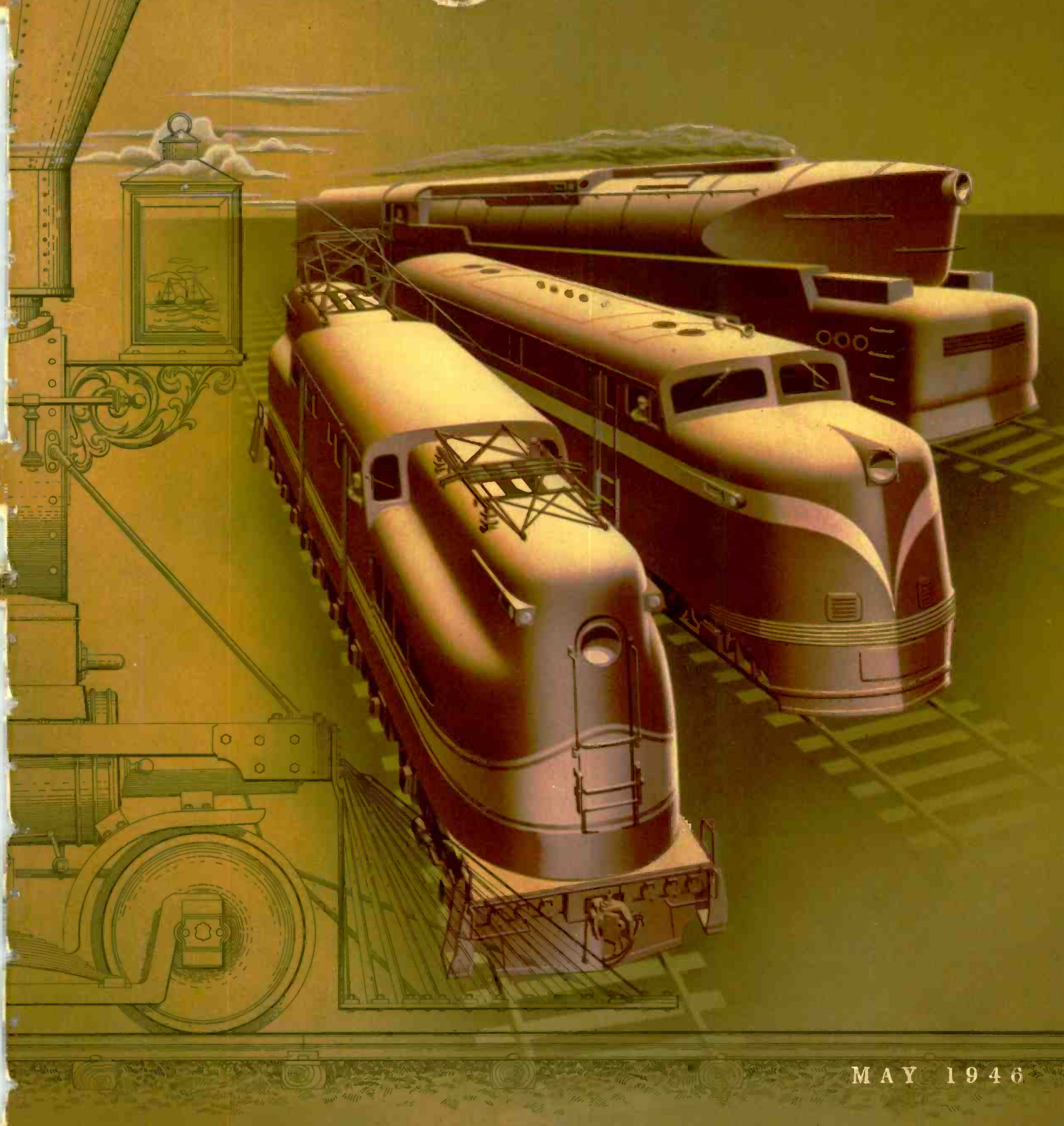
WESTINGHOUSE

Engineer



MAY 1946

Porcelain—An Ancient Art, A Modern Science

The electrical industry, only a little more than two generations old, depends to an extent seldom appreciated on one of mankind's oldest industries—pottery making. The use of porcelain, which is one specialized form of that ancient art, threads through nearly every phase of the electrical engineer's handiwork.

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The beginnings of pottery are lost in antiquity. The art was an independent invention of nearly every primitive people, as testified by the archeological findings in caves and graves the world over. The form of pottery known as porcelain, however, is more modern. Most historians agree that porcelain as we now know it had its beginnings about 600 A.D. in China under master potters of the T'ang dynasty whose work is still unsurpassed.

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Early adventurous European travelers, such as Marco Polo, brought specimens from China to Europe where attempts were made to copy the work of the Chinese artisans. But much secrecy surrounded the making of porcelain, the skills being carefully guarded and handed from father to son. This held true, surprisingly enough, until the turn of the present century. Attempts to make ceramics a science instead of an art appeared in the early 1890's. In 1894 the University of Ohio established a course of scientific study of ceramics, the first in the United States.

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Three qualities distinguish porcelain from other ceramics: its translucency (in thin sections), its vitrification (i.e., glass-like quality), and its high-fired glaze.

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The fundamentals of porcelain making have not changed from the beginning. The changes have been refinements in techniques, firing, etc., and in better controls of raw materials and qualities. Most porcelains consist of clay, flint (quartz), and feldspar mixed with various amounts of water, shaped by molding, pressing, or casting, and fired at from 1200 to 1500 degrees C. Protective glazes—which are but forms of glass—are applied sometimes after a preliminary, partial firing, but always before the high-temperature firing.

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High-voltage electrical porcelain is essentially just a high-grade porcelain. The ingredients do not significantly differ from those in fine chinaware. The processing techniques, however, while not basically different, are more exact. Few flaws can be tolerated. Firing must be more complete and controlled more precisely. The process refinements are extremely important to production of high-quality porcelain suitable for electrical use.

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The skin on an electrical porcelain insulator does a lot more than keep the water off. It provides a large portion of the mechanical strength, all out of proportion to its thickness. The glaze, which is a form of glass, may be only of the order of ten thousandths of an inch thick. However, applied to a porcelain rod that, bare, has a strength in tension of 10 000 pounds per square inch, it may raise the strength to 15 000 psi. Furthermore, not just any glaze will do. Some glazes may actually diminish the strength, by as much as three fourths.

The trick in providing a high-strength glaze is, in effect, to make one that, like a glove, is slightly larger than the body it covers. By using a type of glaze that shrinks in the firing and cooling a trifle less than the body it covers, it is held in compression. Thus considerable stress must be applied to overcome the compression force before the stress in tension is large enough to cause a crack, which is the Achilles heel of porcelain.

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One might think that to make the best high-voltage insulator would require building one with the highest possible surface insulation resistance. Not so. A high-voltage, power-transmission insulator must have built into it a certain small amount of surface conductivity, else the voltage may "pile up" at certain points, surpassing the corona point and allowing the insulator to become a miniature broadcast station and causing radio interference. The voltage is forced to distribute more uniformly over the insulator surface by the inclusion of a slightly conducting layer. This is now done by applying a film of suitable semi-conducting material under the glaze and next to the porcelain body. Curiously enough, one of the problems of building a radio-interference-proof insulator that long defied solution was making the high-resistance film stay put. Many films have the annoying tendency during the firing and curing process of working through to the outside of the glaze, where they can readily be destroyed.

Dr. Russell, author of the article on Zircon porcelain in this issue, had a large hand in developing a radio-interference-proof layer that stays put during processing and in the field of Zircon-type ceramics—a valuable addition to the porcelain family.

WESTINGHOUSE Engineer

VOLUME SIX MAY, 1946 NUMBER THREE

On the Side

The Cover—Our artist attempts to capture the idea of new, promising types of locomotives retaining some feeling of the romantic past of the "old iron horse." As discussed at length in this issue, the reciprocating steam locomotive, no longer has the field to itself. The electric, the Diesel-electric, and now the turbine types—both steam and gas—have their merits.

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Science Forum—An imposing group of the world's leading scientists and engineers will gather this month in Pittsburgh to honor one of America's all-time great inventors and industrialists, George Westinghouse, and to do a great service to scientists, engineers, and to the citizens of the world generally. The occasion is the George Westinghouse Centennial Forum held May 16, 17, and 18, sponsored by the Westinghouse Educational Foundation in celebration of the hundredth birthday of the inventor. The objective is to summarize, correlate, and interpret the great advances of science in the past five years, to estimate their effect on our future civilization and to consider subjects for future research. Symposiums will be held on "Science and Civilization," "The Future of Atomic Energy," "Transportation," "Communication," "Biological Science," and "Planning in Science." Twenty-eight internationally known leaders in their fields will make the addresses. Among these will be such men as Karl T. Compton, Enrico Fermi, J. Robert Oppenheimer, Archibald V. Hill, George Merck, L. W. Chubb, Vannevar Bush, Cornelius B. van Niel, Charles E. Kettering, Emory S. Land, Martin W. Clement, Frank B. Jewett, Robert P. Russell, Hugh S. Taylor, and Selman A. Waksman.

In This Issue

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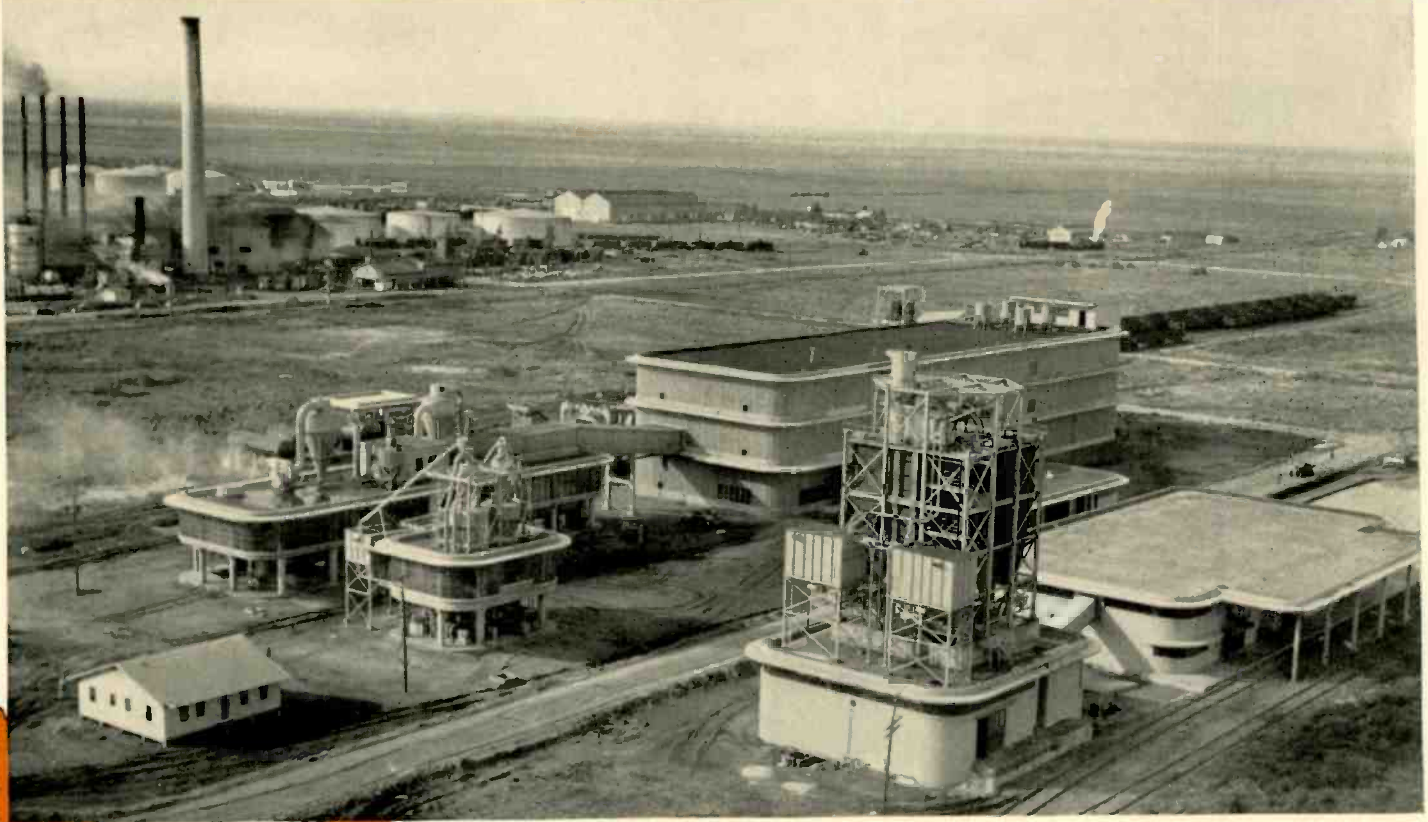


Modern starch plant illustrating agro-industry in Florida

Agro-Industry in the Everglades

The soil of the nation represents its ultimate wealth and its greatest source, not only of the familiar primary products, but of new and basic materials, augmenting those depleted or near exhaustion. Full and conservative use of the soil demands a combined application of modern agronomy, science, and engineering, fusing agriculture and industry. It is this which agro-industry envisions. It is this which agro-industry is achieving in the Everglades of Florida, with the cultivation of cane and root crops and manufacture of sugar and starch as sterling examples.

AGRICULTURE all too often suggests only food. Even then the steps between the growing plant on the farm and the package on the grocer's shelf are glided over negligently. Between the two lies a vast industry devoted to the processing, packaging, and distribution of agricultural products. In still another industrial empire the crops of the soil are converted into such goods as textiles and plastics. And while the interdependence of agriculture and industry—the two basic activities of man—has long been recognized, it has largely been in terms of agriculture as a producer of raw materials and industry as buyer and processor. Their problems were considered distinct, and historically a sharp line of demarcation has set the two apart.

In the last twenty years this segregation has become less and less distinct. The increasing complexity of modern life, the growing dependence of one activity of man on every other, and such broadly significant national phenomena as soil depletion and erosion—these and countless other social and economic factors have led to the concept of *agro-industry* in which modern agronomy, chemistry, and industrial engineering are combined to maintain nature's organic cycles and utilize most fully the diversified produce of the earth.

The concept of agro-industry is palpably large. It is, in fact, one of those grand ideas that stagger the imagination with their scope, complexity and implications. The integration of three fields as extensive as agronomy, chemistry, and engineering is a vast undertaking—of the stuff that dreams are made—but it is being pursued vigorously and successfully, for example, by the United States Sugar Corporation in the Everglades of Florida, near Lake Okeechobee. Here sugar cane, sweet potatoes, lemon grass, and ramie are grown and processed as a combined operation emerging from the processing plants as sugar, starch, oils and textile fibers. And here, where the backyards of the sugar and starch processing plants are cane and potato fields, agriculture and industry are transmuted into a single, integrated activity. Thus the influence of engineering on agriculture, for example, has eliminated soil erosion by introducing water-control systems and has doubled the productivity of field labor by introducing power-driven field cranes, wagons, and railroad-siding hoists and by establishing more efficient and less arduous harvesting systems. There is no soil depletion here. By utilization of the process-plant waste products, lands previously unproductive are made fertile. Meanwhile, during the last ten years, modern agronomy has increased the production of cane from

Prepared by Hugh Odishaw of the *Westinghouse* ENGINEER staff from published material and information provided by executives and technical experts of the United States Sugar Corporation.

23 to 34 tons per acre and raised the sugar content of the cane from 150 to 210 pounds per ton of cane.

Agronomy

Like all growing plant life, the crops of the Everglades produce mainly carbohydrates. The story of the Everglades is thus a story of sugar, starch, and cellulose, that class of organic compounds whose cyclic existence is the direct result of photosynthesis—an intricate process involving chlorophyll. Four agencies foster this process: (1) the soil, (2) the atmosphere with its oxygen and carbon dioxide, (3) water with its moisture-giving union of oxygen and hydrogen, and (4) the sunlight with its warm, actinic rays. (See "Carbohydrate Chemistry in Brief," p. 72).

In these prerequisites for the growth of plant life the Everglades are lavishly rich. Subtropical in character, the climate is suitable for an imposing variety of crops like sugar cane and sweet potatoes. An average rainfall of 55 inches per year insures sufficient moisture, and the land itself has a tendency to retain water. Only 20 feet above sea level, the Everglades region slopes seaward less than gravity flow of surface water requires. The soil itself, high in nitrogen content, is unrivaled in richness and productivity, for it is the result of countless generations of growth and decay of lush vegetation and of the silt carried down by floodwaters from the northern highlands. The heart of this region is Lake Okeechobee, next to Lake Michigan the largest in the United States, covering an area of 730 square miles and receiving the run-off from a watershed of some 5300 miles.

These natural conditions determine the agricultural techniques in the Everglades. Water control is crucial, and it is not a simple matter of drainage or irrigation. Indiscriminate drainage spells death for the soil. Where this has occurred, as in the back-country, wasting soil-fires are common, for the rich surface is high in organic content and burns readily. Adequate surface drainage must go hand in hand with the maintenance of a correct water table. An extensive system of arterial channels, lateral ditches, and underground "mole" drains carries off excess surface water and irrigates the fields when the water is low, using Lake Okeechobee as a depository and reservoir in turn.

The soil itself must be guarded against exhaustion, and chemical analysis of its vital components is continually made by the United States Sugar Corporation. Some fourteen elements are essential for the best growth of plant life, including nitrogen, calcium, magnesium, phosphorus, copper, zinc, sulphur and manganese. Deficiencies in the Everglades project are added prior to planting.

As a result of constant research thousands of improved varieties of sugar cane have been produced. Sturdiness, capacity to resist insect and bacterial pests, high sugar content in the case of cane, high starch content in potatoes, and maximum sugar or starch yield per acre-year—the ultimate criterion—are the goals. Of these thousands only a few have developed unusually desirable qualities and less than fifty have been planted extensively. But the search for new and better ones goes on.

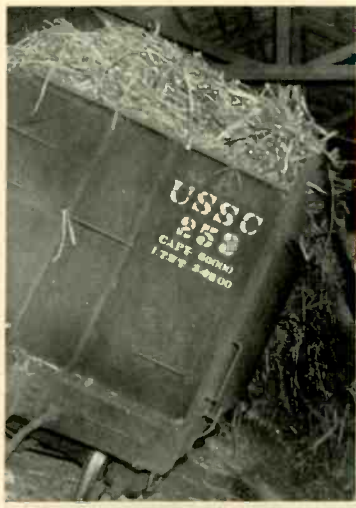
Agriculture is a cyclic process, but industry seeks continuous processes. Cereals generally have a harvest season lasting about three months. Storage is not feasible except at prohibitive cost. This means, first, socially undesirable fluctuations in labor requirements and, second, the impossibility of full utilization of processing plants.

In the Everglades, the agriculturist and the industrialist have pooled their efforts to reduce this disparity, with significant results. The sugar-cane season has been lengthened from three to seven months while the three-month sweet potato harvesting season has been tripled. Moreover, the planned program of transferring field personnel from one crop to another, as harvests dictate, increases continuity of employment. The results have been to provide year-round employment for over 80 percent of the peak number of employees and to keep the sugar- and starch-houses running at maximum capacity throughout most of the year, sugar grinding having expanded from 92 to 208 days, and starch manufacture from 100 to 300.

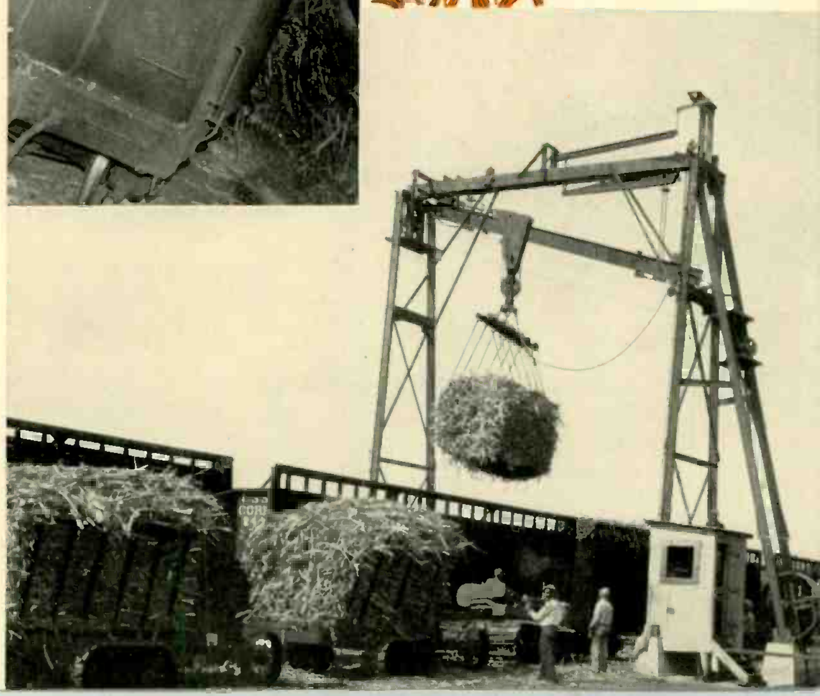
Sugar and starch are not only typical of agro-industrial activity in the Everglades, but they are in their own rights significant products of all agriculture. They are the two great sources of carbohydrates, the first consisting of rather simple molecules of low molecular weight, the second of large molecules of high molecular weight. Chemically both consist of carbon, hydrogen and oxygen—$C_{12}H_{22}O_{11}$ representing cane sugar and $(C_6H_{10}O_5)_n$ representing starch. The processing methods are in a rough way analogous insofar as extraction, purification, and drying can be considered the principal steps.

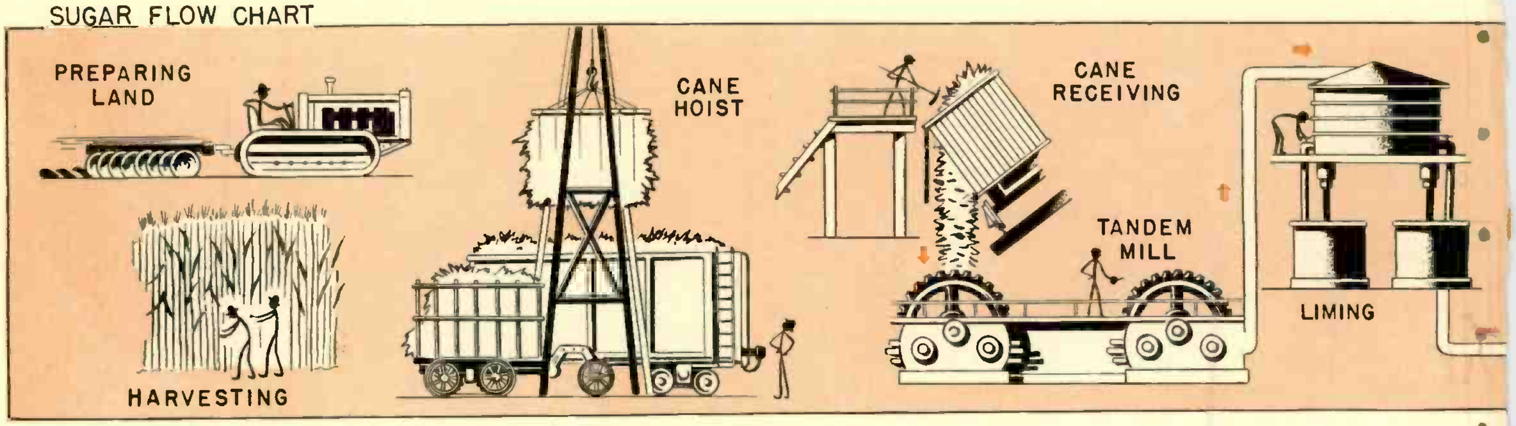
Sugar Processing

Cane has been grown and processed in the Everglades for many decades, but progressive deterioration, agriculturally and commercially, characterized the venture until the application of modern methods of agriculture and industry in the middle thirties. Water control and care of the soil were stressed; ploughing, planting, tilling and harvesting methods have been mechanized and systematized by an application of the same engineering principles so successful in processing; and waste products are fully utilized. In a few years, new procedures permitted the sugar-house, largest in the country, to establish record outputs of more than 7000 tons of cane in twenty-four hours.



Plantation-siding hoists transfer cut cane from field cars to standard-gauge railroad cars (below). At the sugar-house, hydraulic tilting of the cars (insert) dumps the cane onto a continuous conveyor leading to the extracting crushers and grinders.





