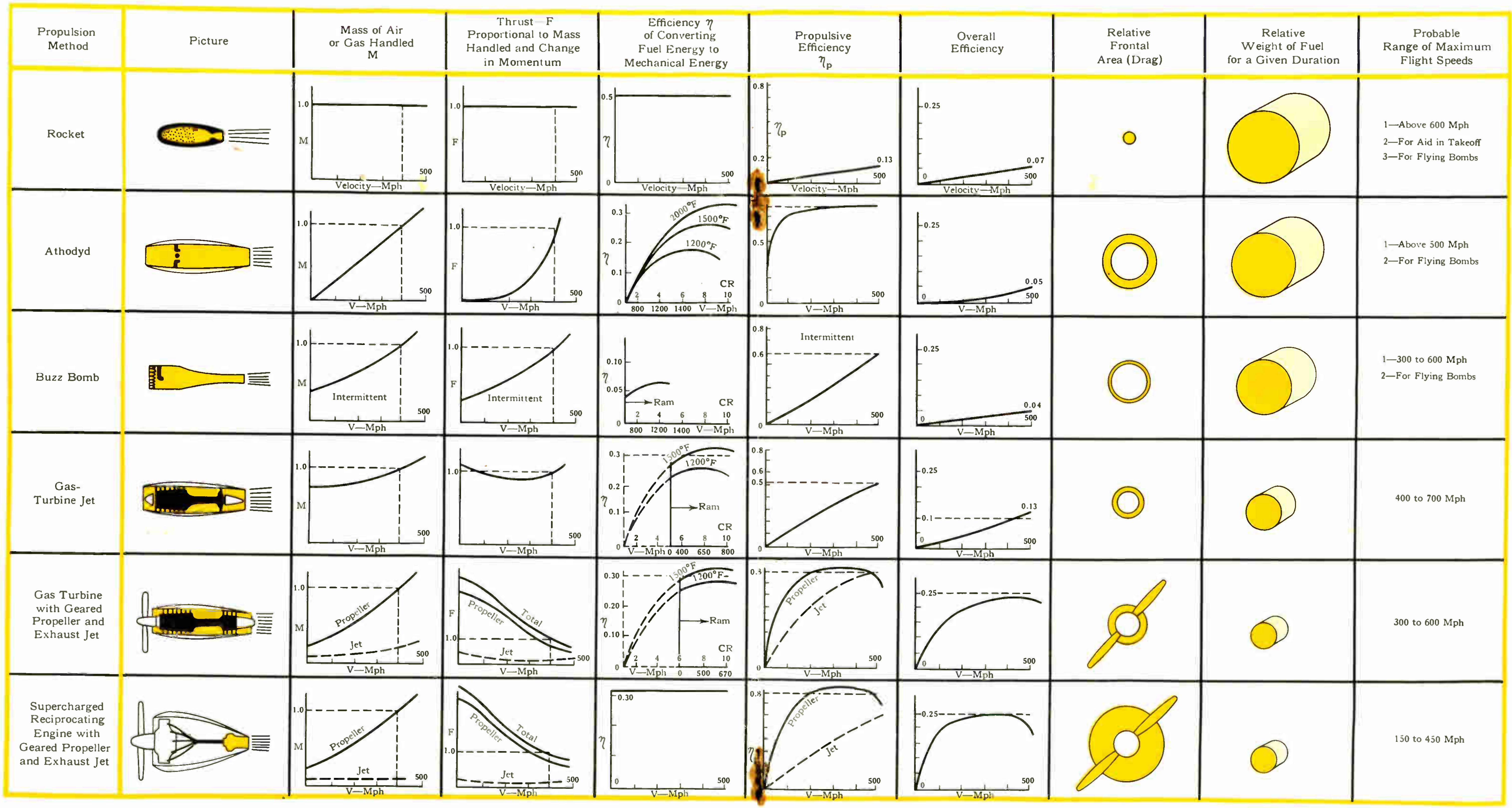
Ceramic dashpots have been found ideal for applications requiring constant damping, or nearly so, under all operating conditions. Made of high-alumina material (corundum), the ceramic dashpot is a rugged, stable instrument impervious to the high and low temperatures normally encountered. There is no deterioration or corrosion of the ceramic components which are nonhygroscopic and self-lubricating. Mass production of the cylinders and pistons with accuracies less than 0.003 inch on each piece is now an accomplished fact.

An important advantage of the ceramic dashpot is its relative freedom from trouble. With the metal or plastic dashpots, should a foreign particle get between the walls of the pistons and the cylinder, not only is a gouge made into the surface but there is also a ridge of metal thrown up about the gouge. This galling is therefore a permanent source of friction, even though the particle causing it is crushed, imbedded in the walls, or works itself out from between the two walls. This is not true of the ceramic dashpot. A particle may cause a gouge in the surfaces of the cylinder or piston, but the ceramic material is not plastic and will not flow. The material gouged out is powdered and about the edge of the gouge no ridge is formed. The only result of scoring one or both walls is a small surface groove that does not affect the precision fit.

Because it can be ground to such close tolerances, and the material is dimensionally stable, ceramic dashpots hold their adjustment and provide damping of the constancy demanded by precise controls such as the Silverstat shown in Fig. 1. The success of this control depends on the maintenance of a constant rate of speed in making or breaking sequential electrical contacts in the multi-contact assembly seen below the dashpot. Obviously, a sudden movement without the snubbing or damping effect of the dashpot would close all the contacts simultaneously. By setting the size of the orifice in the valve that bleeds air into or out of the cylinder, the rate of opening or closing the Silverstat contacts can be established. The dashpot shown in Fig. 2 is about three quarters inch in diameter and one inch long. There appears to be no fundamental reason why the ceramic dashpot should be limited as to size.

**Fig. 2—The simplicity and ruggedness of the ceramic dashpot construction is shown in this cross section. The needle valve controlling rate of flow of air into the cylinder is at the top.**

*Prepared by I. F. Nutting, based on information supplied by B. O. Austin, Aviation Control Section.




**A COMPARISON OF THE PRESENT SUCCESSFUL FORMS OF JET-PROPULSION AND RECIPROCATING ENGINES.**

B—Airstream engines, which get oxygen from the air.

1—The intermittent-firing duct engine.

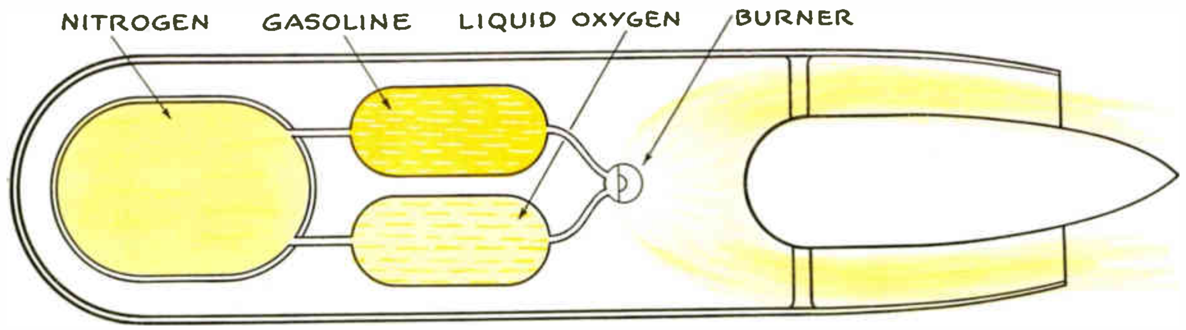
2—The continuous-firing duct engine.

3—The gas-turbine engine.

Along with these we must consider the combination gas-turbine propeller drive and the reciprocating-engine propeller drive.

The fundamental difference between the two basic types is the source of the oxygen. Rocket motors are independent of the atmosphere; the airstream engines are not. All, without exception, work on the reaction principle. All but the conventional reciprocating engine are jet-propulsion engines. While gas-turbine and reciprocating-engine propeller drives are not jet-propulsion engines, their propellers serve the same purpose as a jet, i.e., they accelerate rearwardly a mass of air to generate a thrust. Although some propulsive effect is obtained from the exhaust of a reciprocating engine, it cannot properly be included in a listing of jet-propulsion engines.

From a theoretical point of view, it matters not what the ejected mass is: solid, liquid, or gas. Only the rate of mass ejection and the increase of its velocity counts. The material could be sand, or—as in the case of a squid—water. In the several hundred years of rocket experimentation many materials have been tried. However, the only practical substances now known are gaseous products of combustion. Their mass is comprised of the weight of the oxygen, the fuel, and any inert gases. By the nature of their production they can be ejected at high velocity. In short, all propulsion devices can




The rocket motor differs from airstream engines in that it carries its own oxygen supply, either in liquid form, as shown here, or mixed chemically in solid form with some solid fuel such as cordite or gunpowder.

be considered to consist of a heat engine that converts the fuel energy into mechanical energy, together with a device for converting this energy into a rearward jet. The rocket converts its energy into a rearward jet by expansion in a nozzle. The reciprocating engine uses the familiar propeller to effect a rearward velocity.

*The solid-fuel rocket motor* is the oldest and best known operating on the jet-propulsion principle. History records that rockets constituted a "secret weapon" against Ogdai, son of Ghengis Khan, in his attack on the Tartar city of Kai-feng in 1232 A.D. Except for a few experimenters who had the courage to face the hazards of rocketry and the ridicule of the citizenry, rockets have been considered to be of little practical value other than for fireworks' demonstrations.

A skyrocket chassis consists essentially of a paper cylinder with a cone-shaped nose to decrease air resistance and a trailing stick to give it some stability and guidance in flight. In the fore part of the cylinder is the payload, which in the fireworks' rocket is usually a charge of powder that burns colorfully when ejected by the rocket. The main body of the skyrocket surrounding the combustion chamber is the mass of solid fuel and the oxidizer. At the rear is a crudely shaped nozzle to increase the efficiency of the jet. The fuel when ignited burns rapidly, the products of combustion being gases that are expelled through the downward projecting nozzle to produce the upward thrust.

Bazooka shells, anti-aircraft rockets, projectiles launched from airplanes, and the other items of rocket ordnance do not differ essentially from a skyrocket. They have a war head containing the explosive or what-have-you to be delivered to the enemy. The details of the fuel have not been disclosed but, instead of being gunpowder as in skyrockets it is a form of cordite, which is guncotton and nitroglycerine in stick or extruded form. Instead of a crude guiding stick, steel fins surround the nozzle at the rear to give directional stability.

The solid-fuel rocket has the important advantages of relative simplicity, comparative safety in handling, and ability to receive and store its fuel in advance. Against these merits are pronounced disadvantages. Control is lost once combustion starts. Also, the combustion chamber is a cavity in the fuel. At the start, the chamber is small and grows rapidly larger as fuel is consumed. For a given rocket only one size and shape of combustor gives maximum efficiency of combustion thrust. Hence, greatest efficiency of combustion is achieved at only one brief instant of the burning period. Greatest weakness of all is the much lower energies and jet velocities obtainable with solid fuels as compared to liquid fuels.

*The liquid-fuel rocket motor* avoids many of the limitations of the solid-fuel rockets. The motor that powers the Germans' V-2 is such. The fuel can be any of the common petroleum products such as ordinary gasoline (high-octane fuel is of no advantage, because the heat content of all gasolines, which is the important factor, is almost the same, being in no way dependent on detonation rating). Even kerosene, acetylene, alcohol, and liquid hydrogen are possibilities. The oxidizer is usually liquid oxygen (loxygen).

Combustion with liquid fuel is subject to control. Also the fuel and oxygen are brought together in a combustor of best and fixed dimensions, and provide high-velocity jets.

The liquid-fuel device has these several advantages over the solid-fuel variety, but imposes a family of headaches of its own. Liquid oxygen, boiling at −297 degrees F is a most fractious substance and entails special and expensive precautions in its handling if the accidents that fraught its early use are to be avoided. The extremely high temperatures of combustion have imposed the most rigorous of metallurgical problems on rocket experimenters.

The liquid-fuel motor, however, is yet young, and long strides in solving its problems have already been made. The obstacles to its development are tough but not insurmountable. Those vehicles intended for ascent beyond our atmosphere—such as the meteorological rocket of the future or that space ship to the moon or planet—will be liquid-fuel rockets, barring discovery of some new source of energy.

### Thermal-Jet Airstream Engines

The load any rocket motor must lift against gravity and drive against air resistance is, at each instant, the chassis, its parts, the payload, and the unburned fuel and oxidizing agent. The weight of fuel and oxidizer at the start of the flight comprise by far the greater part of the rocket weight. The amount of oxygen required for combustion always weighs much more than the fuel. With gasoline the weight ratio is three and a half to one; hydrogen, eight to one; acetylene, three to one. This is assuming the motor is using liquid oxygen. If the oxidizer is nitric acid or hydrogen peroxide, the weight is additionally increased by the elements compounded with it. In any case, the largest single component—largest by several times—of the rocket weight at take-off is oxygen or substances associated with it. Until the oxygen is consumed, it is so much dead load. The possibility of lightening the burden of the reaction motor by ridding it of its oxygen load is too attractive to ignore. If the reaction motor travels in the earth's atmosphere, the possibility of using the oxygen in the air is irresistible. This has led directly to the second class of reaction devices, the airstream engines.

The oxygen won't just flow in, of course. It must be pumped in—pumped in in vast quantities. The German V-1 is believed to consume about three gallons of gasoline per minute. To do this, the amount of oxygen needed for combustion is about 450 pounds, or at 5000 feet about 5000 cubic feet of air per minute. The two basic types of airstream engines differ in the means provided of getting this air to the combustor. Herein lies the connecting link between the jet-propulsion unit and the gas turbine.

*The intermittent-firing duct engine* is not new. Its principle has been described in the literature and in patents for many years, but it appeared in no practical form until the Germans succeeded in making it work with hellish success in their V-1, the first rocket bomb to strike England.

