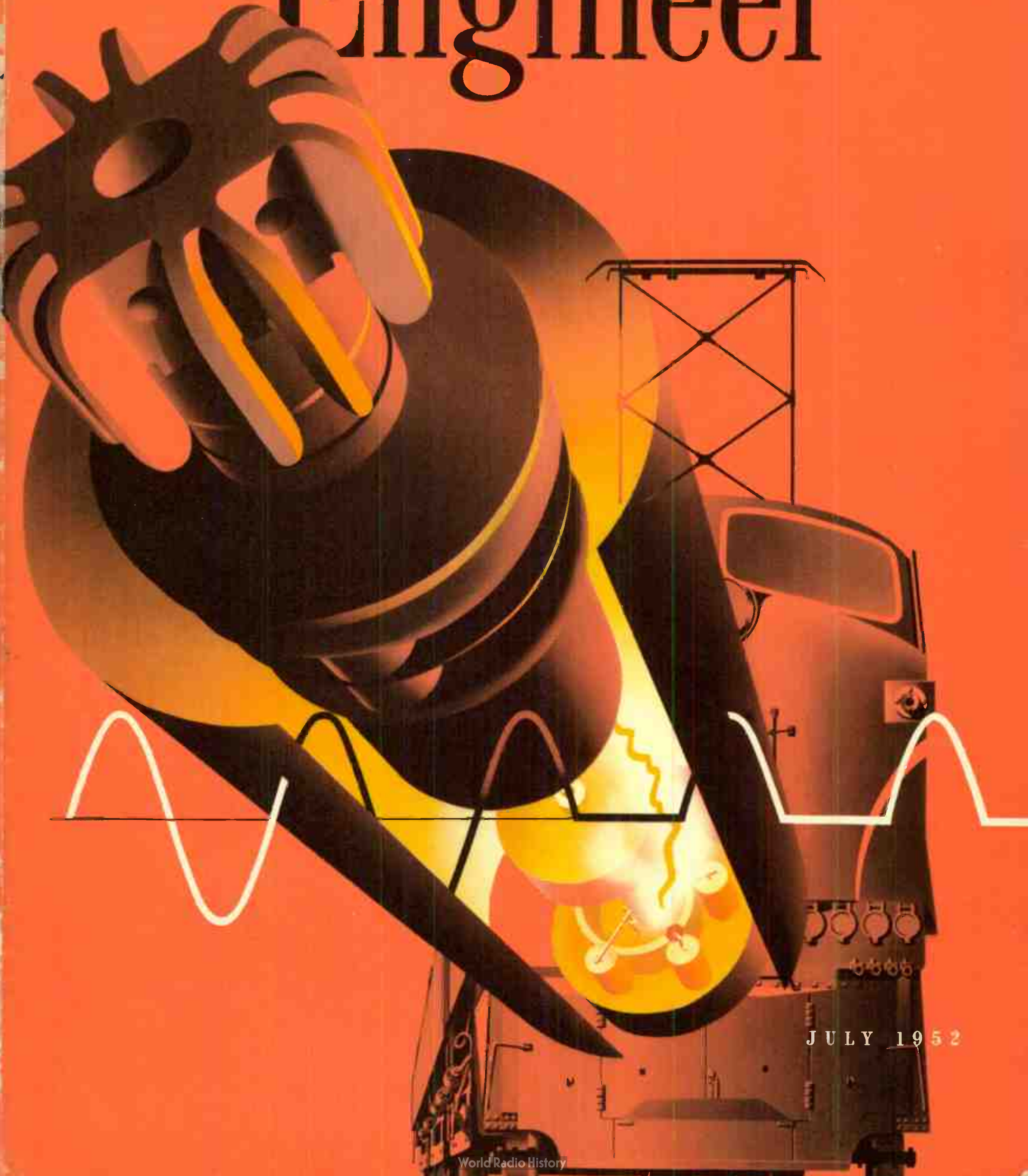
WESTINGHOUSE Engineer



JULY 1952

attention to ECONOMICS—A Must

"Our universities have given us superb engineers, physicians, chemists, physicists, researchers, scholars. We now ask simply that they give us graduates grounded in political economy."

This was not the statement of the head of a bank, a trade association, or a governmental bureau. It was made by the president of an engineering firm—Westinghouse. Mr. Gwilym A. Price, speaking at Johns Hopkins University, February 21, 1952, focused new attention on the importance of economics in our industrial society and, in particular, its essential partnership with the physical sciences. The following extractions from Mr. Price's talk highlight this philosophy, and point to present serious deficiencies in this essential field of training.

• • •

"The Brookings Institution (in a study) for the Sloan Foundation found: One out of every four students in our colleges and universities completes one or more economics courses. In other words, only 650 000 out of two and one-half million college students receive any economic information from their faculties. Not more than two or three percent of the aggregate student body takes economics as an elective.

• • •

"For some time now, other American institutions have been trying to fill this gap with projects designed to bring economic literacy to our people. The Republic Steel Corporation has given its 5000 supervisory employes a basic course in economics. . . . Several years ago, as part of a rather wide range of training and education projects, Westinghouse began to give its supervisory group a course of eleven 90-minute sessions on basic economics. . . . Last year we gave virtually all of our 108 000 employes a brief lesson in elementary economics. It is an honest if oversimplified course of two one-hour periods, taught by the American Economic Foundation.

"These two efforts are typical, or at least representative, of the economic training of employes that is now being given by one out of five of our American corporations. . . . An Opinion Research Corporation survey shows us that 98 percent of all Westinghouse supervisory employes who have taken such courses want to take more.

• • •

"Economic education of this sort, of course, is not adequate—it is not enough, and it is not good enough. It is not a systematic integrated program of education. . . . This is, nevertheless, a symptom of a tremendous ferment. For the first time, people are really concerned with the causes, effects, and cure of high taxes. They want to know how to invest their savings. They realize that economic matters, particularly monetary economics, are of direct and vital importance to them and their children. Inflation is a subject that is being covered in popular weekly magazines along with romance fiction and war reporting. This expanding interest is one of the most hopeful, encouraging signs I know of.

• • •

"Education . . . is still our only hope. Ignorance is a terrible and never-ending threat to any free system. The operator of the machine will wreck it if he lacks the basic knowledge of how the machine works. We can pray that education will clear the fog of political and economic superstition.

• • •

"There is the superstition that a higher standard of living is a political matter; that it can be legislated. It isn't and it can't. Under any system, a higher real wage—a higher standard of living—depends on multiplying the productivity of workers. In the past 30 years, real wages in this country have gone up 89 percent, basically because we are producing that much more goods and services than we produced in 1922.

"In the spell of this particular superstition, people become preoccupied with governmental measures. They expect everything from an all-providing state, rather than from private initiative. If our people do not reject this superstition—in their own broad self-interest—the economy will eventually collapse.

• • •

"There is the superstition that one economic system or another will solve all human and social problems. . . . The English experiment in socialism is highly instructive on this point. The operators of nationalized industries found the same problems as had the private owners, only somewhat accentuated; they found, too, that they had to meet the same acid test of productivity and profitability. They were naive enough to believe that the nature of the English worker would change for the better when the state took over his enterprise. It didn't.

• • •

"Then there is a superstition called hostility to profit that is shared by a considerable portion of the American people. Forty-two percent of them recently expressed the opinion that the profits of American industry could be cut in half without hurting business. Forty-two percent of our professional class declare that profits are too high, and 76 percent of our high-school seniors believe that the owners of an enterprise are the chief beneficiaries of better machinery.

"This economic myth is based on the fallacy that wages and profits are related only in terms of conflict, and on the distorted assumption that profit-seeking business harms the vital interests of the mass majority. The result is government control of production and distribution, in order that profit may be reduced or even prevented.

"The fact is, of course, that only through increased investment in plant, tools, and equipment, leading to improved methods of production, can worker productivity and real wages be increased. That requires the progressive accumulation of capital. The average workman today can turn out three times as much product as the workman of 1900, and almost half again as much as today's European worker, and can do it in two-thirds the time and with a great deal less sweat, only because he is backed up with an investment of thousands of dollars in tools and machinery. I do not suggest that our college students be taught to worship the profit motive—but only that they understand its function and its benefits to society.