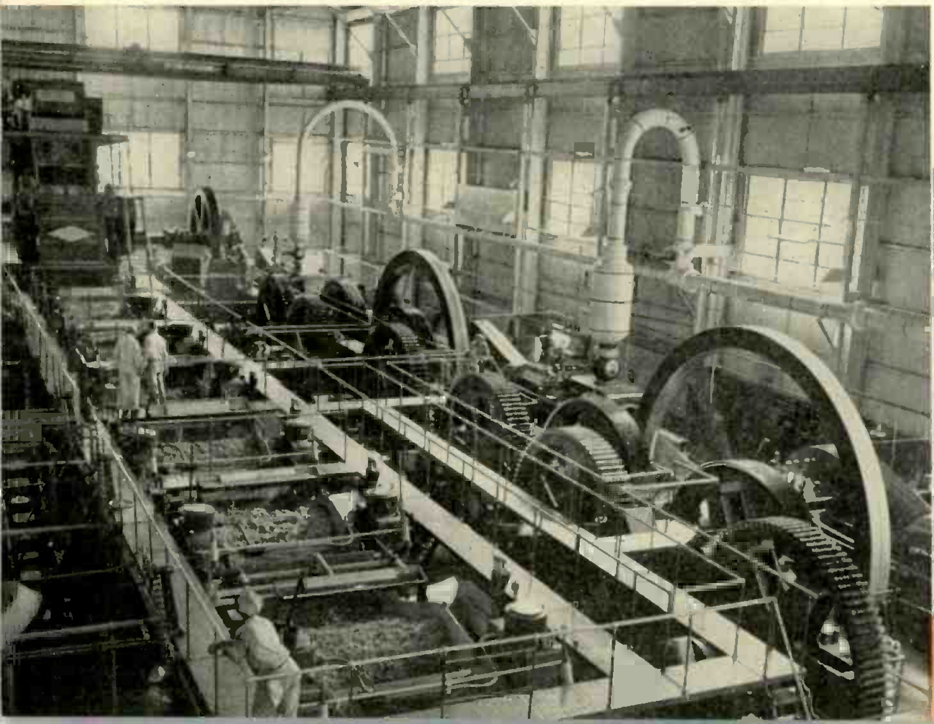
Such productivity requires all steps in the process from planting cane to shipping the raw sugar to be carefully planned and synchronized. At harvest time, the cane is cut and piled in the fields, with excess foliage stripped from the stalk and allowed to remain on the ground as a soil enricher. Mobile field cranes load the cane on field trucks which are drawn by tractors to plantation sidings. Here loading hoists lift and empty the field cars into standard-gauge railroad cars; about five field cars fill a railroad car whose capacity is over 22 tons. At the sugar-house, the railroad cars are first weighed and then the cane is dumped into a pit housing a continuous conveyor.

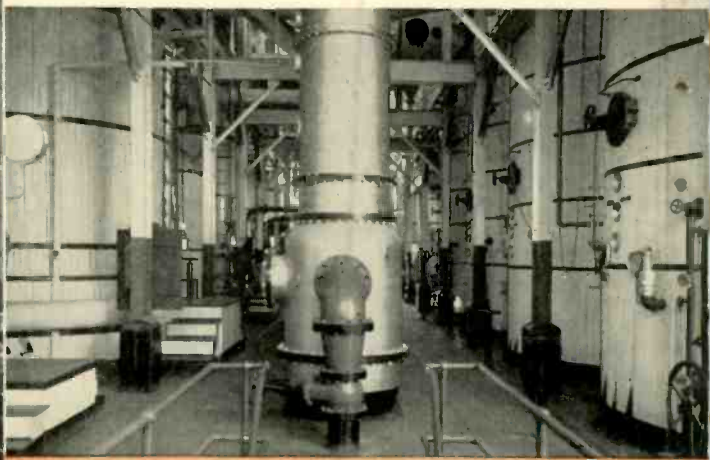
The first step in sugar manufacture is to extract the juice from the cane. This is done in mills that simply squeeze the liquid from the cut stalks by high pressure. As the cane is fed to these mills, it is first smoothed out and cut into short lengths so the flow will be uniform. A mechanical distributor evens out the cane for cutting. The cut cane is conveyed to the grinding tandem, which consists of two sets of shredding knives, a crusher, and seven grinding mills, each of which has three rolls. The crusher receives the finely divided mass of cut cane from the cutters, and squeezes out 77 percent of the juices. The seven succeeding grinding mills extract another 5 percent or so in a similar fashion and deliver the residue as an evenly distributed fibrous mass called bagasse. Bagasse is burned as fuel and supplies almost all the power and steam needed in the processing plant.

The juices from the crusher and mills proceed to the next stage: heating and purification. Centrifugal pumps convey the juice to liming tanks for neutralization after large fibers from the mill have been screened out. The juice is heated to 220 degrees F, to inhibit bacterial growth, and is then passed to Dorr clarifiers where the scum tends to settle towards the center and bottom of the tanks while the clear juices are run off. Successive dilutions and clarifications of the scum remove remaining cane juices, the final scum serving as an excellent fertilizer for the fields.

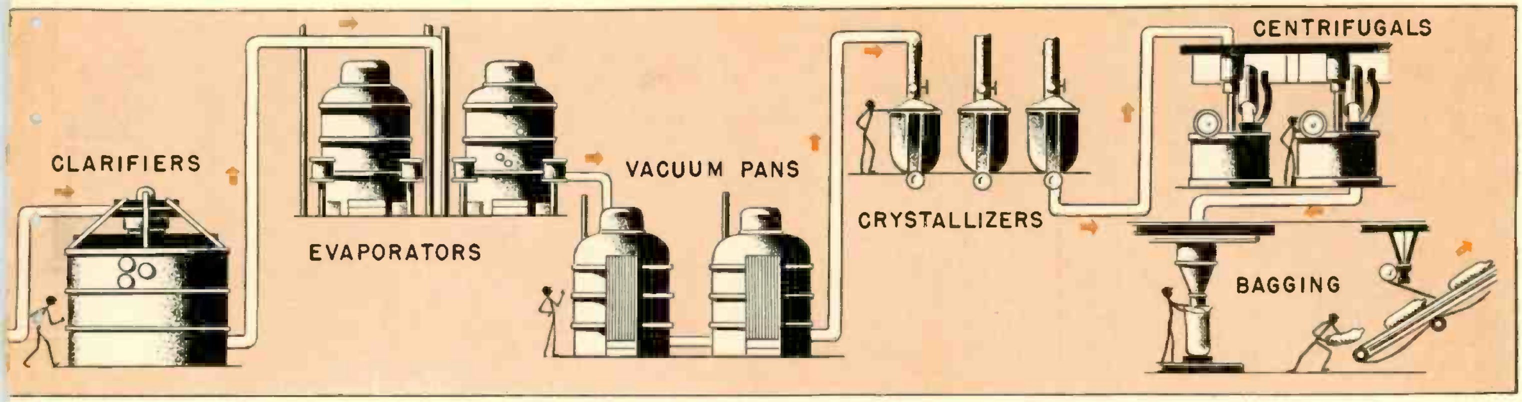
Clear juices are now pumped to a series of four evaporators, which reduce the water content from 85 to 40 percent. In the first evaporator, exhaust steam from the tandem mill motor provides the heat; in the remaining three evaporators, vapor from the preceding stages is used. Successively lower pressures are used because the vapor temperatures decline progressively through the four stages. Additional water extraction is next accomplished in vacuum pans, which convert the syrup to crystals under 25 inches of vacuum at 150 degrees F and reduce the water content to 5 percent. The mass cooked in the pans is called the "massecuite," and the U. S. Sugar Corporation uses a three-stage or "three massecuite" system because a larger portion of sugar can be crystallized from the syrup by reusing the sugar-laden molasses from successive pans. Thus the molasses of the first stage is mixed with fresh syrup entering the second stage, whose molasses, in turn, is fed to the third stage where "seed" crystals (necessary for efficient crystallization in the prior stages) and the final "blackstrap" molasses are the end-products in contrast to the sugar of the preceding stages.

Centrifugals spin the crystallized sugar mass free of molasses, which is returned to the vacuum pan system, while the sugar is conveyed to storage hoppers and subsequently to automatic bag-filling machines. Two end-products thus emerge from the sugar-house: raw sugar and molasses. By-products during the process, however, are carefully utilized. Thus





Shredded cane enters this high-pressure mill (left) where sugar juices are extracted by a crusher and seven stages of grinding. After acid-neutralization and clarification, the water-content is reduced from 85 to 40 percent by heating the



bagasse is turned into steam and electricity; scum residues are returned to the fields as fertilizers; and even the water in the cane juice is used, for on vaporizing in the first stage of juice evaporation it serves as a heating gas for subsequent stages, finally ending as condensate water. Of the primary products, molasses has the lesser value. It can be sold to distillers, but in recent years its value as cattle-feed has opened up a tremendous new field for it.

The sugar, as it leaves the Everglades sugar-house, is known as raw sugar and requires further refining for such uses as table sugar. It is rather large in crystal size compared to table sugar, has a light tan color and a slight but pleasant flavor in addition to its sweetness. The familiar use of table sugar suggests, of course, its great food value. But this familiarity has curious consequences. It is not generally known, for example, that sugar is a pure organic compound and that of all organic compounds it is prepared in the largest quantities in the United States—even chemistry students forget this. Thus, in 1939, over 13 billion pounds of this compound were produced; isopropyl alcohol, next in quantity, accounted for only a fraction of this—some 179 million pounds.

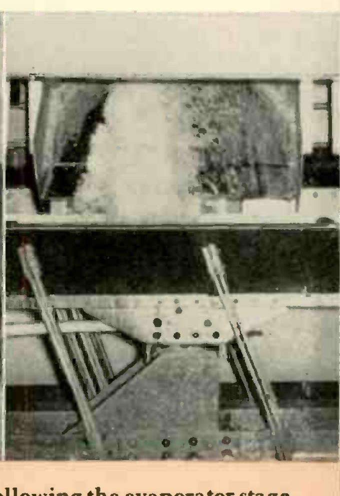
Of the 10 000 or so sugar derivatives known, some half a dozen are outstanding examples of the industrial role of sugar. These include alcohol, acetone, butanol and citric acid. The conventional use of alcohol is already well known; however, the demand for synthetic rubber has bred a new appreciation for this valuable derivative. Acetone, another sugar product, plays a key role in the rayon and film industries. Butanol, an excellent solvent created by bacterial fermentation, has made the nitro-cellulose lacquer industry possible. Citric acid, another fermentation product, is indispensable in the soft-drink industry and important in medicine, while chemical derivatives are used in the plastics industry.

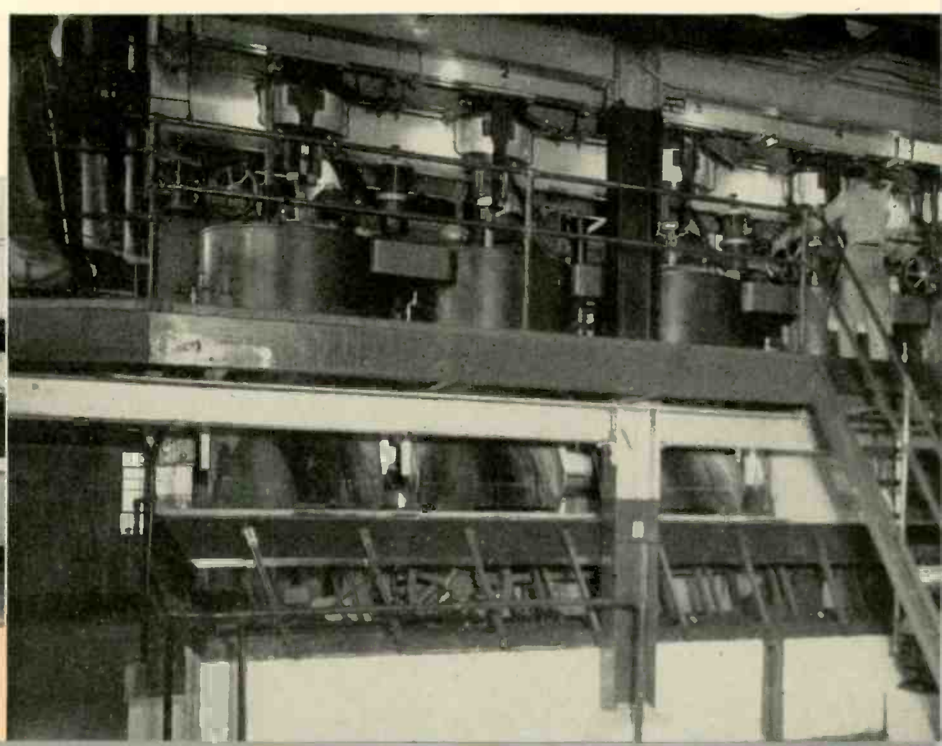
Although sugar is used in these and other industrial applications, its primary role is as a food. An excellent source of carbohydrates for the human body, sugar supplies 15 percent of caloric intake, appearing in countless food combinations—in candies, pastries and soft drinks, and in a variety of consumers' forms like table, icing, or brown sugar. The fact that the average American consumes his own weight in sugar annually suggests the importance of the product.

Starch Processing

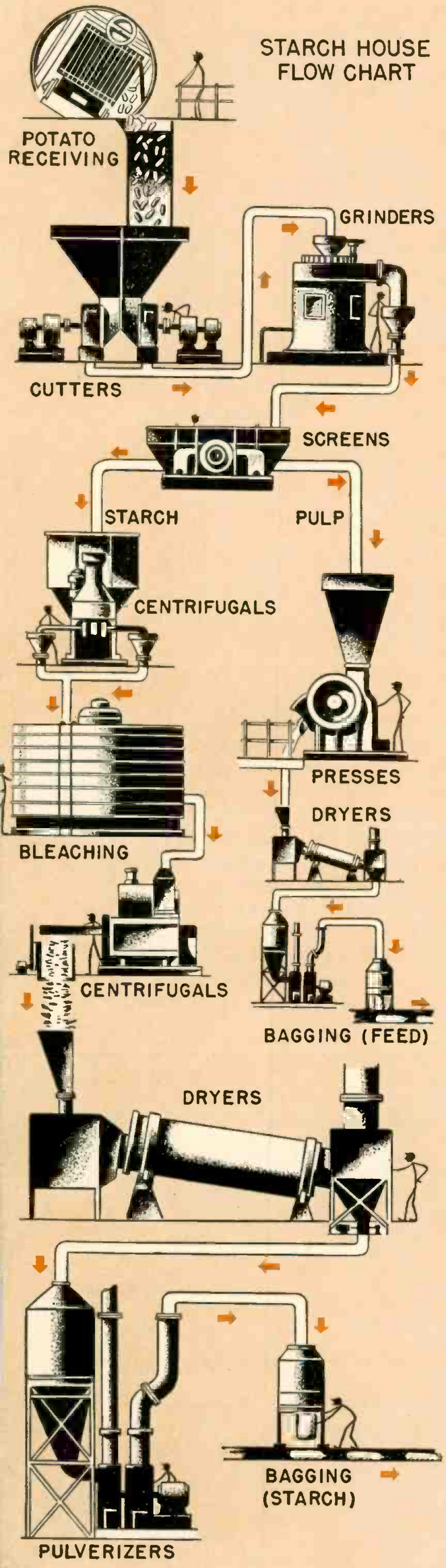
In contrast to cane sugar or sucrose, which is a dissolved component of the cane juices, plant starch appears as microscopic granules having a concentrically stratified structure. The outer layers are denser than the nucleus and are impervious to water. If the outer layers are ruptured, however, water is absorbed and the granules swell, a small quantity of starch passing into solution. The processing problem is largely one of slicing and grinding the root or tuber bearing starch—the sweet potato in the Everglades—so that the cells containing the starch are ruptured. The starch granules are then washed free of the pulp, dried, and pulverized.

Like cane, the potatoes are brought by field cars to railroad cars at plantation sidings and are then hauled to the processing plant, weighed, and dumped into a soaking pit. The roots remain in the soaking pit about thirty minutes to soften and wash off clinging dirt. A continuous drag conveyor picks up the potatoes and conducts them through a series of washers—two rotary washers and a brush washer, all equipped with water sprays. The roots then pass over a picking table where remaining foreign materials like vines and stones are manu-





From vacuum-pan crystallizers following the evaporator stage, the sugar-mass is pumped to centrifugals (upper left). A bank of these high-speed centrifugals (right) spins the sugar crystals free of adhering molasses, and the crystals fall onto a mov-



ally removed. A continuous bucket elevator lifts the roots 60 feet, the height of the wet house, and a belt conveyor conducts the roots to a large storage hopper.

From the storage bin the roots pass to slicing grinders, emerging like shoe-string potatoes, and then to a tank where sufficient water is added to facilitate pumping. Attrition mills grind the pulpy mass, rupturing the cells secreting the starch granules. Classifiers remove waste fruit water and the thick mass is diluted with clear water so that the ratio of water to solids is three to one. The slurry is pumped to vibrating screens. The underflow of these screens is a mixture of starch and water; the overflow, pulp and water. The pulp proceeds through dewatering presses, dryers, storage bins, and the weighing house where it is bagged as stockfeed. The water from the presses contains a small amount of starch and is returned to the processing system.

Three stages of centrifugals thicken and purify the starch underflow of the vibrating tables. The starch slurry is then bleached with sodium hyperchlorite, washed, and formed into cakes by filters. High-speed centrifugals reduce the water content to approximately 35 percent, and the thick white starch is conveyed by belt to the dryer building. The rotary dryers pull in air from the atmosphere through a grid of steam coils. The dry starch is expelled and blown by an air system to the pulverizer building, whereupon the starch is ready for packaging and shipment or storage.

A variety in the quality and moisture content of the end product can be attained, for two lines of flow are maintained after the starch has passed through the centrifugals following the vibrating screen stage. By acid modification, starch of any degree of viscosity can be prepared. Thus blends in accordance with customer specifications are feasible. The capacity of the plant is 720 tons of roots per 24-hour day resulting in the production of 120 tons of starch, 40 tons of feed, and 560 tons of waste fruit juices. The uses of starch are as diverse as those of sugar. Starch, like sugar has an important role as a food, appearing in desserts and countless prepared foods. Industrially, starch is critical in textile and paper finishing, laundry products, dextrines, and explosives—to mention a few of its encyclopedic uses.

Power, Waste Products, and Water

Sugar- and starch-processing plants require electric and steam power for operating motors; electric power is also needed for the lighting and miscellaneous purposes not only in the plants but in the adjacent city of Clewiston; large quantities of steam are used in the sugar-house; and the starch-house requires great volumes of water.

The power plant serving these demands consists of eight boilers and five generators having an electrical capacity of 7160 kw and a capacity of 375 000 pounds of process steam per hour. Either bagasse (the cane pulp left after sugar extraction) or fuel oil can be burned in the boilers. The newest boiler, installed in 1945 for the starch-house, can also burn methane, a by-product of the starch-house waste. Almost all of the power requirements of the sugar, starch, and lemon grass plants and the city of Clewiston are supplied by the burning of bagasse and methane.

The manufacture of methane is a typical illustration of the application of engineering ingenuity to the problems of agriculture and industry. Waste juices, totalling 560 tons per day from the starch-house, have high organic content and must be processed before disposal. Pumps divide the organic matter into particles less than an eighth of an inch. The slurry is heated to 90 degrees F and conveyed at the rate of 1000 gallons per minute to digesters—a bank of four tanks where decomposition occurs in a four-day cycle, producing almost a million cubic feet of methane.

The liquids pass next through large clarifiers and filters. Chlorination follows and excess water, surpassing in quantity and quality the water drawn from the lake for processing purposes, is discharged to canals tied in with the lake. The solids precipitated or settled through the various stages are pumped to sandy-type fields for soil enrichment. Thus, not only is methane gas produced, but barren fields are redeemed and clear water is added to the Everglades land and lake system.

Starch processing, it is evident, requires large quantities of water. The maximum daily demand is 4 000 000 gallons. Of this, 3 000 000 gallons must be purified before use in starch processing; 1 000 000 gallons are suitable in the raw state for the early washing of roots. The demand for water in such amounts led to the construction of a novel pumping station situated in Lake Okeechobee, five miles from the shore and seven miles from the starch-house. Water analysis indicated that the best source, temperature- and purity-wise, was this location and a concrete pumping station was built five miles off shore. A 75-hp, 1175-rpm electric motor is used for normal operation while a 190-hp, 1330-rpm gasoline engine stands by for emergency use.

The relative inaccessibility of the pump accentuated the routine supervision and maintenance problem. Even if three one-man shifts were established, communication posed a problem. Power-line carrier, in the first application of this type, turned out to be the engineering solution. The relatively high-frequency energy is impressed on the cable carrying 60-cycle power to the electric motor. A variety of services are automatically provided by the carrier-current system. First and most important, the system starts the stand-by gasoline engine on failure of the electric motor, regardless of the cause, maintaining continuous pumping. At the option of the controller at the starch-house, either engine may be started or stopped. Thus personnel need not be kept at the pumping station. If maintenance or repair requires the visit of a technician at the station, carrier telephone communication between the station and the starch-house is also available. The carrier system also measures water-flow and responds to photo-electric devices betraying intruders.

This application of power-line carrier, well known in central-station practice but unusual in the food industry, not only solves a special problem but accents the dominant role of contemporary engineering. The design of modern food plants is characterized, above all, by coordinated engineering from the handling of materials to the shipment of the finished product. The starch-house, for example, has humidity-resistant motors while the motor controls are constructed so that they can be hosed down during regular washings of the plant for sanitary reasons. Moreover, automatic indicating panels are strategically placed, revealing any interruptions in the continuity of production.

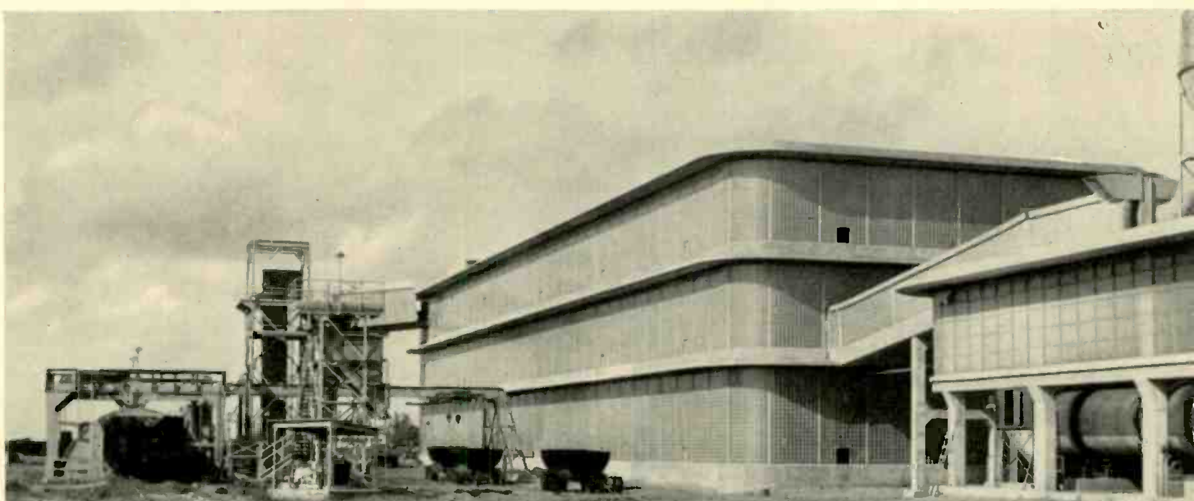
Combined Operations

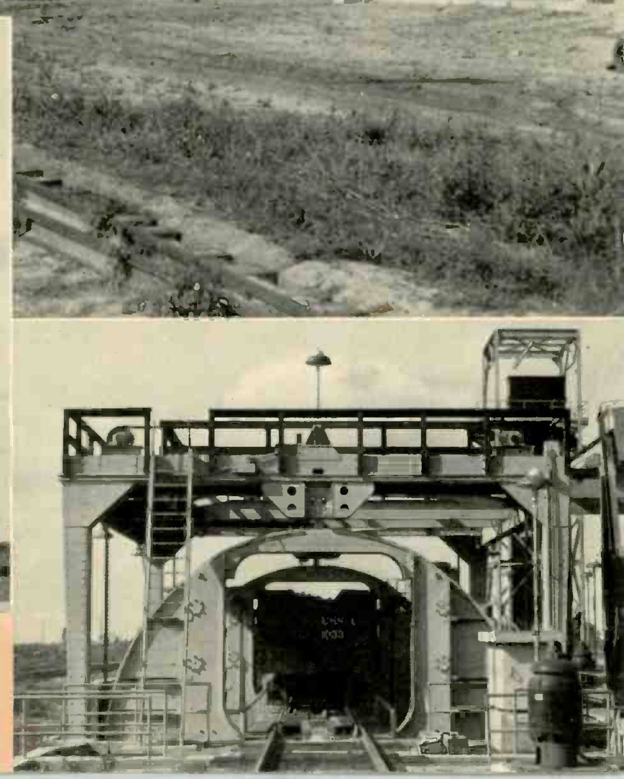
Sugar and starch, the principal products of the Everglades project, are by no means the only ones. Research by the U. S. Sugar Corporation disclosed the need for other growths beyond the original cane, in order to balance the agro-industrial program. Lemon grass was introduced for the production of essential oils. Production of ramie, a plant producing fiber of unusual strength—eight times that of cotton or silk and three times that of hemp—has been undertaken. In addition, research has explored the production of vegetable oils, fats, and proteins from such crops as peanuts and sesame.

The Everglades version of agro-industry has many other tantalizing possibilities. Bagasse, for example, now burned as fuel, consists almost entirely of cellulose and can be utilized in the production of cellulose pulp, synthetic fibres, and plastics. During the war, pilot-plant work saw the production of needed boxboard from bagasse. The waste juices, now providing soil fertilizers and methane for fuel, can be transmuted into solvents, proteins, acids and alcohol. Blackstrap molasses has already assumed an important role as a cattle finishing-feed rivaling corn; four thousand acres of improved pastures have been utilized for cattle raising on the project. Moreover, fermentation of molasses and starch opens the door to the manufacture of solvents, dry ice, carbon dioxide and scores of secondary products.