Air is forced into the combustor by ram effect. In the front end of the motor is a grill, each opening covered by a shutter



# The Day Dawns for Jet Propulsion

**The work of rocket experimenters is now taken more soberly; rocket guns and jet-propulsion cars of the comic strips don't seem as fantastic as they once did. Jet propulsion is a practical thing, unfortunately now used for destruction. But the bazooka, buzz bomb, jet-aided take-offs, and jet-propelled planes reduce to a single engineering principle of vast significance for constructive uses. It is the principle of reaction, described by Newton's third law of motion.**

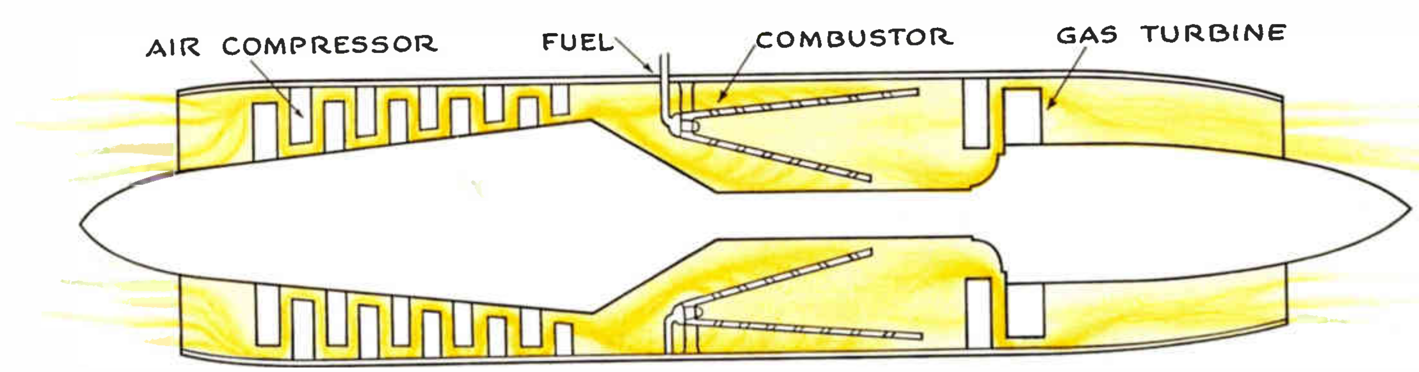
It has taken a war to make us realize that rockets are something more than a fourth-of-July toy. The heartening stories of Allied successes with the bazooka and the thrilling accounts of the anti-aircraft rocket defenses of Moscow made us recognize that rockets are major implements of warfare. Any lingering doubts we may have entertained about the engineering possibilities of the rocket specifically and jet propulsion in general were permanently dispelled by the news of what robot bombs did to London.

The curtain of military secrecy around rockets and jet-propulsion devices only now and then reveals a glimpse of some of the accomplishments of these amazing devices. Some hint, however, of their magnitude even now is indicated by the U. S. Navy's use of $100 000 000 worth of rockets per month by midsummer of 1944. Correspondingly large quantities are undoubtedly being used by the other military services. The newspapers have carried stories, in addition to those about the German's V-1 and V-2, of rocket-propelled shells in several forms, of rocket-assisted take-offs for airplanes, of jet-propelled planes, jet-assisted gliders, of our own robot bombs, and other vehicles and weapons of war.

A host of new terms is abroad upon the land—rockets, buzz bombs, robot bombs, athodyd (pronounced *ath-o-did*), jet propulsion, gas turbines! They have appeared in the public prints so suddenly that what they mean and whether they have a common engineering basis are not too clear.

Their bases are related. These devices are as solidly grounded in engineering as are other heat engines—for such they are. A common principle provides the basis of operation of all propulsion methods—the rocket motor, the athodyd, the buzz bomb, and gas-turbine jet, the combination gas-turbine jet and propeller drive, and, for that matter, the conventional propeller-driven plane. That principle is the third law of motion, expressed by Newton, to the effect that action and reaction are equal in amount but opposite in direction. A more formal way of stating this underlying law is that the net force on a body is proportional to the time rate of change of momentum caused by the body. This means that the propulsive thrust is proportional to the product of the mass of material ejected from the vehicle in a given time and the amount its velocity has been increased with respect to the vehicle. Clearly—and this is important—a given thrust forward can be produced either by ejecting rearward at low velocity a large amount of material in a certain time as does the propeller or a smaller amount of material in this interval but at higher velocity, as does the rocket.

This basic relationship also indicates that nothing is required for the jet to push against. In fact any material outside the jet orifice simply gets in the way of the ejected matter and somewhat reduces the forward thrust. Rockets, for example, produce the maximum thrust in a vacuum. So would any other reaction device were it not for its need of oxygen.




The gas-turbine jet-propulsion unit is essentially simple in construction.

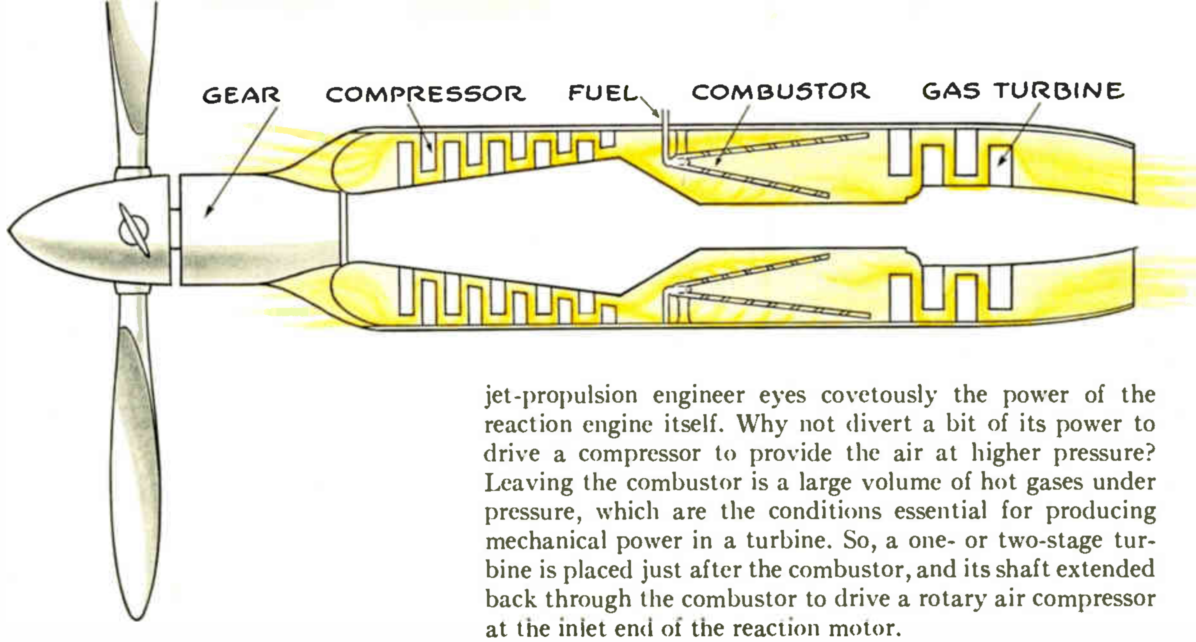
### Types of Reaction Machines and How They Work

The variations in construction, operation, and fuels of reaction motors attempted by rocket enthusiasts and jet-propulsion experimenters in the past several hundred years are numerous. The present known successful ones reduce to two basic types of jet engines. These are:

A—The self-contained or true rocket motors, which carry both the oxygen and the fuel.

1—Dry fuel, 2—Liquid fuel

*This discussion has been prepared by C. A. Scarlott from information supplied by G. Edward Pendray, C. A. Meyer, and A. H. Redding, all of whom are with Westinghouse Electric and Manufacturing Company. Mr. Pendray, Assistant to President of Westinghouse, has long been associated with the development of rockets and jet propulsion, and is Secretary of the American Rocket Society. Messrs. Meyer and Redding are heads of engineering sections in the Steam Division. Much useful information also was obtained from the manuscript of "The Coming Age of Rocket Power," a book by Mr. Pendray that is to be published in April by Harper and Brothers of New York.




**The combination power unit consisting of a gas-turbine driven propeller and some jet effect offers attractive possibilities for some aircraft applications. The propeller is more efficient at the lower speeds while the jet is more effective at higher speeds.**

that opens inwardly against a spring pressure. When the machine is launched—and it must be brought to a speed before it develops sufficient thrust for flight—the shutters are forced open by the pressure of the air. Fuel is injected continuously into the inrushing air in the combustion chamber and the mixture ignited initially by an electric spark. As the pressure builds up by combustion, the shutters are forced shut. The combustion gases are ejected through a suitable tube and nozzle at the rear, which creates a suction at the completion of combustion, causing the shutters to reopen and the cycle to be repeated.

This series of events occurs with great rapidity. In the V-1, firing occurs 40 times per second, which is established by the natural period of resonance for the 13-foot tube. The intermittent firing, of course, means the thrust is not constant. This is the reason for the sound that characterized the V-1 and led to such terms as "buzz" bomb. The efficiency, no doubt, is low. But the Germans have succeeded in making this type of motor work at 250 to 400 miles per hour. It has previously been considered that the principle would not be successful much under the speed of sound (about 765 mph), which would be an almost impossible launching velocity, but the exhaust-pipe tuning has partially eliminated this weakness at low speeds.

*The continuous-firing duct engine* is relatively little known but is credited to Lorin of France in 1913. It has been under development principally in England under the curious name of "athodyd" (from Aero-THermO-DYnamic Duct). It looks something like a slightly elongated barrel with both heads knocked out. Gasoline is fed through a ring of small orifices ahead of the middle of the duct. The air entering at the front is expanded and speeded on its way by the combustion of the fuel. The increased velocity, induced by combustion, provides sufficient jet reaction to keep the device up to speed and produce power for the aircraft to which it is attached. The athodyd is appealingly simple, but the extent of its possibilities is not yet known.

*The gas-turbine jet engine.* The duct engine is ingenious. It is amazingly simple. It succeeds in gulping large volumes of air for combustion without rotating parts. The jet-propulsion engineer, however, is still not wholly satisfied. He would like to improve the heat-engine efficiency by increasing the combustion pressure. This could be achieved by using a separate compressor driven by, perhaps, a conventional reciprocating engine. The Italians did just that with the Campini plane that made the first publicly announced flights with a jet-propulsion plane in August 1940. However, this scheme introduced obvious and undesirable weight problems. So the jet-propulsion engineer eyes covetously the power of the reaction engine itself. Why not divert a bit of its power to drive a compressor to provide the air at higher pressure? Leaving the combustor is a large volume of hot gases under pressure, which are the conditions essential for producing mechanical power in a turbine. So, a one- or two-stage turbine is placed just after the combustor, and its shaft extended back through the combustor to drive a rotary air compressor at the inlet end of the reaction motor.

The turbine absorbs only a portion of the jet energy. The unused portion of that energy remains in the exhaust gases of the turbine. These are ejected to the rear to develop a thrust diminished only by the amount of energy absorbed by the turbine. The jet-propulsion engineer has, in short, combined an open-cycle gas-turbine* with the reaction engine.

There is no essential difference between this gas turbine and those used as prime movers in stationary service. The difference is in the relative amount of mechanical energy produced from the combustion gases. In the jet-propulsion unit the turbine absorbs just enough energy to drive the air compressor. In a gas turbine for driving an electric generator, the turbine must not only drive its air compressor but also deliver as much mechanical energy as possible to an electric generator or other machine. In the open-cycle gas turbine for stationary service whatever energy remains in the exhaust gases is thrown away. The energy level of exhaust gases should be as low energy as practical. The turbine in the jet-propulsion unit has one or two rows of blades; the conventional gas turbine has several.

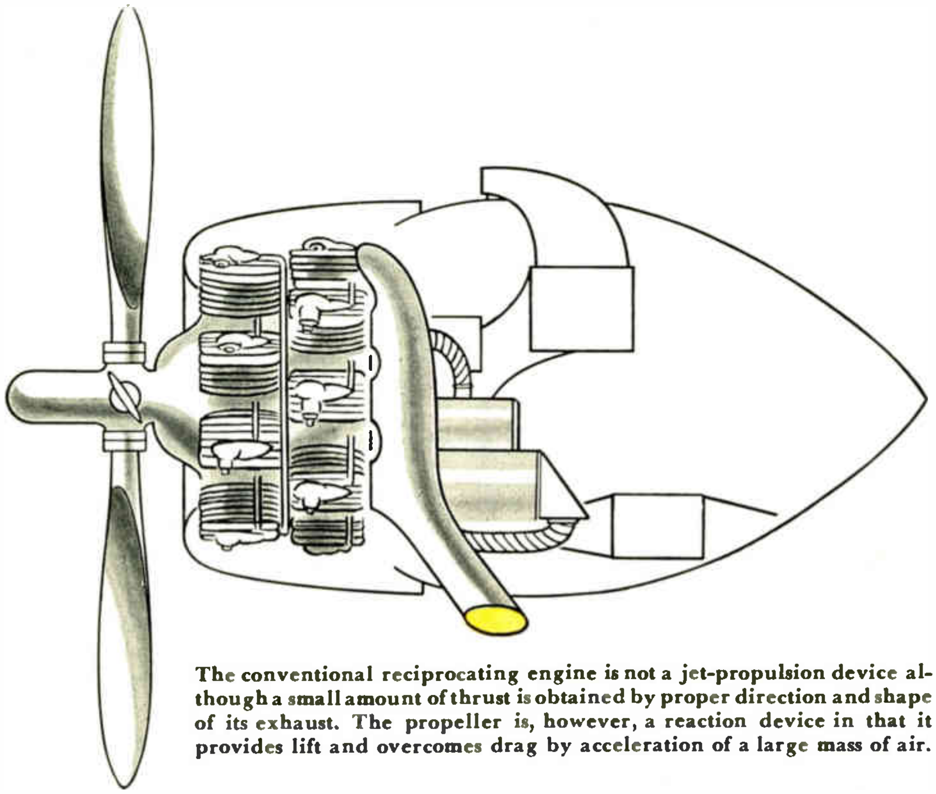
### Jet-Propulsion Engine Performance Compared

The performances of the several forms of propulsion units are compared in the accompanying table for speeds up to 500 mph. This limitation is chosen only because of the difficulty at present of reducing the performance of some of these devices to curve form for much higher speeds. The devices listed are not necessarily competitive in the range of speeds up to 500 mph. Some of them, such as the rocket motor, become real performers only at speeds that are above the upper limits for propeller-driven craft. The curves do show, however, the factors bearing on their relative performance.

*Thrust.* Reaction engines must be compared on the basis of thrust, not horsepower. Horsepower is meaningless when dealing with reaction devices, which develop an essentially constant thrust regardless of speed. To translate this to horsepower requires the additional factors of distance and time, i.e., speed. At zero speed, although a reaction machine may deliver a high thrust, the horsepower (and efficiency) is zero. As a rough translation figure, one pound thrust at 375 mph is equivalent to one horsepower.

The magnitude of the thrust depends on the rate at which mass is ejected and the increase in velocity given to it. With rocket motors this velocity increase is the jet velocity; with airstream engines it is the difference between the jet velocity

*A description of the gas turbine in its several forms is given in some detail in an article in the *Westinghouse* ENGINEER for May 1944 p. 78, "The Gas Turbine—Harness for Hot Air," by Fischer and Meyer.



The conventional reciprocating engine is not a jet-propulsion device although a small amount of thrust is obtained by proper direction and shape of its exhaust. The propeller is, however, a reaction device in that it provides lift and overcomes drag by acceleration of a large mass of air.

and the velocity of the incoming air. In a rocket motor the rate of fuel burning and the jet velocity are approximately constant for all speeds. This factor is fixed by design. Hence rocket-motor thrust is substantially constant at all flight speeds. This is true for either the solid- or liquid-fuel type.