• • •

"I personally feel the deepest conviction that private ownership of the means of production and of distribution of goods is a necessary prerequisite for both comfortable living and national growth. I am convinced that there can be no great progress without incentive. I believe that a free market is a prerequisite of efficient production and distribution, that the total national economy is infinitely too complex to be run by a planning board, and that the final result of central planning must inevitably be convulsion and disaster. I believe that a centrally controlled economy must eventually result in a collectivist, ultimately communist state, in which the immense majority would become servants entirely at the mercy of uncontrolled dictators."

• • •

And, if the editor may add a word. Just as the day of political isolationism is past, the time when technical people can leave economic matters to others is gone. An attempt to understand the principles of good economics is essential to industrial citizenship. It is a must for every professional man in every profession.

WESTINGHOUSE Engineer

VOLUME TWELVE

JULY, 1952

NUMBER FOUR

On the Side

The Cover—We wanted the cover of this issue to illustrate the newest thing on rails—the ignitron locomotive. But, externally, the rectifier locomotive resembles an ordinary electric locomotive. Our artist, Dick Marsh, neatly solved this problem by combining a rectified wave, a portion of the innards of an ignitron, and a goodly hint of the speeding locomotive.

• • •

The last week of June marked an important date in industrial history. It was the 50th anniversary of the American Society for Testing Materials. While the work of this organization involves largely research on the development of standards for engineering materials, and is inherently not of a spectacular nature, the value to our industrial society has been incalculable. For example, the standards of the Society are referenced in Westinghouse specifications covering materials procurement and methods for testing. Westinghouse has been associated with this activity from the outset. At present 55 Westinghouse men are serving on the Society's technical committees.

• • •

Transformer ratings are going out through the roof again! Recently, TVA placed an order with Westinghouse for two 220 000-kva, 3-phase power transformers. These will be the largest ever built. The units will be rated at 55 degrees C temperature rise; will be oil and air cooled (FOA); will have a high-voltage winding rated at 161-kv wye, and a low-voltage winding rated 19-kv delta. The units will be installed at the new Colbert Station.

In This Issue

New lead-lag fluorescent ballast—Locomotives for Holland—Automatic operation of transformer cooling fans—Arc furnaces for phosphate production—Factory-assembled constant-voltage controllers—New speed reducers—Improvements in constant-current regulators—Improved air-cooled unit substation—Submersible CSP transformers—A 16-step voltage regulator—New photoflash test lamp—Explosion-proof motor with built-in starter.

The following terms, which appear in this issue, are trademarks of the Westinghouse Electric Corporation and its subsidiaries:

Rototrol, Silverstat, Inerteen, Axiflo, Electrocam, Hipersil, Coastal, CSP, De-ion, Flexitest, Flash-Chek, Life-Line, Motor Sentinel, Kovar, Refractaloy.

Published bimonthly (January, March, May, July, September, and November) by the Westinghouse Electric Corporation, Pittsburgh, Pa.

Subscriptions: Annual subscription price in the United States and possessions is $2.50; in Canada, $3.00; other countries, $3.00. Single copy, 50¢. Address all communications to *Westinghouse* ENGINEER, P.O. Box 2278, 401 Liberty Ave., Pittsburgh 30, Pa.

Indexing and Microfilm: *Westinghouse* ENGINEER contents are regularly indexed in Industrial Arts Index. Reproductions of the magazine by years are available on positive microfilm from University Microfilms, 313 N. First Street, Ann Arbor, Michigan.

THE WESTINGHOUSE ENGINEER IS PRINTED IN THE UNITED STATES BY THE LAKESIDE PRESS, CHICAGO, ILLINOIS

Titanium, long used in compound form as a paint pigment and as an alloying agent for steels, now wins a place for itself as metal. It has many things in its favor: abundant ores, light weight, high strength, outstanding corrosion resistance. Against these: it is a stubborn, difficult, costly metal to produce, melt, and fabricate.

The Rise of Titanium

TITANIUM is the newest member of the structural-metals group. Three years ago it was almost unknown in metallic form. Now engineering journals carry frequent enthusiastic accounts of the virtues and uses of this "wonder" metal. Because it is only a little over half as heavy as steel and has much better strength at medium temperatures than aluminum, titanium has been called the new "middleweight champion" of the structural metals.

Some claims sound pretty extravagant. To what extent they prove founded remains to be seen. Certainly before titanium metal can move into the high-volume category something major will have to be done about its price, which now runs from $7.50 per pound for ingots to $15 to $20 for forgings, bars, and sheets (i.e., $15 000 to $40 000 per ton). But titanium possesses certain qualities so outstanding that the effort to drive the cost down will be great, and undoubtedly will be successful to a degree.

The Good Qualities of Titanium Alloy

Titanium alloy has many attractive qualities, but two are of special significance. Up to about 800 degrees F, titanium alloys (titanium > 95 percent) have greater strength for their weight than any common metal or alloy. It is virtually noncorrosive in all ordinary situations—including salt water and salt air—and in many extraordinary ones.

The high strength-weight ratio has provided the impetus for the recent rapid and expensive development of methods of producing and fabricating metallic titanium. Specifically, the possibilities for use in aviation gas turbines and other aircraft applications—where cost is secondary—have been the incentive whereby many years of normal development have been telescoped into three or four.

High Strength—Medium Weight

Titanium is a medium-weight metal. It weighs 0.16 pound per cubic inch (density 4.54), which makes it 1.6 times as heavy as aluminum, 2.6 as heavy as magnesium, but only 56 percent as heavy as steel. Although pure titanium is not notable for high strength, titanium alloys (which is the structural material discussed in this article) are strong. These two qualities combine to give them their high strength-weight ratio, shown in comparison with stainless steel and aluminum on p. 119. Of great moment to jet engines is that, whereas the tensile strength of aluminum falls off sharply beyond 300 degrees F, titanium alloys have good tensile strength up to about 800 degrees and are equal or better than stainless steel up to 750. This enables jet-engine designers to use titanium for parts exposed to these middle temperatures where otherwise the heavier metals would be required. The result is a weight saving where weight saving counts. The weight of a typical engine could be reduced by well over a hundred pounds. This additional fuel capacity may well justify the greater cost of titanium, even at today's prices.

This same quality makes titanium attractive for many applications where temperature is not a factor. Some possible ones include aircraft armor plate, electrical components, pontoons, cables, structural braces, and other fuselage members. Army engineers are interested in titanium for truck bodies, girders, portable bridges, and personnel-carried apparatus, when costs are more favorable.

Titanium applications resulting from its good strength and light weight are not all military. There are numerous commercial or industrial ones, although the high-tonnage uses will be few or nil until costs drop markedly. Portable machine tools, fast-moving spindles, spools, warp beams and other moving parts of textile machinery are representative of the many places in industry where a strong but light material is advantageous. It may be used for sporting equipment, such as lightweight, non-corroding golf clubs, tennis rackets, and fishing rods. Doubtless the some two million persons in this country who wear orthopedic braces would welcome the reduction in weight offered by titanium over stainless steel. Spectacle cases would be stronger than aluminum but only slightly heavier. Metallic titanium has also been used as target material in x-ray tubes, and as window material for Geiger nuclear-radiation counters. The ability of titanium, when hot, to absorb large quantities of oxygen, nitrogen and hydrogen—a distinct nuisance to those using titanium structurally—is put to good use in electron tubes. Titanium is added to soak up these gases as they are boiled out of the glass and other tube parts.

Titanium's unique strength, furthermore, is accompanied by good ductility. Titanium alloys already known in this early stage of development are far superior to all the usual

---

Prepared by Charles A. Scarlott from information provided by Titanium Metals Corporation of America; E. I. du Pont de Nemours & Company, Inc.; National Lead Company; U. S. Bureau of Mines; Rem-Cru Titanium, Inc.; National Research Council; International Titanium Corporation; and Westinghouse.

engineering metals and alloys in strength-weight ratio. Titanium is the only structural metal known to have an endurance limit consistently in excess of 50 percent of its tensile strength. Titanium alloys have shown much higher fatigue resistance than aluminum, higher even than steel. Titanium alloys are far harder than aluminum and approach the highly alloyed steels. Surface hardness comparable to nitrided steels are obtainable. Titanium has a far lower linear coefficient of expansion and lower thermal conductivity than either aluminum or alloy steels. As for impact strength—the capacity to withstand mechanical shock—titanium alloy is superior to aluminum and some tests have indicated the likelihood of values rivaling the best of alloy steels.

Corrosion Resistance

Titanium possesses an anomalous set of corrosion characteristics. It is an inherently reactive metal. Yet one of its major uses will be opened by its ability to resist corrosion.