These actualities and potentialities are illustrative of combined operations in the agro-industrial sense, and national welfare calls for concepts which offer opportunities to offset, in part, our diminishing natural resources. For some of the once-considered inexhaustible resources are even now seriously depleted.

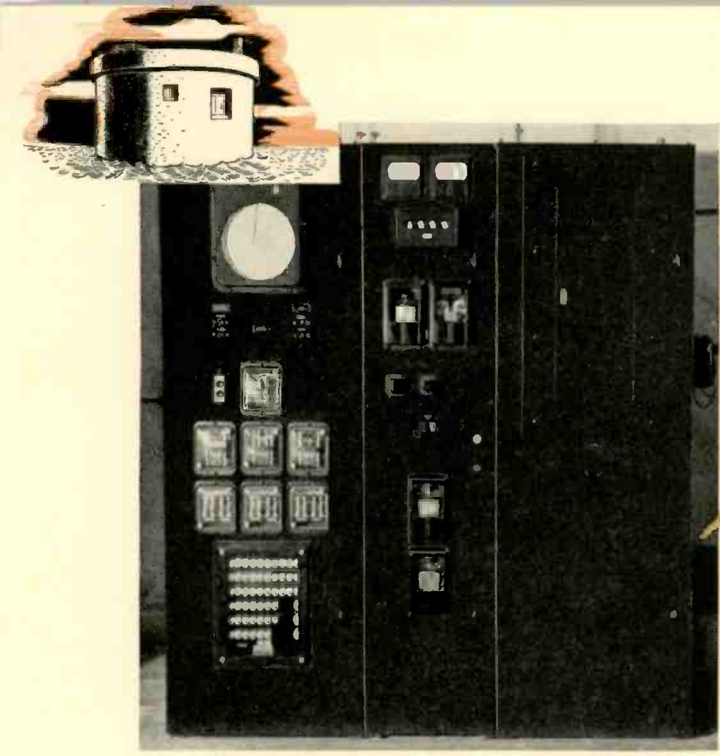
Simple national wisdom suggests the husbanding of that wealth—on or in the earth—which once gone, is gone forever. Lead and zinc production, for example, exists only by virtue of subsidizing depleted mines. Copper reserves of good quality are definitely limited. The rich, easy-to-get iron-ore deposits have an estimated life of only ten to forty years at present rates of consumption.* The extent of petroleum reserves is a matter of debate, but the argument centers solely on whether the reserves will last for fifteen years or fifty. Most of the once unlimited forests are gone. Some—but not all—of these could be regrown in a few generations, although only trivial attempts have been made.





Electrically tilted cars (right) dump the sweet potatoes into soaking pits beside the "wet-building" of the starch-house (above). The extracted starch is dried in rotary dryers (upper right), blown to the pulverizers, and then weighed and packed in the "scale-building" (insert above).

*See "Iron Ore—What It Is, Where It Comes From, How Much Is Left," *Westinghouse* ENGINEER, July 1945, p. 110.



The offshore concrete station (insert) pumps four million gallons of processing water daily. Power-line carrier controls pump motors, measures water flow, and provides telephone service. Pump carrier unit is shown above.

Whether or not the path of conservation is followed, economics will inevitably force two courses. One is the use of lower grade reserves or substitutes. Thus taconite, an inferior iron-ore, is important in the long-range picture of the ferrous industries, while lighter metals—in particular magnesium,** for the sources of magnesium are more extensive than of aluminum—can replace iron and steel in many applications.

The other course is to grow raw materials. Such crops as those of the Everglades, for example, offer untold opportunities in the production of plastics, capable of assuming some of the roles of metals and of fuel alcohols. Timber offers the same possibilities. The chief value of our forests, however, lies in soil retention, for the top eight or nine inches of soil—the essential wealth of the nation—depend on trees and certain grasses for continued existence. Where deforestation has occurred, soil erosion, dust storms, and floods have followed inexorably.

Depletion of such critical commodities as metals and petroleum has turned attention to the soil, but this is obviously paradoxical if the soil too is being laid waste. It is self-evident, even to the point of being a platitude, that conservation of the soil is mandatory. Yet agro-industry, as practiced in the Everglades, is turning this very platitude into a sane, rational reality. Water control, fertilization, crop diversification combined with a thorough use of all parts of plant growth and an imaginative application of science and engineering are the secrets. Agro-industry—synonymous with agronomy, chemistry, and industry teamed together—spells, in short, a balanced agricultural and industrial economy.

**See discussion of magnesium, *Westinghouse* ENGINEER, March, 1944, pp. 43 and 46.

Carbohydrate Chemistry in Brief

Carbohydrates comprise a great class of organic compounds including sugar, starch, and cellulose and embracing all growing plant life. The building blocks of carbohydrates are carbon, hydrogen, and oxygen. Carbon is secured from the atmosphere in the form of carbon dioxide (CO_2), present in the atmosphere to the extent of 3 to 4 parts in 10 000 by volume. Hydrogen and oxygen are secured from the soil as water. The formation of organic compounds in plant cells results from the reduction of CO_2 in the presence of H_2O.

The process, extremely complicated and imperfectly understood as yet, involves photosynthesis in which chlorophyll, the "green" of plants, plays a key role. Carbon dioxide and water are converted by the chlorophyll into organic compounds, a reversible reaction:

$$CO_2+H_2O \rightleftharpoons O_2+\text{Organic Compounds}$$

There are, however, a number of complicated intermediary steps in this reaction. The green parts of growing things constitute, in effect, a rather elaborate chemical factory. Here are located the two chlorophyll pigments — the blue-green chlorophyll-a ($C_{55}H_{72}O_5N_4Mg$), the yellow-green chlorophyll-b ($C_{55}H_{70}O_6N_4Mg$) and certain yellow pigments, in particular carotene ($C_{40}H_{56}$) and xanthophyll ($C_{40}H_{56}O_2$). The first step in the process sees a combination of carbon dioxide and water to give carbonic acid (H_2CO_3):

$$CO_2+H_2O \rightarrow H_2CO_3$$

This is reduced by chlorophyll-a to formaldehyde (H_2CO) and chlorophyll-b also results:

$$H_2CO_3+C_{55}H_{72}O_5N_4Mg \rightarrow H_2CO+C_{55}H_{70}O_6N_4Mg+H_2O$$

This process is continuous because carotene reduces chlorophyll-b to chlorophyll-a, becoming xanthophyll in the process:

$$C_{40}H_{56}+2C_{55}H_{70}O_6N_4Mg+H_2O \rightarrow 2C_{55}H_{72}O_5N_4Mg+C_{40}H_{56}O_2$$

Xanthophyll, in turn, is reduced by plant enzymes to carotene, and the regeneration permits the repetitive production of formaldehyde.

This highly active compound tends to condense into what may be considered the first sugars—glyceraldehyde and dihydroxy acetone:

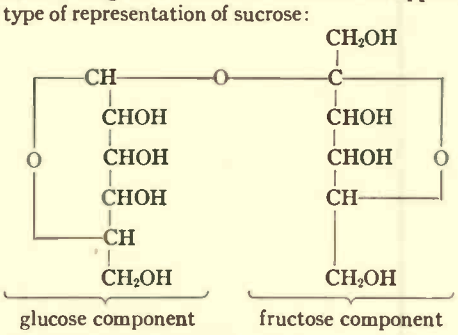
$$3\left(\begin{matrix}H\\H\end{matrix}\!\!>C{:}O\right) \rightarrow CH_2OH.CHOH.CHO \quad \text{(glyceraldehyde) or}$$

$$\rightarrow CH_2OH.CO.CH_2OH \text{ (dihydroxy acetone)}$$

Two molecules of glyceraldehyde may condense to yield glucose (grape sugar), or one molecule of glyceraldehyde plus one of dihydroxy acetone to yield fructose (fruit sugar). Both of these sugars may be represented by the formula $C_6H_{12}O_6$ and the chemical differences arise out of differences in the structural arrangement of the elements in the molecules. Glucose and fructose are two of the five most important natural sugars; the other three are sucrose (cane sugar), maltose (malt sugar), and lactose (milk sugar), which have the general formula $C_{12}H_{22}O_{11}$. The relations among these sugars are close, and it is simple to change from one to the other. Thus maltose and water combine to give glucose, while the glucose and fructose present in cane combine to form sucrose and water:

$$\underset{\text{glucose}}{C_6H_{12}O_6}+\underset{\text{fructose}}{C_6H_{12}O_6} \rightarrow \underset{\text{sucrose}}{C_{12}H_{22}O_{11}}+\underset{\text{water}}{H_2O}$$

The structural arrangement within the molecule is apparent in the following type of representation of sucrose:

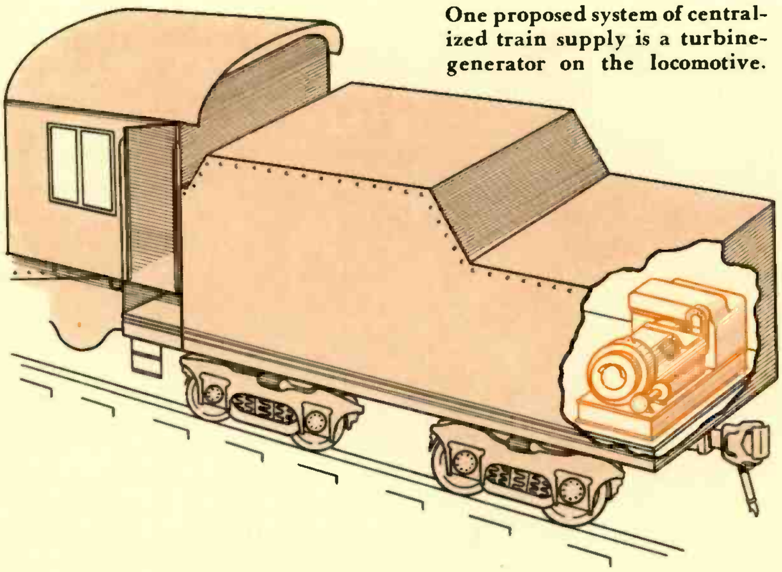


The process of producing sucrose in cane is a cumulative one; and, whereas equal portions of fructose, glucose, and sucrose are present in young cane, the proportions in almost ripe cane are 1:3:82.5.

Dehydration of many molecules of glucose yields starch, a white, odorless, tasteless compound having the formula $(C_6H_{10}O_5)_n$. Similar dehydration of fructose results in the compound known as inulin, akin to starch in its properties and formula. Not much is known about the structure of starch and inulin, but they are valuable as sugar-storage devices and in the formation of cellulose.

Oxidation of sugars can produce organic acids: enzyme action produces organic hydroxy compounds or alcohols, while esters result when compounds are formed between such acids and alcohols. Oils and fats, for example, are the esters produced when acids of long carbon chains react with one of the polyhydroxyl alcohols. If nitrogen is brought into the picture, proteins ensue. The condensation of the $-NH_2$ complex, or amino group as it is commonly called, with certain stages of carbohydrate synthesis or degradation creates compounds of high molecular weight comprising the plant proteins, which are digested and synthesized by animals into animal protein.

The intimate, successive, and complex carbohydrate relationships recapitulated here account for the importance of carbohydrates as foods, as primary factors in the production of fats and proteins (the two other basic foods), and as versatile materials in the creation of such synthetic products as fuels, butadiene, textiles, and plastics.



One proposed system of centralized train supply is a turbine-generator on the locomotive.

As the load in railroad cars has grown from watts to kilowatts, the time-honored d-c system with battery and axle generator has struggled manfully to keep pace. But even greater electrical loads, about to materialize from the vivid imagination of car designers, must be accommodated. The conventional axle-powered d-c system can by no means be counted out, but the time has arrived for consideration of other types of power plants and of alternating current.

H. H. Hanft
Railway Engineering Department

H. W. Graybrook
Transportation Equipment Engineer,
Westinghouse Electric Corporation

Power Plants for Railroad Cars

The electrical load of a modern passenger car has become so sizable that the power supply can no longer be readily dismissed as a minor component of car design. The plans for the new air-conditioned cars call for connected loads of nearly 20 kilowatts per car. This in itself is a power plant of not inconsequential size, but it becomes surprisingly large when considered in train-length proportions. The total connected load of a 14-car train with two electrically equipped diners will be 316 kw. This is significant on several counts. The size and weight of individual power plants become troublesome. The weight alone of batteries and generators adds noticeably to the train load. And finally, because power in the conventional system must in the last analysis come from the locomotive, a significant amount of the engine power is absorbed in supplying the electrical system. The 316-kw connected load represents a drain on the locomotive—considering all intervening losses—of about 650 horsepower, or nearly one fifth of the output of the average locomotive.

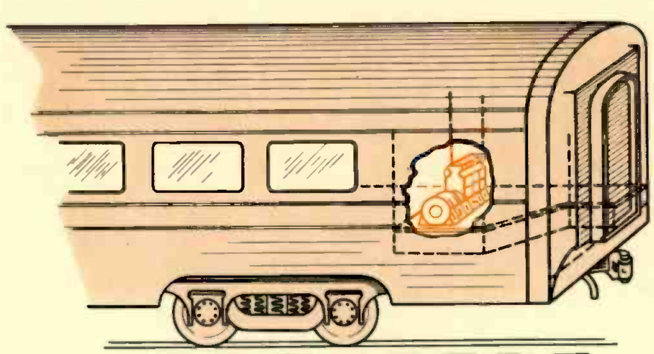
The Direct-Current System

The present and traditional power supply for railroad cars is a battery and a d-c generator belted or geared to the axle. Until about 1905 no electrical equipment was carried on passenger cars. Lighting was by gasoline, kerosene, or Pintsch gas lamps. Then a few incandescent lamps were introduced. These were served by 300-ampere-hour electric storage batteries carried in boxes under the car. The connected load of 600 watts drew about 20 amperes at 30 volts. The battery was charged by a 2-kw, 40-volt generator mounted under the car, and driven by flat belt from a pulley on a car axle.

In the mid-1930's, electromechanical air conditioning necessitated far greater battery and generator capacity. Thirty-two-volt systems required 16 lead-acid cells of 1200-ampere-hour capacity, weighing approximately 4800 pounds. Sixty-four-volt systems needed 32 cells rated at 600 ampere-hours, likewise weighing 4800 pounds. The corresponding generator capacity, at least 20 kw, was far too large for flat-belt drive, especially in northern states where snow is encountered. V-belts became general. Later, a geared drive with propeller shaft and automatic clutch appeared. This d-c system now is widely used on most air-conditioned railway cars.

With axle-powered generators the load of a stationary train must obviously all be taken from the battery. Only when the car is moving faster than a certain speed is the generator able to carry the load and also supply power to recharge the battery. A current element in the generator control limits generator output to a safe value, and a voltage element prevents overcharging the battery. Inverters or small motor alternators supply alternating current to utility outlets serving electric shavers and other a-c appliances.

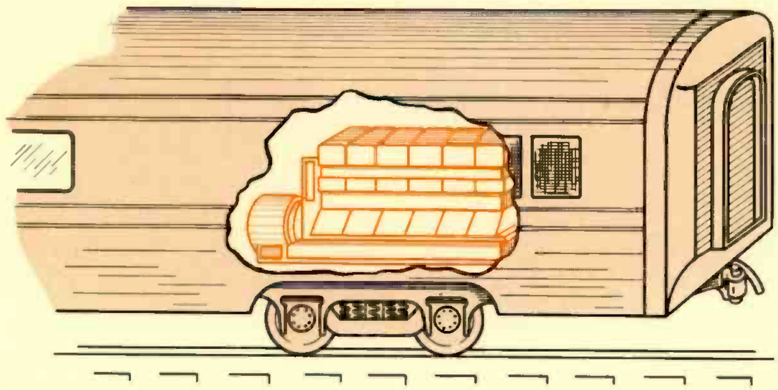
The axle-powered system clearly entails the weight and bulk of two complete power plants, a battery and a generator, each large enough to supply all of the connected load. Nearly all existing air-conditioned passenger cars are direct-current operated, and will continue so. The investment in batteries, drives, generators, and air-conditioning compressors is very large (around $10 000 per car, and there are on American railroads about 15 000 cars so equipped). Some railroads intend to remain standardized on direct current. Purchasers of new cars, however, especially in western areas, are definitely interested in a-c equipment.



The passenger-car load can be carried by an individual engine-driven generator located in or under the car.

Self-Contained Alternating-Current System

Almost the sole reason for the use of direct current in railroad cars is the battery, necessary to carry the load at standstill. There are numerous reasons why

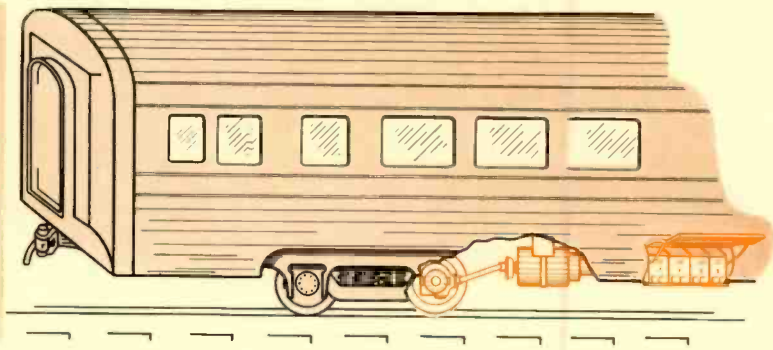


the two air-conditioning compressors, and cuts in on the power circuit of an adjacent car. That car, too, drops an air-conditioning compressor and other portions of its load. The single generator then carries two cars at reduced load until the defective power plant can be replaced. Engine-generators and air-conditioning units are mounted on slide rails for ready removal and replacement.

Use of an engine-driven generator means that hot water is available in the engine cooling system. This might as well be utilized for car heating. Hot-water coils located in the car, plus some electric heaters,

Another type of central power plant for a passenger train is a Diesel-powered alternating-current generator mounted in a compartment of a car at the head-end of the train. This system requires running a three-phase line through the train but does unburden the locomotive and affects the weight and economy of one power plant instead of many.

The time-honored system of supplying the passenger-car load has been a storage battery and an axle-driven d-c generator. This system performs well and has many merits from an operator's point of view, but the increasing loads warrant study of other types of power plants for new cars and trains.



alternating current would be preferable. The trend toward increased electrification of cars is to utilize more and more devices for which alternating current is preferable or essential. Alternating current is far superior for fluorescent lights, which are highly desirable from both an aesthetic and an engineering point of view. Compressor drives for air conditioners and water coolers can be hermetically sealed and are lighter in weight if motors without commutators are possible. Electrostatic air-cleaning equipment can be better supplied through transformers than from a primary d-c system in which a rotating inverter is required. Almost without exception the equipment that designers are dreaming about for the future, such as radios, movies, and television, can better be served by the a-c system, with its readily altered voltages, than by direct current. Furthermore, standard a-c apparatus is less expensive and cheaper to maintain.

With the growing desirability of alternating current and with the loads becoming excessive for axle-powered systems, it seems logical that some other method of providing electric power for passenger cars should be considered.

One obvious possibility is to use an engine-driven a-c generator on each car. Such an installation is, in fact, already being made. A car is being equipped with a Diesel-driven generator to supply three-phase, 60-cycle, 220-volt power. The only direct-current motor on the car is the one used to crank the engine. This car will be placed in revenue service by midsummer of this year and should provide answers to many of the questions relating to alternating-current versus direct-current operation of passenger-car auxiliaries.

The rotating field of the three-phase generator is excited at no load by a small 32-volt battery, which is floated across a battery-charging rectifier. This battery also serves to energize the small starting motor. Control power also comes from this d-c circuit. Series transformers in the three main generator leads serve a second rectifier that provides generator excitation to compensate for varying loads.

Train-line jumpers are provided to carry the electrical load on to adjacent cars in the event of a power-plant failure. When power is lost on one car, control automatically drops one of

provide enough heat to maintain comfortable car temperatures in extremely cold weather. This eliminates the drain of steam from the motive-power unit for car heating, except under emergency conditions.

Head-End Power

A typical modern passenger car, with 8.4 tons of a-c air conditioning, has a total connected load of approximately 17.5 kw, made up as indicated in table I. A train made up of fourteen such cars and a twin diner would have a total connected load of 316 kw. Obviously, considerable economies in weight, bulk, and fuel are possible if the entire train load could be supplied by one power plant instead of by the use of individual car units.

A steam-turbine generator set has been studied for installation on locomotive tenders. It is rated at 250 kw, with 25-percent two-hour overload capacity. Approximate characteristics of this head-end power plant are listed in table II.

The turbine generator is designed for mounting in a recessed compartment across the rear of the locomotive tender. The main steam valve is located at the fireman's position in the locomotive cab. A generator speed indicator gives the fireman a check on operation of the set. A separate steam line with flexible connection can be run to the turbine from the locomotive, or an oversize steam-heating line can be installed. The turbine exhausts to atmosphere, with an exhaust stack designed to lift the steam well above the train. Turbine nozzles are proportioned so that rated capacity is developed at steam pressures as low as 80 percent of rated inlet pressure.

Head-End Diesel-Engine Power Supply

If the electrical power supply for the train is to be consolidated into a single unit at the head end of the train, the use of a Diesel-driven a-c generator merits consideration. This may have several advantages, which include relieving the locomotive of the steam load for power generation and securing the higher efficiency of energy conversion of the Diesel as compared to the locomotive boiler and steam turbine. Such an engine-powered set, using a Diesel designed specifically for railroad service, would be located on a leading car for ready observation and maintenance. Characteristics of the set are listed in table III.

A suitable small battery is provided for engine cranking, emergency lights, and control. The battery is charged by the a-c generator through a rectifier.

Operation Details

For either type of head-end power system, a three-phase, 250 000-circular-mil power line is installed along the length of each car in the train. The gap between cars is bridged by jumpers and receptacles. A De-ion circuit breaker taps the trainline in each car, energizing a dry-type transformer that supplies 110 and 220 volts to the utilization devices. Cars not equipped for a-c operation, as those from other railroads using the conventional d-c system, must be added to the rear end of the train so as not to break the power line.

Turbine and engine governors can be designed to maintain frequency regulation within the limits imposed by fluorescent lights, motors, and other a-c equipment normally found on passenger cars. Automatic generator-voltage regulation is achieved by adjusting the field excitation of the generator in accordance with changing loads.

Control is provided to prevent electrical equipment on all cars in a train from starting simultaneously when the train is first energized in the yard. It is arranged so that all equipment on a given car must start and run normally before the main contactor on the next car in the train can close. The result is a gradual build-up of load on the head-end generator, with only slight frequency and voltage disturbance on the power system of cars already energized.

Weight Economy

In an air-conditioned train, the change to head-end power results in a substantial reduction in weight of the train, as indicated in table IV.

The 250-kw turbine or engine-generator set and control carried at the head end of the train weigh 11 000 and 16 000 pounds respectively. The total weight saved on a 14-car train with twin diner thus approximates 92 000 to 97 000 pounds [(16 x 6760)—16 000 or 11 000]. If small individual storage batteries are carried on each car for emergency lighting (charged through rectifiers) the weight saving per train is reduced by some 10 400 pounds, leaving a total net saving of 80 600 to 85 600 pounds.

Effect of Head-End Power on Train Performance

Any reduction in train weight lightens the load on the locomotive. By saving more than 40 tons on a 16-car train, the locomotive is able to pull the passenger train faster, especially up grade.

Use of head-end engine-generator sets is equivalent to increasing net locomotive traction horsepower by an amount equal to the horsepower drag of the axle generators otherwise carried on each car. When generators carry the full connected load, plus 5 kw each for battery charging, their combined output is 396 kw. With 85-percent generator efficiency and 95-percent drive efficiency, the total axle-generator drag is 657 horsepower at the rail. This is nearly 20 percent of the rail horsepower rating of most large passenger locomotives now in service. Schedules can be speeded up considerably by eliminating axle-generator drag.

Steam-turbine generator sets increase net available locomotive traction horsepower through more efficient use of steam and elimination of battery charging. At a total load of 316 kw, the turbine uses 9500 pounds of steam per hour. The locomotive requires approximately 20 pounds of steam per rail horsepower hour, or 13 140 pounds per hour to carry the 657-hp axle-generator load. The hourly saving of 3640 pounds of steam means 182 additional locomotive horsepower available for hauling the train.

The use of individual engine generators on each car saves very little weight as compared to axle-generator systems. However the axle-generator load is eliminated, making available 657 additional locomotive horsepower for traction purposes, which is a sizable total.

Railroad-car evolution continues. For the new cars, by which railroad operators will attract the public to their services, modern electrical systems are available.