Because the weight of fuel and oxygen a rocket can carry is definitely limited, a high thrust can be developed only by production of a high jet velocity. This is why rocket designers seek to use fuels that have the maximum energy release (i.e., as high a temperature as possible) for their weight. Also it is the main reason for liquid-fuel rocket motors.

The continuous-firing duct engine or athodyd obtains its thrust by handling more mass. This mass of air accelerated by an athodyd is large compared to the mass of fuel and oxygen burned. In considering the performance of any air-stream engine, it must be remembered that the mass handled is not just the small amount of fuel and the larger amount of oxygen consumed but also the still larger weight of inert gases—mostly nitrogen and carbon dioxide—present in the air along with the oxygen.

The thrust of an athodyd varies considerably with flight speed for three reasons. The mass of air handled varies directly with flight speed. Also the efficiency of converting fuel energy into jet energy depends on the compression ratio, which in turn depends on flight speed. Finally the thrust depends on the increase in momentum, which is proportional to the difference between jet velocity and the flight velocity.

The intermittent-firing duct engine or buzz bomb is able to develop some thrust at zero speed because its construction enables it to swallow some air even at standstill. Otherwise its thrust characteristic and that of the athodyd are similar and for the same reasons.

Thrust of the gas-turbine jet engine is nearly constant with flight speed. This is because the air flow (mass) increases with speed while the amount of acceleration of the air swallowed decreases as the difference between jet velocity and flight speed decreases. The product of the two factors, one decreasing, the other increasing with flight speed, results in a thrust curve shaped as shown in the table.

Because of the propeller characteristics of the combination gas-turbine with geared propeller and exhaust jet, the thrust falls off steadily as speeds increase. As speeds ot the propeller tips approach sonic velocity the propeller becomes inefficient.

*Thermal Efficiency*—The efficiency of converting fuel energy into mechanical energy (i.e., thermal efficiency) is generally dependent on the maximum temperature and pressure during combustion.

The rocket motor having no highly stressed moving parts permits operation at high temperatures and pressures and thus has a high efficiency of conversion. The athodyd, however, is limited in maximum pressure because the compression is obtained by the "ram effect" of its swift passage through the air. At standstill the athodyd has no compression (no ram) and therefore is inoperative. Further, the compression ratio for optimum conversion of fuel energy to mechanical energy for the athodyd is about eight, whereas even with a flight speed of 1200 mph it is possible to obtain from the ram effect a compression ratio of only about four. Thus large thrusts can be obtained with the athodyd only at high flight speeds.

The athodyd becomes attractive at speeds higher than 500 mph as does the rocket. This is because the cycle requires a high compression ratio for efficient operation. Also, inasmuch as the mass swallowed increases with the flight speed it is possible to burn more fuel for a given top temperature. The increases in air flow and compression ratio result in an increased heat-engine output. This energy output is applied to the incoming air as an increase in its energy in a rearward direction. The thrust is proportional to the difference in jet velocity and the flight velocity. Actually the air flow does not increase indefinitely with flight speed because of compression shocks, etc., at the inlet at (and above) the velocity of sound.

At high speeds the buzz bomb improves in engine efficiency because the ram effect increases the compression ratio. Finally a speed is reached where the inlet grill begins to suffer due to approach of the velocity of sound. Probably 600 mph is a practical upper limit of this device, set by the effect of high velocities on the drag and operation of the inlet grill.

The gas-turbine jet corrects this disadvantage resulting from lack of sufficient compression by employing a compressor and a driving turbine so that even at standstill the compression ratio is approximately four or five, according to the design. Also the combustion pressure (or the compression ratio) of the gas-turbine jet is further augmented by the ram at flight speed. The air flow through the gas-turbine jet varies with flight speed as shown in the table under the column for mass handled. Even at standstill the air flow is large as compared to no flow for the athodyd.

The gas-turbine jet having a highly stressed turbine rotor cannot operate with as high a combustion temperature as the athodyd. The gas-turbine jet thus gains over the athodyd by operating with a greater combustion pressure at low flight speeds and loses by having to operate at a lower combustion temperature limited by the stressed parts.

The buzz bomb obtains high combustion pressures at low flight speeds by means of intermittent combustion. The gas-turbine thermal efficiency is dependent on the compression ratio (which is increased with ram). The reciprocating engine has a "designed-in" compression ratio, due to its piston compression ratio. The increased ram effect does not alter the efficiency of the conventional engine because the manifold pressure is the feature limiting engine operation so that the engine cannot avail itself of the increased ram. Reciprocating-engine efficiency is therefore high and constant with flight speed because of the high temperatures and pressures allowed by its intermittent operation. The intermittent operation, however, limits the maximum capacity for which an engine can be built. In other words, the reciprocating engine can swallow air in pistonfuls whereas the gas turbine swallows air equivalent to the inlet diameter and air velocity. Further the piston engine must be cooled, which introduces a drag much greater than present with the gas turbine.

*Propulsive Efficiency*—With jet-propelled devices thermal efficiency tells only part of the story. Equally important is how much of the mechanical energy produced from the chemical energy can be employed to drive the craft. In other words, how good is its propulsive efficiency? Bear in mind that overall efficiency is the product of thermal efficiency and propulsive efficiency.

At zero speed, all the energy produced by a rocket motor is in the jet. At speeds between zero and the jet velocity the energy is divided between the rocket and its wake. The energy in the wake is proportional to the square of the wake velocity. Rocket-motor jet velocities are high (to obtain high thrust), being at least 3000 feet per second (about 1500 mph). Hence rocket-motor propulsive efficiencies below 500 mph are poor; again showing the field of the rocket to be at high speeds. When the rocket reaches jet velocity, i.e., the jet particles in the wake are moving at zero speed with respect to the earth, all of the mechanical energy is going into propelling the craft (and none, so to speak, in propelling the ejected matter). Propulsive efficiency is then 100 percent. If, when the speed of the rocket reaches the velocity of its jet, additional mechanical energy is produced, the rocket will exceed the speed of its jet. In other words, some of the mechanical energy is again going into the jet (now moving in the forward direction with respect to the earth) so the actual propulsive efficiency again begins to fall, but not at a rapid rate.

Because a given thrust can be provided either by handling mass at a high rate but at low velocity or a smaller mass at lower rate but higher velocity, air-stream engines do not depend on as high jet velocities as do rocket motors. To keep the jet velocities low, i.e., to decrease the losses in the wake, large masses of air in excess of that required for combustion pass through the gas-turbine jet. This provides the large mass at low velocity required for a given thrust.

The athodyd, because of its relatively low jet velocity, has a high propulsive efficiency. However, its overall efficiency is low as a result of the poor conversion of the fuel energy particularly at low flight speeds where low compression of the incoming air is obtained.

The buzz bomb has a fairly decent propulsive efficiency as a consequence of its relatively low jet velocity. The overall efficiency is low as a consequence of poor thermal efficiency.

The gas-turbine jet, being of higher velocity than the athodyd, or buzz bomb, has a somewhat lower propulsive efficiency. The better combination of fuel conversion efficiency and wake (or propulsion) efficiency of the gas turbine gives it a higher overall efficiency at subsonic velocities than the rocket motor, athodyd, or buzz bomb.

The gas-turbine propeller drive, with the larger mass handled by its propeller, permits a smaller increase in velocity for a given thrust. The propulsive efficiency of the propeller at low speeds is therefore high. The propulsive efficiency of the jet is dependent on jet velocity selected for the design. The efficiency of converting fuel energy into mechanical energy for the propeller drive is high due to the favorable compression ratio obtained by the compressor. The ram effect improves this efficiency similar to the manner of the athodyd, buzz bomb, and gas-turbine jet. The propeller, by providing a large mass flow, has high thrust at standstill. The propeller-drive, gas-turbine combination has the disadvantage as does the gas-turbine jet of being limited in top temperature by its stressed rotating parts.

The supercharged reciprocating engine has a high fuel-conversion efficiency and a high propulsive efficiency. The compression ratio of the reciprocating engine is a matter of cylinder design and is practically unaffected by flight speed. Its intermittent combustion permits the reciprocating engine to operate at high temperatures and pressures and thus obtains a high efficiency of conversion of fuel energy to mechanical energy. The reciprocating engine, however, is limited, by cooling requirements, to horsepower capacities smaller than can be built in the gas-turbine propeller drive.

Factors other than efficiency bear on the overall performance of flight engines. Inasmuch as the frontal area is related to the "nacelle drag" the relative frontal area is an important factor in selecting any of the devices for a given application. The relative fuel weights for a given flight duration are important because for long-distance flights the weight of fuel carried becomes an important factor compared to the weight of the device itself.

Altitude, i.e., air density, has important bearing on performance of jet-propulsion engines. All air flows diminish with altitude. The rocket motor, being independent of the air for its oxygen, would do best in a vacuum or at extremely high altitudes. This is both because air resistance is less and because the back pressure is less. The lower ambient temperatures improve to a varying extent the efficiency of all air-stream engines and reciprocating engines. The supercharged engine is less affected by altitude because the air pressure at the cylinders is maintained, but the compressor still must suck in air at the reduced pressure as does the gas turbine. In other words the gas turbine is essentially all supercharger and exhaust gas turbine with no cylinders, pistons, valves, and other rotating parts in between. Increasing altitude also hampers the propeller-driven plane because the sonic velocity—a limit to propeller efficiency—decreases significantly. Obviously, of course, all devices benefit from decreasing air density to the extent that air resistance decreases.

## Tomorrow

Judgment of the engineering worth of the new reaction machines demands a long range, broad point of view. It is not too much to call these devices revolutionary. Placed in engineers' hands is a fundamentally new type of engine, different in principle, different in performance than those to which he has been accustomed. Any thought that jet-propulsion engines are to be considered solely as competing with conventional engines in our present fields of aerial transportation is both narrow and erroneous.

By that we do not infer that trips to the moon are imminent —although it is equally foolish to rule this out as an eventuality. We mean things not so distant. Of these at best we can only suggest a few. Obvious, of course, are the military applications both for jet-driven projectiles and for high-speed aircraft. Gas-turbine jet units even now appear attractive for high-speed commercial aircraft. Then there are others more remote, such as the meteorological rocket, robot rocket mail and express. The implement is at hand for again pushing back the limits of aerial transportation.

# What's New!

## Electronic X-ray Timer

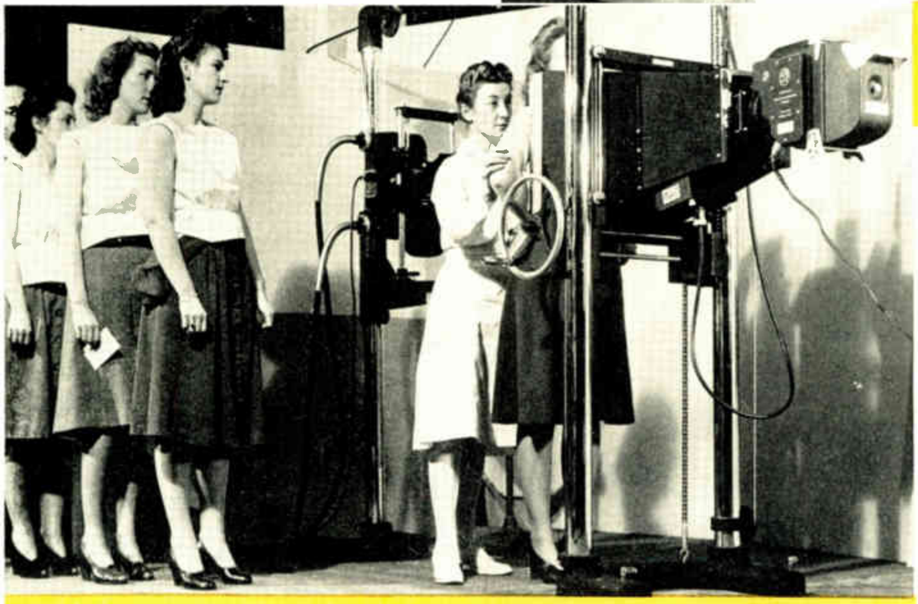
To take an x-ray image or picture the operator must consider several variables. For a chest picture these include the thickness and structure of the patient's chest, sex, amount of voltage to apply to the x-ray tube, the amount of current to discharge through the tube, and the length of the exposure. At best, estimations of these variables are only approximate. Long training is needed for x-ray technicians to acquire the judgment and experience to enable them to produce exposures of proper density.

An electronic mechanism has been devised by Dr. Russell Morgan which times these x-ray exposures. The machine weighs all factors and produces negatives of uniform density regardless of differences in patients. It also makes computations while the exposure is actually in progress although this period may be as short as one-tenth of a second and if for any reason the correct exposure is not made, it sounds a warning bell so that the x-ray can be retaken immediately before the patient leaves.

With the phototimer a single crew of x-ray technicians can examine the chests of a thousand people a day, double the number previously possible. These mass x-ray examinations are made possible by miniature fluorography. Small-film photographs are taken of full-scale images created on a fluoroscopic screen by the action of x-rays. Uniform film negatives on which reliable diagnosis rests are insured by the automatic exposure control of the electronic phototimer.

The timer consists essentially of a photoelectric cell to measure the light emanating from the fluoroscopic screen, a capacitor to store the electric current which flows in the tube as a result of this light, and an electronic type "trigger tube" to shut off the x-ray tube.

Using this new device, the operator is required only to position the patient before a fluoroscopic screen, make an approximate voltage setting . . . high, low, or medium . . . and turn on the x-ray tube. This creates a "shadow picture" which is photographed by a motor-driven miniature camera, having a fast lens focused on the reverse side of the screen. Also aimed at this screen is the phototimer, which integrates the amount of light coming from the x-radiations that have penetrated the body of the patient, and stops the exposure at the right time.



**The small black box on the underside of the wedge-shaped screen hood times the x-ray exposure to assure prints of proper density. Removing the human element from the timing enables technicians to make a thousand negatives a day in x-ray surveys that are a vital part of the growing program for combating tuberculosis.**

## Joint Effort Produces Material for Navy

The Navy called upon Westinghouse and a group of companies to evolve, and quickly, a panelboard material of high strength, good electrical properties, and suitable physical properties with the additional provisos that the material must not support combustion or give off toxic fumes. To expedite the development, available materials were utilized. These materials were then adapted to established manufacturing processes. The result was a panelboard fulfilling the requirements for specialized Navy maritime applications.