As a self-protecting metal, titanium is best known for its indifference to sea water. In this respect it has no peer among common engineering materials. It has been subjected at naval test stations to the corrosive action of sea water for extended periods under all conditions of exposures, with no observable attack. Specimens exposed for three years to salt atmosphere 80 feet from the breakers retained their original luster.

This property naturally suggests many marine applications. To mention but a few, there are lightweight piping systems handling salt water, condenser tubes operating with high water velocities, plumbing fixtures, and pump rods and rotor shafts. Relative economies will determine how many of the large-tonnage structural marine applications titanium can win for itself from stainless steel, cupro-nickel, Monel metal, Hastelloy "C," and other alloys. But, the opportunity for large-scale marine use of titanium is there. The incentive to titanium metallurgists is great.

Aside from high resistance to salt corrosion, titanium has other interesting self-protecting qualities. In resistance to moist chlorine gas it is superior to all other ordinary materials. (Curiously, titanium burns in dry chlorine gas.) An important feature of the behavior of titanium in nitric acid is that it retains its good resistance to attack even when the temperature and pressure are raised. Other materials, such as stainless steel, which are resistant to boiling acid at atmospheric pressure, are attacked severely when hot and under pressure. Titanium possesses good resistance to many other common chemicals, such as boiling, concentrated acetic acid and lactic acid, and to dilute sodium hydroxide, hydrochloric acid, sulphuric acids at room temperature. It is attacked slowly by concentrated sulphuric acid and hot dilute sulphuric acid. It is vulnerable to mild hydrofluoric acid—but, oddly, not to the concentrated variety.

Titanium is also highly resistant to erosion, as in sea water at high velocity, which suggests its use for pump and ship propellers as a replacement for bronze. It withstands vibratory cavitation erosion better than brass or manganese bronze.

Corrosion studies with various foods, such as pineapple juice, cider vinegar, lard, tea, coffee, grapefruit juice, and lactic acid show no attack on titanium. This opens the door for its use in food-processing plants and restaurants when and if its cost declines.

High-Temperature Behavior

Pure titanium melts at a high temperature, 3140 degrees F, (stainless steel melts at 2550) which suggests that it is a high-temperature metal. But it isn't. For two reasons. By absorbing oxygen and nitrogen a titanium alloy increases in surface hardness and loses strength rapidly at temperatures above 1000 degrees F. While this temperature is far above the service range for aluminum it does not approach the operating zone of high-temperature alloy steels or complex refractory alloys such as Refractaloys, Inconels, and stellites.

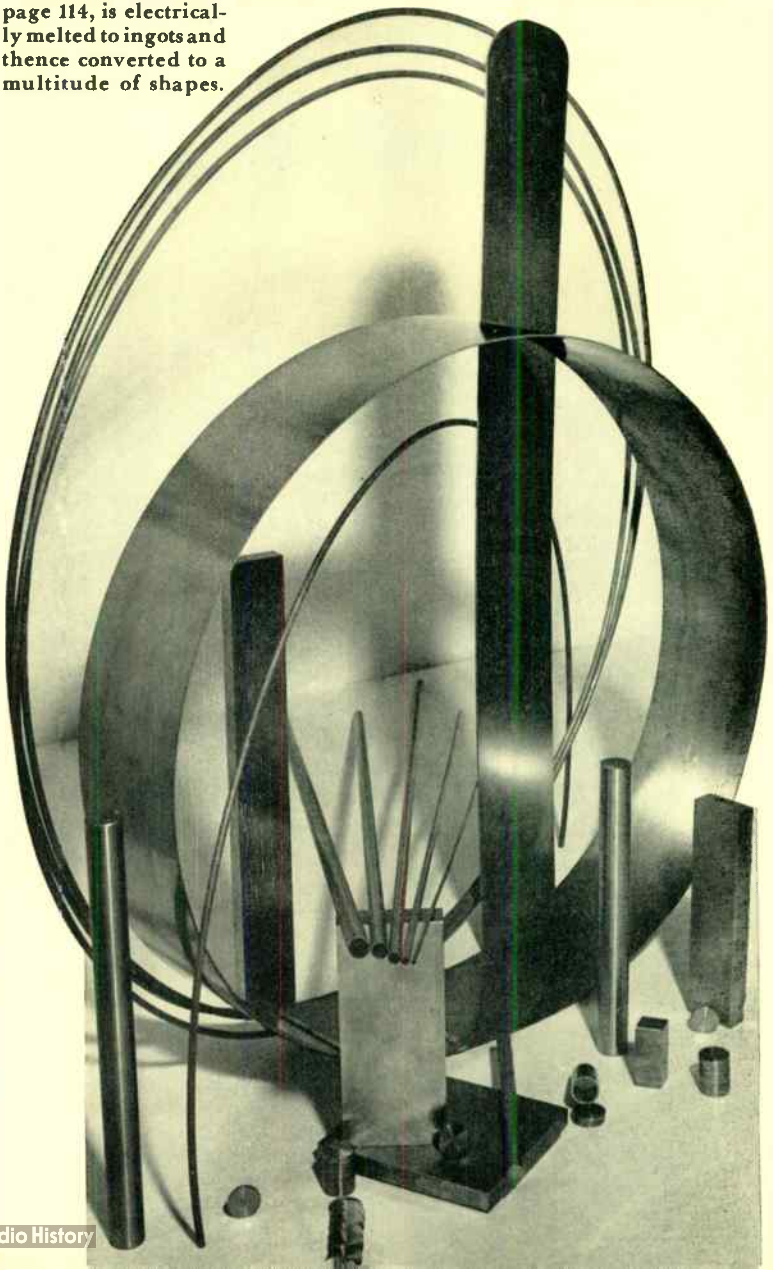
Also, while titanium is a superlative salt-water metal, it is a highly reactive metal. At temperatures above about 1000 degrees F, it begins to absorb oxygen and, at higher temperatures, nitrogen. Above 1600 degrees F, absorption is very rapid, which is permanent and leads to embrittlement.

Where Titanium Comes from

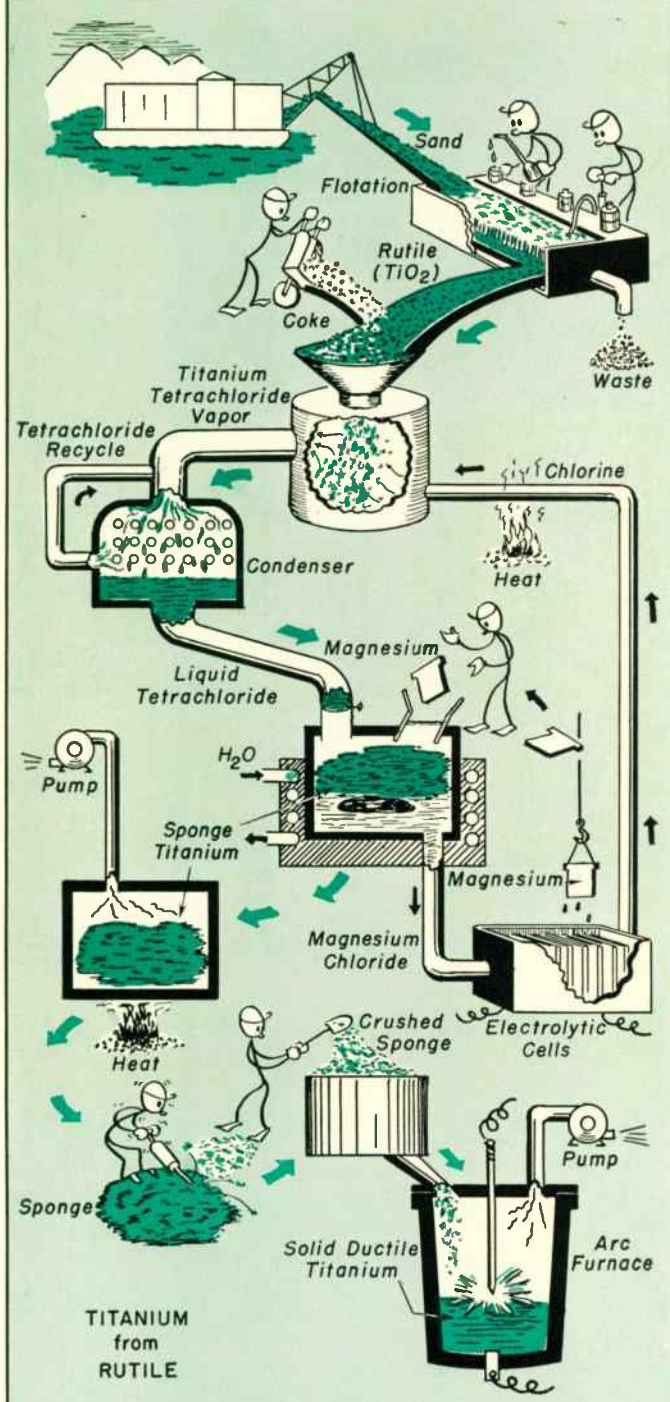
Titanium-bearing ores are plentiful and widely scattered about the world. The United States is amply endowed.