TABLE I—CONNECTED LOAD OF A MODERN PASSENGER CAR

Service	Kw
Air-conditioning compressors	10.400
Car air-circulating fan	1.450
Air pre-cleaner fan	0.600
Evaporative condenser pump	0.325
Exhaust fans	0.200
Electrostatic air cleaner	0.090
Fluorescent lights	3.000
Water cooler	0.215
Conditioned-air reheat	1.000
Control	0.150
	17.430
Dining car, with some electric cooking	50.000
Twin dining cars with full electric cooking	72.000

TABLE II—ESSENTIAL CHARACTERISTICS OF TURBINE-GENERATOR POWER PLANT

Nominal turbine rating, kilowatts	250
Locomotive boiler pressure, pound per sq in	225
Turbine inlet pressure*, pounds per sq in	200
Steam temperature, deg. F	650
Turbine back pressure, pounds per sq in. gauge	5
Steam consumption, lb per hour	
125 percent load	9400
100 percent load	7500
75 percent load	6100
50 percent load	4640
25 percent load	3300
Generator speed, rpm	1800
Generator voltage	450
Frequency, cycles	60
Phase	3
Dimensions of Set, feet—Length	8
Width	3½
Height	4
Estimated weight, pounds	10 000
*Reflecting typical pressure drop in superheater and steam line.	

TABLE III—ESSENTIAL DETAILS OF 250-KW DIESEL-ENGINE POWER PLANT

Two-hour overload capacity, percent	25
Generator speed	1200
Generator voltage	450
Frequency, cycles	60
Phase	3
Dimensions of Set, feet—Length	11.5
Height	5.5
Width	5
Estimated weight, pounds	15 000

TABLE IV—WEIGHTS, PER CAR, OF D-C POWER SYSTEM AND HEAD-END POWER SYSTEM

Weights of D-C Power-System Apparatus	Pounds
1200-Amp-Hr Battery (32 V.)	4800
Axle-generator drive	810
Axle-generator with control	1500
Lamp regulator, auxiliaries	150
D-c compressor motor	575
Compressor motor control	75
Total	7910
Weights Head-End Power Equipment per Car	**Pounds**
Cable Three-wire-250 000 cir mil	285
6—Bus-line receptacles	120
3—Bus-line jumpers	90
1—Transformer—15 kva-440/220/110 v	400
1—Train-line contactor-3 pole	50
1—Train-line De-ion breaker	5
2—Four-ton direct-current compressor motors	200
Total	1150
Weight saved per car (7910–1150) pounds	6760

A Double Monochromator for the Infrared

MUCH routine industrial research involves accurate analysis of unknown materials, detection of extremely minute impurities, or determination of molecular structure. Often the research scientist has as little to go on as the crime detective with only a shred of evidence, but highly specialized tools for analysis are at the disposal of both. One well-known scientific instrument is the mass spectrometer, now of atomic bomb fame. Another is the infrared spectrometer, which Westinghouse Research has recently carried to new levels of sensitivity.

In the infrared spectrometer, heat rays, lying in the infrared region just longer than the visible wavelengths, are beamed at the molecules of the sample under analysis. The molecules absorb some and leave the rest untouched. It is the absorbed energy that tells the story.

Like the visible spectrum, the infrared spectrum contains a band of frequencies, and just as ordinary, sizable objects absorb radiations of a particular light frequency, so too the atoms of a molecule absorb certain portions of the infrared band. The infrared absorption at specific frequencies is a unique characteristic of the molecule as a whole and depends on the natural frequency of vibration of its atoms. Comparison of absorption curves for known and unknown compounds reveals the constituents of the unknown, while the amount of absorption is an indication of the quantity of the components.

The infrared region of the electromagnetic spectrum includes wavelengths ranging from slightly less than a micron (1 micron = one ten thousandth of a centimeter) to about 500 microns. The energy source usually used in infrared spectrometers is a solid body electrically heated. The radiation is focused into a narrow beam and passes through the sample. The molecules absorb energy from the radiation at those frequencies which correspond to their natural modes of vibration. It turns out that a molecule having n atoms will, in general, have $(3n-6)$ modes of vibration. The radiation remaining after the specimen has absorbed its characteristic energy is dispersed by a prism or grating—much in the fashion that visible light is dispersed into a rainbow spectrum by prisms. Successive portions of this dispersed spectrum can be reflected onto a thermocouple, and the output energy at various wavelengths can be measured. Since the specimen has absorbed energy at certain wavelengths, the output intensity in this portion of the spectrum is low, and an absorption curve plotted over the entire spectrum shows typical dips at these points, indicating the presence of particular molecules in the specimen. Measurement of the energy absorption reveals the quantity of the molecules present.

The infrared spectrometer designed by Dr. D. K. Coles of the Westinghouse Research Laboratories for both fundamental research and industrial analysis is the largest prism double monochromator known. Using two prisms with base lengths of 17 centimeters and passing the infrared waves twice through each prism, the instrument has a resolving power equivalent to that of a single prism with a base length of 68 centimeters or four times that of a 17 centimeter prism.

The instrument is highly responsive to incredibly small amounts of energy. Less than one tenth of a watt enters through the entrance slit and passes through the specimen. At the final exit slit, after dispersal, energy of the order of a millionth of a watt is emitted, but the sensitivity of the receiver is so high that such quantities are precisely measured.

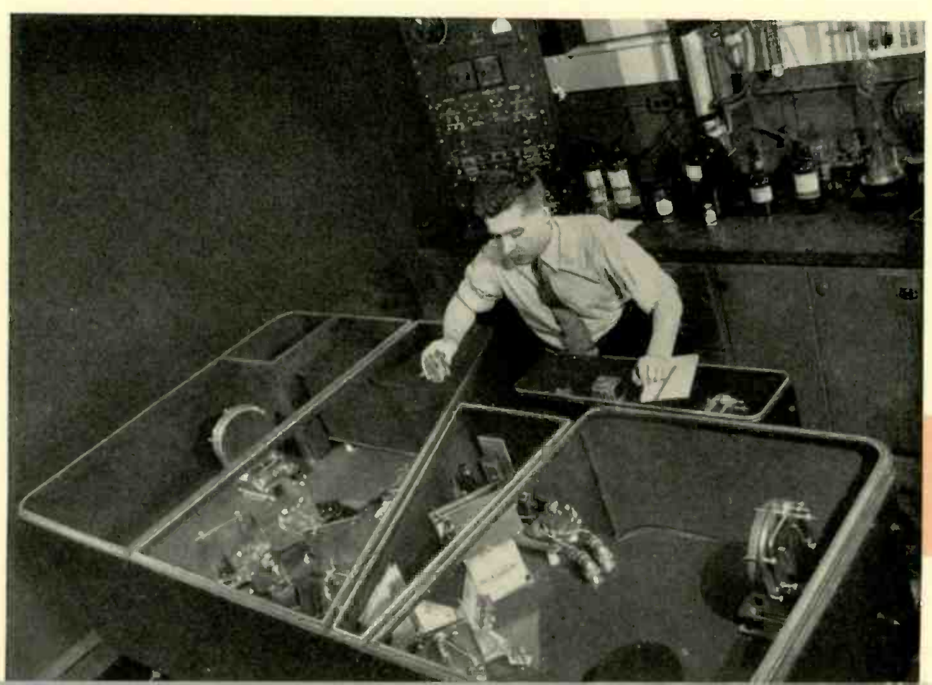
The principal advantage of the double monochromator, having two dispersing prisms, over the single monochromator with its single prism lies in the reduction of stray radiation. In the ordinary spectrometer, the dispersed spectrum is swept step by step across the exit slit so that the thermocouple can measure the energy intensity at various frequencies. A narrow slit is used in order that only the desired region may be measured, but random reflections from the other frequencies reach the slit and decrease the precision of measurement.

The double monochromator reduces this error by taking the limited output at the intermediate exit slit and dispersing it again, eliminating a large portion of the stray radiation at the second and final exit slit. At first glance, this double filtering suggests that system losses will be serious, but the double dispersion method permits the use of twice as much initial energy, more than compensating for the losses.

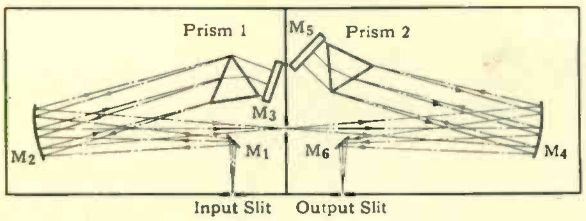
A further advantage of the double monochromator is its nullification of mirror aberration—a blurring of the energy imaged by the mirror on an exit slit. Proper positioning of a second prism with respect to the first entirely cancels out this effect. The exit slit at the first stage is made sufficiently broader than the entrance and final exit slits so that all of the desired energy reaches the second stage.

The vast majority of previous spectrometers have used rock salt prisms having a range from about 2.5 to 15 microns. Using potassium bromide prisms, the double monochromator extends this to 25 microns, permitting the analysis of compounds outside the range of ordinary spectrometers. For very short wave lengths, bromide prisms have low dispersion, but high dispersion gratings are included for precision work in this region.

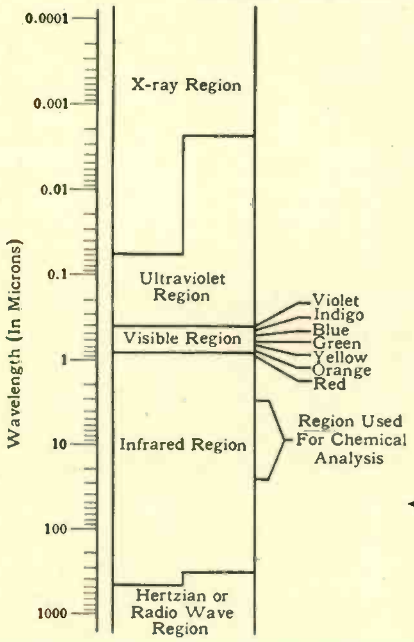
Slit widths in spectrometers are critical for precision work and depend on the wavelength of the energy which is to be measured at any given instant. As the dispersed spectrum is swept across the exit slit, the slit must vary in width. The Westinghouse instrument uses a series of fixed slits at the entrance and the exit



Dr. D. K. Coles, designer of the double monochromator, prepares to position the specimen holder between the infrared energy chamber and the entrance slit.



The infrared rays, having passed through the specimen, enter the double monochromator through the input slit. The first plane mirror M_1 directs the rays to paraboloid mirror M_2 which focuses the energy on the dispersing prism 1. Plane mirror M_3 reflects the dispersed energy back through the prism and to the intermediate slit via M_2. Rotation of the prism and mirrors sweeps discrete portions of the dispersed spectrum through the intermediate slit so that the full spectrum passes in steps to the second stage of the double monochromator. In the second stage, an analogous sequence occurs. Mirror M_4 beams the energy through prism 2 for a second dispersion. Reflection from mirror M_5 returns the energy to M_4 and finally to plane mirror M_6, which directs the energy through the output slit to the energy measuring unit. Rotation of the second stage is coordinated with rotation in the first stage.



← The infrared region lies just below the visible portion of the electromagnetic spectrum, ranging from slightly less than one micron to about 500 microns. The portion used for chemical analysis extends from about 3 to 30 microns.

which are automatically changed during operation in step with the rotating mirrors. Larger slits are used at the longer wavelengths because the energy density decreases with increases in wavelength.

Operation is automatic. Once the specimen is mounted in position, the pushing of a button starts the analysis, rotates the mirrors, changes the slits, records the outputs, and returns the instrument to its original status for the next test.

In fundamental research, this new and sensitive spectrometer has vast capabilities for the investigation of polymerization, the identification of unknown compounds, and studies of the structure and orientation of crystals. In the more familiar field of industrial analysis, the instrument is valuable in detecting and identifying small amounts of impurities and in the qualitative analysis of mixtures of organic compounds. Control of such processes as those involved in the production of butadiene, petroleum products and plastics, for example, falls within the scope of the infrared spectrometer.

Leak Detector

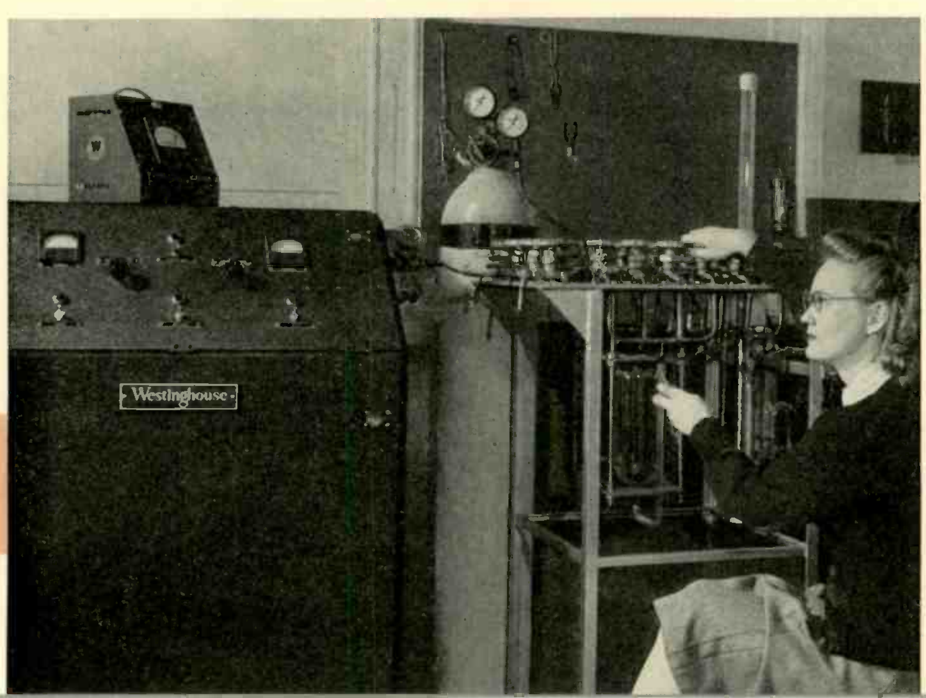
Scientists in late years have been able to achieve vacua of a very high order. Many inroads into the heretofore imperfectly explored realms of pure physics and electronics have thus been made possible. In much of this work completely vacuum-tight systems must be maintained to prevent the introduction of contaminating elements. Discovery of the existence of leakage and its precise location are formidable tasks—particularly for minute leaks.

A special application of the mass spectrometer developed at the Westinghouse Research Laboratories now makes it possible to detect leaks in a vacuum system that are overlooked by any other method. The introduction of but one part in several hundred thousand of a contaminating element into the system is instantly detected. The exact location of the leak also is shown by this device which proved invaluable in the atomic bomb project where extensive use was made of extremely high vacuum systems.

The heart of the detector is a mass spectrometer tube, which responds to the presence of gases. Gas molecules entering the mass spectrometer are ionized and then accelerated by proper voltages. A magnetic field is impressed across the path traversed by these ionized particles, which are then deflected in accordance with their masses. Because the molecules of a particular gas have a specific and unique mass, proper accelerating and deflecting fields can be established so that only particles of a particular mass, and hence of a particular gas, reach the exit slit and actuate the recorder. This means that the presence of a known gas can be detected. For leak detection, helium—a stable and harmless gas—is used because it permits the construction of a light and small instrument by virtue of its non-conflicting mass that stands out clearly against any traces of other light gases.

To test a vacuum system, the mass spectrometer is coupled to it and the evacuating process started. Each suspected location (or the entire system) can be readily checked by playing a thin jet of helium gas on the evacuated vessel. In the absence of leaks, the detector gives no indication because no helium molecules enter the system. If, however, the mass spectrometer shows a reading when the helium nozzle is held at a certain location, it is obvious that helium must be entering some opening in the vacuum system at that point. The characteristics of this detector that made it indispensable to certain phases of the atomic bomb project—simplicity, speed, and absolute certainty—promise it a significant future in the high vacuum field, which is steadily assuming greater industrial prominence.

Miss Janet L. Shultz of the Research Laboratories here tests a vacuum system for possible leakage, using the new and accurate leak detector at the left.



Locomotives, Present and Future

Two 1500-hp Diesels enable the Baldwin-Westinghouse locomotive in the photo to rush Florida fruit to the North.

There is nothing quiet about the railroad locomotive scene. Even the venerable centenarian, the iron horse, is displaying more development activity than at any time in its history. Electrification is bound to grow. Diesels in their short history have established an enviable record of performance and glamourization. And two newcomers—the steam turbine and gas turbine—appear as major contenders in the locomotive field.

The demise of the steam locomotive has been prophesied on many occasions during the last forty years. It is, however, far from extinct; it is most active. Only the most avid proponents of other forms of rail motive power predict the complete disappearance of the iron horse within the next generation. But this by no means indicates that the steam-engine locomotive, almost unchallenged for a hundred years, now has the field to itself. It has competition. Serious competition, not from just one but from several quarters—at least four.

The electric locomotive was the first competitor, and has found its natural place in the railroad scene. In its field it stands without challenge and, if electric power costs continue their long downward trend while coal and petroleum products rise in cost, its place in the railroad picture may be considerably enlarged. The Diesel electric already dominates in construction of new switchers, and has become a major factor in the road-locomotive field. The Diesel-electric road locomotive didn't appear until about 1934 but by June 1945, 642 of the 1350- to 2000-hp units* were in service. On a road-locomotive mile basis, however, the steam locomotive is still far in front, the 1943 freight figures being for steam, 97 percent; for electric, 1.8 percent; and for Diesel electric, 1.2 percent. For passenger service, the comparative road-locomotive mileages were: steam, 86 percent; electric, 5.4 percent; and Diesel, 8.6 percent.

Two other types of locomotives are on the horizon. Both are turbine driven. One is the steam turbine; the other is a newcomer, the gas turbine. Each has an extremely promising future. After a hundred years of railroading, the motive-power picture is less settled than ever.

The Reciprocating Steam Locomotive

When Trevithick of England, in order to win a bet in 1801, put his steam engine on wheels to draw a ten-ton load at a mine, the rail locomotive was born. Trevithick made a basic contribution to the steam locomotive and one that has had as much to do with its success as any other single invention. He directed the exhaust steam up the stack to create a draft

Prepared by Charles A. Scarlott, based on information supplied by engineers of Westinghouse, Baldwin Locomotive Works, and of the motive-power departments of several major railroads.

*The manner of rating locomotives is far from standardized. Steam and electric locomotives are commonly rated as horsepower available at the rail. The ratings of most Diesel-electric locomotives are given as the engine outputs, from which electric-transmission losses of about 20 percent total must be deducted to obtain rail horsepower. Unless otherwise stated this discussion will conform to standard practice of referring to Diesel ratings as engine horsepower.

for his fire. Then with the fire-tube boiler and a new valve linkage and piston arrangement applied by Stephenson to the "Rocket," which won the public locomotive competition in England in 1829, the basic pattern for the steam locomotive was established. Most improvements since have been refinements to improve economy or performance.

The "Peter Cooper"—the locomotive that in 1830 gave a creditable performance on the Baltimore and Ohio Railroad and the first built in this country—introduced the trend to high pressures, with consequent improvement in fuel economy. The boiler pressure was 25 pounds per square inch compared with the 50 pounds of Stephenson's "Rocket." By 1895 pressures had increased to about 160. Pressures generally accepted have risen since to 310. It is not likely that pressures will be increased much on reciprocating engines with fire-tube boilers.

The energy obtained from a given quantity of steam is increased by raising the pressure and temperature of the steam; consequently less water is required to develop a given amount of power. More power can be obtained by expanding the steam to a greater degree in the cylinder and therefore an engine of greater capacity is obtained for the same weight.

However, these advantages of higher pressures cannot be realized with the conventional fire-tube boiler for at pressures higher than 350 psi a firebox with surfaces supported by staybolts becomes increasingly impracticable. With the necessary increase in staybolt diameter and the accompanying reduction in spacing, the water space between staybolts becomes inadequate for proper water circulation. If pressures above 350 psi are to be used water-tube construction is essential. Such boilers have been built. A 500-psi, 800-degree F water-tube boiler, for example, is being built now to ascertain what can be accomplished.

The steam locomotive is a rapid converter of chemical to mechanical energy, but is not efficient. The average locomotive has an overall thermal efficiency of from six to nine percent. Locomotive designers know many ways by which this could be increased significantly. But how to utilize them without adversely affecting simplicity, maintenance costs, maximum output, and availability has been the stumper. And these are the factors that loom larger to railroad operators than do fuel costs. Really large improvement in thermal economy cannot be expected from non-condensing steam locomotives.

Some efficiency gain has been achieved by the addition of feedwater heaters, and superheaters, now standard. Compounding, i.e., expanding the steam in two stages in separate cylinders—would add about one more percent. Compounding although attempted at times and still used extensively in Europe where fuel costs are higher, has been virtually abandoned in this country because the extra complication is not worth the saving in fuel.

One of the most important efficiency improvements is the substitution of poppet valves for slide valves. (Incidentally piston valves replaced flat slide valves on locomotives long ago, but this was largely to accommodate the increasing steam volumes.) The poppet valve allows independent adjustment of inlet and exhaust ports at different speeds and loads, which is not possible with a single valve where all events, except cut-off, are fixed. It makes possible an efficiency gain of about 20 percent at high speed (where the greater power is most needed) well worth the additional complication as it means not just better fuel economy but a corresponding increase in horsepower from a given boiler.

Poppet valves have as yet been used only on a few locomotives but their use is likely to become more general. The Pennsylvania Railroad has applied poppet valves on its new four-cylinder locomotives (the T1 class).

Condensers are attractive, efficiency-wise, and have been attempted on several occasions. Most of the reason why the modern steam power station has a thermal efficiency of 30 percent and the locomotive less than 10 lies with the condenser. But locomotive condensers must be air cooled and, on the powerful locomotives involved, the weight, space, complexity and the fact that lubricating oil gets into the steam have struck them out. Also condensing the steam would leave the very large problem of providing adequate draft. There is no immediate prospect of steam condensers on reciprocating steam locomotives although the potential gains are so great that further attempts undoubtedly will be made.

Use of pulverized coal would increase combustion efficiency, but entails some solution to the problem of slag accumulation on superheater tubes at the high temperatures of combustion in the cramped spaces that can be provided in locomotive boilers. This problem of pulverized fuels is being aggressively investigated.

The reciprocating steam locomotive is simple to build, and operate. It can be built in units of very large horsepower; reciprocating locomotives of nearly 8000 indicated horsepower are in service. It can be maintained with simpler tools and by less skilled personnel than any other type. It is reliable. Its first cost is low. These factors have enabled the steam locomotive to dominate thus far and will keep it in the

Electrification has been particularly successful on the Pennsylvania where the train density is extremely heavy.

race for some time to come. But it is facing competition, and the competition can be expected to gain strength.

Electric Locomotives

The electric locomotive, which made its introduction on main-line service in 1895 on the Baltimore and Ohio Railroad was hailed by many during its early years as the successor to the steam locomotive. Such sweeping enthusiasm has proved unfounded. The electric locomotive has, however, found its place—and it is a big place—in the American rail scene. In general the electric system finds favor under one or more of three conditions. When traffic is heavy, trains frequent and fast—as in the East—no other system can maintain the schedules under adverse as well as normal conditions as can electrification. In mountainous regions where grades are heavy, the high horsepower available and the large short-time overload capacity of the electric locomotive are big arguments in its favor, and the fact that power can be recovered in the braking operation makes it additionally attractive. Also where fuel is expensive and waterpower is abundant, as in the Northwest, complete electrification becomes more attractive.

The electric system requires a high initial investment but the electric locomotive is unmatched in horsepower available in a single unit. Also it far outdistances every other type in instantaneous and short-time overload capacity. This is largely because it is backed by a virtually unlimited supply of power and because of the characteristics of electric motors. Single-cab electric locomotives of 5000 hp continuous and 9000 hp short-time rating are in service. Units of 10 000 hp continuous are both possible and contemplated. In the length now required for a 5000-hp (rail) Diesel locomotive, 20 000 continuous rail horsepower could easily be obtained with an electric locomotive, if such capacity could be utilized.

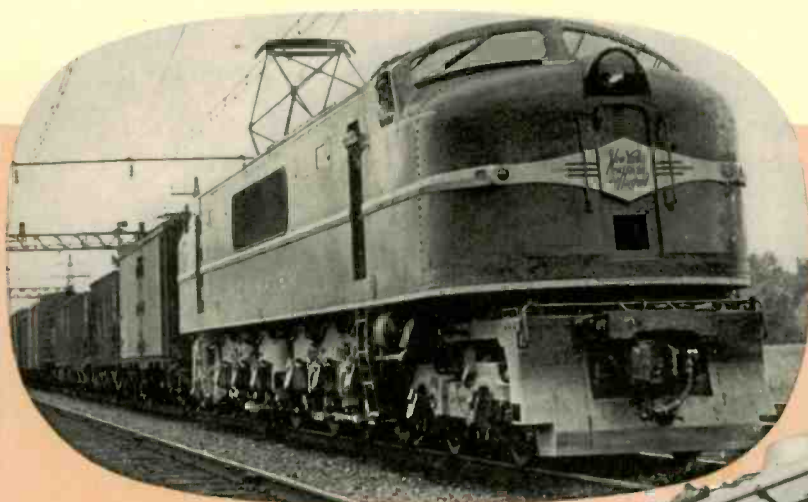
Electrification has several advantages to compensate for its higher first cost. The three principal factors that will come to the front in the future are:

1—Demand for heavy trains at high speeds, both passenger and freight. The electric locomotive will always be able to out-perform its competitors. As the power demands increase, which high speed requires, the economy of electrification increases, and its field is correspondingly broadened.