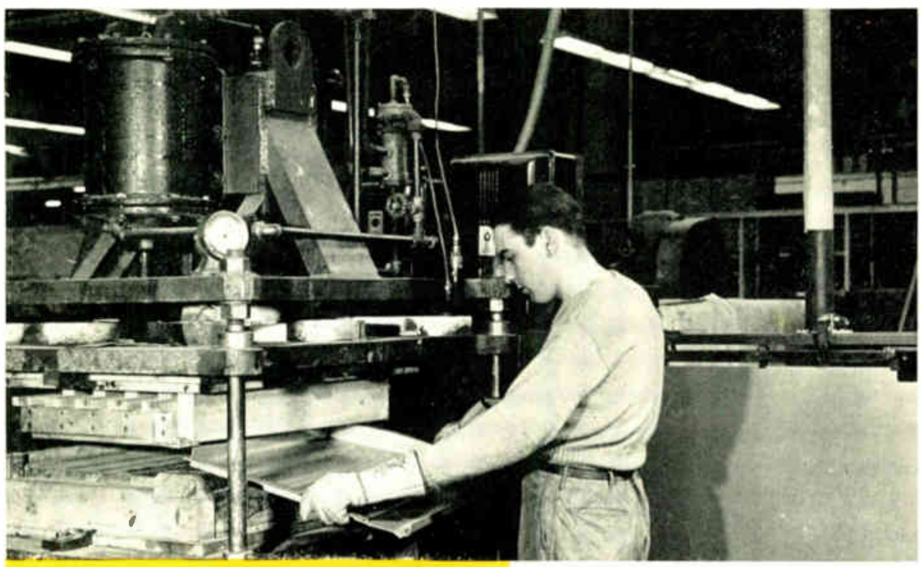
**The melamine impregnated glass cloth panelboards emerge in dazzling white sheets from the ponderous forming presses.**

The required board is of laminated construction. The filler is of glass cloth, itself inorganic and noncombustible. The binder is melamine formaldehyde, a thermosetting resin that does not support combustion and, when exposed to high heat or open flame, gives off no toxic fumes. Electrically and physically, the board is sound. By adapting the fabrication of this board to manufacturing equipment already established, facilities are insured to supply the current needs of the Navy.

## Hot-Forming of Phenolic Laminates

Spurred by the ever-pressing need for lighter aircraft sections and parts, a means has been developed whereby Micarta, a phenolic laminate, can now be post-formed into pieces having complex contours. Used in aircraft for nonstructural and semistructural members, a weight saving of some 50 percent over a comparable volume of metal has been achieved. In addition, a considerable saving in man-hours of labor has been made, together with a great reduction in cost.

In general, phenolic laminates are classed as thermosetting, i.e., as a result of pressure and heat, a nonreversible polymerization of the resin takes place. Thus solidified, the ordinary thermosetting laminates do not lend themselves to further working. By modification, the character of the resin in standard Micarta was changed. At elevated temperatures, the new forming grade (#444) of Micarta is capable of being formed in deep-drawn and involved shapes. Unlike many thermoplastic materials it is not embrittled at ordinary room temperatures.



Hot-forming the new #444 Micarta is accomplished with inexpensive dies and using low molding pressures and temperatures.

The great cost of laminated plastic parts had previously prohibited their use. Expensive and time-consuming dies were necessary to hot-form and cure the parts from the semiplastic "B" stage to the completely polymerized "C" stage. Deep-drawn aluminum was quicker and cheaper.

Post-formed Micarta requires no expensive dies. Pressures involved are from 10 to 100 pounds per square inch. Dies are made of hardwood or thermosetting laminates. This makes the manufacture of a relatively small number of parts from a single die economical as the cost of these parts is not loaded with the distributed cost of an expensive forming die of metal.

In one particular operation, a single sheet of formed Micarta replaced a plane part fabricated of four separate pieces of aluminum. The aluminum sections were welded together. Forty inches of weld were saved which contributed to the one and one-fourth man-hours required for the aluminum part. The formed Micarta part, a cheaper material, requires 19 minutes to produce and weighs but half as much. These savings are indicative of the possibilities afforded in applications where high impact strength and good thermal stability are required.

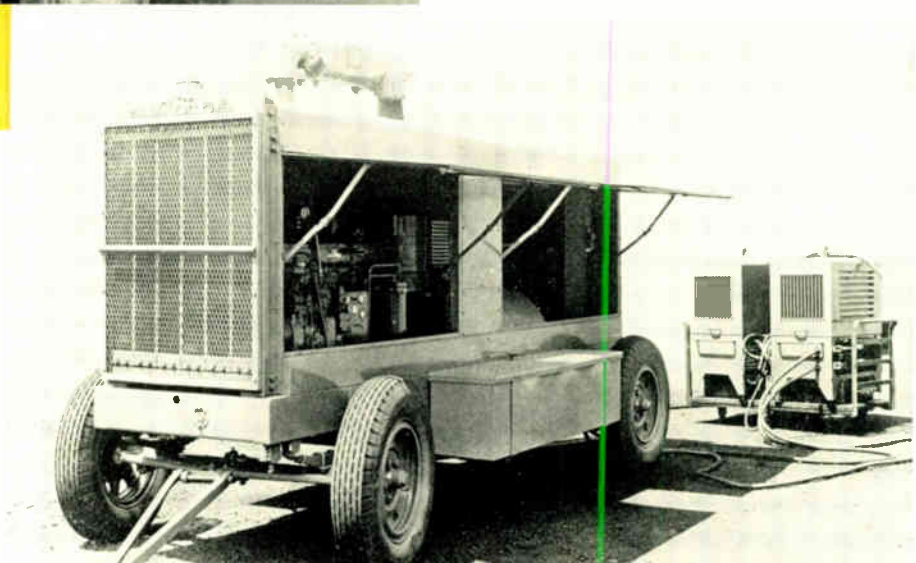
## Fluorescent Commercial Luminaires

Fluorescent luminaires for essential wartime applications have been approved by the War Production Board. Two new Westinghouse luminaires, which meet the requirements for conserving strategic materials, provide the quality of light necessary in offices and drafting rooms and similar applications.

The design of one luminaire that uses four 40-watt fluorescent lamps is such that by a simple change of accessories it can be installed as a ceiling or suspension-mounted unit. Using twin-stem hangers, the luminaire is of the semi-indirect type. The glass panels in the bottom are clear ribbed glass and the side panels are single-piece diffusing glass. The luminaires can be mounted against the ceiling with ceiling-mounting brackets. These luminaires can be joined end to end to provide continuous-strip lighting either as surface- or suspension-mounted units. Such continuous-strip lighting provides high-intensity, glare-free lighting for drafting rooms.

Another style of semi-indirect luminaire, using two 40-watt fluorescent lamps, is also so constructed that it can be ceiling or suspension mounted and used either as an individual unit or for continuous-strip lighting. The diffusing, ribbed glass body is vee shaped.

Ample wire ways are provided in these two new luminaire styles for easy strip-lighting assembly. A special ballast is enclosed in a streamlined case to conform with the modern design of the luminaire. Ballasts are removable without disturbing other parts when used as surface-mounted ceiling units. The ballast operates at high power factor (95 to 99 percent) and cyclic flicker is reduced to a minimum. The supporting members, ballast case and wire-way channel, are finished in a light gray enamel. The luminaire finish is baked-on white enamel.



For arc-welding needs, where electric power is not available, a Diesel-powered generator provides 1500 amperes at 60 volts. The 135-hp, 1600-rpm, six-cylinder supercharged Diesel engine, together with the Westinghouse generator and control, is mounted in a trailer. Assembled by the Cummins Diesel Engine Company of New England, the trailer provides welding current in remote areas of shipyards.

# Corrosion Ratings for Metals and Alloys

**Weather forecasting and corrosion prediction have much in common. Neither can yet be done with high accuracy because both are fraught with so many interrelated and often unknown variables. In each field, experts have been steadily making headway; accurate predictions may not always remain outside scientific boundaries. Engineers of several organizations* have pooled their experience with many commonly used metals and alloys. The resulting tables, although not absolute, can serve as guides for selecting the material most resistant to atmospheres (outdoor or industrial) or to sea water, paying particular attention to restrict their use to specific conditions.**

H. D. Holler
*Research Engineer*
R. A. Frye
*Materials Engineer*
*Westinghouse Electric & Mfg. Co.*

In building any structure, all known factors affecting its useful life must be considered and allowance made for unforeseen circumstances. Thus, in product design the size and shape of the parts are computed from the existing data on the properties of materials, allowing a safety factor to provide for uncertainties in the reliability of the data and abnormal conditions of use, such as overloading, accidents, and abuse. The physical properties of most materials are well known. For example, mechanical, electrical, magnetic, and thermal constants are tabulated in many available places.

In the field of corrosion, however, little use can be made of mathematically precise equations. In fact, a knowledge of chemistry without a background of actual corrosion experience could be dangerous because rules of general chemistry are not followed. When predicting the probable corrosion resistance of a metal or alloy, the influence of both physical and chemical factors must be considered. Even if someone were to develop an equation expressing rate of corrosion in terms of such factors, it would be of little practical use because of the impossibility of evaluating all factors. Changes in concentration and temperature of a chemical solution, for example, may increase or decrease the rate of corrosion in an unpredictable manner. Whether water is still or flowing, whether open sea or polluted harbor water, and the rate of flow are all factors to be considered in a corrosion problem involving these elements. Thermodynamics may indicate whether corrosion of a certain metal will occur but furnishes no hint of its rate. Slight differences in composition of seemingly identical pieces of copper or steel (no piece of metal is absolutely uniform) also affect the rate of corrosion.

### Pattern of Corrosion Attack Important

What is more important than rate in many cases is the pattern of attack. For example, the rate in terms of weight loss of metal per unit time may be low, but if this loss is concentrated at points or small areas, the damage may be many times greater than the rate would indicate. Thus, the pitting type of corrosion may cause a leak in a tank, or intergranular attack in a highly stressed airplane part may lead to destruction, though the actual loss of metal may be small.

Clearly, corrosion-resistance cannot be expressed in a simple manner like most other properties, such as electrical resistance or tensile strength. An attempt to assign values of corrosion-resistance to a metal for all possible combinations of conditions would result in an infinite number of such ratings. Such a program is, of course, impossible. It need not be dismissed entirely, however, if we are willing to restrict conditions. This is largely a matter of judgment. Because judgment is based on experience and desires, the specification of corrosion conditions and assignment of ratings of these conditions become a matter of opinion. Tabulated ratings of corrosion-resistance should be considered as the composite opinion of specialists.

The value of such ratings depends on a restriction of their use to the specified conditions. This means that the materials engineer must ascertain the conditions of use and determine for himself whether the tabulated ratings should be applied. Herein lies the danger in the use of such ratings, because it is frequently impossible to ascertain all conditions. If the available evidence indicates conditions of serious character, then the selection of material is not a clerical detail but a problem of chemical engineering.

An important simplification factor does exist in classification of corrosion data for use in the electrical industry—most electrical apparatus is not used in chemical solutions. When selecting a metal or alloy for use in a chemical solution the engineer should consult some source of firsthand experience, such as the supplier of the material, or the customer, and not attempt to obtain the answer from any table of corrosion ratings. This suggestion holds true to a considerable extent for exposure to water. Ratings in fresh water are not included here because all waters contain various amounts of dissolved substances, which make them essentially chemical solutions of widely different corrosive properties.

Sea-water ratings are listed because the problem of selecting materials for use in sea water frequently arises. The selection of materials for use in cooling systems involves so many factors affecting corrosion that only specialized experience should be relied upon.

Fortunately, most electrical equipment is used in the air. Atmospheres, as defined by ASTM, are of three general kinds: rural, industrial, and marine. The ratings in chemical atmospheres are predicated on an average humidity. Most dry atmospheres are not corrosive. In the case of condensation from humid gases, the problem of corrosion becomes one of chemical solutions and should be handled as such.

### Corrosion Ratings Are Comparable Irrespective of Material

Although the tabulated information comes from various sources, an attempt has been made to assign ratings that are comparative throughout the entire listing of materials. For example, a ferrous alloy rated *A* in a given atmosphere might be equivalent to a nonferrous one rated *A*, insofar as corrosion is concerned. *A* or *B* materials are ***probably safe*** to use; *C*

*Among the many companies cooperating in tabulation of this corrosion experience, special credit is due to the Aluminum Company of America, American Brass Company, and International Nickel Company.

It is intended that rating comparisons shown in tables I, II, and III be made only vertically. Generally useful conclusions can be reached, however, in horizontal comparisons if such comparisons are restricted to atmospheric conditions. It is important that a survey of all possible contaminations of the atmosphere be considered in conclusions drawn from horizontal comparisons. The following legend is applicable to the recommendation designations of the three tables.

### LEGEND

A—Practically complete resistance, or the alloy is the best of materials within its class.

B—Good resistance, as proven by being in common use. May replace materials given A rating to secure some other advantage.

C—Adequate resistance under favorable conditions which should be investigated beforehand.

D—Sufficient resistance if adequate precautions are taken to reduce effect of corrosive conditions, as by coatings, cathodic protection, re-design, etc., or where appearance is not important and appreciable corrosion may be provided for, or tolerated.

E—Poor resistance—use only if no better material is available.

Plus and minus signs are used to permit a better differentiation between the corrosion-resistant qualities.

### TABLE I—CORROSION RATINGS OF COMMERCIAL ALLOYS OF ALUMINUM AND MAGNESIUM

| Material | Alcoa Designation | Westinghouse Designation | General Outdoor Air | | | Sea Water† |
|---|---|---|---|---|---|---|
| | | | Rural | Urban | Marine | |
| **Aluminum and Aluminum Alloys** | | | | | | |
| 99% Al | 2S | 7601 | A | B | B | B |
| Al—Mn | 3S | 7602 | A | B | B | B |
| Al—Cu—Mg—Mn | 17S | 7603 | B | B | C | D |
| Al—Cu—Mn—Mg | 24S | 8490 | B | B | C | D |
| Al—Cu—Mn—Mg | 24C2 | 8538 | A | B+ | B+ | B |
| Al—Si | 43 | 4458 | A | B | B | B |
| Al—Si | 13 | 4257 | A | B | B | B |
| Al—Cu—Si | 195 | 32* | B | B | C | D |
| Al—Cu—Si | C113 | 5298 | B | B | C | D |
| Al—Cu—Fe—Zn | 112 | 12 | B | B | C | D |
| Al—Si—Cu—Mg | 355 | 40 | A | B | B | C |
| Al—Si—Mg—Cr | 53ST | 5859 | A | B | B | B |
| Al—Mg—Cr | 52S | 7250 | A | B | B | B |
| Al—Mg—Si—Cu—Cr | 61S | .... | A | B | B | B |
| **Magnesium and Magnesium Alloys** | | | | | | |
| 99.8% Mg | AM2S | 3033-7751 | C | D | D | E |
| 98% Mg—1.5% Mn | AM35 | .... | B | C+ | D+ | E |
| 95.8% Mg—3% Al—1.0% Zn—0.2% Mn | AM52S | .... | B | C+ | D+ | D |
| 88.8% Mg—9% Al—2% Zn—0.2% Mn | AM260 | .... | B | C | D | E |
| 90.8% Mg—6% Al—3% Zn—0.2% Mn | AM265 | .... | B | C | D | E |

*Requires heat treatment.