The principal titanium ores are rutile, ilmenite, arizonite and titaniferous magnetite. Rutile is titanium dioxide (TiO_2) in which the metal comprises 57 percent of the weight of the compound. Ilmenite is titanium in combination with iron and oxygen ($FeTiO_3$) in which titanium is 32 percent of the total. Arizonite is $Fe_2O_3 \cdot 3TiO_2$, with titanium 36 percent of the total. The titaniferous magnetite is a complex compound, also with iron, $FeO(FeTi)_2O_3$, usually with six percent titanium.

Rutile, the simpler and much more desirable ore for titanium recovery, is the smaller supply. The tiny reddish brown



Titanium sponge, page 114, is electrically melted to ingots and thence converted to a multitude of shapes.



TITANIUM
from
RUTILE

From Ore to Titanium—The production of ductile titanium from rutile is still undergoing rapid development. The steps shown here are representative of present practice. Sands in Florida and Australia are dredged and processed by water flotation or other mechanical means to obtain an approximately 90 percent rutile (TiO_2) concentrate. On exposure to hot chlorine gas in the presence of carbon the tiny black grains of rutile are converted to titanium tetrachloride vapor, which is condensed to a liquid and sent to a batch-type, heat-resistant steel reactor. In an inert-gas atmosphere (generally helium), the tetrachloride reacts exothermically with magnesium to produce liquid magnesium chloride and sponge titanium. The magnesium chloride is drawn off to electrolytic cells for dissociation into magnesium and chlorine for reuse. The metal crucible, with titanium sponge and absorbed magnesium chloride and unutilized magnesium, is removed and heated to drive off the magnesium and magnesium chloride. The sponge is chipped out, crushed, and fed to an inert-gas arc furnace. The sponge melts and solidifies as a solid ingot suitable for forging.

to black particles that can be seen, usually in trace amounts, on the sands of most beaches, are rutile, ilmenite, and arizonite. The world's principal deposits of rutile are in Australia, Brazil, and in Florida near Jacksonville and Vero Beach. The Piney River district of Virginia has a large occurrence of rutile but the grade is low. Large deposits of rutile and other titanium ores also are found in Arkansas. Various quantities of rutile appear in other parts of the world. However, rutile is in short supply, particularly with our growing appetite for the metal. While most of the titanium metal is produced at present from the simpler ore, rutile, as outlined at left, it is generally recognized that production of the metal will soon have to be based on the other and more plentiful ores or on titanium-rich slags. The rapidly rising demand for the metal and the distinctly limited rutile sands in the United States will see that this fact is accomplished. Ilmenite deposits are enormous. The great deposit in the Allard Lake region of Quebec tops them all. This whopping deposit is being developed by Kennecott Copper Corporation and New Jersey Zinc Sales Company. When diamond drilling ceased at 300 feet, a deposit of more than 100 million tons, averaging about 82 percent combined iron and titanium oxides, had been outlined. Other ilmenite deposits measured in tens and hundreds of million tons occur in Japan, India, Norway, and Russia. The principal body of ilmenite ore now being exploited in the United States is at Tahawus, New York, owned by the National Lead Company. It has been actively worked since 1941 and is estimated to contain over 100 million tons.

At Iron Mountain, Wyoming, is a 40-million-ton reserve of titaniferous magnetite. There are other occurrences in the United States and elsewhere.

A survey a few years ago produced an estimate that in the United States we have ores containing about 9 million tons of TiO_2 or a little over 5 million tons of contained metal. (Not all of which could be recovered.) An exhaustive search for titanium-bearing ores in the United States has not been made. Doubtless there are undiscovered titanium-ore bodies. The estimate also concluded that known Canadian reserves amounted to 175 million tons of TiO_2 or 100 million tons of metal. Which simply says that we have ample titanium ores.

Production of Titanium Metal

Production of titanium from even the simpler ore—rutile—is not easy. This is suggested by the fact that rutile sells for about six cents a pound, titanium sponge for $5 per pound, and the structural forms for $6 to $15, base price. (From titanium content of concentrate to titanium forging the cost ratio is 1 to 50; the comparable for iron is 1 to 3; for aluminum, 1 to 12.)

The first man to produce titanium in the United States was Mathew Hunter of Rensselaer Polytechnic Institute in 1912. He used sodium to replace the titanium. The present process, however, employs magnesium. It is outlined at left. This is the famous process devised by William J. Kroll of Luxemburg in 1939, and arduously developed with his help by the U.S. Bureau of Mines.

The problems that must be lived with in producing titanium are formidable—the liquid metal appears to be a universal solvent or a good reducing agent. It either dissolves or is contaminated by any known refractory. The metal has to be won from its ore with extreme purity, for the contaminants, mainly oxygen and nitrogen, that would come along, are ruinous to the physical properties. Furthermore the metal when molten is so active chemically, absorbing oxygen or nitrogen from the air with such ruinous rapidity, that all extractive and ingot-melting processes must be carried out either in vacuum or under the protective blanket of an inert atmosphere. As a further complication, any trace contaminants picked up along the way cannot subsequently be removed from the metal by any technique yet announced. Such a set of conditions is hardly conducive to large-scale industrial production and has no parallel in the common structural metals. However, it must be remembered that these matters are being aggressively researched. Titanium technology is yet young. Doubtless many troublesome obstacles will be removed. The discussion of titanium production contained herein is based on public announcements but some people close to the industry (which is not noted for open discussion of its accomplishments) hint that significant improvements have already been effected.

The present processes for producing titanium sponge are of the batch type. Titanium sponge consists of hard, grey, coke-like, porous lumps, which must be consolidated into solid ingots for production into titanium forgings or rolled or drawn shapes. This is done by melting in an electric furnace, rigorously protected from air contamination by a protective blanket of argon or helium. Most of the titanium ingot production is achieved by batch methods although the Du Pont Company has successful continuous furnaces in operation.

Starting with the process developed by the Bureau of Mines, commercial firms—principally the Du Pont Company and Titanium Metals Corporation—have, in the last three or four years, made great strides in the techniques of raw titanium production. Melters and fabricators, notably Rem-Cru Titanium, Inc., have made similar advances in their field. Obstacles to production of large ingots on a commercial basis seemed insurmountable. But these have been overcome to the point that ingots up to almost a ton in size are regularly produced. Further very great improvements, even in the present metal-winning process, can be expected. Also it is not impossible that some completely different process will be worked out. Many others have been tried, such as reacting purified calcium with titanium dioxide, and electrolysis. Horizons Titanium Corporation (a Horizons, Inc. and Ferro-Enamel Corporation combine) is reported to have a new, low-cost, electrolytic process and has built a pilot plant in Cleveland to test the method. There is no published announcement of experience in the chlorination of ilmenite or the high-titanium slags obtained by blast-furnace smelting of ilmenite-iron ore mixtures, although it is generally known that Du Pont is working an ilmenite deposit in Florida on a commercial scale. However, the industry expects that the problems of such chlorination, while rather complex in nature, will not long elude the development engineers.

Once titanium has been produced in ingot form, rolling, drawing, and forging operations are performed with essentially standard techniques. However, machining of titanium, particularly of the higher carbon grades, has presented exasperating problems (as outlined in the accompanying article by engineers DeHuff and Hazelton). These, in large measure, have resulted from the tendency of titanium to work harden, to gall, or cause fouling of the tool.

The galling characteristic of titanium touches on another interesting property, sometimes useful, sometimes a nuisance. This is its ability to leave a mark on glass.