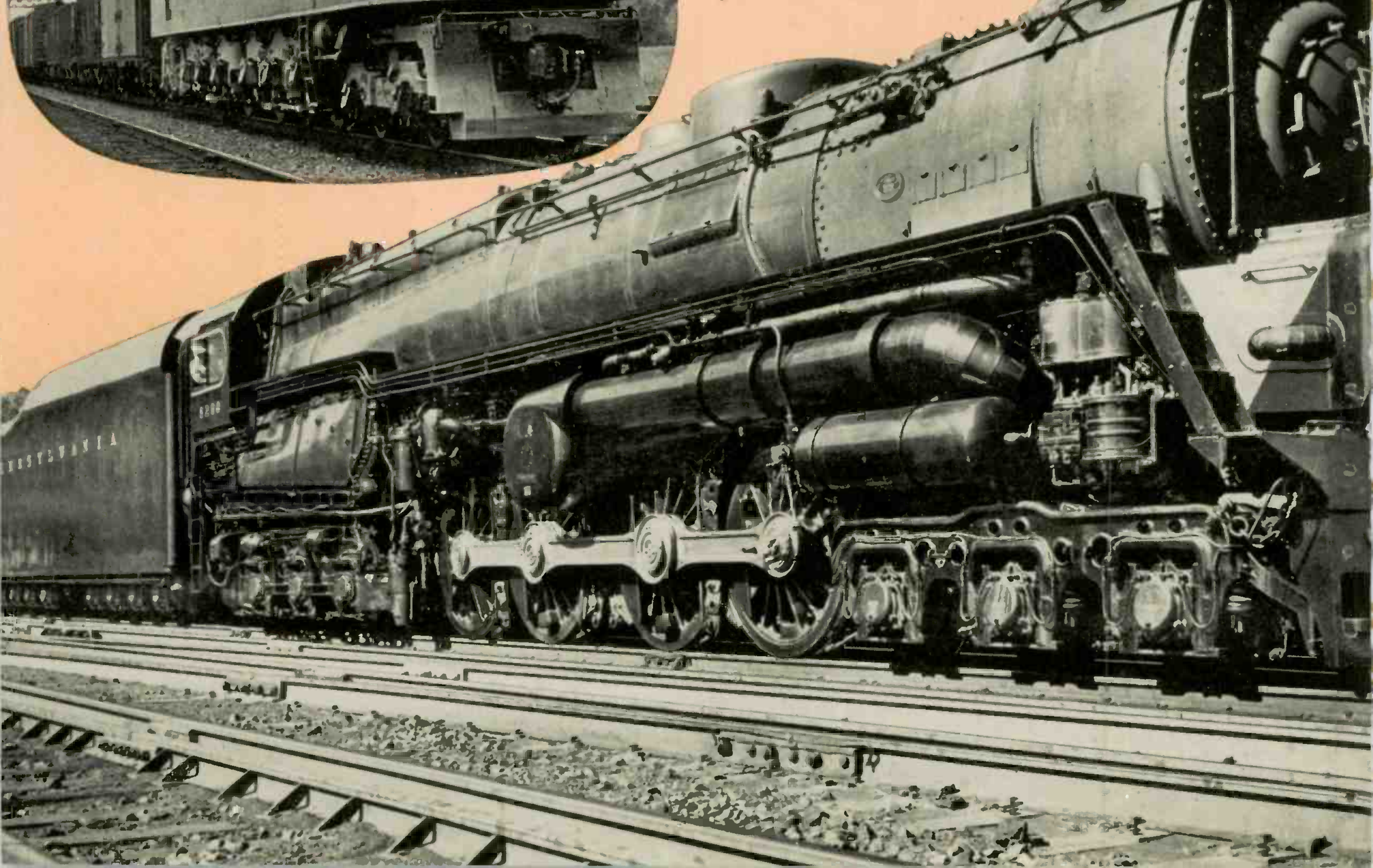
2—Cost of electric power has declined steadily for many years. The cost of fuels has shown a definite trend upwards. As the cost of power is important in the expense of operating an electrified railroad this trend will extend the economic field of electrification.

3—The railroads will face stiff competition in the future. They must meet this competition with better service. An electrified railroad gives the best service known.

The cost per locomotive mile of maintenance for electric locomotives is only about one third that of either Diesel or steam locomotives of comparable capacity. With rising labor



The New York, New Haven and Hartford was an electrification pioneer. At left is one of its newest locomotives. Below is the 6900-hp geared-turbine steam locomotive.



costs, maintenance is becoming increasingly important.

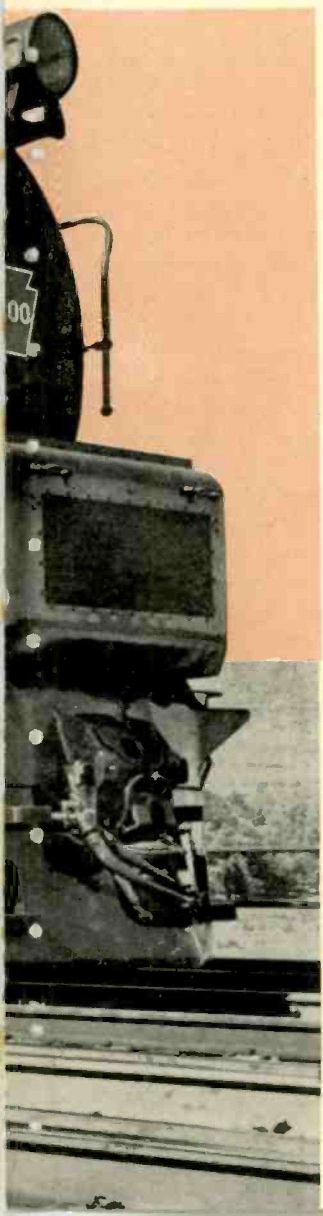
Further electrification, chiefly in important areas of heavy traffic density and areas of low power cost, can be expected. Backers of the government's water-power systems are actively promoting the wholesale electrification of railroads in those regions. While there is considerable national economic justification for this, the outcome of these programs is problematical. However, complete electrification of the nation's rail lines seems less likely than two decades ago.

The Diesel-Electric Locomotive

That young upstart in the field of railway motive power—the Diesel has come far closer than the electric to upsetting the old iron horse. The great upswing in use of Diesel-electric locomotives began in 1934 when the Chicago Burlington & Quincy Railroad introduced the streamliner to a startled but enthusiastic public. Its use has since grown by leaps and bounds in all parts of the country.

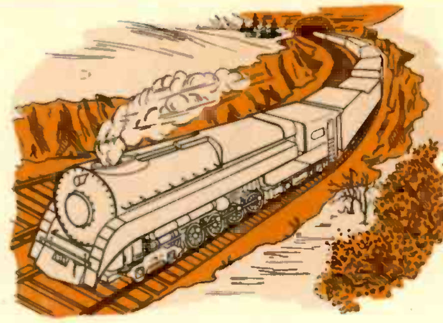
Much of the acceptance of the Diesel locomotive is undoubtedly due to solid technical merits—high efficiency (25 percent overall), high percentage of time available for service, ability to make long runs, and freedom from water, coal, and ash problems that plague steam locomotives. Another, and less tangible factor, is something that can best be described as "smart promotion," i.e., the streamlining idea, which has had great popular appeal, a plus not to be underestimated.

That appearance appeal, because it greatly stimulated passenger business, has been a boon to all railroading. Certainly the competition was good for the old iron horse itself. It has spurred designers of steam locomotives to greater efforts, with the result that steam locomotives now coming out of the shops are far better than had not the Diesel risen to challenge them. In a measure, the virile competition posed by the Diesel and other and newer types of locomotives led to the establishment of an intensive locomotive research program by a group of coal-utilizing railroads. Out of this, superior coal-fired locomotives will appear.



The great weight and length, while mostly a disadvantage, entail a large number of powered axles. From this springs an incidental advantage—very high starting tractive effort without wheel slippage. This means that in freight service a Diesel may be able to start or maintain speed of a heavy train without slippage of the wheels, whereas with another type of locomotive with fewer drivers an additional unit would be required. As railroad men say it, a Diesel locomotive carries its helper with it. Also this high tractive effort feature without slippage of the Diesel allows the engineers to stop a train without slack so that it can be restarted without the jerking many passengers associate with steam-engine trains.

The Diesel is essentially a constant-speed engine. It must be connected to the drivers by some speed-change device. Electric transmission (d-c generators and motors) has been used on all road locomotives to date (and, for that matter, nearly all switchers as well). The electric drive is superlative in performance. No hydraulic or mechanical drive having high horsepower capacity, satisfactory performance characteristics, and low cost has come forward. The characteristics inherent in the d-c traction motor give the Diesel the high starting tractive effort that has helped make it popular with the public and with railroad managements.



The more conspicuous weaknesses of the Diesel locomotive are twofold. Of these, one may be overcome; the other is inherent. The first is the limit of engine size, i.e., the horsepower that can be developed in engines of acceptable bulk. The other is that the Diesel is a piston engine with many reciprocating parts.

Until recently Diesel road locomotives have had a high degree of standardization in which each cab consists of 2000 engine horsepower or less, using engines of 1350 or 1500 hp. Thus a 6000-horsepower Diesel locomotive consists of three cabs or more, with a total length of about 225 feet. (For comparison an electric locomotive of equivalent horsepower capacity is 65 feet; steam, including tender, about 120 feet.) The tendency is to increase the amount of horsepower available in a given cab. At least one 3000-hp, single-cab unit about 92 feet long, in which is located two 1500-hp Diesel engines, is in service. Before the war there was some talk of building high-capacity Diesel locomotives in which several smaller size engines are arranged crosswise of the locomotive frame taking advantage of the high-speed Diesel engines (1000 rpm as against about 650) that weigh perhaps 10 to 15 pounds per horsepower instead of 20 to 25 pounds per horsepower now in common use. With such a scheme a single-cab Diesel locomotive of 5000 hp might be built. Whether by materialization of this prewar idea or by use of improved Diesel engines of higher horsepower but lower relative weight, we can expect to see in the relatively near future single-cab Diesel locomotives much more powerful than present ones.

The Steam-Turbine Locomotive

The two newest forms of locomotives avoid the disadvantages attendant to piston engines. They are both turbine locomotives, one steam, the other gas.

One steam-turbine locomotive is now in successful service in the United States. In fifteen months it accumulated 47 700 miles in revenue freight and passenger service on the Pennsylvania Railroad before it was opened for inspection for the first time in late February. Turbine blades and gear teeth were in perfect condition, and the unit was reassembled without repair either to turbine or gears. This is a remarkable feat for the first unit of any new type.*

The limit to horsepower rating of a turbine locomotive is set by the boiler, just as with the reciprocating steam engine. But because the turbine is more efficient than the piston engine, the turbine drive develops roughly one fifth more horsepower at high speed than the piston engine from a given boiler. A 9000-hp geared-turbine locomotive is contemplated.

Because the turbine locomotive is not concerned with piston speeds, smaller wheels and a shorter rigid wheelbase are

*Turbine-locomotive performance is discussed on p. 89.

possible, providing a locomotive suitable for operation over short-radius curves without excessive flange wear. The short wheelbase also accommodates a firebox with larger grate area, permitting fuel to be burned at a more economical rate.

Torque flow of the turbine drive is smooth instead of pulsating, a great advantage, particularly at high speed. The absence of reciprocating motion means less wear, fewer lubrication problems.

The steam turbine can effectively use higher steam pressures, higher steam temperatures, and lower exhaust pressures.

The turbine can also apply its power to the drivers by electric transmission. Indeed, three turbine-electric drives are being built for the Chesapeake & Ohio Railroad. Each is rated at 6000 hp. For each unit one turbine is geared to two direct-current generators (i.e. four armatures), which supply power to eight motors on separate axles. The gain of electric drive as compared to gears is in flexibility of locomotive performance. The turbine can operate most of the time at its most efficient speed. At standstill and low speeds very large tractive efforts can be developed. The loss is in greater weight, lower efficiency at high speed. Whether a turbine should drive through gears or electric motors depends to some extent on the number of drives. As the number of trucks increase, the advantage swings to the electric drive because of the increasing difficulty of linking a single turbine to a multiplicity of trucks. It is still too soon to predict the economic balance point. The steam-turbine locomotive is a practical, attractive form of motive power fully competitive to the piston engine. Its greatest weakness is the oldest thing on it—the boiler.

The steam-turbine locomotive is not new. Many have been built for service on European railroads and are reported to be successful. Several years ago a turbine-electric was built and used experimentally on western railroads. It utilized a condenser and was somewhat complicated. It has since been dismantled, but the turbine itself performed creditably.

The Gas-Turbine Locomotive

The second form of turbine locomotive will be built around the suddenly popular gas turbine, the prime mover given such an enormous lift along its development road by the war and military aviation. In many respects the gas-turbine locomotive appears to be close to being the ideal road locomotive, and because its thermal efficiency rises rapidly as turbine-inlet temperatures increase, recent advances in high-temperature metallurgy bring it within the range of practicality.

The gas-turbine locomotive like its cousin, the steam-turbine locomotive, has no reciprocating parts. That's good. But the similarity almost stops there. The gas-turbine locomotive requires no boiler and no clean water with all of its headaches to operating men. No one will know its costs until someone builds one, or better yet, several. However, it should be cheaper to build than the Diesel, will require less maintenance, and—it is hoped—will eventually burn coal. Furthermore single units can be built in as large capacities as needed.

In the gas turbines the three functions of combustion—compression, burning, and expansion of hot gases, which are combined in one mechanism in the Diesel and hence must be successively interrupted—are each accomplished in a component designed for that exclusive purpose. As a consequence each can function continuously instead of intermittently as in piston engines. Furthermore, a large gain in simplicity results. A gas-turbine unit consists of a rotating compressor of several stages that feeds large volumes of air, several times in excess of that required for combustion, to a chamber where fuel is burned. The heated gases then expand through a gas turbine of several stages that provides the power to drive the compressor and some surplus for useful work. There are no moving valves or pistons, no reciprocating auxiliaries.

All present gas turbines burn liquid fuel, but it can be of lower grade, such as bunker C, which is abcut half as expensive as Diesel fuel. However, coal is plentiful and petroleum is not, or perhaps a better way to say it is that the cost of liquid fuel is likely to rise more rapidly than the cost of coal. A coal-burning gas-turbine locomotive would be very desirable from a national economy point of view and is likely to materialize eventually because extensive development programs backed by plenty of funds, talent, and incentive are under way. The problem seems to center around obtaining a pulverizer that will reduce *all* the coal to ultra-minute particles far smaller than heretofore. More has been learned in the last few years about burning pulverized fuel. Some engineers believe that if the fuel is reduced to particles small enough burning will be complete and avoid ash adhering to or eroding the turbine elements. Extensive research is in progress to verify this.

Westinghouse is now testing a 2000-hp oil-burning gas turbine-generator unit of the sort that might be applied to a locomotive. The surprising fact about it is its small size. It is only 26 feet long, 3½ wide by 6 high and weighs, including bed plate, 35 000 pounds. Thus two units totaling 4000 hp side by side would occupy only 26 feet of locomotive length. That will be tough for any other type of locomotive to beat. A 1500-hp Diesel engine and generator of comparable power is approximately 20 by 4 by 10 feet high and weighs 35 000 pounds.

The efficiency of the gas turbine is tied to the temperature of the gases entering the turbine. With temperatures of about 1300 degrees, which are immediately practical, the thermal efficiency for the simple open-cycle gas turbine is approximately 20 percent. This is well below Diesel-engine efficiencies of 30 to 35 percent, but fuel efficiency is by no means the whole story in railroading. Furthermore, when materials and designs for operating at 1500 degrees F have been developed the efficiency of gas turbines runs up to about 24 percent, and should 1800 degrees be attainable the efficiency rises to 30 percent. Metallurgists and designers are hopeful.

The above statements are based on the simple, open-cycle gas turbine. Other types of gas turbines offer considerable efficiency gains, sacrificing simplicity thereby. Undoubtedly they will be attempted.

The simple gas turbine driving its own compressor is essentially a constant-speed machine and has no starting torque. Hence, applied to a locomotive it requires a starting device and must be connected to the drivers through some speed and torque conversion mechanism. Its problems in this regard are essentially the same as those of the Diesel and probably will be solved the same way—with electric drive, but the appearance of a light-weight mechanical or hydraulic drive might change this.

The gas turbine has another feature that makes it of interest as railroad motive power. Its output declines as ambient temperature rises, which sounds bad until it is said the other way. Its output increases as air temperature drops. This gain in output of the gas turbine in cold weather is ample for heating the average train. This is fortunate as the gas-turbine locomotive may be spared the complication of a separate train-heating plant required of Diesel-electric and electric locomotives.

The gas turbine is also its own brake. Energy can be absorbed on downgrades by allowing the compressor to exhaust to the atmosphere. The compressor of a gas turbine consumes two thirds of the turbine output. Hence with the fuel shut off a braking power of at least double the engine full-load rating is obtainable, which is considerably more than is required of locomotives.

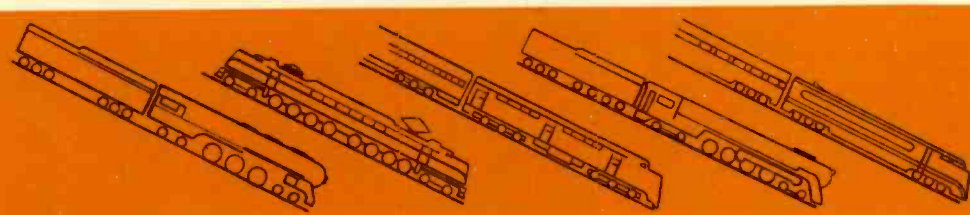


TABLE I—COMPARISON OF LOCOMOTIVE TYPES

	Steam Reciprocating	Electric	*Diesel Electric	Steam Turbine[1]	Gas Turbine
Maximum capacity, rail hp/cab — Present / Future	7000 8000	5000 10 000	2500 5000	6500 9000	7000 (?)
Probable economical sizes, horsepower/cab	1500–8000	1000–10 000	400–5000	5000–9000	2000–7000
Type of fuel	Coal or Oil	Coal or Water	Oil	Coal or Oil	Oil or Coal (?)
Fuel costs, cents/hp hr	0.5 to 0.7	0.3 to 0.7	0.4 to 0.6*	0.4 to 0.6	(Oil) 0.4 to 0.6
Thermal efficiency, per cent °	6 to 9	20–25	20–25	7–10	15–20
Weight efficiency, pounds/rail hp	140–150	70–100	180–220	120–140	100–125
Length efficiency, feet/1000 rail hp	20–25	10–16	35–45	16–20	15–20
Availability, per cent of time	60–75	90–95	85–95	65–75	85–95
First cost/rail hp, dollars	40–50	40–60	100	45–65	90–100
Maintenance cost—Relative	100	30–40	80–100	90	70–90
Short-time overload capacity, per cent	Nil	75–100	Nil	Nil	Nil
Water requirements/hp hr, pounds	15–20	None	Nil	12–16	None
Effect of adverse weather	Appreciable	None	Slight	Appreciable	Slight
Standby losses	High	Low	Low	High	Low
Field of service	All	All	All	Road only	Road only

*Not including Diesel lubrication costs, which are about 15 per cent of the fuel costs. For all other locomotive types lubrication costs are negligible. [1]Mechanical drive. °Including transmission.

Comparison of Locomotive Types

A simple appraisal of railroad motive-power types is precluded by the many factors of comparison. No locomotive is best from all points of view, a situation further involved by the many types of railroading encountered in this enormous land — the extreme range of traffic densities, great variations in distances of runs, grades, and curves. Blanket comparisons of different locomotive types are open to the hazards of oversimplification, but are helpful for a general understanding of the reasons that underlie the present rapidly changing locomotive scene. Some of these are set down in table I, which admittedly is open to argument in certain specific cases.

One factor in long-range relative evaluation, easily overlooked, is that of age of the different types. The reciprocating steam locomotive by comparison with all other kinds is aged. One would expect at this relatively advanced age that the steam locomotive is rather fully developed. Doubtless it is as to form, but its problems are so great—efficiency, boiler, water, fuel, maintenance—that competing forms will be a spur to steam-locomotive improvement. Recent remarkable improvements bear this out. In 1921 steam locomotives averaged about 25 000 miles between major overhauls. The modern steam locomotive runs 150 000 to 300 000 before general repairs are necessary. Twenty years ago 100 miles was a long single run for a passenger steam locomotive. Now 195 miles is average, and runs of 1800 miles have been made. We can look for more improvements, but whether in the aggregate these will be sufficient for the steam locomotive to compete with the newer forms is another matter.

The electric locomotive is of this century and has reached a high state of development. In fact it is probably the most stable of the quintet of types. Larger ones no doubt will be built but significant changes in the locomotive itself that will greatly alter its position in railroading are not anticipated.

The Diesel, although young, is well along its development curve. The steam turbine is really just borrowed from central-station and marine practice, where it has long since reached a high peak of development. It is so simple anyway that not much can be looked for in turbine improvement. The same is true, but to a lesser extent for gears, where metallurgical developments may result in smaller size. The gas turbine, on the other hand, is new and much improvement is possible, particularly in combustors and in design of the turbine parts.

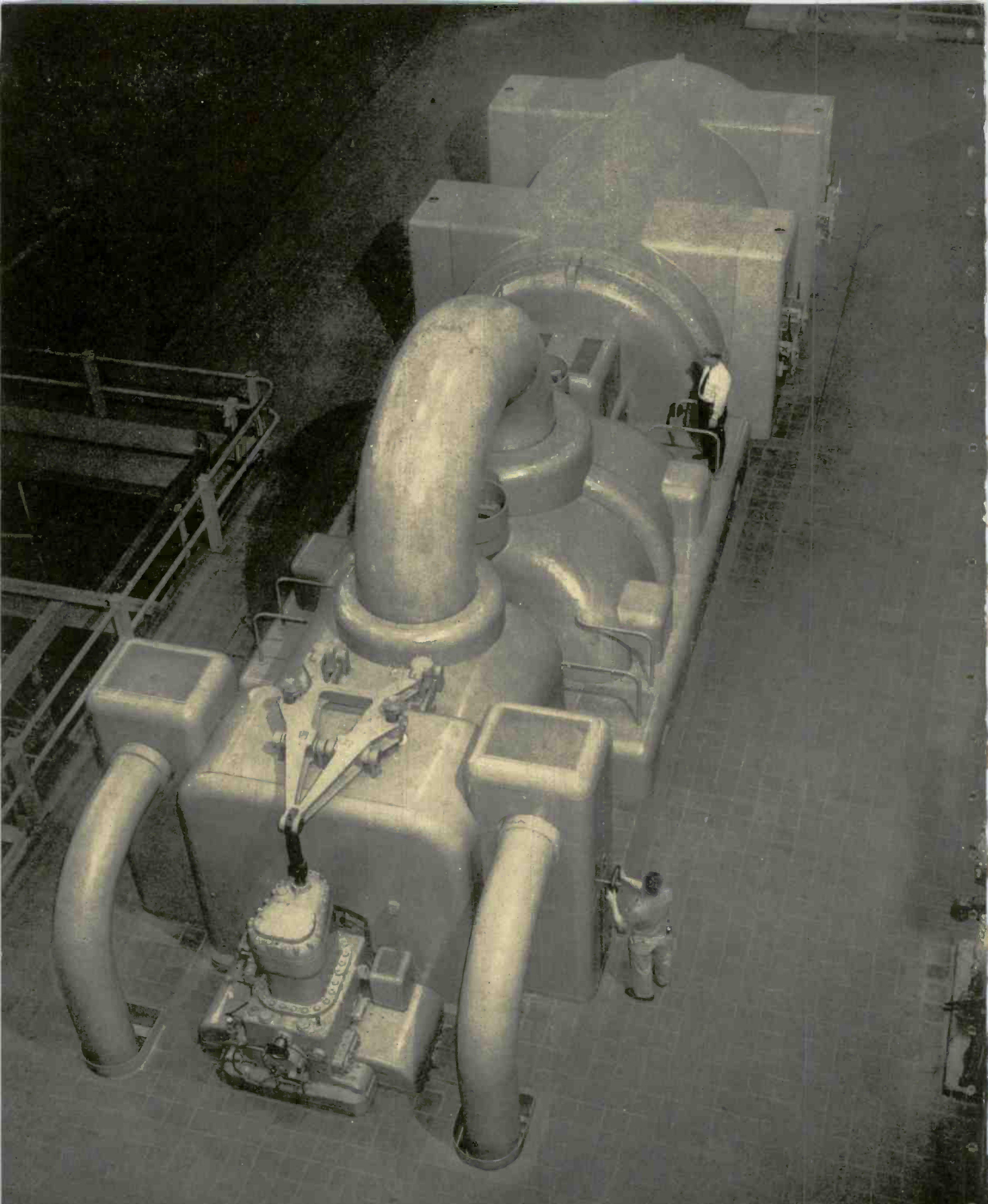
First cost, while important, is by no means first in the minds of railroad management. The ordinary steam locomotive carries the lowest price tag, which in large-size units is 40 to 50 dollars per rail horsepower. Electric locomotives and steam-turbine locomotives cost slightly, but not significantly, more, about 40 to 60 dollars, although the electric system necessitates an expensive power-supply system. Diesel costs run higher, about 100 dollars per rail horsepower. Complete Dieselization of a railroad system would cost from 70 to 90 percent of a complete electrification, although it should be remembered that Diesels can be bought a few at a time whereas electrification has to be done in complete sections at once. This gives the Diesel a financing advantage. The cost of a gas-turbine locomotive is problematical at this stage, but should be competitive with a Diesel-electric.