†Corrosion ratings for metals in contact with sea water are subject to variations, depending upon harbor water pollution and flow. Ratings given for sea water applications shall be considered as a supplement to, rather than a replacement of, other means of arriving at a proper choice of material.

### TABLE II—CORROSION RATINGS OF COMMERCIAL COPPER AND COPPER ALLOYS

| Material | Westinghouse Designation | General Outdoor Air | | | Specific Industrial Atmospheres (Wet) | | | | | Sea Water† |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Rural | Urban | Marine | Ammonia | Hydrogen Sulfide | Hydrogen Chloride | Sulfur Dioxide | Chlorine | |
| **Coppers** | | | | | | | | | | |
| Copper, Tough Pitch | 2007 | A | A— | A | E | C | C | B | C | B— |
| Copper, Phosphorized | 5536 | A | A— | A | E | C | C | B | C | B— |
| Copper, Oxygen Free | 2003-3 | A | A— | A | E | C | C | B | C | B— |
| Cupaloy | 7550 | A | A— | A | E | C | C | B | C | B— |
| Cadmium Copper | 4623 | A | A— | A | E | C | C | B | C | B— |
| Beryllium Copper | 7534 | A | A— | A | E | C | C | B | C | B— |
| Selenium Copper | 8540 | A | A— | A | E | C | C | B | C | B— |
| **Brasses** | | | | | | | | | | |
| Gilding Metal (95-5) | .... | A | A— | A | E | C | C | B | C | B— |
| Commercial Bronze (90-10) | 8012 | A | A— | A | E | C | C | B | C | B— |
| Red Brass (85-15) | 7292–7790 | A | A— | A | E | C | C | B | C | B— |
| Low Brass (80-20) | 7410 | A | B+ | A— | E | C+ | E | C | E | C+ |
| High Brass (70-30) | 8010 | A | B | B+ | E | B— | E | C— | E | C |
| High Brass (68-32) | 2677 | A | B | B+ | E | B— | E | E | E | C |
| High Brass (66-34) | 2411–2676 | A | B— | B+ | E | B— | E | E | E | C— |
| Muntz Metal (60-40) | 6811 | A | B— | B+ | E | B— | E | E | E | C— |
| **Leaded Brasses** | | | | | | | | | | |
| Leaded Commercial Bronze 88-10-2% | .... | A | A— | A | E | C | C | B | C | B— |
| Hardware Bronze | 7790 | A | A— | A | E | C | C | B | C | B— |
| Low-leaded Tube Brass | 2430 | A | B— | B+ | E | B— | E | E | E | C— |
| Low-leaded Brass | 8182 | A | B— | B+ | E | B— | E | E | E | C— |
| Medium-leaded Brass | 7785 | A | B— | B+ | E | B— | E | E | E | C— |
| High-leaded Brass | .... | A | B— | B+ | E | B— | E | E | E | C— |
| Extra-high-leaded Brass | 1523–2724 | A | B— | B+ | E | B— | E | E | E | C— |
| Leaded Muntz Metal | 6377–2840 | A | B— | B+ | E | B | E | E | E | C— |
| Forging Brass | 4907 | A | B— | B+ | E | B | E | E | E | C— |
| Architectural Bronze | 3134 | A | B— | B+ | E | B | E | E | E | C— |
| **Bronzes** | | | | | | | | | | |
| Phosphor Bronze 1¼% | 7342–7413 | A | A— | A | E | C | C | B | C | B— |
| Phosphor Bronze 5% | 2383–2709 | A | A— | A | E | C | C | B | C | B— |
| Phosphor Bronze 6% | .... | A | A— | A | E | C | C | B | C | B— |
| Phosphor Bronze 8% | 4118 | A | A— | A | E | C | C+ | B | C | B |
| Phosphor Bronze 10% | 3503–4121 | A | A— | A | E | C | C+ | B | C | B+ |
| Hard Bronze (88-4-4-4) | 6014 | A | A— | A | E | C | C | B | C | B |
| **Special Brasses** | | | | | | | | | | |
| Admiralty | 7634 | A | B | B+ | E | B— | E | C | E | B+ |
| Naval Brass | 2824 | A | B | B+ | E | B | E | E | E | B— |
| Leaded Naval Brass (60-38-1.5%) | .... | A | B | B+ | E | B | E | E | E | B— |
| Manganese Bronze | 5184 | A | B | B+ | E | B | E | E | E | B— |
| Aluminum Brass | 6052 | A | B | B+ | E | B— | E | C | E | A— |
| **Cupro-Nickels** | | | | | | | | | | |
| Cupro-nickel (70% Cu—30% Ni) | .... | A | A— | A | E | C— | C+ | B | C+ | A |
| Nickel Silver, Alloy A (18% Ni—65% Cu—17% Zn) | 8130 | A | A— | A | E | C— | C+ | B | C+ | B+ |
| *Nickel Silver (30% Ni—47% Cu—23% Zn) | 1498 | A | B | A | E | C | E | C | E | B |
| *Nickel Silver, Alloy B (18% Ni—55% Cu—27% Zn) | 3296 | A | B | A | E | C | E | C | E | B |
| **Special Bronzes** | | | | | | | | | | |
| Silicon Bronze | 7610 | A | A— | A | E | C | C+ | B | C+ | B— |
| Silicon Bronze | 8308 | A | A— | A | E | C | C+ | B | C+ | B— |
| Silicon Bronze | 4448 | A | A— | A | E | C | C+ | B | C+ | B— |
| Silicon Bronze | 4788 | A | A— | A | E | C | C+ | B | C+ | B— |
| 5% Aluminum Bronze | .... | A | A— | A | E | C+ | C | B | C | B+ |
| Al Ni—Fe—Cu | 6799 | A | A— | A | E | C+ | C | B | C | B+ |

*Used principally for electrical resistance properties.

†Corrosion ratings for metals in contact with salt water are subject to wide variations, depending upon geographical location, flow and cyclic heating. Ratings given for sea water applications shall be considered as a supplement to, rather than a replacement of, other means of arriving at a proper choice of material.

TABLE III—CORROSION RATINGS OF COMMERCIAL ALLOYS OF IRON, NICKEL AND CHROMIUM

| Material | American Iron & Steel Institute Number | Westinghouse Designation | Outdoor Air | | | Specific Industrial Atmospheres (Wet) | | | | | Scaling Temp Degrees F Note 1 | Sea Water* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Rural | Urban | Marine | Ammonia | Hydrogen Sulfide | Hydrogen Chloride | Sulfur Dioxide | Chlorine | | |
| Low Carbon Steel | .... | 1555<br>2084 | D+ | D | D | B | D | D | D | D | 1000 | D+ |
| Copper Bearing Steel | .... | 4225 | D+ | D+ | D | B | D | D | D | D | 1000 | D+ |
| 4-6% Cr Steel | 502 | 6396 | D+ | D+ | D+ | B | D+ | D | D | D | 1150 | D |
| 12-14% Cr Steel | 420 | 8213 | B+ | B | C− | A | C | D | D | D | 1250 | C− to E<br>Note 6 |
| 12-14% Cr<br>0.60% Mo | 416 | 5161 | B+ | B | C− | A | C | D | D | D | 1250 | C− to E<br>Note 6 |
| 16-18% Cr | 430 | 5284 | A | B+ | C | A | B | D | D | D | 1550 | C− to E<br>Note 6 |
| 23-30% Cr | 446 | 6770 | A | A | C+ | A | A | D | B | D | 2000 | C to E<br>Note 6 |
| 7% Ni—17% Cr | 301 | 7670 | A | A | B+ | A | A | D | C | C | Not used for oxidation res. | C to E<br>Note 6 |
| 8% Ni—18% Cr | 302<br>303<br>304 | 4562<br>6478<br>5872 | A | A | A− | A | A | D | B | C | 1650 | C to E<br>Note 6 |
| 8% Ni—18% Cr—1% Cb | 347 | 7968 | A | A | A− | A | A | D | B | C | 1650 | C to E<br>Note 6 |
| 8% Ni—18% Cr—0.5% Ti | 321 | .... | A | A | A− | A | A | D | B | C | 1650 | C to E<br>Note 6 |
| 14% Ni—23% Cr | 309 | 5758 | A | A | A | A | A | D | B | C | 2000 | C+ to E<br>Note 6 |
| 12% Ni—18% Cr—3% Mo | 316 | 8685 | A | A+ | A+ | A | A | C | A | B | 1650 | C+<br>Note 6 |
| 20% Ni—25% Cr | 310 | .... | A | A+ | A+ | A | A | D | B | C | 2000 | C<br>Note 6 |
| Nickel | .... | 1921 | A | A− | A+ | C−E<br>Note 5 | B | C−B | C | B | Note 2—1900<br>Note 3—1000<br>Note 4— 700 | C− |
| 30% Ni—70% Cu | .... | .... | A | A− | A | C−E<br>Note 5 | C− | C+ | B | C+ | .... | A<br>Note 7 |
| Monel | .... | 2718 | A | A | A | C−E<br>Note 5 | B | B | C | B | Note 2—1000<br>Note 3—1000<br>Note 4— 650 | A<br>Note 7 |
| 80% Ni—20% Cr | .... | 3012 | A | A | A+ | A | A | B | B | B | 2100 | C− |
| Inconel—80% Ni, 7% Fe—13% Cr | .... | 8153 | A | A | A+ | A | A | B | B | B | Note 2—2000<br>Note 3—1500<br>Note 4—1000 | C− |

*Corrosion ratings for metals in contact with salt water are subject to wide variations, depending upon geographical location, flow and cyclic heating. Ratings given for sea water applications shall be considered as a supplement to, rather than a replacement of, other means of arriving at a proper choice of material.

Note 1—Values assume substantially constant temperature operations—should be lowered for cyclic heating and cooling to an extent dependent upon the frequency and range of temperature fluctuations.

Note 2—Scaling temperature in low-sulfur atmosphere.

Note 3—Scaling temperature in high sulfur oxidizing atmosphere.

Note 4—Scaling temperature in high sulfur reducing atmosphere.

Note 5—Not recommended primarily to resist ammonia attack, but may be used where resistance to ammonia in low concentrations is an incidental requirement.

Note 6—With the stainless steels, the lower ratings refer to exposure to quiet, or slowly moving sea water, especially where marine organisms may become attached and induce pitting. The higher ratings refer to contact with sea water at high velocity, e.g. pump impellers for which the better stainless steels frequently give excellent service, especially in polluted harbor waters. The straight chromium stainless steels give their best performance when used at high velocity and in contact with ordinary steel, but should not be combined with bronzes.

Note 7—The 70:30 copper nickel alloy is preferred for condenser tubes, salt water piping and boat sheathing. Monel provides high strength, excellent resistance to erosion, and a favorable galvanic relationship to bronzes. Because of the favorable galvanic relationship, it is the preferred material for valve trim, shafting, and for vital parts of assemblies which include bronze components.

materials should be used with *caution;* and *D* or *E* material should be *avoided.*

These recommendations are general because the suitability of a material for a given purpose from a corrosion standpoint depends upon many factors, such as the physical and chemical properties of the substance produced by the corrosion, and the corrosion product, which might be adherent or loose, conducting or insulating. For most purposes tarnishing can be neglected, but usually the nature of the final surface must be considered.

The ratings given refer to bare metals only. In many applications the low rating of an alloy can be compensated by a suitable coating. Ordinary steel, properly coated, can often be used instead of the more expensive alloys.

In using the given ratings it is important that consideration be given to the form in which the metal is to be used; that is, whether as a sheet, casting, or forging, and also that the engineer visualize the possible damage caused by the more vicious types of corrosion such as deep pitting or intergranular attack. Consideration should always be given to the possible serious effects of corrosion-produced stresses, internal and applied (particularly cyclic stresses), on the fatigue strength of metals and alloys in corrosive atmospheres. When fabrication or design produces such stresses in the material, necessary steps such as proper annealing or redesign should be taken to reduce the possibility of damage.

While it is intended that comparisons in ratings should be made only in vertical columns, that is, for given conditions, the tendency toward making comparisons along horizontal lines is hard to resist. If such horizontal comparisons are limited to atmospheric conditions, it is believed that generally useful conclusions can be reached. For example, if a material has an *A* or *B* rating in general outdoor city air, and it also has a lower rating in a certain "Specific Industrial Atmosphere," it is important that the engineer survey the possibilities of contamination of the air from the surroundings. This is particularly true of copper alloys because they are adversely affected by many chemical vapors. Such precautions as protective coatings and air conditioning may then be considered for applications under these corrosive conditions.

### Corrosion Resulting from Galvanic Couples

When two metals are in contact and this contact becomes wet with a conducting solution, an electric potential is set up between them. For example, if magnesium touches silver, both being in an electrolyte, a difference in potential of more than a volt will exist between them. Likewise, if different metals and alloys are brought into contact with silver or any other metal, they will exhibit a characteristic potential. The relative positions of several metals and alloys in the electromotive series are shown in Fig. 1. It is dangerous to use metals in the upper end (anodic) of the list in contact with those in the lower (cathodic) end of the electromotive series without some safeguard for the contact such as a coating to prevent its being wet by a conducting solution. In sea water, which is an electrolyte of high conductivity, galvanic potentials should generally be avoided. This is true especially with alloys of aluminum, magnesium, iron, steel, and high-zinc brasses, in contact with copper. If, however, the area of the corroding (anodic) metal is large as compared with the cathodic copper, the corrosion is spread over this large area, and the actual damage is mitigated. For example, copper pipe can usually be connected to steel tanks without serious results; but the connection of steel pipe to a copper tank would result in a different story. The anodic metal suffers accelerated corrosion to an extent determined by the corrosivity of the environment, the area of the cathodic metal and the resistance of the galvanic circuit (the two metals and the solution).

Galvanic couples do not always result in corrosive attack of the anodic metal as indicated by the relative positions of the two metals in the electromotive series. The condition that prevents the expected attack is called passivity but is without accepted explanation. Alloys containing chromium are most pronounced in their passivity, which accounts for the wide use of chromium in corrosion-resistant alloys.

Passivity also depends upon the nature of the solution. If the solution is one that destroys passivity, the alloy is then said to become active and will be attacked. In electromotive series, Fig. 1, these active-passive alloys are designated in three groups, *A*, *B*, and *C*, which under certain conditions become active and are placed higher in the list. The conditions of use must be investigated before a passive metal or alloy is recommended. When in doubt as to whether an active-passive material will be active or passive, assume that it will be active if its area is relatively small, and passive if its area is relatively large.

The information contained in these tables represents the accumulation of years of corrosion experience. However, this summation of experiences is not without exception and the values presented in the tables are to be used merely as guides.