The Titanium Industry Today

The titanium-metal industry today stacks up like this. The two largest producers of sponge are Du Pont and the Titanium Metals Corporation. A third firm, the Crane Company of Chicago, turns out a small quantity. The three combined in 1951 to produce 600 tons of titanium sponge—a pretty small figure as metal tonnages go. By the end of the year production was at the rate of 1400 tons per year. Output in 1952 will be more like 5000 tons.

Du Pont's production comes from its plant at Newport, Delaware, where output is expected to reach 2½ tons per day this year. Du Pont is currently negotiating for the construction of a plant at Edge Moor, Delaware, to have a capacity of about 3500 tons annually. The bulk of the Titanium Metals Corporation sponge is now coming from its plant at Henderson, Nevada, the former Basic Magnesium plant built during the war. This will have a yearly capacity of 3600 tons.

Several firms convert titanium sponge to ductile titanium and produce forgings of rolled or drawn shapes. These include Allegheny Ludlum Steel Corporation, owner with National Lead Company of Titanium Metals Corporation; Rem-Cru Titanium, Inc., (a company formed by Remington Arms Company, a Du Pont subsidiary, and Crucible Steel Corporation); Republic Steel Corporation; and Mallory-Sharon Titanium Corporation (P. R. Mallory & Company, Inc. and Sharon Steel Corporation).

Non-Metallic Forms of Titanium

Non-metallic titanium has long had a big place in the industrial economy. In fact, ductile titanium is a Johnny-come-lately. Less than one percent of total titanium ore is used to produce metallic titanium. The big usage has been as titanium pigments. Titanium oxide is the whitest material known (and is produced, oddly, from the blackest of sands). Also, titanium-oxide pigments have great hiding or covering power, and are non-toxic. Thus in paints they mean fewer coats are required for good coverage. By using titanium-oxides in porcelain enamels of electric ranges, refrigerators, a single coat is used instead of two.

The amount of titanium pigments used annually runs into large figures. Titanium pigment production figures are not available but the estimated TiO_2 content of ilmenite consumed for pigments in the four years, 1948 through 1951, averaged 320 000 tons. Roughly two thirds of the pigments are used in paints, varnishes, and lacquers. They are also used in manufacture of linoleum and felt-base floor coverings, as coating for fabrics and textiles, such as oil cloth, window shades, and artificial leather, and in rubber and paper manufacture. These four uses each average from 4 to 9 percent of the total titanium-pigment consumption, while printing inks take another 1.5 percent.

Virtually all the titanium pigments are obtained from ilmenite, of which about 75 percent (1951) comes from United States pits, most of the remainder from India and Norway.

Another important use of titanium is as rutile coatings for welding rods. The rutile greatly increases arc stability. In recent years this has amounted to about 9500 tons TiO_2 per year.

Titanium is an important alloying agent for steels. When so used it is added as ferrotitanium, not as metallic titanium.

In Summary

Titanium has a definite place among the structural metals. It will be a big place, but how big will be determined by how far its costs can be reduced. Its ores are abundant. It has some superlative qualifications. It is not expected that any steel mills or aluminum plants will have to shut down because of it, but it can be counted on to carve out for itself certain segments of the metal-fabrication province, simply because for some jobs it is better than any other material.

Titanium at Work in Jet Engines

Problems of winning titanium from its ores were tough, but no less tough were those attendant to its application as a structural material. Answers have been found for most of these, with the result that titanium is taking its place with aluminum and steels as a jet-engine material.

P. G. DeHuff *and* W. S. Hazelton
Metallurgical Engineering Section
Aviation Gas Turbine Division
Westinghouse Electric Corporation
South Philadelphia, Pennsylvania

Broaching the blade slots in a titanium alloy forged jet-engine disc using jets of carbon dioxide as a coolant. Prevents galling.

Although titanium is but a youngster among metals, it has heeded the call of Uncle Sam's draft. It has been used in experimental jet engines, and plans are being made for its application to the newest models of production engines. That a job so important is entrusted to such a newcomer can be ascribed both to the unusually advantageous properties of titanium and to the great amount of research and development completed on its technology in the last three years.

The primary reason for the interest of the designer of aircraft and aircraft power plants in titanium and its alloys is the substantial weight saved when it is used in place of steel and aluminum. It is obvious that titanium alloys weighing three fifths as much as steel and having the same strength reduce the weight of engine parts. It can also be seen in Fig. 1 why weight savings can be made in many cases by the substitution of titanium for aluminum and magnesium alloys, especially at temperatures above 300 degrees F. Commercially pure titanium starts to lose some of its advantage over stainless steel around 200 degrees F, but titanium alloys still hold a significant advantage up to at least 800 degrees F. Above 700 degrees, however, the creep strength of titanium alloys available today starts to decrease, and in some applications this limits their use.

Titanium also has advantages in addition to its strength-weight ratio for jet-engine parts. It is very resistant to the corrosive gases to which a jet engine is subjected. It is more resistant to salt air and water than 18-8 stainless steel, which is considered to be good in this respect. In fact, titanium is comparable to platinum in resistance to corrosion by salt air and water. Because many Westinghouse jet engines are used in carrier-based Navy aircraft, such salt-air corrosion resistance is of great importance. Again, titanium ores are plentiful in this country, and therefore would be readily available in any emergency. Use of titanium, furthermore, would save significant amounts of critical materials such as chromium and nickel. Use will also bring its cost down.

Problems in Using Titanium Alloys

Each component for which a titanium alloy is eligible, Fig. 2, presents problems basic to the use of any new metal and poses difficulties incident to its manufacturing on a production scale. One of the greatest deterrents to use of titanium and titanium alloys has been the almost complete lack of fundamental knowledge of the metallurgy of titanium. The art is so young that, literally, there has not yet been time enough to develop the metallurgy fully. Little has been known of the structures of titanium and its alloys, i.e., how the variables in chemical composition, processing, and heat treatment affect the structure and the properties. Strides have been made in the past year toward an understanding of these all-important factors, but much research must yet be done before the understanding of titanium compares with that of steel, aluminum, and other alloys.

Titanium Forming

Forging was one of the first processes studied. Forging presented serious difficulties, but, as discussed on p. 120, these have been effectively solved.

Joining—The ease with which sound-appearing welds can be made with titanium led to the early belief that there would be no joining problems. However, this view quickly vanished. Although strong welds can be made with commercially pure titanium by Heliarc and resistance-welding processes, great care must be taken to prevent absorption of gases, which engender embrittlement. Even with optimum practices, welds in commercially pure titanium are much less ductile than the parent metal. However, we have succeeded in developing techniques for making simple welds on commercially pure sheet. More complicated joints are being investigated.

Welding of alloyed titanium is a more difficult matter. The main problem, aside from the embrittling effects of gas contamination, is the quench-hardening of the sheet during cooling from the welding temperature. Heat treatments designed to soften the hardened structure do not result in the same ductile microstructure produced by hot working.

Flash-butt welding permits hot working of the material and has been applied to large rings for Westinghouse jet engines. Work is being done on the flash-butt welding of sheet with promising results. We now have a technique for hot rolling Heliarc and resistance seam welds that improves the ductility of titanium-alloy welds.

Silver-alloy brazing as an alternate method of joining also has its problems. The very thin and adherent oxide that gives titanium its corrosion resistance also offers the same resistance to fluxes. Several different fluxes and alloys have been investigated. Fluoride fluxes and high-temperature brazing alloys can be used, but the resulting joint is brittle. Although some progress has been made, no completely satisfactory techniques have been devised.

Partly because of these joining problems, and partly because of design considerations, it was felt from the early stages of titanium development that the most promising application of titanium in jet engines was for forged compressor discs.

Machining—One of the basic difficulties encountered in getting titanium into production was the development of machining and grinding techniques. Titanium alloys particularly are difficult to machine. Tool wear is very rapid. Although these alloys are not excessively hard (about 293-321 BHN), the abrasive particles of titanium carbide found in some alloys quickly cause tool breakdown.

Another reason for tool wear is the smearing tendency common to all titanium alloys. This causes build-up and attrition of the tool edge. When the tool edge is dulled by these two factors, the machined surface is work hardened and the machining problem is intensified.