Amount of power in a unit of maximum size, i.e., in a single cab, is important. Here the electric is the winner by far, as table I shows, with the Diesel, using present engine sizes, at a serious disadvantage. A 10 000-hp electric locomotive is easily possible. With developments now in sight the others trail in about this order: steam turbine, 9000; gas turbine, perhaps 7000 hp; steam reciprocating, 8000, and Diesel-electric, 5000 hp.

The other more important qualities of locomotives that concern railroads are listed in general terms in table I. The relative importance of these qualities varies widely with the transportation problem, the particular railroad system as it now exists, and with the man doing the evaluating.

There has been much talk about an atomic-energy locomotive. This is ignored here because the cost and the problems of shielding from the radioactive products are so great as to place this locomotive type indefinitely in the future.

That the railroad motive power picture after a century and a quarter is so unsettled is good. It shows a growing versatility in new tools by which the railroads can better compete for the passenger and bulk transportation business. It shows an aggressive industry from which the average citizen can expect better transportation, perhaps at lower cost.



This 81 250-kva turbine generator, unit number seven, and newest and most powerful of any at the Springdale generating plant of the West Penn Power Company, will eventually depend upon an electronic exciter for its field supply.

Electronics, fabulous and versatile new tool, has been entrusted with a chore where the reliability demands are of the highest—the supply of excitation direct current for a major unit.

Why the Electronic Exciter

C. M. LAFFOON
Manager, A-C Generator Engineering
Westinghouse Electric Corporation

DIRECT CURRENT for excitation of an 81 250-kva generator—one of the largest high-speed machines built—is to be supplied by an ignitron rectifier. This is the first application of an electronic exciter to a main generating unit of large size, although this type of excitation supply for smaller generators and large synchronous condensers has been used in some cases in the past.

Excitation for a-c generators has been supplied by d-c generators, generally connected directly or through gears to the same prime mover that drives the a-c generator. This provides the greatest isolation of the excitation system from the a-c system, and thus gives maximum freedom from system disturbances. During recent years, availability of the steam-driven generator units has increased due to improvements in design of the generators, turbines, and associated control and auxiliary devices. Fewer shutdowns result when maintenance work on the exciter units, such as the changing of brushes, can be done.

With the advent of a 3600-rpm generating unit of large size, the requirements of the exciters have been more severe. This in part is because of the higher speeds, but also the increase in availability of the unit has demanded continuous operation of the exciter over much longer periods.

Large capacity and high speed introduce serious design problems in connection with commutators and with thermal expansion, contraction, and stresses of other exciter components. Design, however, has in general kept pace with the demand. Commutation performance on exciters has been excellent. However, brushes inevitably wear much faster on the high-speed machine. As a result, brush replacements have at times necessitated shutdown of the main exciter, although recently designed machines have provided means for changing brushes under load and operation, and without the use of tools or without undue hazard to the operator. Slower operating units and speed-reducing gears, have been used with some of the larger generators. This has not in itself solved the problem, since the slower speed exciter is larger on account of its lower speed, and commutating peripheral speeds are reduced only about 20 percent. Ratings of shaft-driven exciters for 3600-rpm generators, up to 260 kw, are in service, and a unit capable of 300 kw has already been built and tested. And higher capacities may be possible in the future.

The general performance of the shaft-driven exciter for 3600-rpm generators has been reasonably satisfactory. However, no d-c machine provides the same degree of performance or reliability as obtained from an a-c machine because the entire output of the d-c machine must be commutated and collected from the rotating member. Also the more frequent need for brush replacements and the requirements of smoother operation of the generating units to eliminate vibration, which would be detrimental to exciter operation, emphasizes the desirability of providing excitation not mechanically tied in with the turbine-generator unit. Such excitation systems could be separate steam-driven exciters, motor-generator sets, or the ignitron rectifier. The satisfactory performance of the ignitron in transportation, mining, and general-purpose applications, has placed this type of conversion equipment in a position for being favorably considered as an excitation unit.

The ignitron rectifier, at present, is attractive because it is a static device with no mechanical ties to the main unit. As such, it can be designed to be operated and maintained without requiring a shutdown of the main unit. The one disadvantage of this type of excitation, in addition to higher cost, is its dependence on the a-c supply. If the rectifier is fed from the generator it serves, any electrical disturbances on the generator itself will be reflected in the rectifier. The excitation system, however, can be designed to overcome this deficiency. By coordinating the design of the main generators, the electronic exciters, and the voltage-regulator equipment, it has been demonstrated by test and by actual experience that this type of exciter can perform all of the necessary excitation functions essentially as well as those obtained by a shaft-driven exciter. In addition, the speed of response is higher, the regulating equipment simpler, and the overall excitation system is easier to maintain and operate. The cost, however, of such a system, is greater than that of the rotating type of exciter.

Several electronic excitation systems using ignitron rectifiers are in satisfactory operation for synchronous condensers ranging in speed from 600 to 3600 rpm. One electronic excitation system is now being placed in service for a large 3600-rpm turbine generator of the West Penn Power Company. This is described in more detail in the accompanying article. This actual installation will give the desired operating experience with the electronic exciter. It is anticipated that it will meet all of the expected requirements and will thoroughly demonstrate that the ignitron-type excitation system is satisfactory for use on large high-speed turbine-generator units.

The electronic exciter is mounted in steel cubicles. The operator is here shown operating the cathode disconnecting switch.

Construction and Tests

R. F. Lawrence
Central Station Engineer
Westinghouse Electric Corporation

The electronic exciter* as built for the 81 250-kva West Penn Power Company generator consists essentially of three basic pieces of equipment: a transformer, an ignitron rectifier, and a control, which includes a voltage regulator. There are in addition certain adjuncts in the nature of auxiliaries and protective devices. None of the equipments—basic or auxiliary—are new. Each has an extensive record in service. Only their combination and their function are new.

Description of the Exciter

A simplified circuit diagram of the ignitron exciter is shown in Fig. 1. The delta, six-phase star transformer is energized, through disconnects and fuses, from a reliable source of power. This may or may not be the system to which the generator being excited is connected, as explained later. The ignitron rectifier consists of three groups of two ignitrons each. The anodes of each group are connected through a two-pole anode breaker to diametrically opposite phases of the transformer secondary. Three field-discharge switches in series, one on each anode breaker, and in series with the field-discharge resistor are connected across the d-c bus.

Trip-free anode breakers have the advantage that an arc-back occurring on an ignitron can be cleared by opening only the circuits to the tube or tubes involved and the sound tubes will continue to supply field excitation. The tubes are tripped in pairs to minimize operating mechanisms, and connecting the two poles of a breaker to opposite windings on the transformer avoids transformer saturation and provides most nearly balanced conditions during partial capacity operation. If, instead of the anode breakers in the secondary, a breaker were used in the primary circuit, an arc-back on one ignitron would cause an interruption of the entire output of the exciter.

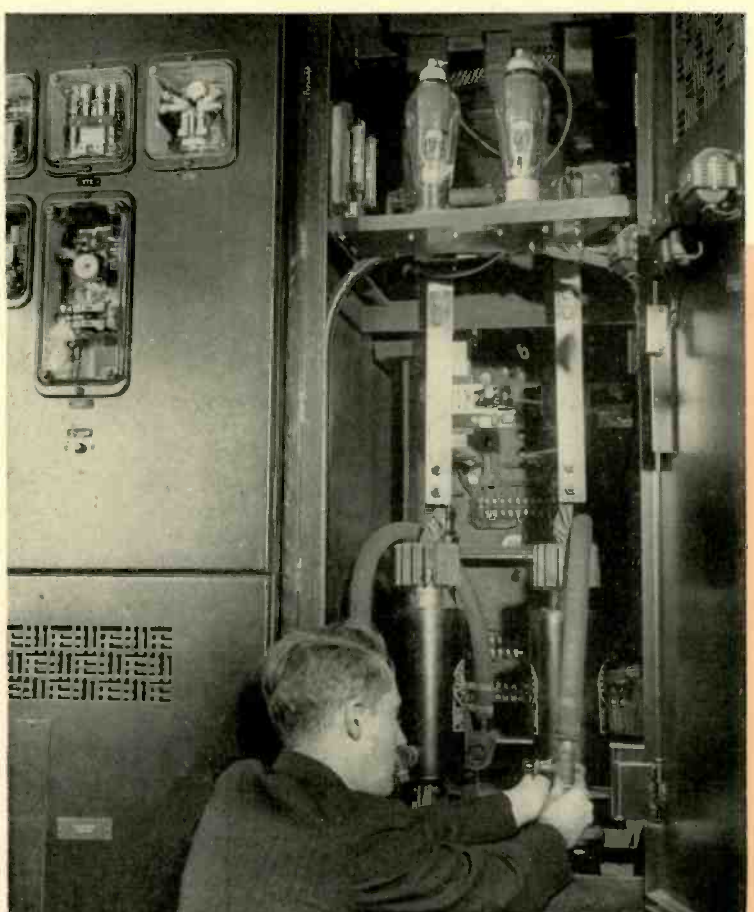
The delta, six-phase star transformer, with the anode breakers, gives satisfactory rectifier reliability without complicating the design. With one two-pole breaker open for maintenance, the remaining four ignitrons can supply full-load field current, and should one of the four ignitrons arc-back, causing a second anode breaker to open, the two remaining ignitrons can supply field current until the second breaker is automatically reclosed.

The ignitor excitation circuit used is of the anode-firing type. This type of excitation is the simplest and, because of its flexibility of control, it is the most suitable for synchronous-machine excitation. The ignitor, in series with a thyratron, a current-limiting resistor and a fuse, is connected to the anode. A sine-wave voltage with a superimposed d-c bias voltage is applied to the grid of the thyratron. The bias voltage can be varied to regulate the rectifier output voltage, and consequently the generator terminal voltage, either automatically by a voltage regulator of the electronic or Silverstat type, or manually by a potentiometer.

The thyratron grid transformer and filament power are essential for operation of the exciter, therefore an automatic transfer scheme is included in the supply of these two so that power can be taken from either of two sources that have the correct phase relation with respect to the anode voltages.

The control of the exciter includes several safety and reliability features. Automatic reclosing is supplied for the anode breakers. In case of arc-back, ignitron over-

*A symposium of papers on electronic exciters was presented at the midwinter convention of the AIEE, New York, Jan., 1946.



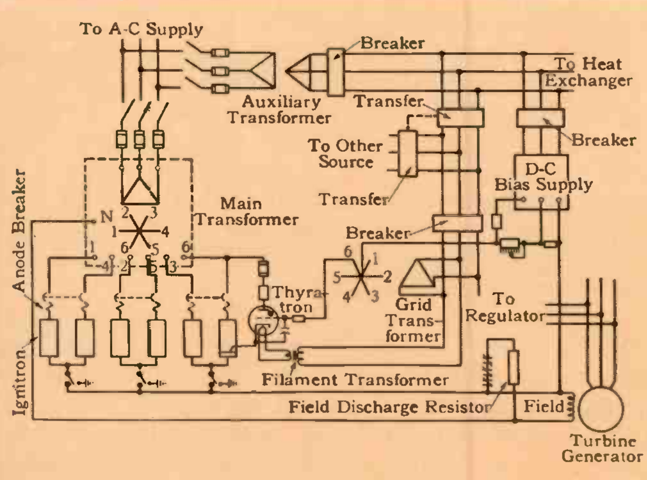


Fig. 1—The electronic exciter contains six ignitrons and six thyratrons. Only one thyratron and control is shown here.

One of the rectifier cubicles has been opened to show the ignitron tubes in the lower portion while the thyratrons are mounted on the shelf near the top of the cabinet.

# of an Ignitron Exciter

C. R. MARCUM
Rectifier Engineer
Westinghouse Electric Corporation

temperature, ignitron-misfires, transformer over-temperature, loss of water pressure, or loss of filament power, an alarm sounds and a target drops on the annunciator. If any of the ignitron troubles occur, the annunciator is so connected that the compartment number and trouble are annunciated. To insure the maximum continuity of service, only an arc-back opens a power circuit and, as mentioned above, even in this case only one third of the capacity is interrupted.

Method of Supplying A-C Power to Rectifier

The source of alternating-current power can be either (1) the generator to which the exciter is supplying excitation or (2) a station auxiliary bus. For the first condition, the generator is self-excited and the electronic exciter is subject to voltage dips at the generator terminals under sudden load application or system fault conditions. At this time excitation is needed most by the generator and some method of compensation for these voltage dips is necessary. Two compensation methods are practical. One is to supply series compensators, the primaries of which are connected in series with each phase of the generator while the secondaries are connected in series with the rectifier transformer. The voltage boost obtained is in proportion to the reactive current fed from the generator.

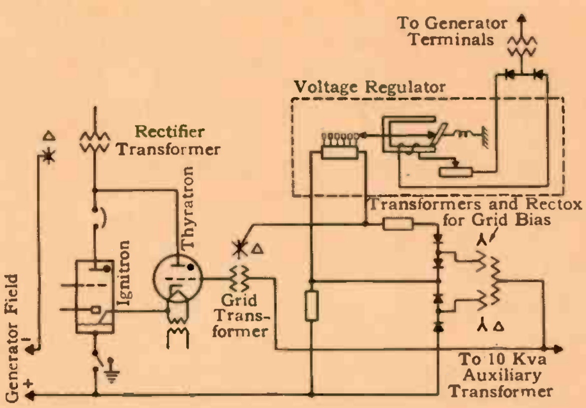


Fig. 2—The firing time of the ignitron tubes and hence the generator-field current is controlled by thyratrons. The method of regulating the thyratrons is shown here.

The second method is to design the rectifier to give an abnormally high d-c output ceiling voltage so that with reduced voltage applied, a normal ceiling voltage is obtained. Firing delay reduces the rectifier output during normal operating conditions. The rectifier transformer of the West Penn Power Company exciter was designed to give approximately 400 volts no-load d-c ceiling with 100 percent a-c voltage applied, or a normal no-load d-c ceiling of 300 volts with 75-percent a-c voltage applied. An extension to the high-voltage winding gives a normal no-load d-c ceiling of approximately 300 volts with 100-percent a-c voltage.

If the electronic exciter were supplied from a separate a-c source, system disturbances would not affect the output of the rectifier and no series compensators would be necessary. Only one tap position would be required on the rectifier transformer to give a normal d-c rectifier output with 100-percent a-c voltage applied to the terminals.

Regulation of Rectifier Output Voltage

The voltage output of the rectifier is regulated by controlling the firing delay of the ignitron tubes. The voltage-regulating circuit is shown schematically in Fig. 2. By varying the d-c grid-bias voltage on which is superimposed the a-c grid voltage wave, the firing delay of the thyratron, and consequently the ignitron, is varied. The firing delay is dependent upon the time at which the resultant a-c grid voltage wave becomes positive. The d-c grid-bias voltage is the algebraic sum of a varying negative bias and a fixed positive bias. This varying negative voltage is the drop across the voltage-regulator resistance. A torque motor energized from the generator terminals through suitable potential transformers and Rectox units determines the position of a pivoted arm that opens or closes silver-button contacts connected to taps on the regulating resistance.

Laboratory Tests

Extensive tests were run on this exciter in one of the a-c high-power laboratories to obtain data not readily available in service. The laboratory consists of a 3300-hp motor driving

The controls for the electronic exciter are mounted on this switchboard located in the main control room.

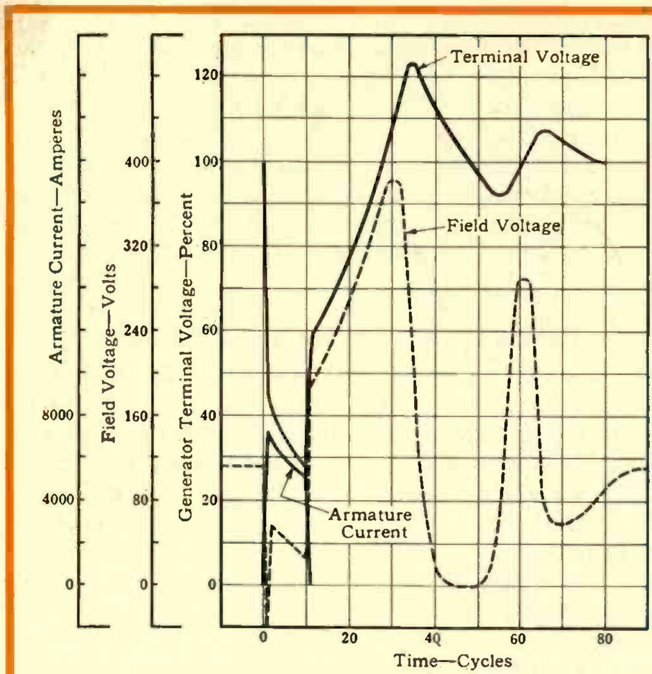


Fig. 3—These curves show variations in terminal voltage, field voltage, and armature current during a ten-cycle fault on the 20 000-kva laboratory generator through ten-percent external reactance. The generator was self-excited and the exciter connected to give maximum rectifier voltage.

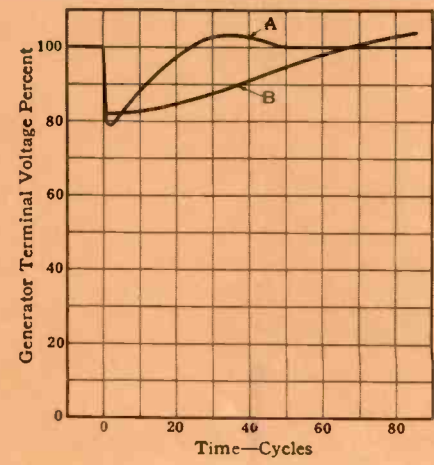


Fig. 4—The 20 000-kva laboratory generator used for tests was here connected for a 60-percent zero-power-factor reactive load. Curve *A* shows the generator self-excited electronically with maximum rectifier voltage. Curve *B* shows the response with a standard rotating exciter. The electronic exciter shows much quicker rate of voltage recovery time.

two 20 000-kva generators synchronized mechanically and electrically. Facilities are available for applying any type of fault through zero to five ohms reactance. Reactive load of zero power factor lagging can be applied by paralleling the two machines with one underexcited.

The electronic exciter was connected through a 450-kva auxiliary transformer to the terminals of the generator to which it was supplying excitation. Provision was made for connecting the exciter to a separate 2300-volt bus so that the generator could operate separately excited. The series compensators were connected so that tests could be made with or without them in the circuit. The generators were wye connected for 6600 volts. Three turns were wound through the primaries of the compensators so that approximately the same number of ampere-turns would be obtained as with one turn through the primary on the actual installation. All faults were applied through ten percent external reactance to simulate faults on the high-voltage terminals of the transformers connected to the machine for which it was designed.

The tests consisted of the application of all types of faults, application and dropping of reactive load, change-over from self-excitation to separate excitation, simulated arc-backs, and "build up" of generator terminal voltage. With no compensators, tests were run with the generator self-excited with the rectifier transformer connected to give maximum d-c rectifier voltage; generator self-excited with rectifier transformer connected to give the lower d-c rectifier voltage; and with the generator separately excited with the rectifier transformer connected to provide the lower d-c rectifier voltage. Tests were run with the compensators connected into the circuit with the generator self-excited and with the rectifier transformer connected to give the lower d-c rectifier voltage.

The curves of Fig. 3 show generator terminal voltage, armature current, and field voltage versus time for a ten-cycle, three-phase fault through ten-percent external reactance. This is representative of a severe fault with modern high-speed circuit-breaker clearing time. It also simulates a fault on the high-voltage terminals of the transformers connected to the Springdale No. 7 machine. For about two cycles the field voltage is negative because the induced voltage in the field resulting from fault current in the armature is higher than the rectifier output voltage. In about three cycles after the application of the fault the voltage regulator has advanced the firing delay in the rectifier and increased the field voltage. The curve shows the field voltage fluctuations, resulting from voltage-regulator operation, until the terminal voltage returns to a constant value of 100 percent. For the same condition of a ten-cycle three-phase fault, a rotating exciter with a rheostatic-type voltage regulator would require a longer time to return the generator terminal voltage to normal.

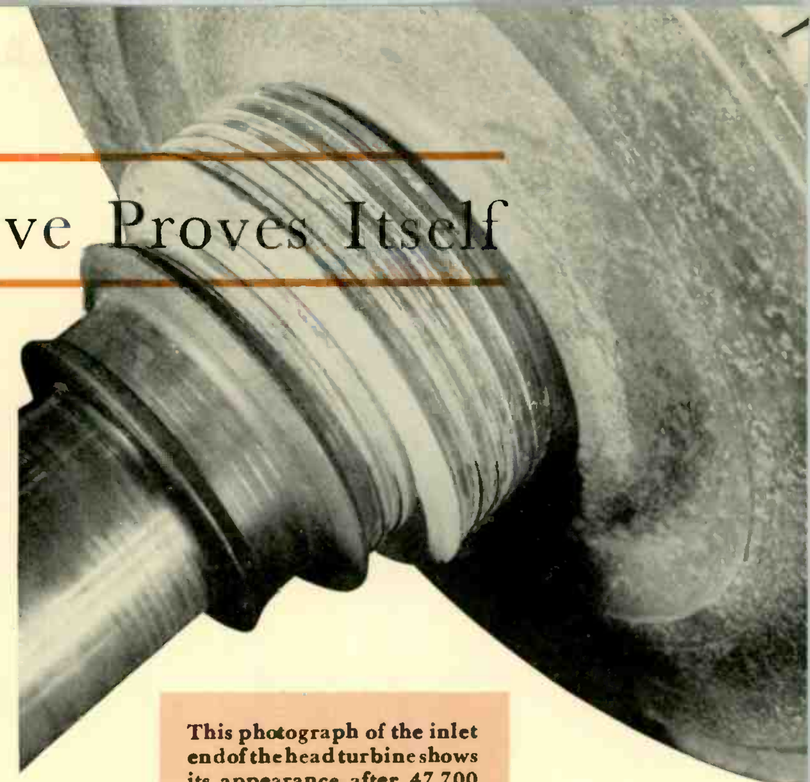
In Fig. 4 are curves of generator terminal voltage versus time for application of 60-percent reactive load using the electronic exciter and a rotating exciter. Comparison of the performance of the electronic and rotating exciters for this condition shows that the electronic exciter returned the terminal voltage to a constant value of 100 percent in about 50 cycles. With the rotating exciter, the terminal voltage was returned to 100 percent in about 70 cycles. Because a voltage regulator was not used on the rotating exciter, the time required to return the voltage to a constant value of 100 percent was not obtained.

Test results showed that the performance of the electronic exciter with and without series compensators was about the same. This was primarily because of the high voltage regulation in the a-c supply circuit to the rectifier. The high regulation was a result of the high field current requirements of the test generator and the high reactance of the auxiliary transformer (450 kva in the laboratory compared to 7500 kva in the installation) between generator terminals and rectifier.

For applications of large loads and for faults cleared in a normal time the electronic exciter will return the terminal voltage to normal faster than will a rotating exciter. Under severe fault conditions in which the terminal voltage of a generator self-excited by an electronic exciter is caused to decay to zero, the decay of the short-circuit current prevents excessive fault damage.

The electronic exciter can be serviced while in operation; it has an inherent high speed of response but the cost is higher than that of a rotating machine. With the direct-acting voltage regulator, the exciter voltage increases from no-load excitation to ceiling excitation in about three cycles. With a no-load, d-c ceiling of 400 volts, this exciter has a response ratio (ASA definition) of about 4.1; with a no-load d-c ceiling voltage of 300 volts, the response ratio is approximately 2.2. The extensive laboratory tests, based on pessimistic conditions that are unlikely to be matched in actual service, demonstrate that the electronic exciter can be depended upon as a reliable source of excitation for large a-c generators.

The Turbine Locomotive Proves Itself



This photograph of the inlet end of the head turbine shows its appearance after 47 700 miles of main-line service.

The final test of any locomotive is performance in service. The first U.S. geared-turbine locomotive has met this test in 47 700 miles of revenue service in 15 months, and the first inspection of turbine and gears indicates that they can continue that performance indefinitely.

T. J. Putz
Steam Turbine Engineer

F. L. Alben
Railway Mechanical Engineer

Westinghouse Electric Corporation

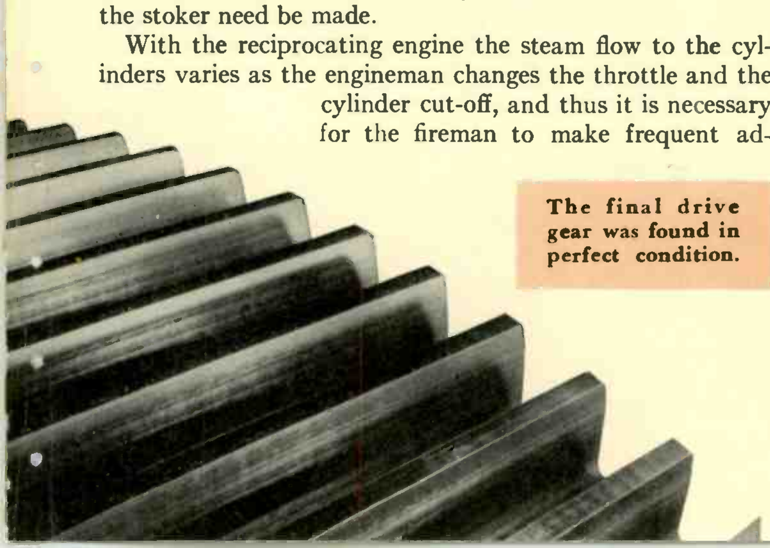
The first geared steam-turbine locomotive built for a United States railroad has been in operation on the Pennsylvania Railroad since October, 1944. It has accumulated 47 700 miles in main-line service. It has been subjected to all kinds of railroading, pulling passenger trains at high speed, heavy freight trains, and in one severe test operated upgrade in reverse with a heavy load of sand cars.