FIG. 1—THE ELECTROMOTIVE SERIES

| | | |
|---|---|---|
| | ANODIC END | |
| | Magnesium | |
| | Magnesium Alloys | |
| | Zinc | |
| | Aluminum 2S | |
| | Cadmium | |
| | Aluminum 17ST | |
| | Carbon Steel | |
| | Copper Steel | |
| | Cast Iron | |
| | 4–6% Cr Steel | |
| A | 12–14% Cr Steel | Active |
| A | 16–18% Cr Steel | Active |
| A | 23–30% Cr Steel | Active |
| | Ni-Resist | |
| B | 7 Ni—17% Cr Steel | Active |
| B | 8 Ni—18% Cr Steel | Active |
| B | 14 Ni—23% Cr Steel | Active |
| B | 20 Ni—25% Cr Steel | Active |
| B | 12 Ni—18% Cr—3% Mo Steel | Active |
| | Lead-Tin Solder | |
| | Lead | |
| | Tin | |
| C | Nickel | Active |
| C | 60 Ni—15% Cr | Active |
| C | Inconel | Active |
| C | 80 Ni—20% Cr | Active |
| | Brasses | |
| | Copper | |
| | Bronzes | |
| | Nickel Silver | |
| | Copper Nickel | |
| | Monel | |
| C | Nickel | Passive |
| C | 60 Ni—15% Cr | Passive |
| C | Inconel | Passive |
| C | 80 Ni—20% Cr | Passive |
| A & B | 12–14% Cr Steel | Passive |
| A & B | 16–18% Cr Steel | Passive |
| A & B | 7 Ni—17% Cr Steel | Passive |
| A & B | 8 Ni—18% Cr Steel | Passive |
| A & B | 14 Ni—23% Cr Steel | Passive |
| A & B | 23–30% Cr Steel | Passive |
| A & B | 20 Ni—25% Cr Steel | Passive |
| A & B | 12 Ni—18% Cr—3% Mo Steel | Passive |
| | Silver | |
| | Graphite | |
| | Gold | |
| | Platinum | |
| | CATHODIC END | |

## ENGINEERING PROFILES

Brick making is an ancient art whose origin is lost in antiquity. Subsequent fundamental changes in brick manufacturing have not been many. Tests now have been completed that show the drying of bricks by dielectric heating is feasible. To be economically justified, the method must be applied to special high-temperature ceramic bricks such as used in glass furnaces where the time element and storage space required contribute substantially to the cost. These large bricks (12 x 12 x 20 inches) normally require three months to dry by present methods. Using a 100-kw oscillator operating at 10 megacycles, 75 of these blocks were dried in less than 24 hours. These tests point out the possibility of automatic brick forming and drying that not only would reduce the handling of the bricks but also would eliminate the huge drying lofts otherwise required.

• • •

To the many industries that have been speeded up through the use of infrared lamps, add the pottery industry. Chinaware is formed on hand-operated or automatic machines. The freshly formed ware, known as green chinaware, must remain in its mold until after an initial drying that normally takes some three hours. Thus there will be from 1000 to 10 000 molds in the drying oven at a time. Such a supply of molds is necessary for every item of china manufactured. The use of infrared lamps has reduced this drying period to about 15 minutes with a corresponding reduction in the number of molds required. This reduced number of molds and a combined hot-air and infrared drier enable small manufacturers to replace their hand-operated machines by ones fully automatic.

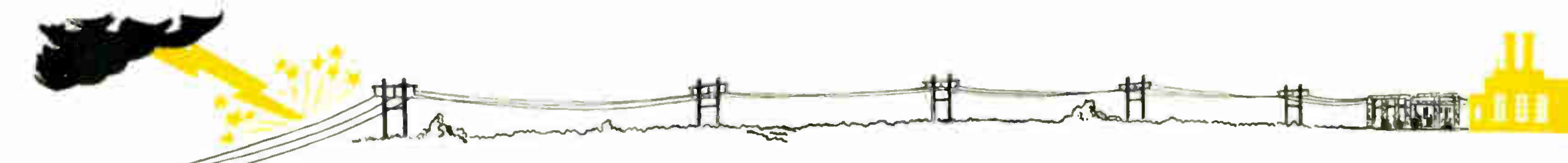
Electric furnaces are widely known in the manufacture of steel. Not so well known is their use in the glass industry. As in the steel industry, the use of electric furnaces is largely limited to the manufacture of special grades of glass. They are mostly on the small side as compared to the huge gas-fired furnaces for making common glass. Such furnaces are justified economically for making optical glass and other specially developed glass where close heat control and protective atmospheres are necessary. Such electronic heat controls as the Furnatron give to an electric furnace a precision temperature control not possible with other types of furnaces. With the electric furnace, the glass can be protected from contamination of certain gases by using a harmless protective atmosphere.

• • •

Electric furnaces are used in manufacturing pottery and china of certain colors because it is necessary to provide a protective atmosphere during the heating process. Gases in fuel-fired furnaces react with the pigments of these colors, ruining them.

• • •

Tandem rolling of steel requires d-c motors to drive the individual stands. These motors are generally driven by individual m-g sets. On merchant mills that do not require regenerative braking, the m-g sets have been replaced by 2500-kw mercury rectifiers. The motors are started with the mill empty by means of a phase control on the input of the rectifier which then operates as a variable-voltage unit. This a-c to d-c conversion eliminates rotating equipment with its attendant problems.



# Reclosing Single-Circuit Tie Lines

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**The war leaves its mark even on circuit-breaker practice. Single-circuit tie lines have in many cases become a wartime necessity. To give them the reliability comparable with double-circuit lines the scheme of opening and quickly reclosing only the faulted conductors has found widespread favor. Selective-pole, high-speed reclosing of circuit breakers is now well accepted.**

Mobilization of the nation's electric power has been complicated, not merely because of the magnitude of the loads, but also because of the dispersion of plants. The use of single-circuit tie lines to interconnect major power sources or systems, dictated by economics and limitations on materials, was made possible by improvements in transmission-line performance and the gradual development of equipment necessary to the successful operation of the scheme. Other important factors contributing to the increased reliability of single-circuit transmission are: highly effective shield wires, the general increase in insulation level, and a better knowledge of the characteristics of natural lightning.

In spite of preventive measures included in good line design, outages still do occur. The preponderance of these remaining outages is transient, hence high-speed reclosing circuit breakers further enhance transmission-line reliability. The outstanding limiting factor inherent in high-speed reclosing is the maintenance of transient stability during the operation. Also, power surges and voltage dips accompanying such system disturbances must not cause excessive shock to the system. The single-circuit tie line, as a system interconnection, is sound when judged by all practical criteria.

What happens in a reclosing operation is primarily a function of the changes in the outputs of the generators in relation to their respective prime-mover inertias and inputs. The fundamental aspects of the transient-stability problem involved are:

1—Initial phase-angle relation of machine rotors at the instant of fault is determined by the generation and load relationships of normal operation.

2—Fault causes electrical outputs to be altered.

3—Changed power relations cause rotors to tend to change their speed (accelerate if electrical output is less than prime-mover input and to decelerate if output exceeds prime-mover input).

4—Changed phase angle of rotors causes changes in the electrical power outputs of machines.

5—The time at which these changes occur and their magnitudes determine whether the initial conditions are restored or whether the systems reach an out-of-step condition requiring resynchronization.

For any particular problem of tie-line reclosing involving a specific system, the factors affecting the stability problem, and thus determining the choice of switching and control equipment, depend upon the electrical power output of the synchronous machines during the four periods in the reclosing cycle, and the duration of these periods. The power relations between systems can be obtained from an analytical or calculator solution of the electrical networks involved.

### System Performance During a Reclosing Cycle

A complete reclosing cycle consists of four steps: (a)—The initial condition (steady state prior to fault); (b)— The fault condition; (c)—The fault-cleared condition (breakers open, or de-energized period); (d)—Condition after breakers are reclosed (line energized.)

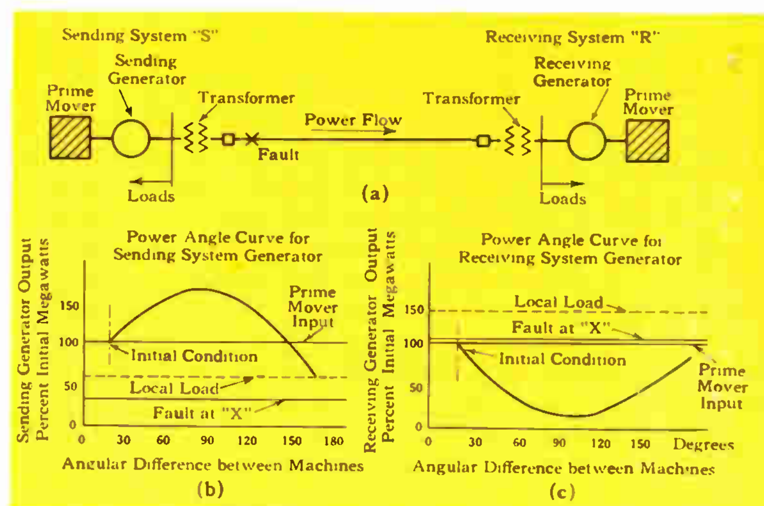



**Fig. 1—Power-flow characteristics of two systems connected by a single tie line. (a) System diagram; (b) Power-angle curves of the sending system for normal three-phase fault and line-open conditions; (c) Same conditions as b applied to receiving system.**

The initial condition shown in Fig. 1 (a) is a typical case where reclosure is required following line faults. The single-line diagram represents a sending and a receiving system connected by transformers and a single tie line. Both systems consist of a prime mover, a generator, and a load. In this general case, it is assumed that the sending generator supplies 60 percent of the local load and transmits the remaining 40 percent over the tie line to the receiver system. Deviations from the assumed values affect the magnitude but not the character of the system oscillation following a fault. The receiving-end local load absorbs the input from the tie line and the entire output of the receiver generator. The receiver-system load and frequency cannot be maintained unless reclosure is successful.

The second step of the reclosing cycle begins with the fault. When a fault occurs on the tie line near the sending end, the

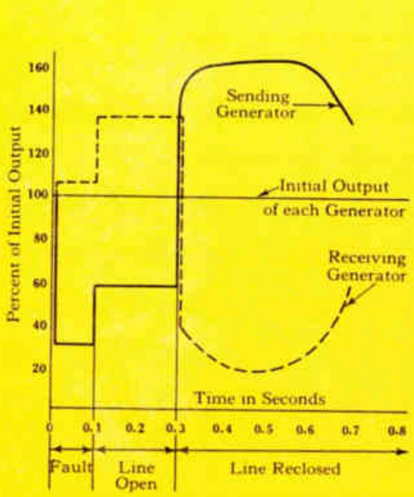
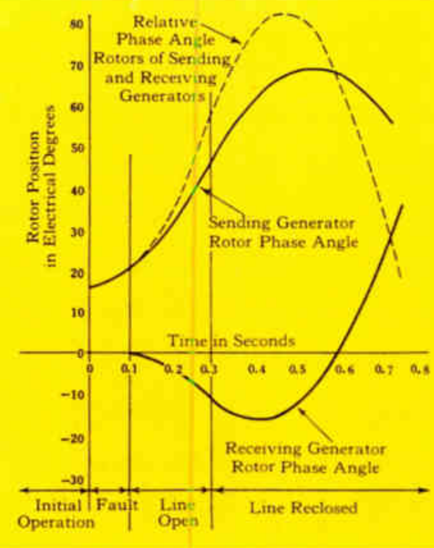



**Fig. 2—Electric-power output of generators for a typical reclosing cycle of the tie line of Fig. 1. The fault near the sending end of the line is cleared in 0.1 second, and the line reclosed in 0.3 second.**

**Fig. 3—Rotor positions during the fault-clearing and reclosing cycle of the tie line of Fig. 1. A stable solution is represented because the angular displacement between the machines reached a maximum and is decreasing.**




electrical power output of the sending-end generator decreases. The output of the receiving-end generator usually increases but, in some cases, the fault causes a low-voltage condition on the receiver system, thus decreasing the load so that the resultant output of the receiver generators may not change greatly from normal. Typical relative values for a three-phase fault are shown in Fig. 1 (b) for the sender and 1 (c) for the receiver. The power changes are also indicated in Fig. 2. Because the prime-mover inputs are unchanged by the fault (and do not change during the time being considered), the differential power (the differences between the prime-mover inputs and the generator outputs) acts on the rotors to cause the sending generator to speed up rapidly and the receiver to slow down gradually. The phase-angle difference between rotors thus increases as Fig. 3 shows. The total angular separation attained in a given time is a function of the differential power of each system and the inertia of the synchronous apparatus in that system.

The three-phase fault-cleared condition (breakers open) initiates the third step of the reclosing cycle. After the breakers have opened, each generator supplies its own local load. At the sending end, mechanical input exceeds electrical output by about the amount of power that was transmitted over the tie line before the fault occurred. Simultaneously, the receiver system electrical loading exceeds the prime-mover mechanical input by an amount nearly equal to the tie-line loading. Any change between these differential powers and the tie-line loading is caused by changes in voltage on the load buses. Because the power relations are in the same direction as under the fault condition, the sending-end generating unit accelerates still more, while that at the receiving end slows down. The separation in angle relationship continues.

After the line is reclosed—the fourth step of the cycle—the power relations between the systems change because of the synchronizing power transmitted over the tie line. The amount of electrical power delivered or received by the machines depends upon the difference in their angle and upon the power-angle characteristics of the system. For the case assumed, reclosure occurs at a point where the output of the sending generator is much greater than the prime-mover input and where the output at the receiver generator is much less than its prime-mover input.

The power relations are now reversed from the previous conditions, and the differential powers cause deceleration of the sender and acceleration of the receiver. The forces that previously caused separation of the rotors now are in a direction to bring them together. However, as it takes time for these forces to overcome and reverse the increase in velocity previously acquired, the machines continue to separate in relative angle until the velocity of separation becomes zero. Then, if the sending generator still has an excess of load over its prime-mover input, and the receiver an excess input over its load, the power relations are still in the direction to bring the rotors toward each other, and incremental velocities are developed in this direction. Again, because of their inertias, the rotors swing past their initial angular relationship. These oscillations, of smaller and smaller amplitude, proceed until the rotors finally resume the initial relative angular positions. The case of a successful reclosure with the maximum angle of separation, 82 degrees, is shown in Fig. 3. No attempt is made to show in detail the subsequent oscillations. If the velocity of separation is not overcome quickly enough, the angle between rotors becomes too large to maintain restoring accelerations, and instability results.

The example illustrates the general nature of the problem.