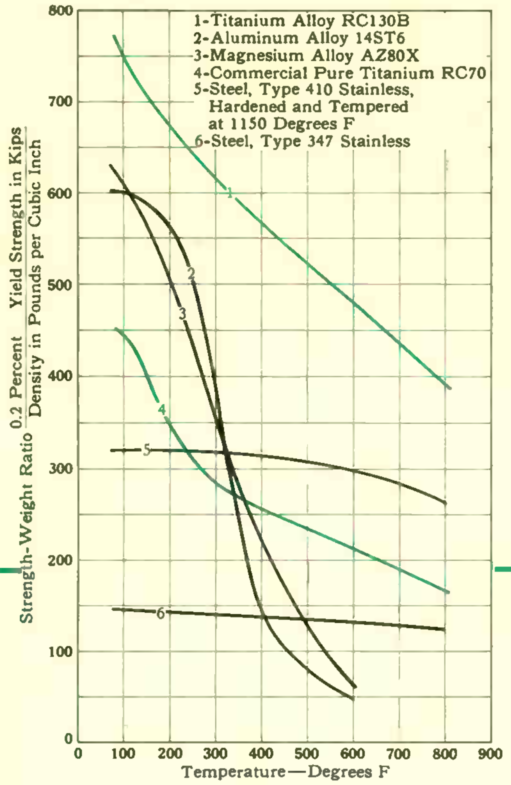
Although machining and grinding problems have been tough ones to solve, we now have tools and techniques by which titanium alloys are machined in production at costs comparable to those of stainless steels.

Tool life when machining titanium alloys is, as in other materials, dependent on cutting speed. The abrasiveness of titanium alloys can be reduced by new methods of melting that keep the carbon content to a minimum, thereby eliminating most if not all of the very hard titanium carbides in the structure. Early melting practice utilized a graphite crucible heated by induction. Although this technique permitted carbon pick-up from the crucible, the contamination resulting from the use of other refractory materials was much more detrimental. With the successful development of the arc-melting process, using a water-cooled copper crucible and a graphite electrode, carbon contamination can be held easily to a maximum of 0.25 percent as compared to about 1 percent in the induction-melted product. Use of a tungsten electrode permits melts to be made with only a trace (0.05 percent maximum) of carbon, but with some tungsten pick-up, which is undesirable when it is in the structure as hard particles or stringers. New methods have recently been announced whereby even less contamination is claimed.

The abrasive action of titanium can be reduced by the use of super-hard grades of carbide tools for lathe and boring-mill operations. These materials also seem to resist tool breakdown caused by the smearing action of titanium. The great superiority of carbide-tool materials has led us to investigate broach designs that utilize carbide inserts. The broaching of blade root grooves in titanium alloy discs to very close tolerances is impossible with high-speed steel broaches because of rapid tooth wear. With proper tooth loads and design the carbide-tipped broach has proved very satisfactory.

Another new wrinkle has been developed for the machining of titanium. This is the use of carbon dioxide as a coolant in place of liquid oils or emulsions. Jets about 0.010 inch in diameter direct streams of gas directly at the tool-work interface. This effects much better cooling than is possible by the usual methods. This better cooling action helps prevent tool breakdown not only by eliminating over-heating of the tool edge, but also by reducing smearing of the titanium.

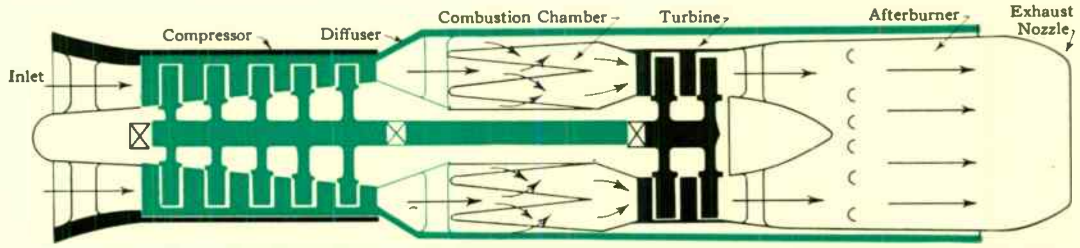
Carbon dioxide has another great advantage in the machining of titanium. Because titanium is so expensive, it is imperative that all possible scrap be saved and reclaimed. The amount of scrap in the form of turnings produced in the manufacture of a compressor disc weighs more than the finished part. Unfortunately, in order to be remelted, this scrap must



↑

Fig. 1 — Comparison of strength-weight ratios of titanium alloy with various common structural metals.

Fig. 2—Schematic diagram of a jet engine with the components that might be made of titanium alloy indicated in color. Parts that have been or are being investigated for the use of titanium, in addition to compressor discs, include compressor blades, compressor stationary vane assemblies, bolts, compressor and turbine liners, and sheet-metal parts. As new titanium alloys are developed, the upper temperature limit at which titanium holds an advantage over steel is expected to increase and more of the parts in the hot end of the engine will fall into this category saving much weight.



be almost chemically clean, or the impurities will cause brittleness in the remelted material. Even the films and oxides left on turnings produced with a water-soluble cutting fluid cannot be sufficiently removed to permit them to be remelted satisfactorily. Chips produced during machining with carbon dioxide as a coolant, however, are clean and bright and an excellent material for remelting.

Grinding—Another operation involved in the manufacture of titanium-alloy compressor discs threatened to cause trouble on a production basis. This was an automatic grinding operation that had to hold dimensions to extremely close tolerances (within 0.0002 inch). The titanium wore the grinding wheels so fast that automatic operation was impossible. The main reason for this rapid wheel wear was probably associated with the smearing tendency of titanium, because wheels hard enough to hold their shape glazed over quickly. A systematic study of wheel abrasives, bonds and grit size, coolants and wheel speeds has, however, resulted in suitable techniques.

The result of all this effort means that a completely new material is available for the designers of Westinghouse jet engines. Lighter, more durable power plants for jet planes will aid our country's defense. Although many problems remain to be solved, we are firmly convinced that titanium has a large place among our structural metals.

The Tribulations with Early Titanium Forgings

The events surrounding man's first use of iron as a structural material, or copper, or zinc, or even the relative newcomers like aluminum or magnesium are lost to history. Titanium is so young that the events of its birth for structural purposes are still fresh in the participants' minds. They comprise a story that is not only interesting, but also instructive of how, by industrial teamwork, extreme difficulties can be met.

In 1948 the Pigments Department of the Du Pont Company was able to produce 10-pound ingots of ductile titanium. Although these sizes were too small for commercial use, Du Pont was completing an induction furnace that was expected to be able to turn out 100-pound ingots. The Westinghouse Materials Engineering Department initiated a program, sponsored by the Aviation Gas Turbine Division, aimed at developing suitable forging techniques, and a determination of the physical properties of the forged titanium in cooperation with the Westinghouse Research Laboratories. Shortly thereafter Du Pont modified their 100-pound furnace so that ingots large enough to produce jet-engine discs could be cast. Two 360-pound ingots were shipped to Materials Engineering (June, 1949) and forged into 300-pound "pancake" compressor disc forgings. One of these is shown below.

Many difficult problems had to be overcome up to this point. The Du Pont Company had many seemingly impossible obstacles to overcome in the processes of sponge reduction and sponge melting. The early melting furnace was a crude affair, and there were plenty of heartbreaking incidents that made them often wonder if it all was worthwhile.

Largely because of the intense interest and support of the Bureau of Aeronautics and the engineering staff of the Westinghouse AGT Division, the small group of men at Du Pont kept working and accomplished their part of the task.

In the forging operation, too, there were many problems. The titanium ingots, although a great accomplishment at the time, were far below the quality usually considered commercial. Because they had to be melted in graphite crucibles, (titanium is such an active element that it will combine with almost all mold materials) the titanium had picked up about 1 percent carbon, and this evidenced itself in a dendritic structure of titanium carbide. These carbides had to be well broken up during the forging operation, or the resulting material would be brittle. The ingots had a nasty tendency to crack during forging. The problem of developing a forging technique that would produce a sound and ductile forging was a formidable one. The high-temperature alloy forging experience of the Materials Engineering Department enabled them to solve these problems quickly and effectively, so that the first two large titanium discs were finished by mid-1949.

As the task of sectioning and evaluating one of these disc forgings was being accomplished at Materials Engineering and the Research Laboratory, the other forging was being machined to a standard J40 compressor disc at the AGT Division, South Philadelphia Works. Here again, problems arose. The abrasive action of the titanium carbides in the metal, plus the smearing tendency of titanium, rapidly dulled the conventional high-speed steel tools used for machining the disc. The work-hardening characteristics of titanium also added to the difficulty. Although the disc was completed in a short time, the cost in tooling and man hours was very great, so another problem, that of machining, faced those who were trying so hard to utilize the unusual properties of this new metal.