Most of the mileage has been accumulated in high-speed passenger service between Crestline, Ohio and Chicago, pulling such name trains as the Broadway, the Trail Blazer, and the Admiral, although it also operated for a time in passenger service on the eastern slopes of the Alleghenies between Altoona and Harrisburg. It has easily made existing schedules for these trains even under severe operating conditions. At no time did any of its trains fail to maintain schedule because of any malfunction of the turbines or gears, the only features new to locomotives.

The locomotive has also been in the Altoona test plant of the Pennsylvania Railroad for steaming tests. Overall performance tests were not made; however, the locomotive developed more horsepower than any other locomotive ever tested in the plant.

Among the advantages expected of this type of modern power, one of significance is the extreme simplicity of operation. Service experience has borne out that expectation. In starting a train from a station it has been found that the throttle should be opened just enough to start the train after which the engineman opens the throttle to permit between one-half and three-fourths maximum steam flow. The train is allowed to accelerate with a constant flow of steam through the turbine. The train reaches a balanced-speed condition and operates there for periods of more than one half hour without further manipulation of the throttle. This type of operation simplifies the job of the engineman and also the fireman inasmuch as only one adjustment to the throttle and the stoker need be made.

With the reciprocating engine the steam flow to the cylinders varies as the engineman changes the throttle and the cylinder cut-off, and thus it is necessary for the fireman to make frequent adjustments in the rate of steam generation and coal feed. With the turbine locomotive, both of these are constant with optimum steam conditions at all times for one setting of the throttle regardless of the speed at which the locomotive may be running.



The final drive gear was found in perfect condition.

The turbine locomotive has demonstrated its ability to start full-length passenger trains without jerk. Smooth starts such as with the Diesel electric and the electric locomotive are easily made. The starting tractive effort of the turbine locomotive exceeds that of the reciprocating-type engine.

Early this year the locomotive was returned to the Juniata shops of the Pennsylvania Railroad at Altoona for a complete inspection of the propulsion equipment. Until then inspection of any of the parts had been limited to the turbine which can be easily removed from the locomotive. The only repairs made to these parts during this test period were such things as a redesign of the means of locking bolts, control changes to speed up reverse operation and to prevent clutch disengagement, all of which required but a few days.

The recent complete inspection at Altoona showed that there was no accumulation of scale on the turbine blading or any indication that these turbines would not give service comparable with that expected in central-station or marine service.

All reduction gearing is in perfect condition, there being no evidence of undue wear, pitting, galling, or any of the afflictions of gearing subjected to such severe loadings.

The flexible drive that connects the axles with the final drive gears and cushions the gears against road shocks showed some wear. Minor design changes to the lubrication system and to parts of the flexible drive have been made. With these changes the flexible drives are expected to have a life equal to that of the remainder of the propulsion unit.

While this initial test period must be regarded as a short time in the total life of a locomotive, there is reason to believe that this geared turbine equipment will have a life of many years comparable with geared turbines for ships. If subsequent operation bears out this expectation, the direct-drive geared turbine is a practical, reliable propulsion unit for transportation applications.

Dr. Russell tests the impact strength of standard and Zircon porcelains. Foreground pieces have equal strengths although Zircon specimen is much smaller.

Zircon Porcelain

To our list of war-born materials of permanent value must be added Zircon porcelain, originally developed during the war as a high-frequency insulation. Its unusual properties—high mechanical strength and thermal shock resistance, low electrical loss, high-temperature electrical resistivity, and great moisture resistance—make it almost the ideal ceramic and promise it an extensive future.

Dr. Ralston Russell, Jr.
Section Engineer, Research Laboratories, Westinghouse Electric Corporation

Zircon porcelain is a widely useful and promising addition to the class of high-quality ceramic materials known under the generic name of porcelain. Although these special Zircon porcelains are essentially new, high-fired Zircon porcelains have been used to some extent for a decade or more in the spark-plug field. Not until the war, however, were the qualities of this porcelain fully appreciated. During this period occurred the original development of Zircon porcelain as a substitute for the Steatite type of porcelain universally used for high-frequency electrical insulation.

The new porcelain has proved invaluable in radio and radar components where mechanical strength and electrical characteristics are vital. Its applications in coaxial-cable terminals and bushings for transformer and capacitor cases are typical. Furthermore, it has proved exceedingly useful for electrical applications at elevated temperatures. Zircon porcelain has such a uniquely excellent combination of electrical, mechanical and thermal properties, coupled with diverse manufacturing possibilities, that its application is foreseeable in many engineering fields. One of its primary uses, for example, is in low-frequency, high-voltage insulation, supplementing its already established high-frequency role. Having low electrical losses, unusually high mechanical strength and thermal shock resistance, and equally effective at both normal and elevated temperatures, Zircon porcelain constitutes a significant and versatile member of the porcelain family.

Types of Porcelain

The term "porcelain" describes a class of ceramic materials composed of various mixtures of inorganic minerals which are molded or shaped in different ways before glazing and finally firing at a high temperature, usually 1200–1450 degrees C, for a sufficient time to effect the thermochemical changes which transform the mineral mass into a vitreous (i.e., absolutely non-porous) material with a glassy surface. Such a material—a white-ware ceramic of highest technical quality—is known as true porcelain.

The term also designates a class of ceramics, and there are numerous types of porcelain as well as untold varieties possible for any selected type. The common porcelains are (1) Clay-Quartz-Feldspar porcelains, (2) high mullite or alumina porcelains, (3) Steatite and related types, and (4) Zircon porcelains. The distinguishing features of the common porcelains are summarized in table I. The theoretical compositions of the raw materials listed are seldom attained in actual practice. For example, as many as six different clays, all having somewhat different chemical and physical characteristics, may be blended along with other minerals in a single porcelain.

It should be noted that beyond the field of porcelain exists the sintered oxide or refractory oxide field of vitreous ceramics. These ceramics are made from the processed pure oxides of aluminum, magnesium, beryllium, thorium, and zirconium, singly or in a mixture, limited amounts of other inorganic constituents sometimes being used. The sintered oxide ceramics are usually fired at extremely high temperatures of 1600–1950 degrees C, and are comparatively costly and difficult to fabricate, but in general possess the most outstanding properties known in the field of vitrified ceramics. Their existence does not seriously detract from nor do they compete with porcelain for most applications. Such competition could only occur if the lower fired porcelain materials could be improved considerably more than current knowledge permits. Zircon porcelain represents the farthest step yet made in this direction, but it is not claimed to be the equal of the better sintered oxide ceramics in overall properties.

Before considering Zircon porcelain in detail, a recognition

—A Modern Ceramic

of the general properties which an ideal vitrified ceramic might possess, is important. It must be remembered that specific applications require special properties in many cases and that the properties of greatest importance vary with the application. In considering technical and industrial applications, it is necessary to evaluate the thermal, mechanical, electrical, chemical, and general physical character in varying degrees of importance. Overall cost of finished product, ease and flexibility of manufacture with existing methods and equipment, and continuity and uniformity of product are, of course, important factors. Assuming that all such factors are acceptably good, if not the optimum, the ideal ceramic might possess properties somewhat as follows (noting that there is no such thing as a universal ideal):

Thermally, the ceramic should have high thermal conductivity and low coefficient of thermal expansion in order to avoid overheating, to insure stability of size, and to promote thermal shock resistance.

Mechanically, the ceramic should have maximum tensile, compressive and impact strength, and elasticity over a wide temperature range.

Electrically, the ceramic should at normal and elevated temperatures have maximum dielectric strength, high surface resistance under all humidity conditions, low dielectric constant, and low power factor at all frequencies.

Chemically, the ceramic should be resistant to deterioration or change by chemical action over a range of temperature.

Physically, the ceramic should be absolutely dense—i.e., free from open and sealed pores, be light in weight, and be extremely hard if not soft enough to permit machining.

In the light of these ideal properties, which are of most general interest and are sought after in porcelains, some of the characteristics of present Zircon porcelain as a ceramic material may best be considered.

The Nature of Zircon Porcelain

Zircon porcelain consists predominantly of the mineral "Zircon" ($ZrO_2 \cdot SiO_2$), but it also contains lesser amounts of clay substance and fluxes which are generally of the alkaline earth type (CaO, MgO, BaO, SrO). Special fluxes and auxiliary materials are used advantageously in some cases. The mineral Zircon is a constituent of many igneous rocks and is found throughout the world. However, the usable sources are largely confined to beach sands, which interestingly enough often gradually replenish themselves. Some of the more important beach sand deposits are found in Australia, Brazil, India and Florida, and the pure Zircon is fairly easily separated from its accessory minerals, Ilmenite ($FeO \cdot TiO_2$) being a common one. The processing of mineral Zircon to prepare a usable porcelain raw material is largely one of purification and grinding as required. Zircon thus lends itself to much closer control than many ceramic raw materials, including

Zircon porcelain insulators are turned on a lathe during spraying for uniform application of a special glaze.

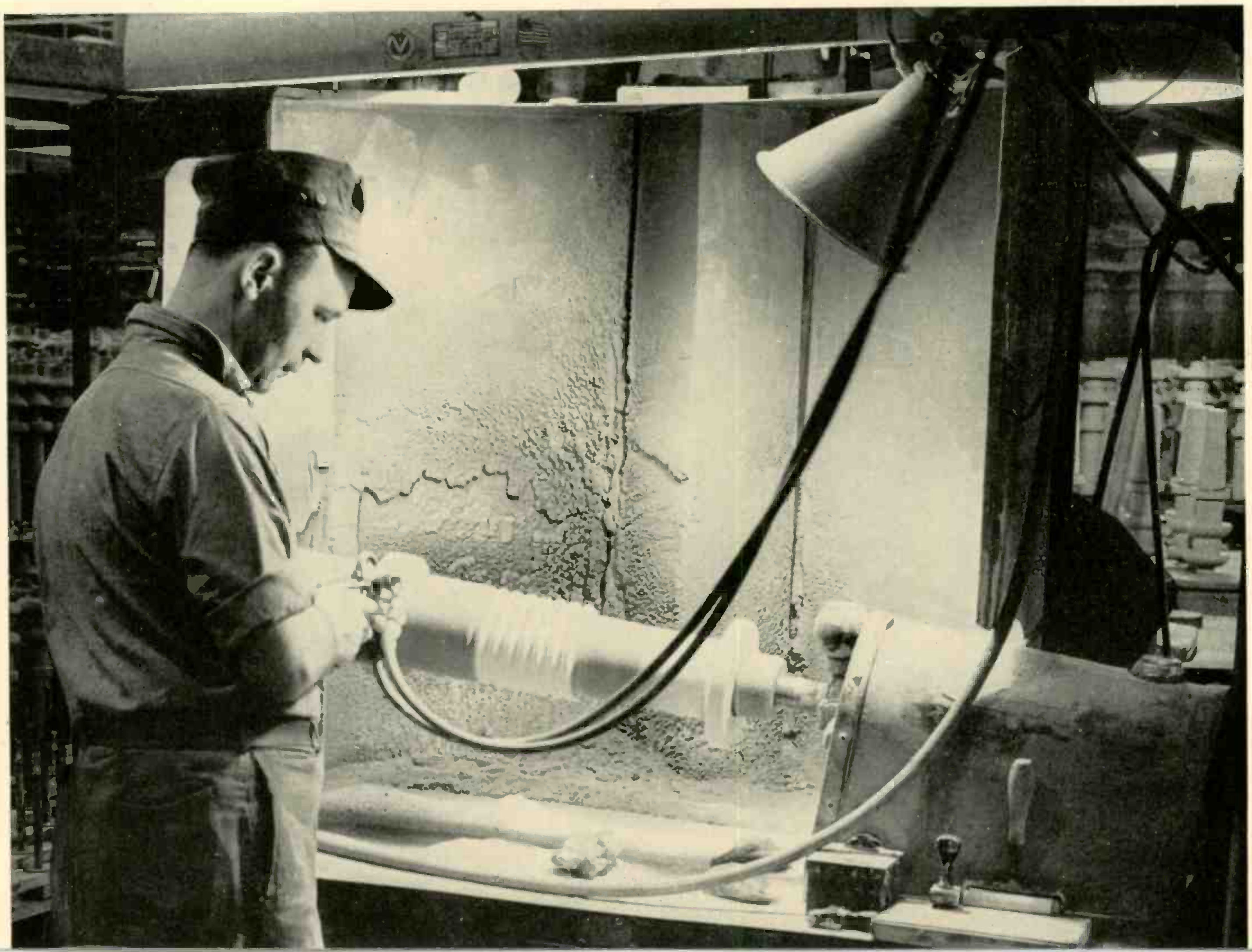


TABLE I — COMPOSITION AND USES

Type of Electrical Insulation	Non-Plastic Constituent	Plastic Constituent	Fluxing Constituent	Primary Electrical Uses
Zircon Porcelain	Zircon ($ZrO_2 \cdot SiO_2$)	Clay ($Al_20_3 \cdot 2 SiO_2 \cdot 2H_20$)	Compounds of CaO, MgO, BaO, SrO	Radio, radar and miscellaneous high-frequency equipment requiring a material of low electrical losses. Also for low-frequency, high-voltage insulation where highest mechanical strength or thermal shock resistance is required. Effective at normal and elevated temperatures.
Steatite and Cordierite	Talc ($3Mg0 \cdot 4SiO_2 \cdot H_2O$)	Clay	Compounds of Na_2O, K_2O, BaO, CaO, MgO, ZnO, BeO, Li_2O	Radio, radar and miscellaneous high-frequency equipment requiring a material of low or moderate electrical losses. Cordierite is used where thermal shock resistance or dimensional stability is involved. Effective at normal and elevated temperatures.
Mullite Porcelain	Cyanite ($Al_2O_3 \cdot SiO_2$) Mullite($3Al_2O_3 \cdot 2SiO_2$)	Clay	Compounds of K_2O, Na_2O, CaO, MgO	Automotive spark plug insulation, and high-voltage, low-frequency insulation involving elevated temperatures or thermal shock conditions.
High Voltage Porcelain	Quartz (SiO_2)	Clay	Feldspar ($KNaO \cdot Al_2O_3 \cdot 6SiO_2$)	All high-voltage, low-frequency applications where excessive temperatures are not involved; primarily for power transmission and distribution.
Sintered Alumina	Alumina (Al_2O_3)	Clay, if any	BeO, ZrO_2, MgO, CaO	Aircraft and automotive spark plug insulation, electronic and power applications involving extremely high temperatures.
Fused Quartz	Quartz Sand or Quartz Crystals(SiO_2)	Molded by special methods	None	High-frequency applications requiring material of lowest electrical losses, extreme dimensional stability, or highest thermal shock resistance.
Mica-glass Products	Mica	Molded under pressure and heat	Lead Borate Glass	High- or low-frequency applications where some machinability of product may be required or where service temperatures are not high.
Glass	Quartz Sand	Glass is shaped in molten condition	Compounds of Na_2O, B_2O_3, Al_2O_3, CaO, MgO, K_2O	Miscellaneous high- and low-frequency applications where lowest electrical losses are not involved but where high dielectric strength may be required. Useful at only moderately elevated temperatures, but has good thermal shock resistance.

talc or soapstone, the principal ingredient of all the Steatite type of ceramics.

Zircon porcelain is an extremely hard, dense, white mass which is somewhat heavier than the conventional types of porcelain due to the high specific gravity of mineral Zircon. The ware may be glazed to develop an exceptionally smooth, glassy surface during firing. The hardness of the porcelain precludes appreciable shaping, drilling or tapping after firing, although some grinding may be done with difficulty. Zircon porcelain lends itself admirably to the development of vacuum or hermetic metal-to-porcelain seals of all types. Stability of mechanical properties and shape at temperatures up to 1000 degrees C or higher merits careful consideration for special applications.

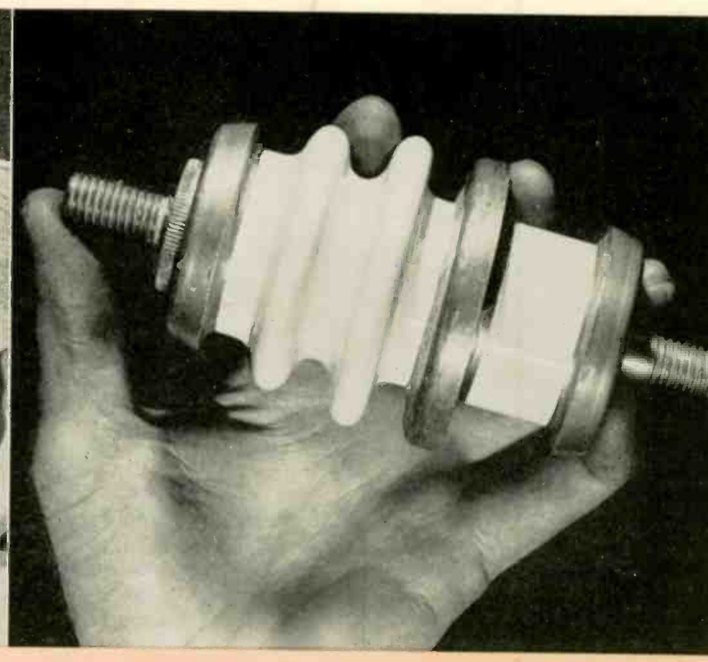
The porcelain is exceptionally strong mechanically, has good electrical characteristics at normal and elevated temperatures, low electrical losses at high frequencies, and very good thermal shock resistance. This excellent combination of properties affords Zircon porcelain a wide field of application in the low-frequency power field, high- and ultra-high-frequency communications and signaling equipment, and in special installations where resistance to thermal shock or insulation of electrical circuits at elevated temperatures are prerequisites. No other known porcelain has such a diverse field of usefulness.

The Manufacturing Process

Zircon porcelain may be manufactured by any of the conventional ceramic molding processes including extrusion, turning, dry or semi-wet pressing, and casting. The body mixing may be accomplished by either the dry-mixing or wet process. The manufacture is considerably more flexible than that of Steatite, which is best adapted to dry-press forming because of the natural softness and lubricity of mineral talc. Special methods involving the use of auxiliary binders and plasticizers are required for the successful extrusion of Steatite and it is cast only with comparative difficulty. Steatite usually must be bisque-fired at a low temperature before turning, whereas Zircon porcelain is turned in the dry state.

A true porcelain is fired to the vitreous state—i.e., it is absolutely impervious and of essentially maximum density. A limited amount of minute sealed pores are usually present, but these are not deleterious to the quality of the ware. An important manufacturing advantage of Zircon porcelain is the ease with which it may be fired to complete vitrification, as is also true of high-voltage porcelain. This is due to a comparatively wide firing range for the development of vitrification. For example, Zircon porcelains often have firing ranges of 30 degrees to 50 degrees C between the point at which they are porous due to underfiring and distorted due to overfiring.

Zircon porcelain bushings, solder-sealed to radar network case-covers, combine not only excellent high-frequency characteristics and vacuum-tight seals but also high shock resistance



The two metal caps and the flange are hermetically sealed on this glazed Zircon porcelain bushing for radar transformers, providing an assembly unusually high in [illegible]

TABLE II—MECHANICAL, THERMAL & PHYSICAL PROPERTIES

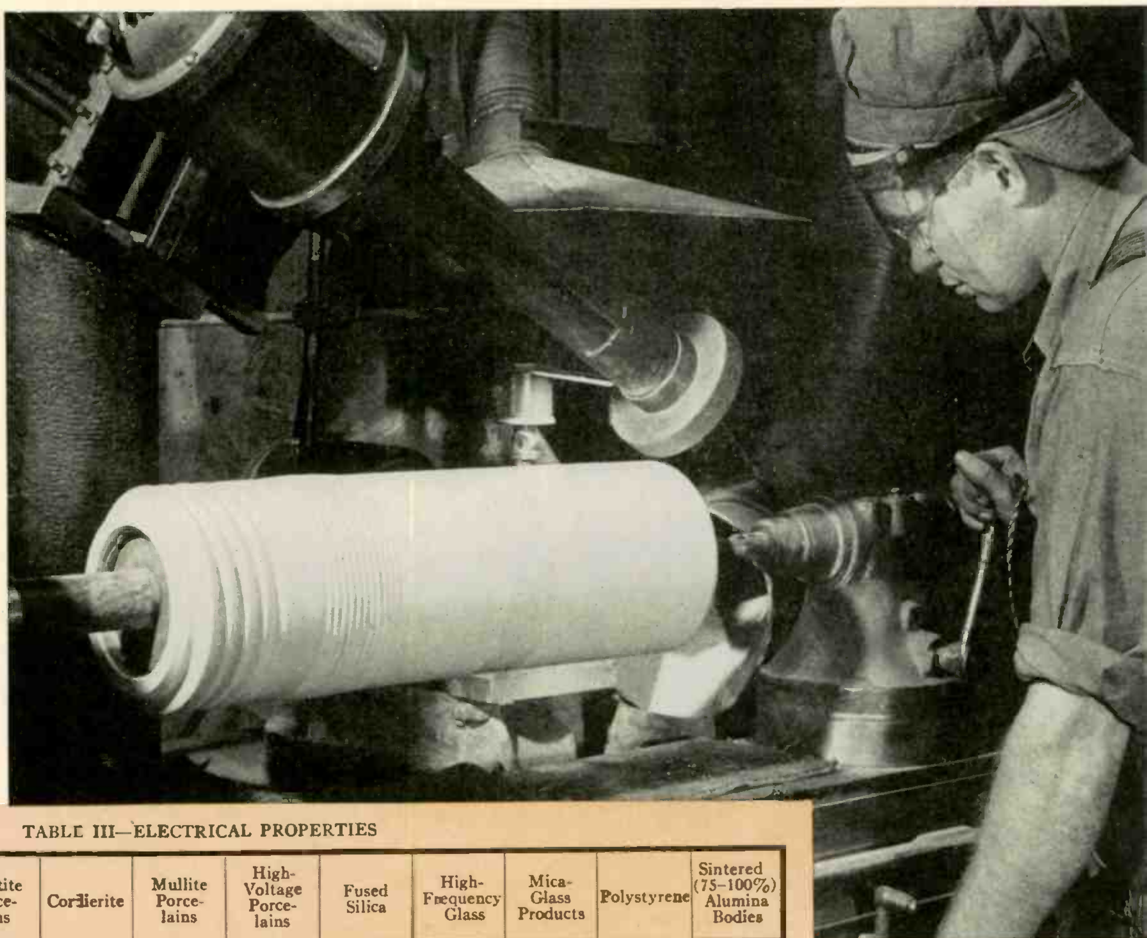
	Westinghouse Standard Zircon Porcelain	Miscellaneous Zircon Porcelains	Steatite Porcelains	Cordierite	Mullite Porcelains	High-Voltage Porcelains	Fused Silica	High-Frequency Glass	Mica-Glass Products	Polystyrene	Sintered (75–100%) Alumina Bodies
Specific Gravity gm/cc	3.68	3.0–3.8	2.5–2.8	2.1–2.2	2.4–3.1	2.3–2.5	2.2	2.1–2.3	3.0–3.5	1.05–1.07	3.1–3.9
Absorption %	0.0	0.0	0.0–0.2	0.0–12.0	0.0	0.0	0.0	0.0–0.01	0.0–0.1	0.0–0.1	0.0
Mohs' Hardness	8.0	7.5–8.5	7.0–7.5	6.0–7.5	7.5	7.0	5.0–7.0	5.0–6.0	3.0–4.0		8.5–9.0
Coefficient Linear Thermal Expansion 20–700°C x 10^{-6}	4.9	3.5–5.5	7.8—10.4	2.0–2.8	4.3–5.0	5.0–6.8	0.55	0–300°C 2.8–3.2	20–400°C 9.2	0–60°C 60–80	5.5–8.1
Safe Operation Temperature °C	1050	1000–1300	1000–1100	1200	1250	1000	1000	425–500	300	50–60	1350–1600
Thermal Conductivity cal/cm²/cm/sec/°C	0.0117	0.010–0.015	0.0053–0.0061	0.0025–0.0061	0.0037–0.0073	0.0025–0.0039	0.0033–0.0036	0.0027	0.0010	0.00019	0.0073–0.0560
Tensile Strength #/in²	12 700	10 000–15 000	6200–13 000	1500–5000	5000–10 000	3400–8000	2500–7000		5000–12 000	5000–9000	8000–36 000
Compressive Strength #/in²	90 000	80000–150000	65000–130000	30 000–70 000	50 000–120000	40 000–80 000	20000–30000		20000–38000	11 000–15 000	80000–410000
Transverse Strength #/in²	25 000	20 000–35 000	14 000–24 000	4000–12 000	13 000–21 000	9000–15 000	10000–11000	7000–18 000	14000–20000	8000–19 000	18 000–55 000
Modulus of Elasticity #/in²	24 000 000	20 000 000–30 000 000	13 000 000–15 000 000	7 000 000–13 000 000		7 000 000–14,000 000	10 000 000			170 000–470 000	15 000 000–52 000 000
Thermal Shock Resistance	Good	Good	Poor	Excellent	Good	Fair	Excellent	Good	Fair	Fair	Excellent

Steatite, on the other hand, is comparatively difficult to fire properly due to its short vitrification range of about 10–20 degrees C and its extreme tendency to distort if even slightly overfired. The production of uniformly high-quality Zircon porcelain is thus much easier than is the case with most Steatite ceramics. Zircon porcelain does, however, warp more easily during firing than high-voltage porcelain unless the firing temperature is closely controlled at the lower limit of vitrification. However, warping is serious only when large parts or parts of thin section are not fully supported during firing.