TABLE I—PERCENT BUS VOLTAGE DURING MAXIMUM SYSTEM SWING

| Type of Fault | Percent of Normal System Voltage | |
|---|---|---|
| | Three-Pole Switching | Single-Pole Switching |
| Three phase | 73.5 | 73.5 |
| Two lines-to-ground | 74.5 | 82 |
| One line-to-ground | 78.0 | 93 |

TABLE II—EXAMPLES OF USE OF FIG. 5 TO DETERMINE RECLOSING EQUIPMENT REQUIREMENTS

| Item | System Characteristics* | | | | | Per Unit Pt. | $\frac{Mi}{Kv^2} x Base$ | Ps/Pr | †Types of Reclosing Applicable to Maintain Stability—From Fig. 5 |
|---|---|---|---|---|---|---|---|---|---|
| | Ps | Pr | Pt | Kv | Miles | | | | |
| 1 | 50 | 50 | 25 | 69 | 40 | 0.5 | 0.42 | 1.0 | 3-pole, 20 cycle<br>1-pole, 30 cycle<br>1-pole, 20 cycle |
| 2 | 100 | 100 | 60 | 110 | 100 | 0.6 | 0.83 | 1.0 | None |
| 3 | 200 | 50 | 39 | 69 | 50 | 0.78 | 0.53 | 4.0 | 3-pole, 20 cycle<br>1-pole, 30 cycle<br>1-pole, 20 cycle |
| 4 | 300 | 100 | 65 | 110 | 100 | 0.65 | 0.83 | 3.0 | 1-pole, 20 cycle |
| 5 | 50 | 100 | 30 | 138 | 85 | 0.30 | 0.45 | 0.5 | 3-pole, 20 cycle<br>1-pole, 30 cycle<br>1-pole, 20 cycle |
| 6 | 100 | 500 | 70 | 110 | 90 | 0.14 | 3.72 | 0.2 | 1-pole, 20 cycle |
| 7 | 150 | 200 | 68 | 161 | 140 | 0.34 | 1.08 | 0.75 | 3-pole, 20 cycle<br>1-pole, 30 cycle (Marginal)<br>1-pole, 20 cycle |
| 8 | 140 | 70 | 40 | 138 | 70 | 0.57 | 0.26 | 2.0 | Any |

*Ps=Generation at sending end, Pr=Generation at receiving end, Pt=Maximum power to be transmitted. These units expressed in megawatts.

†When more than one type is suitable from stability standpoint, final choice will depend on other factors, such as the severity of the disturbance as measured by voltage collapse and power surges.

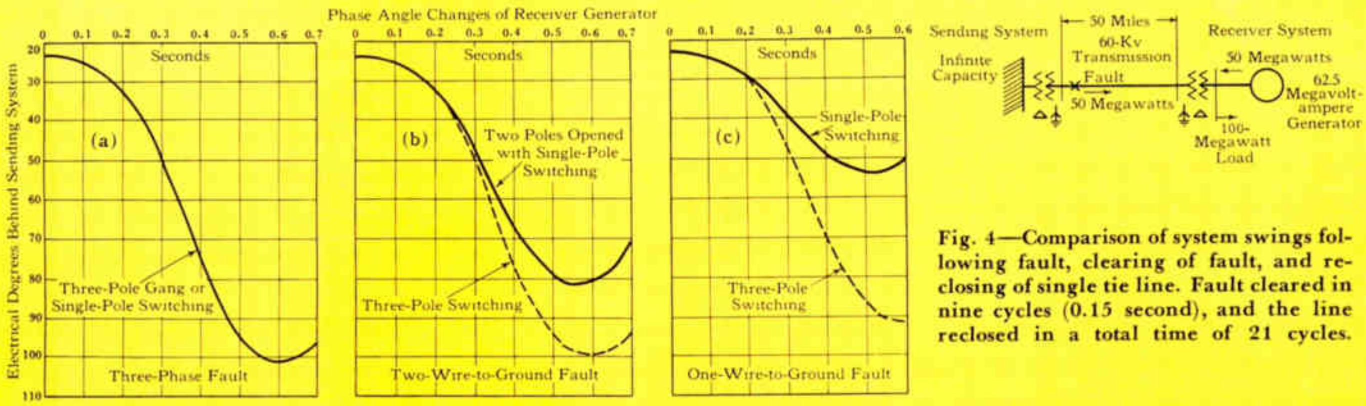


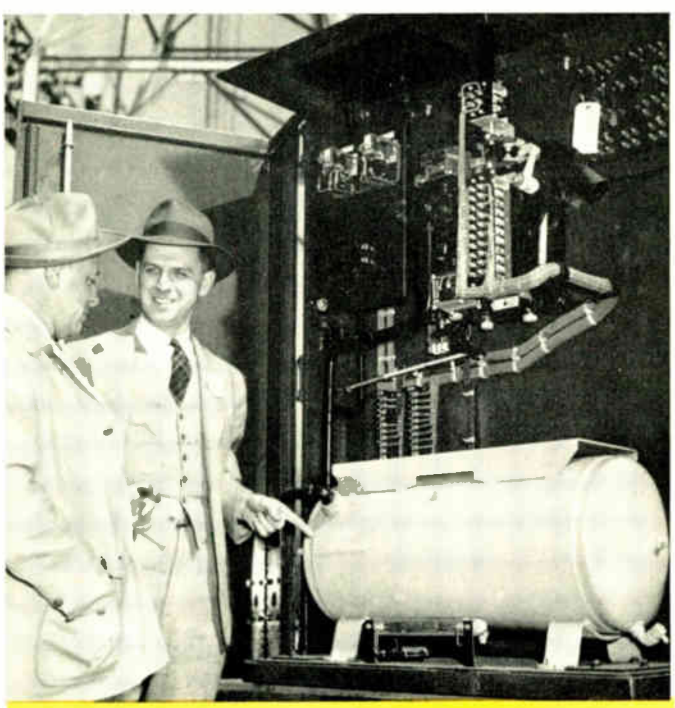

**Fig. 4—Comparison of system swings following fault, clearing of fault, and reclosing of single tie line. Fault cleared in nine cycles (0.15 second), and the line reclosed in a total time of 21 cycles.**

The variations in system conditions during the fault, during the circuit-open period, and during subsequent reclosure cause the electrical outputs of the generators to differ from the prime-mover inputs. These changes result in swings of the rotors, the magnitudes of which are determined by the specific system characteristics and operating conditions.

The results obtainable with high-speed reclosing of a single tie line are shown by this typical general case. If reclosing had not been applied, two lines with a total of four breakers and associated control equipments would have been required to transmit "firm power" between the systems.

### Stability Enhanced with Single-Pole Breakers

In the example, the three-phase fault required all three poles to be opened and reclosed. If the fault does not involve all three phases, it can be cleared by opening only those breaker poles that are connected to the faulted wires. The fundamental difference between three single-pole breakers and a three-pole breaker is that with three-pole breakers, regardless of the type of fault, all poles are opened, while with single-pole breakers only those poles necessary to clear the fault are opened. If the transformers at each end of the tie line are grounded, an electrical connection, consisting of the unfaulted wire, or wires, and the ground return is available for transferring power and maintaining voltage during the period when the faulted wire or wires are de-energized.



**The pneumatic breaker-reclosing mechanism is mounted on the side of a 138-kv, 1½-million-kva single-pole breaker.**

The gain in system performance that results from single-pole switching instead of three-pole switching is entirely the result of improved power relations during the de-energized period, that is, between the time the fault is cleared and the time the breakers are reclosed. For a single tie line, no power is transferred during the de-energized period with three-pole gang-operated breakers regardless of the type of fault. With single-pole switching, some power is transferred for all types of faults except those involving all three wires.

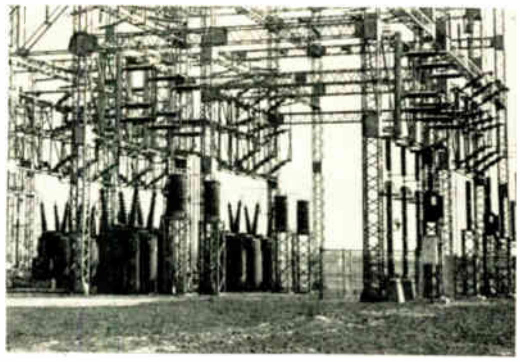
A comparison of the phase-angle swings for three-pole (gang-operated) versus three single-pole (individually operated) breakers, for various types of faults for a typical system, is shown in Fig. 4. For a three-phase fault, Fig. 4 (a), all three poles must be opened to clear the fault regardless of whether single-pole or three-pole switches are used. However, for other types of faults, Figs. 4 (b) and (c), improvement in system operation is obtained with single-pole switching, as is indicated by smaller swings in phase angle of the generators.

Another measure of the severity of the disturbance to the system is the voltage on the load bus in the receiver system. Because this voltage decreases with increase in phase-angle displacement, the larger this angle the lower is the voltage at the load. For the case of Fig. 4, the voltage at maximum swing is given in table 1.

### Type of Switching for Specific Applications

The amount of power to be transmitted a given distance over a single line between two systems decides the selection of reclosing breakers and associated reclosing equipment. For determining the minimum equipment that can be safely applied for a given set of conditions, Fig. 5 is useful. These curves are not intended as a solution of all problems concerning high-speed reclosing, but are presented merely as a guide. These general curves are calculated to apply specifically to tie lines between systems on which steam turbines predominate. They are based on many a-c network calculator solutions of reclosing operation problems on typical tie-line circuits in common usage.

The solution of any single-tie-line reclosing problem that results in a point on one of the curves falling above the particular per-unit power to be transmitted is a stable solution; points below indicate unstable solutions. The practical applications of these curves is illustrated by solutions of representative cases summarized in table II. In this table, the type of reclosing equipment necessary to maintain synchronism is selected for each case by determining which of the four parts of Fig. 5 would render a solution providing stable operation. In each case solution of the problem began with the slower and less expensive three-pole, 30-cycle reclosing breaker and progressed toward faster breakers and single-pole operation until stable solutions were indicated.



**Single-pole switching in a 138-kv station.**

The data plotted in Fig. 5 are taken from transient-stability solutions of examples employing constants and operating conditions so chosen that the results apply to a large range of systems. The initial operating condition for each case was obtained by establishing voltage and power flows that could reasonably be expected in practice. In every case, the base selected is equal to the kilowatt capacity of the receiver system. The total generation in either the sender or receiver system is assumed to be made up of 1800-rpm machines of 80-percent power factor operating at full load and the necessary excitation. The rotating-machine constants, transformer reactances, and transmission-line characteristics selected are typical. The shunt loads are assumed to be at 85 percent power factor. In each case, line regulation is adjusted to 10 percent. In certain cases, this requires that synchronous condensers be used at the receiver system to furnish reactive kva in excess of the capacity of the receiver generators. The inertia of these condensers is not included in the swing calculations because it is usually small enough to be negligible. Even where large condensers are used, the omission of their greater inertia tends to give conservative results.

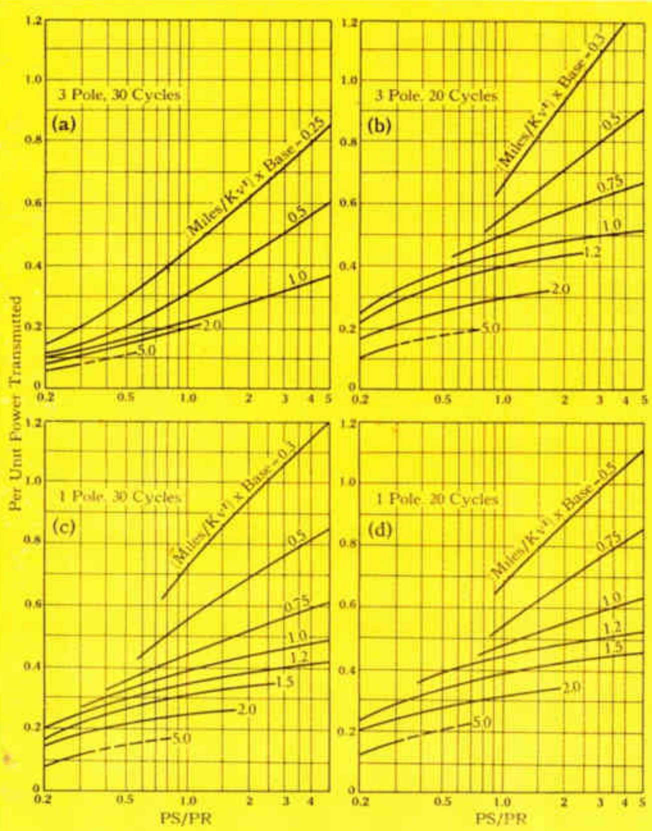



**Fig. 5—The transient-stability limit for the reclosing tie line between two systems. Each curve is the transient-stability limit based on double line-to-ground faults for various ratios of sending-end to receiving-end inertia, plotted against the power transmitted. Each curve represents a specific value of (miles/kv²) x Base, which ratio is a measure of the electrical length of the transmission circuit. The four parts of Fig. 5 represent the four commercially available speeds and types of reclosing equipment. It is recognized that in some of the higher voltage classes, thirty-five cycles is the standard reclosing time rather than thirty cycles. This departure from the data in Fig. 5 should be remembered when this divergence in parameters is present.**

Conventional a-c network calculator studies were carried through for each typical system chosen until a critical point in the transient-stability solution was reached by varying line length while all other system elements were held constant. At this critical point any increase in line length results in instability and any decrease proves definitely stable.

The solutions of stability problems of single-tie-line reclosing developed by using Fig. 5 consider only the minimum reclosing equipment that can be safely applied. Allowance should be made for system growth. Consideration should also be given to the seriousness of system voltage collapse during the disturbance in question. All of these additional factors point toward the use of single-pole switching as an ultimate. Single-pole reclosing is justified in many cases where a knowledge of future system operation points toward more critical stability.

While Fig. 5 can be used as a practical guide to the selection of reclosing equipment on tie lines between steam-generating systems, cases will be found where a thoroughly dependable answer will require a-c network calculator studies. In other cases, the curves of Fig. 5 indicate the presence of a critical stability problem for which network calculator solution may be necessary.

Double line-to-ground faults have been used in all solutions here presented. The apparent advantages of single-pole reclosing as compared to three-pole reclosing, using double line-to-ground faults, are greatly increased if single line-to-ground faults are considered. Single-pole switching was originally advanced to take advantage of the large gains in transient-stability limits obtainable during single line-to-ground faults. Operating records indicate that upwards of 70 percent of transmission-line faults are single line-to-ground in nature, and on new lines specifically designed with this factor in mind, the percentage may be higher. Thus, single-pole switching has greater advantages than Fig. 5 alone would indicate. A consideration of transient stability under single line-to-ground faults as well as double line-to-ground faults, remembering the additional advantages of reduced voltage dip and system shock, gives the true comparison between the alternate schemes of reclosing breakers.