This completed disc was tested by spinning in the Aviation Gas Turbine Laboratory hot-spin test pit at elevated temperature and at speeds equal to and above those it would be subjected to in an engine. The data from this test, together with that obtained from the sectioning and testing of the other large disc forging proved that substantial weight savings could be effected in jet engines only if the problems encountered in the large-scale production of titanium discs could be solved.

A set of four titanium discs was then made for incorporation in an actual engine. In making these four discs, a great deal was learned, but at a cost of two of the discs. One was made from an ingot that had been cast by a different technique, which proved to be detrimental to the strength of the material, although it increased the ductility. Another disc was ruined in a more spectacular manner. During the automatic grinding of the curvic coupling, the intensely hot sparks produced by grinding titanium set fire to oily dust in the machine, causing a very hot fire that destroyed both disc and machine. This taught respect for the white-hot titanium sparks. Now only non-inflammable oils are used.

Also, it was found that, as the reduction and melting processes advanced, purer metal was being produced, thus increasing the ductility but lowering the strength. Therefore, ways were sought to increase the strength obtainable in titanium forgings. Two possibilities were investigated. It was known, through the work of Materials Engineering, that forging at a low temperature could increase the strength of titanium greatly, so this was tried on a series of large disc forgings. At the same time, the possibility of alloying the titanium with small amounts of other metals looked very promising, and two experimental ingots were melted by Du Pont, and forged by Materials Engineering. While some increase in strength is possible by cold working titanium, alloyed titanium for compressor discs has proved more satisfactory.

Personalities IN ENGINEERING

With *Philip G. DeHuff*, events don't always follow the usual pattern. As a child, instead of buying toys he made and sold them; he entered college with $100 and a scholarship and came out with a tidy sum in the bank; in War II he was drafted *out* of military service, not into it; and five years after graduation, while only 26 years old, he was head of a section of metallurgical engineers in the fast-moving jet-engine industry.

When DeHuff was nine years old his mechanical-engineer father gave him a toy metal-casting set. Young Philip was not content to create an army of toy soldiers, Indians, and other figures for himself. He turned them out in quantity and sold them to a local hardware store for the Christmas trade.

According to the story books, we would say that this was the foundation step that led to DeHuff's present position as a nationally recognized authority in metal-casting techniques. DeHuff says it didn't happen that way. As he puts it:

"While still in the Lebanon, Pa., High School I happened to hear Eugene Grace speak on the need of trained metallurgists in industry. He made the profession sound interesting. Also, if they were badly needed the pay probably would be pretty good too."

Thus, in the fall of 1936, DeHuff enrolled in the School of Metallurgy of Lehigh University. With the absolutely imperative need to establish a source of income with least consumption of time, he rehabilitated an old Essex and rented it out to fellow students for a fee. His private U-drive-it service worked so well he added an old Buick.

When graduated in 1940 he went to the Homestead Works of the Carnegie Illinois Steel Company as an observer in the mill, and, later, as a laboratory assistant on armor-plate problems. This observation work was no arms-length, academic matter. It meant overalls, swing-shift contact with metal-making and metal-rolling operations.

At this time the clouds of War II were gathering. The Navy, already embarked on a large ship-building program, was concerned about getting the best possible steel castings for ship-propulsion units. To this end Westinghouse, General Electric, Bethlehem Steel, and Lebanon Steel Foundry underwrote a study of steel-foundry techniques at Lehigh University. To assist Dr. G. E. Doan, Head of Metallurgical Engineering, execute this investigation, Lehigh University crooked a finger at DeHuff. For 14 months, beginning in March, 1941, he was thus occupied. He now looks on this period as proving better than most work on a post-graduate degree. It was intensive effort, supplemented by scrutiny of all available literature on the subject. But Phil had been an Army reserve officer and in May, 1942, was called to military duty.

His period of service in uniform as an ordnance officer at Vigo near Terre Haute, Indiana, was brief. In January, 1943 he received "Greetings" in reverse. The Navy had persuaded the Army that DeHuff could serve his country better as a civilian expert on steel castings at Westinghouse, then working at top speed on propulsion machinery for destroyer escorts, elevated to high priority by submarine depredations. In 1945, when this project was pretty well solved, DeHuff moved to the newly formed Aviation Gas Turbine Division as head of the metallurgical engineering section. This brought him in intimate contact with the relatively new precision-casting activity. He took a lead part in the use of cast high-temperature alloy blades for Westinghouse jet engines instead of forged blades commonly employed. DeHuff points out that precision-cast blades are lower in cost, give greater flexibility in manufacturing facilities in time of war, and permit design changes to be made quickly.

In 1949 when titanium as a structural metal was little more than an idea, DeHuff became convinced of the metal's potentiality. He became one of its most enthusiastic boosters and, working with companies producing and forming titanium, he has had as much to do as anyone with the present bright position of structural titanium. His native enthusiasm and determination helped carry the project through some very dark days when difficulties with the metal seemed insuperable.

DeHuff is not only an engineer. He is also a farmer. He lives on a 30-acre farm near Paoli, Pa., where he raises apples, chickens, and boys—four of them. All "Indians," he says. He is keenly interested in soil conservation, has read enough to make himself an authority on the subject and applies the ideas on his own farm.

We asked him if metallurgy and farming constituted his principal interests and activities. He said, "Well—not quite. I like to play tennis." We later learned that on more than one occasion he reached the semi-finals in the Eastern States Tennis Competition—an area in which competition is particularly severe. In off moments he acts as Cub Master for a Scout group. DeHuff believes time is something to be used—and used well.

The Ignitron Locomotive

C. C. Whittaker *and* W. M. Hutchison
Transportation Engineers
Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania

Fig. 1—One of the two 6000-hp ignitron locomotives now in service on the Pennsylvania Railroad.

The first really new type of electric locomotive in almost 20 years—the ignitron locomotive—hit the rails last November. In its first big test, operation in regular revenue service, it has proved to be everything expected of it. But in addition to providing significant advantages in present-day service, the ignitron locomotive may have an important effect on future railroad electrification.

A few months after the first ignitron locomotive went into service, a second similar one joined it. These two locomotives have rolled up a combined total of 60 000 miles of service and proved eminently satisfactory in the tough freight service between Harrisburg, Pennsylvania, and the East Coast.

The ignitron locomotive represents a completely new principle of electric-locomotive operation. Single-phase a-c power from the overhead trolley is rectified by means of sealed ignitron tubes, and the d-c output of the rectifier is supplied to series-wound, d-c traction motors that drive the locomotive. Thus, the economies possible with an a-c trolley system plus the tractive advantages of d-c motors are combined in the same locomotive.

Both the d-c and a-c systems have advantages. Low-voltage d-c traction motors inherently cost less than the a-c commutator type and require less maintenance. The a-c series commutator motor, although it serves its purpose well, has always had high first cost and high maintenance expense. This is because the a-c motor requires a low operating voltage and, therefore, high current, which results in a longer commutator and more brushes per brushholder. Also, the a-c motor is essentially a low-flux-per-pole motor. Therefore, it has more poles than a corresponding d-c motor, and proportionately more brushholders. It requires a revolving brushholder yoke and a complicated system of main and interpole field shunts and relays, which have proved expensive in first cost and maintenance, especially since a failure of these devices usually carries with it a motor failure. Consequently, the d-c series motor is preferable. On the other hand, a high-voltage a-c trolley system reduces transmission losses and lowers first cost of electrification in comparison with d-c transmission. Although some 1500- and 3000-volt d-c systems are used, most railroad electrifications in this country use single-phase a-c power.

The first attempt to combine the advantages of the two systems was made in 1914, when a mobile, mercury-arc rectifier was installed on a multiple-unit car of the New Haven Railroad. That car traveled over 22 000 miles, giving satisfactory service; however, the rectifier tubes then available

In service on the Pennsylvania Railroad is a new locomotive scarcely distinguishable in outward appearance from any of the others on the electrification. But inside it is different; it has a totally different set of "works." It is the first ignitron rectifier locomotive.

...an idea from the past... a promise for the future

had several disadvantages that made them impractical for use on railroads. With the seals then available, the vacuum in the tube could be maintained for only about three months, and frequent repumping was necessary. There were also frequent arc-backs. The idea had to be shelved temporarily until a better rectifier could be developed.