Commercial Zircon porcelain is currently made by the one-fire process, in which the glaze is applied before firing and matured to a glassy surface in a single high-temperature fire. Such glazes are intimately bonded to the porcelain body and can be designed to beneficiate the mechanical strength. Most Steatite, on the other hand, is glazed after the body has been fired to maturity, and the glaze is gloss-fired at a lower temperature. This is largely a commercial expedient due to the necessity of fully supporting Steatite parts to prevent warpage during high-temperature firing, since the design of a one-fire Steatite glaze offers no problem. Low-temperature glazes are less resistant to abrasion and chemical attack. They are also less amenable to mechanical strength improvement than high-fired glazes which can be designed for the best stress relationships between porcelain and glass.

The Properties of Zircon Porcelain

The flexibility of Zircon-porcelain manufacture with respect to body preparation, fabrication, glazing and firing means that it may be produced with uniformly high quality in a wide variety of shapes and sizes to accommodate its many current and probable applications. The cost of Zircon porcelain should compare favorably with all competitive ceramic materials. Mineral Zircon is somewhat more expensive than conventional porcelain constituents such as clay, quartz, feldspar, talc, and cyanite. Zircon also causes greater wear of dies,



Here a Zircon porcelain bushing for high-temperature use is being finished to close tolerances.

TABLE III—ELECTRICAL PROPERTIES

	Westinghouse Standard Zircon Porcelain	Miscellaneous Zircon Porcelains	Steatite Porcelains	Cordierite	Mullite Porcelains	High-Voltage Porcelains	Fused Silica	High-Frequency Glass	Mica-Glass Products	Polystyrene	Sintered (75–100%) Alumina Bodies
Power* Factor at 1 Megacycle	0.0010–0.0014	0.0002–0.0020	0.0002–0.0035	0.003–0.007	0.004–0.005	0.006–0.010	0.0002–0.0023	0.0006–0.0042	0.0012–0.0035	0.0001–0.0008	0.0010–0.0020
Dielectric Constant	9.2	8.0–10.0	5.5–7.5	4.1–5.4	6.2–6.8	6.0–7.5	3.2–4.2	4.0–4.7	6.4–8.5	2.5–2.6	7.3–11.0
Loss Factor	0.009–0.013	0.0016–0.020	0.0011–0.026	0.012–0.038	0.025–0.034	0.036–0.075	0.0006–0.0097	0.0024–0.0197	0.0077–0.0298	0.00025–0.00208	0.007–0.022
Dielectric Strength Volts/mil	290	250–350	200–350	100–250	250–400	250–400	100–400	>500	50–325	400–600	400–1100
Resistivity Ohm–cm	10^{13}	10^{12}–10^{15}	10^{12}–10^{16}	10^{12}–10^{14}		10^{12}–10^{14}	10^{18}	10^{14}–10^{17}	10^{12}–10^{15}	10^{17}–10^{19}	10^{14}–10^{15}
Te Value °C	>700	>700	450– >700	600–700	500–650	300–500	700–900				>700

augers and other metal equipment parts than do the softer minerals, particularly talc. However, the ease and flexibility with which Zircon porcelain may be processed, and the uniformity and high quality of product certainly more than offset these disadvantages. The hardness of the fired product precludes most shaping or drilling at this stage but insures durability once the final size and shape have been attained. The ease with which Zircon porcelain lends itself to the rigors of hermetic sealing is important where ceramic-to-metal seals are required. Zircon porcelains are 30–50 percent heavier than other conventional porcelains, but this factor is not considered a major one, even in aircraft communications equipment, due to the small weight of ceramic insulation involved. Furthermore, the superior strength of Zircon porcelain permits a reduction in thickness of section in many cases so that the total weight of insulation is not increased.

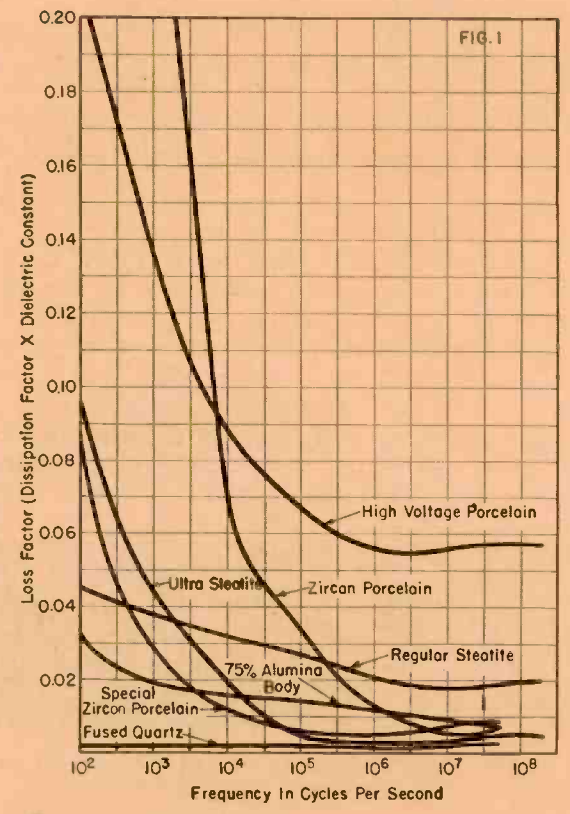
The detailed properties indicate clearly the high quality of Zircon porcelain. Table II includes important physical, mechanical, and thermal properties of Zircon porcelain and various other electrical insulating materials. The electrical properties are included in table III.

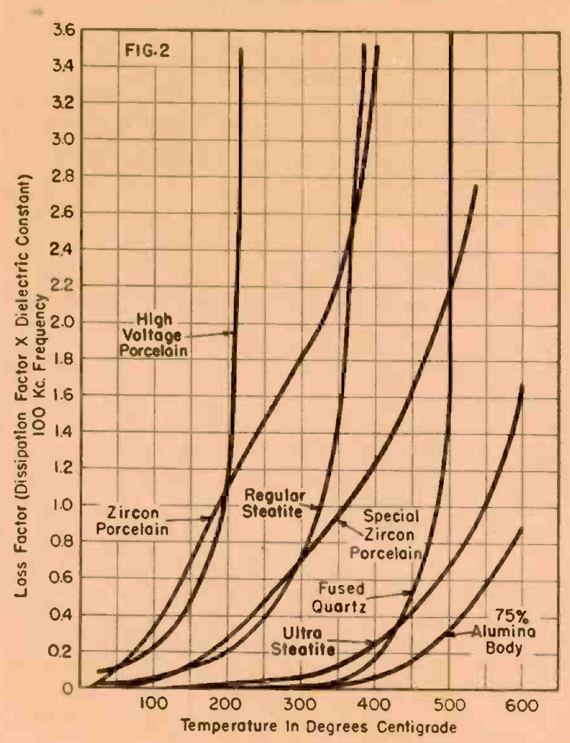
The general superiority of commercial Zircon porcelain to all except the expensive, non-competitive sintered alumina is readily apparent. It is 50 to 200 percent stronger than Mullite and high-voltage porcelains, and 10 to 50 percent stronger than Steatite, heretofore the strongest of the porcelain-type materials. Thermally, Zircon porcelain is equal or superior to any of the other porcelains. It has the highest thermal conductivity and approaches the low thermal expansion of Mullite porcelain. It has been observed to have very good thermal shock resistance, as is also true of Mullite porcelain. High-voltage porcelain is mediocre in this respect, while Steatite porcelain is decidedly the poorest.

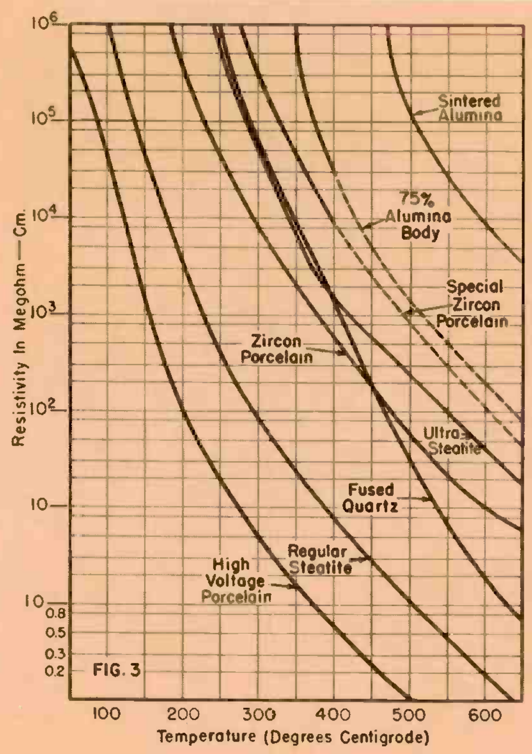
All of the porcelains have good resistance to all alkalies and acids except hydrofluoric. Sintered alumina is, however, known to resist corrosive vapors and reducing conditions at high temperatures more effectively than any porcelain and to resist hydrofluoric acid.

The electrical properties of Zircon porcelain further substantiate its high quality and wide usefulness. The electrical losses (dissipation factor × dielectric constant) are a primary criterion in selecting insulation for high-frequency applications. Zircon porcelains generally fall within the three best classes of ceramic high-frequency insulators; namely, classes[1] L-4, L-5, and L-6 having loss factors at 1 megacycle of 0.016, 0.008, and 0.004, respectively. This is also true of most Steatite ceramics which have been universally exploited for high-

[1]American Standards Association, American War Standard C-75.1-1943, Ceramic Radio Insulating Materials, Class L.







The curves at the left present electrical properties of several typical ceramic materials. Fig. 1 plots loss factor versus frequency. Figure 2 shows the effect of temperature upon loss factor, while the dependence of resistivity on temperature is indicated in Fig. 3.

frequency equipment. The electrical loss characteristics of some typical materials at different frequencies are shown in Fig. 1. The high loss factor of one of the Zircon porcelains at low frequencies is of no particular importance, since electrical losses assume a major role only at high frequencies. The somewhat higher dielectric constant of Zircon porcelain is offset by its low power factor at high frequencies, the product of the two being sufficiently low to insure satisfactory classification. It is noteworthy that some Zircon porcelains fall within the superior L-6 class although the current commercial varieties are in classes L-4 or L-5, the classes which are usually specified in the selection of high-frequency insulation.

The effects of temperature upon loss factor and electrical resistivity are shown in Figs. 2 and 3. Zircon porcelains are seen to compare favorably with all other porcelains currently available, being superior to high-voltage porcelains and the average grade of Steatite. A special grade of Steatite was found to be next to sintered alumina in high-temperature electrical loss properties, but it is believed that special Zircon porcelains will be found to at least equal this high-quality Steatite. There is some doubt at present, however, that the properties of pure sintered alumina can be attained in any porcelain type of material.

The characteristics of Zircon porcelain are largely covered in the tables and curves, and the advantages and disadvantages can be summarized briefly. It is worth noting that the raw materials are readily available and that the product can be formed by a number of conventional methods. Zircon porcelain is amenable to production in uniformly high quality. It can be fired with ease to complete vitrification, for it has a long firing range, and it can be made by a one-fire process. It has a high resistance to abrasion and to chemical attacks, and it is not only strong mechanically but quite resistant to thermal shock. Zircon porcelain falls within the best classes of high-frequency ceramic insulators as classified by the American Standards Association, possessing low electrical losses over a range of frequencies and temperatures in addition to high electrical resistivity and good dielectric strength at both normal and elevated temperatures. Finally, Zircon porcelain responds satisfactorily to metal sealing.

On the other hand, there are several apparent disadvantages to Zircon porcelain. First of all, the raw materials are moderately expensive. Raw Zircon, moreover, is a very hard substance and causes considerable tool and die wear. During the firing process, Zircon porcelain has a slight tendency to warp in thin sections. The fired ware itself is difficult either to cut or grind because of the extreme hardness of the material. Finally, glazing of Zircon porcelain requires special care and attention. In spite of these short-comings, all of which relate only to the manufacturing process, the predominantly advantageous characteristics of Zircon porcelain make it an exceptional porcelain material.

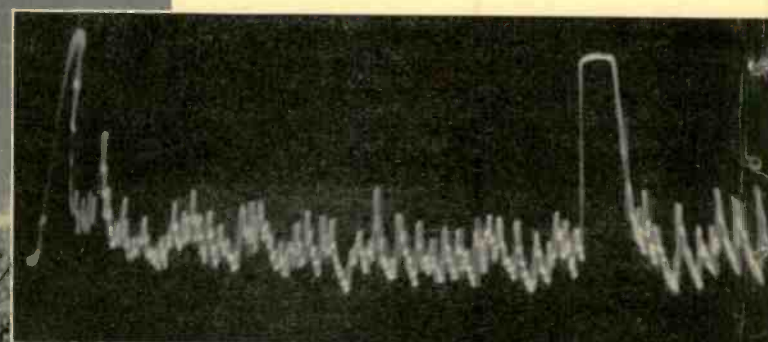
Vacuum-tight seals are necessary for terminal assemblies in high-frequency applications. Here a Zircon porcelain coaxial-cable bushing undergoes a solder-seal operation.

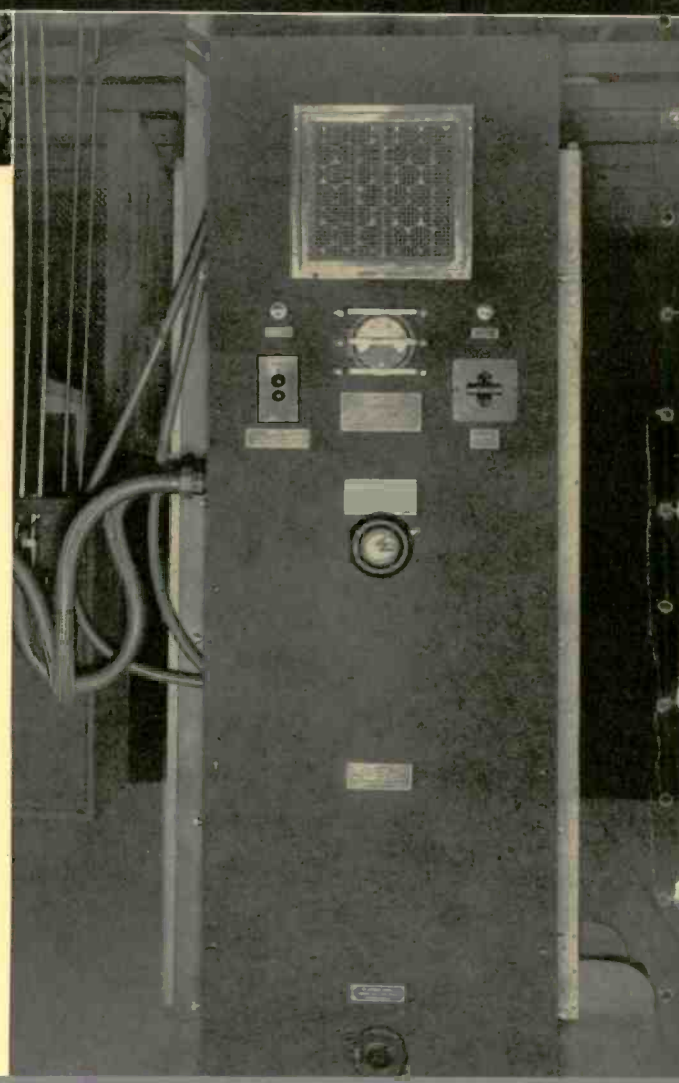
The Future of Zircon Porcelain

It is obvious that Zircon porcelain ranks closest of all porcelains to the "Ideal Ceramic" previously outlined. This promises increased usage of Zircon porcelain, not only in replacing other ceramics for many applications, but also in new electrical equipment where Zircon porcelain may solve some of the more vexing insulation problems. Among the current electrical uses for Zircon porcelain are radio, radar, and high-frequency applications (e.g., sockets, tube bases, coil forms, terminal and switch plates, antenna insulators, etc.), coaxial cable terminals, capacitor dielectrics, spark-plug insulators, and tubes for wire-wound resistors of all types. Still other applications include strain insulators, bus supports, bushings for transformer and capacitor cases, and bushings and supports for use at elevated temperatures or over a wide range of frequencies. In addition to their electrical applications, Zircon porcelains will find technical and mechanical applications where the properties of a superior ceramic are required.

Improved Zircon porcelains and new applications will be developed, and exploitation will continue until Zircon porcelains have a position of lasting importance commensurate with their high quality, uniformity, and diverse usefulness. It is almost certain, for example, that the next new vitrified, porcelain-type ceramic will be evaluated in comparison to Zircon porcelain, just as Zircon is currently evaluated in respect to Steatite, Mullite, and high-voltage porcelains. This tendency to establish Zircon porcelain as the comparative standard is an indication of its position as an outstanding modern ceramic, and its successful application during the wartime emergency leaves little doubt as to the future importance of Zircon porcelain in the field of vitrified ceramics.

The war-famed SCR-271 radar set, built by Westinghouse for aircraft detection, was used by the Army Signal Corps to establish radar contact with the moon. For handling the high power necessary for the 476 000-mile round-trip journey of the radar pulse, the system was modified considerably. Two antennas were mounted side by side on a 100-foot tower, giving a beam 12 degrees in both azimuth and elevation. The transmitter (below) was stepped up to provide one-half second pulses of 50 000 watts peak power at intervals of five seconds. The first deflection on the cathode-ray indicator (below) is part of the powerful, outbound pulse. The second "pip" on the scope shows the weak reflected signal from the moon arriving 2.4 seconds later with a power of only 9×10^{-16} watt. (Signal Corps Photos.)





To the Moon by Radar

For the first time in history, man has penetrated beyond the atmospheric confines of the earth. On January 10, 1946, the Army Signal Corps at Belmar, New Jersey, transmitted a radar pulse aimed at the moon. In 2.4 seconds, the reflection from the moon appeared as an unmistakable deflection of the horizontal trace on the cathode-ray tube indicator.

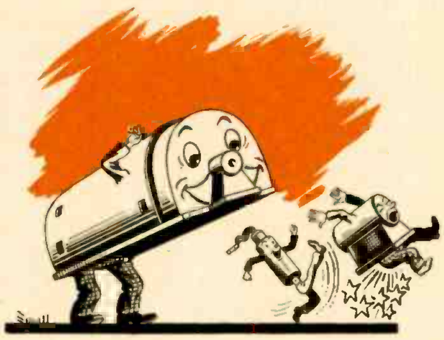
The radar set used for this epochal experiment was originally designed for 150-mile maximum range aircraft detection and was one of the many sets built by Westinghouse during the war. The 238 000-mile lunar range required the Signal Corps to make a number of modifications in the apparatus. Considerably greater average power is required; the pulse length and the pulse interval of silence, during which reflected signals could return to the receiver, must be longer. The system was altered to transmit a 50-kw half-second pulse at five-second intervals.

The primary significance of the experiments lies in their demonstration that high-frequency radio energy can penetrate the ionosphere and cosmic space. The addition of vertical rotation—only horizontal rotation was used in the early tests—promises not only further studies of the moon but of the ionosphere. Past tests were made with the radar beam almost tangent to the ionosphere; with vertical rotation, varying angles of incidence will be possible. These tests also suggest the feasibility of sending radar-directed space-ships for instrumental studies of cosmic rays, pressures, and temperatures in the regions beyond the earth's atmosphere.

PERSONALITY PROFILES

People out late one Saturday night not long ago in downtown Pittsburgh were astonished to see an antique street car cruising the streets carrying a gay party of young men and women, singing and dancing. It was a gang of young Westinghouse engineers—members of a well-known Pittsburgh social club—and their dates, enjoying one of their monthly entertainments in unique fashion. The man behind it was *R. F. Lawrence*, entertainer par excellence and co-author of one of the electronic exciter stories in this issue. Lawrence, in addition to being an extremely capable young engineer, has a growing reputation as an entertainer, both in amateur dramatics and as a member of "barber-shop" choruses.

When Lawrence completed his course of graduate-student training at Westinghouse in 1944, he first had his eye on sales engineering, where for a time he had a roving commission. However, the general problems of power generation and distribution fascinated him, so he graduated to the Central Station Engineering Department. In a short time Lawrence distinguished himself here for his work on problems of circuit breakers, relaying, and excitation. His formal electrical engineering training was obtained at Pratt Institute, where he graduated in 1943.



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It is a high distinction to have been one of the protegés of the great B. G. Lamme. *C. M. Laffoon* had that good fortune. He spent two years under Mr. Lamme's personal direction while he was chief engineer for the Westinghouse Company. Among other things during that period, Laffoon undertook some fundamental studies on magnetic circuits, which have been of great value in his work on large generators. Laffoon was graduated from the University of Missouri with an Electrical Engineering degree in 1914 and a year later received a Master of Science degree from the same institution. He came to Westinghouse in 1916 and after the tutelage by Lamme, he began work on a-c generators. He is now manager of A C Generator Engineering.

Nearly everyone when a child delighted in making mud pies. With most, it was a passing fancy. But *Ralston Russell, Jr.*, upon growing up, has gone into it in a scientific way, making ceramic engineering his life work. Curiously enough, many still do not appreciate the scope of this science which today embraces such apparently diverse fields as electrical insulation, china-ware, glass, enamels, abrasives, and refractories. Russell studied ceramics at Ohio State University,

obtaining his B.S. degree in 1932, followed the next year by his M.S. For the ensuing four years Russell worked in the research and development sections of A.C. Spark-Plug Company, where he helped develop the sintered alumina spark-plug body that became so important on aircraft engines during the war. With General Ceramics and Steatite Company, in 1937, Russell had an introduction to the insulation problems of communication equipment. There he specialized in heat-shock refractories and radio insulators. To obtain his doctor's degree, Russell returned to Ohio State in late 1937. Since 1940 Russell has been associated with ceramic research at Westinghouse and has contributed considerably to such important developments as high-strength glazes for high-voltage porcelain, radio-interference-proof insulators, and the Zircon-type insulation that played such a big part as a high-frequency and high-temperature insulation during the war.

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Although *C. R. Marcum* had been in the mercury-arc rectifier design section of Westinghouse only a short time, he showed an uncommon interest in correlating and organizing the design information. Complimented by the section head, Marcum replied, "It's not that I am ambitious; it's just that I am lazy and this will save me work." Marcum is anything but lazy though he does come from the South where work allegedly proceeds at a more leisurely pace. Although Marcum completed the Westinghouse graduate-student course only three years ago, he is already at the head of the group charged with ignitron design production. This work has brought him in touch with a variety of mercury-arc rectifier applications, such as for mines and chemical plants. All this gave him the background necessary to assist in the design of an exciter built around ignitron rectifiers. He has also established his name in the industry by service on the AIEE subcommittee dealing with mercury-arc power converters, now at work on a set of standards in this field. He is adding to his E. E. degree from the University of Kentucky in 1942, a master's degree from the University of Pittsburgh.

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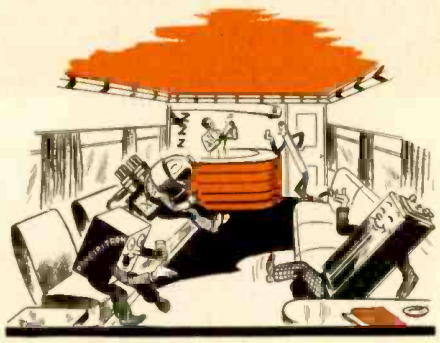
H. H. Hanft has had a varied career that has taken him into many fields and even into many countries. Hanft studied electrical engineering at the University of Minnesota, graduating therefrom in 1925. Upon completing the graduate-student course at Westinghouse, he joined the Railway Equipment Engineering Department, specializing on control and layout of electric locomotives. In the fall of 1927 he went to Germany as an exchange engineer with a large electrical equipment manufacturer, there concentrating again



on railway controls and gathering information on railway practices in Germany that could be applied with profit in the United States. His experiences were put into practice with Westinghouse again in 1928 and 1929. At the beginning of 1930 Hanft entered the general field of market research and analysis for various midwest firms, working in a variety of industrial fields including a special study of commercial refrigeration. He returned to Westinghouse in 1941 as a member of the Market Development Section, and in 1944 completed the cycle by returning to Railway Application Engineering, where his railway background and his more recent market analysis experience give him an excellent foundation for his present activity of applying electrical products to modern railroading.

The sugar-house of the Everglades lies flanked by fields of cane in bloom, suggestive of the merging of agriculture and industry described on page 66.