# STORIES OF RESEARCH

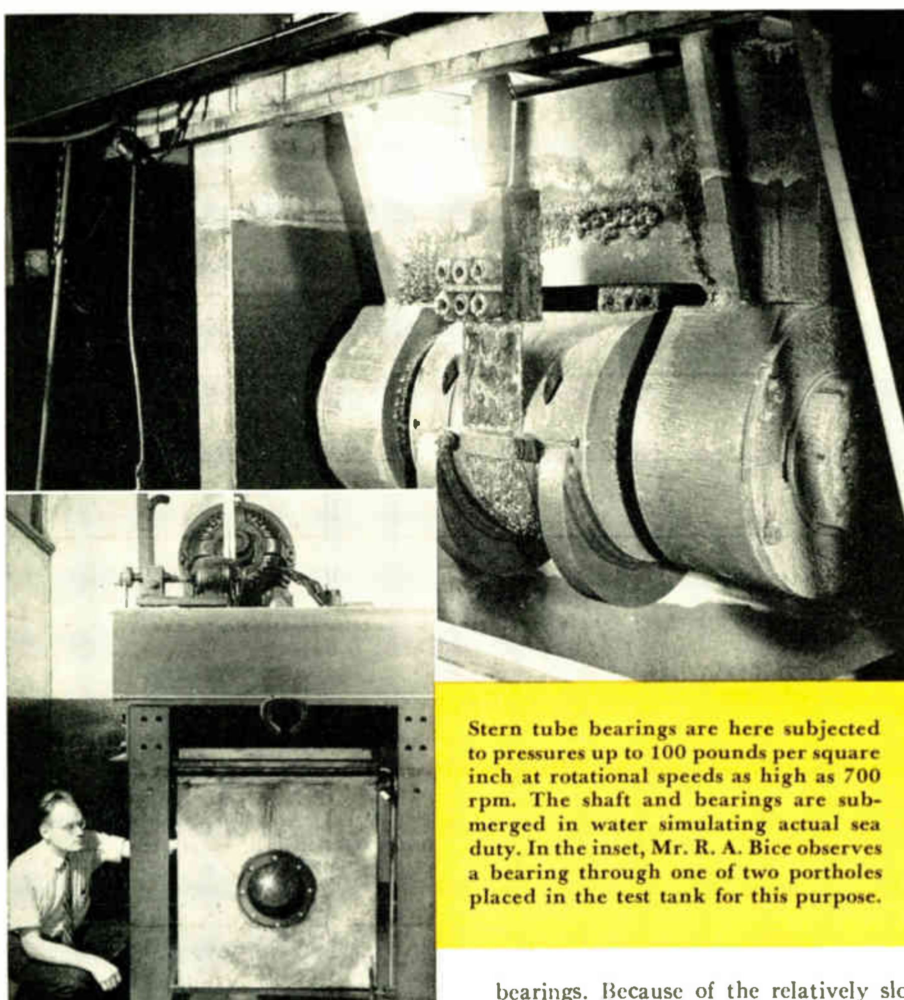
## Sea Water—A Lubricant

Ordinarily, water is not considered a lubricant until one's car slithers on a wet street or a wet dish slides into the sink. Actually, water early was found to be the most feasible lubricant for ship-propeller drive shafts. The material used in the bearing must be suitable for this type of lubrication and, for many decades, the two materials most used have been lignum vitae and rubber, the former a hard, close-grained wood. As its name implies, this wood is long lived. Both of these materials went on the scarce list with the advent of the war. Micarta, a hard, durable, plastic material, proved such an excellent substitute that it has supplanted in large measure the other materials for bearings of this type.

At the Westinghouse Research Laboratories, a machine was built that enabled the research engineers to determine exactly the qualities of these three materials—hard rubber, lignum vitae, Micarta—when used in ship-propeller shaft bearings. Service conditions are reproduced, including the provision of bearing pressures up to 100 pounds per square inch (total pressure of over three tons) while the shaft is revolving at a peripheral speed up to 700 feet per minute. The bearing and shaft, of course, are immersed in water.

Bearings of this type operate the same in principle as oil-lubricated, babbitt-type bearings. Because of the relatively slow rotational speed, and the great weights of the shaft and the propeller, the shaft does not center itself in the bearing but lies more toward the bottom. There the shaft is separated from the bearing by a lubricating film of water no more than two to three mils thick.

In general, there is a certain value of speed×viscosity/load at which the friction coefficient is a minimum. Below this, the coefficient increases rapidly because the bearing and journal are in rubbing contact. Above this value, there is a film of lubricant separating the two and the coefficient of friction increases slowly.



**Stern tube bearings are here subjected to pressures up to 100 pounds per square inch at rotational speeds as high as 700 rpm. The shaft and bearings are submerged in water simulating actual sea duty. In the inset, Mr. R. A. Bice observes a bearing through one of two portholes placed in the test tank for this purpose.**

The rubber in the stern tube bearings of a ship (through which the propeller shaft emerges from the hull) is about the consistency of automobile tire treads. These bearings show a gradual increase of friction as the speed is increased. It is felt that perhaps, because of the squeegee action of the rubber lands in the bearing, the shaft in this type of bearing is just starting to ride on a water film at 700 rpm. On both Micarta and lignum vitae bearings, the shaft is fluid supported from about 300 rpm upward.

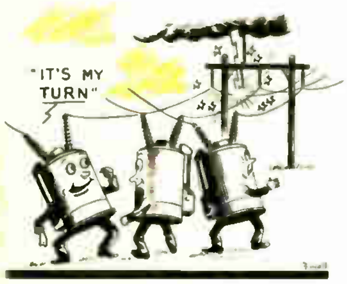
As with most products of nature, lignum vitae varies widely as to density and grain structure, whereas Micarta is a uniformly manufactured product held to close specifications and one whose performance can be anticipated. These tests also show that the Micarta bearing staves are more resistant to deformation than rubber. The great pressures cause the rubber to "flow" and assume a permanent set.

A great advantage possessed by Micarta over lignum vitae is that the bearing staves can be stocked without the necessity of any undue care. Lignum vitae, on the other hand, needs to be preserved under special conditions to control swelling, warping, splitting, etc.

**To minimize the work involved in testing magnetic materials a new testing control desk has been developed at the Westinghouse Research Laboratories. Heretofore, such tests required a considerable amount of equipment, occupying a large work area, and wired in "breadboard" fashion. In the new magnetic-testing control desk most of the elements necessary for testing have been housed in a corner-type switchgear cabinet. Controls with suitable name plates permit the testing to be done as a matter of sequential routine. Laboratory technicians are able to do quickly the testing that formerly required a research engineer.**

# PERSONALITY PROFILES

*H. N. Muller, Jr.* came with Westinghouse in 1935 immediately after being graduated from Dartmouth with a degree in physics. After but six weeks in the student-training course, the Central Station Engineering Department made a bid for his services—a bid he accepted. The catholicity of his interests is evidenced by his experience in such diversified fields as harmonic analysis of rectifier wave shapes, stability investigations, central-station problems, and current distribution and other characteristics of cables. He is the Westinghouse representative on the AIEE Committee on Power Generation. "Hank's" writing is straightforward English (see Feb., 1944 issue of *Westinghouse* ENGINEER) but at social (and business) gatherings, he convulses his friends with yarns in various dialects.




The second half of the team writing on selective-pole switching in this issue is *W. W. Parker*. He gains his authority on the subject from his position as master of the calculating board, on which selective-pole switching for specific systems has been tried in miniature. Parker has spent nearly 16 years working with the calculating boards at Westinghouse. Many of the improvements in the new a-c calculator, described recently in the *Westinghouse* ENGINEER, were produced by him. Probably no one has as intimate acquaintance with as many of the power systems of the United States as has Parker. Since assisting with the preparation of the article in this issue Parker has set out for new fields. By the time this is in print, he will be in Brazil as district engineer for the Westinghouse Electric International Company.

* * *

The problems of the Old Woman Who Lived in a Shoe are nothing as compared to those of *R. A. Frye*. He has to watch over more than 4000 purchasing specifications, some 1300 general process specifications and nearly 1000 general finish specifications of materials used by the Westinghouse Company. Yet he does it with apparent ease, unquestionably the result of a prodigious memory and long experience. Joining Westinghouse in 1913 as a production clerk, he became engaged in engineering standards work during the last war. In 1931 he was appointed Section Engineer, having supervision of the prepa-


ration, issue and coordination of all types of specifications (purchasing, process, finish, etc.) for all divisions of the Company; guidance of engineering standards on sizes of materials and all grades of materials; engineering data, small parts and general practices relating to drawings, nomenclature, definitions, etc.; preparation of all Materials Standards Books and all Design Standards Books; and the design of nameplates for most types of apparatus produced. When these duties leave him time for a variety of activities with national associations promoting standardization, no one can quite figure out. Frye insists that almost anything can be standardized—except hunting and fishing. Thank goodness!

* * *

A native Ohioan, *H. D. Holler* received his B.S. degree at Denison University in 1911 and continued his education in his home state, collecting three degrees at Ohio State University, Ch.E., M.A., and Ph.D. In 1915 he joined the Bureau of Standards, electrochemical division. The Westinghouse Research Laboratories at East Pittsburgh welcomed him in 1929, where, in addition to many physical chemistry activities, he has been a tower of strength in connection with a host of corrosion problems. A few years ago the call of the soil became too strong to resist and he purchased a 130-acre farm and has acquired the title of "Squire." He now combines research and farming.

* * *

Before *Charles Kerr, Jr.*, finished the work for a Bachelor of Science degree at the University of Virginia in 1919 he determined to become an engineer. So he moved to Boston and in three more years was graduated with his degree in electrical engineering from Massachusetts Institute of Technology. He came directly to Westinghouse, and received the usual introduction to industry through the graduate-student course. Railroads fascinated Kerr—as indeed they do perhaps a majority of men—so he indulged his desires by joining the Transportation Engineering Department. In these intervening two decades, nearly every type of electric vehicle on rails has seen his hand. However, his major interest has always been with heavy stuff; he has had much to do with the big electric locomotives on the Pennsylvania and the New Haven electrifications.

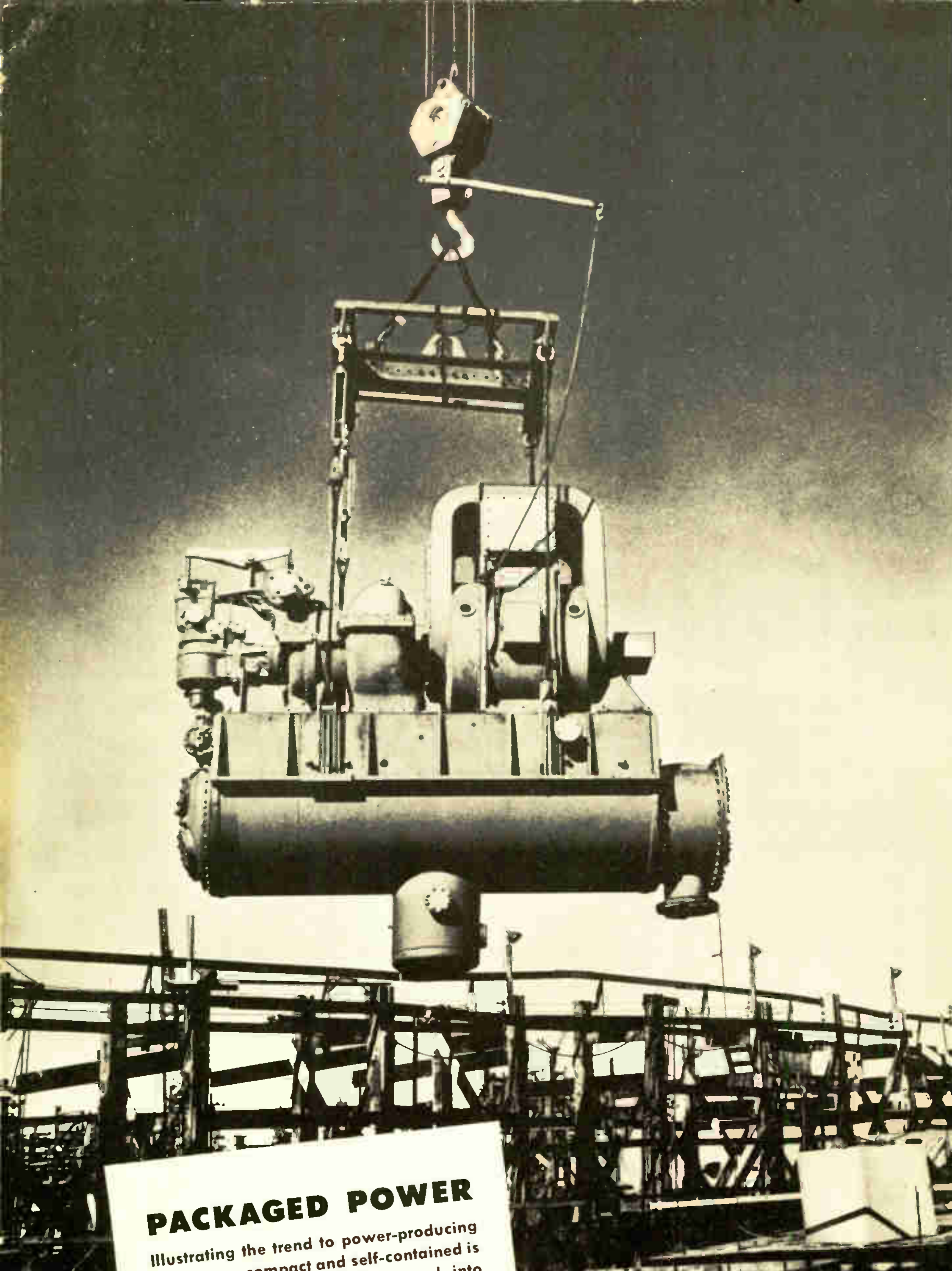
* * *

*W. Allen Brecht* gives proof that a mechanical engineer can distinguish himself in the electrical manufacturing field. Graduating with a B.S. degree in mechanical engineering from Penn State in 1922, and after a period in the Railway and In-

dustrial Motor Department, he set to work in Transportation Engineering and in 1935 became head of the mechanical section. Three years later he was elevated to manager of Transportation Engineering, and hence has under his direction the mechanical and electrical engineering of all sorts of electrically propelled vehicles.

* * *

Some people, like certain plants, transplant well. *John S. Newton* is one who does. Upon completion of the graduate-student course at Westinghouse in 1931, Newton spent seven years designing heavy rotating d-c machinery. Although he graduated from Oregon State in 1930 as a mechanical engineer, he has adapted himself to electrical design with the greatest of ease—seemingly. This electrical experience was followed by a period assisting in the application of marine propulsion machinery. Next came a plunge into steam engineering at Philadelphia in 1939. In 1942 he was made Manager of Marine Application Engineering and two years later Assistant Engineering Manager of the entire Steam Division. In these few years Newton has become a recognized authority on steam problems.



## PACKAGED POWER

Illustrating the trend to power-producing units, more compact and self-contained is this 3000-shp unit being lowered into the engine room of a troopship. With the engine room of a troopship. With the condenser for a foundation the turbine (left) and generator, complete with lubrication system, make a packaged unit, supplying power at 80 cycles to synchronous motors driving the propellers.