The second attempt to team alternating current with direct current was more successful. The motor-generator locomotive, introduced in the 20's, was the first practical use of a-c power and d-c motors. In this type of locomotive, d-c power for the traction motors was obtained by means of a transformer and motor-generator set. A number of such locomotives have been built and have proved successful in low-speed, heavy-drag service; however, their application is limited because the motor-generator sets are large, heavy, and expensive, and stand-by losses are high.

The next step on the road toward a satisfactory a-c to d-c locomotive was not a railroad equipment development, but rather an unrelated electronic-tube development. When the pumped-type ignitron tube was invented in 1932 and the sealed type developed in 1937, a rectifier locomotive once more became a possibility. The extensive use of sealed ignitron tubes during World War II to provide the large amounts of d-c power required for light-metals production, coupled with large-scale production of d-c traction motors, brought about by the rise of diesel-electric locomotives, did much to make the rectifier locomotive practical. To prove that the modern ignitron was suitable for railway service, a multiple-unit car for commuter service on the Pennsylvania Railroad was so equipped. It has given excellent, trouble-free service since 1949. The performance of that car was so successful that development—and acceptance by the Pennsylvania Railroad—of an ignitron freight locomotive soon followed.

Electrical Apparatus

Although the rectifier principle as applied to locomotive service is new, the apparatus is new only in this combination and for this purpose. Each component has been proved through long service. With the exception of the rectifier and associated circuits, the apparatus on the ignitron locomotive is similar to that on other electric locomotives.

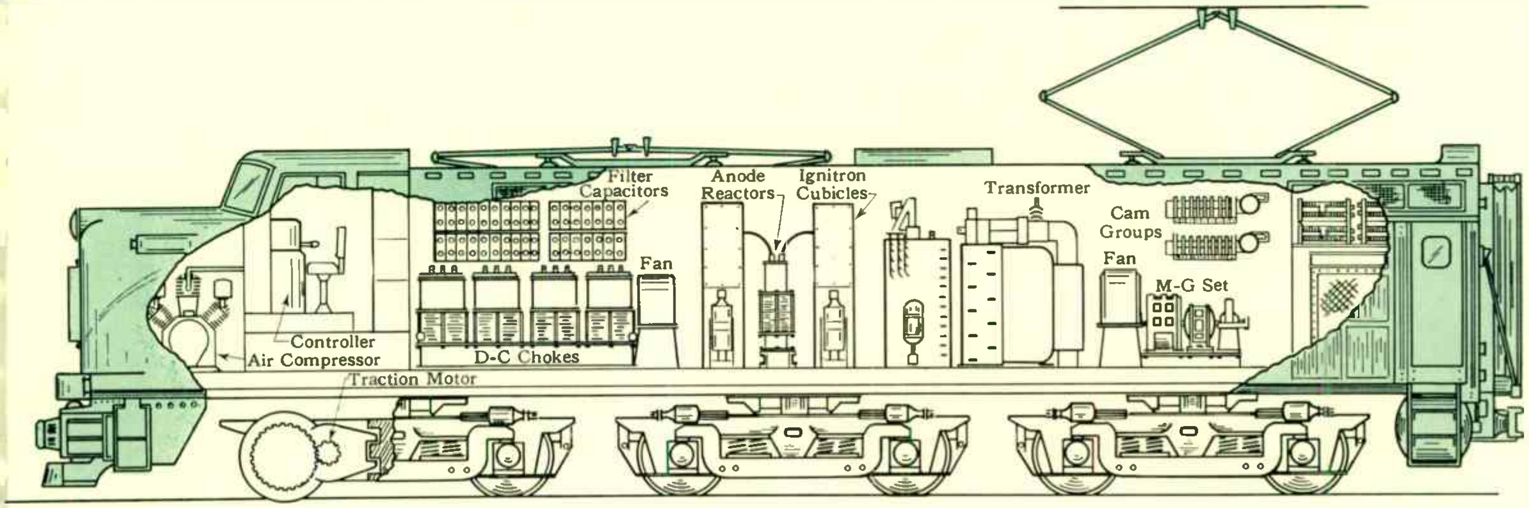
Each of the locomotives is a 6000-hp, two-unit locomotive as shown in Fig. 1. (This is equivalent in rail horsepower to a 7300-hp diesel locomotive, since diesel ratings are based on net horsepower delivered by the diesel engine to the generators.) Each unit is rated at 3000 rail horsepower and is driven through six axles by six 500-hp d-c traction motors.

The principal electrical apparatus in a cab includes the following: two ignitron cubicles, each containing six ignitron tubes and associated firing and switching apparatus; a main transformer, which steps down the 11-kv trolley voltage to a maximum of 832 volts; a d-c choke and d-c filter to control the ripple in the output of the rectifier; an a-c filter to minimize communications interference; and an anode reactor to limit the current flowing during an arc-back. Series-wound d-c traction motors are mounted on the trucks and drive the axles through gears and pinions. These motors are the same as those used on the Baldwin-Westinghouse and Fairbanks-Morse diesel locomotives. The arrangement of apparatus in each unit is shown in Fig. 2. Operation of the apparatus is indicated in Fig. 3.

The 4200-kva transformer is Inerteen-filled and of form-fit construction. It is essentially the same as the transformers used in conventional a-c locomotives, except that the secondary has accelerating taps on each side of a center tap.

The heart of the locomotive, of course, is the ignitron rectifier. Each locomotive unit contains two cubicles, like the one

Fig. 2—One unit of an ignitron locomotive, in profile, showing the arrangement of the principal items of electrical apparatus. The motor to the right of the transformer drives the transformer blower, a control generator, and a centrifugal pump, which circulates cooling water for the ignitron tubes. At the back of the car, below the braking resistors, is a vertical Axiflo fan that furnishes cooling air for the ignitron tubes. This air is then forced past the dynamic-braking resistors and is expelled through the roof.



shown in Fig. 4. A resilient structure holds each tube approximately at its center of gravity.

These locomotives were equipped with the maximum amount of a-c and d-c filter apparatus for experimental purposes and because the degree of filtering required had not been definitely determined. This resulted in a somewhat crowded layout; however, extensive tests indicate that the entire d-c filter and about half of the a-c filter can be removed without undesired effects. This will result in more accessibility and will reduce the weight of the apparatus by approximately 11 000 pounds.

Dynamic braking is provided by exciting the motor fields with direct current supplied from two of the ignitron tubes. These two tubes are connected to feed all motor fields in series through a stepped resistor, as shown in Fig. 5. The circuit then goes through d-c chokes to the center tap of the transformer. By varying a series resistor and utilizing phase delay on the ignitron tubes, 14 notches of braking are obtained from four transformer taps, two on each side of the center tap of the secondary. A dynamic-braking resistor is connected across each motor armature and commutating field to dissipate the braking energy. Additional braking is provided by air brakes in the conventional manner.

Cooling and ventilating air for the transformer, ignitron tubes, motors, and braking resistors is supplied by blowers mounted in each locomotive unit. These can be seen in Fig. 2.

Mechanical Parts

The mechanical parts on these ignitron locomotives are similar in many respects to those on diesel-electric locomotive units, with the exception of the trucks. For experimental purposes, each cab of one locomotive is mounted on three 2-axle trucks; the other locomotive has more conventional 3-axle trucks. This was done to prove by actual experience which type is more satisfactory. These truck arrangements are illustrated in Fig. 6.

On the locomotive with three-axle trucks, each cab is supported at three points on each truck: the center pin, located between the first two axles; and two spring-loaded side bearing pads between the second and third axles. The center pin bearing is carried on a bolster supported from the truck frame by swing-links and springs. The side bearing pads are mounted directly on the frame.

The two-axle truck arrangement consists of three trucks

Fig. 3—Connection of apparatus in one unit during motoring is shown in the schematic diagram. Accelerating taps on each side of the transformer center tap feed an anode bus, which supplies six ignitron tubes. Each pair of tubes furnishes full-wave rectified power to one d-c traction motor. The circuit is completed from each motor through a d-c choke reactor that limits voltage ripple to 30 percent, a motor switch, a cutout switch, and back to the transformer center tap. All six traction motors in each unit are connected in parallel. By means of phase delay on some notches, a total of 35 notches for motoring is provided by the control.

↓

←

Fig. 4—Each ignitron cubicle houses six tubes and associated apparatus. Tube-firing controls are at the top left; anode breakers, upper right.

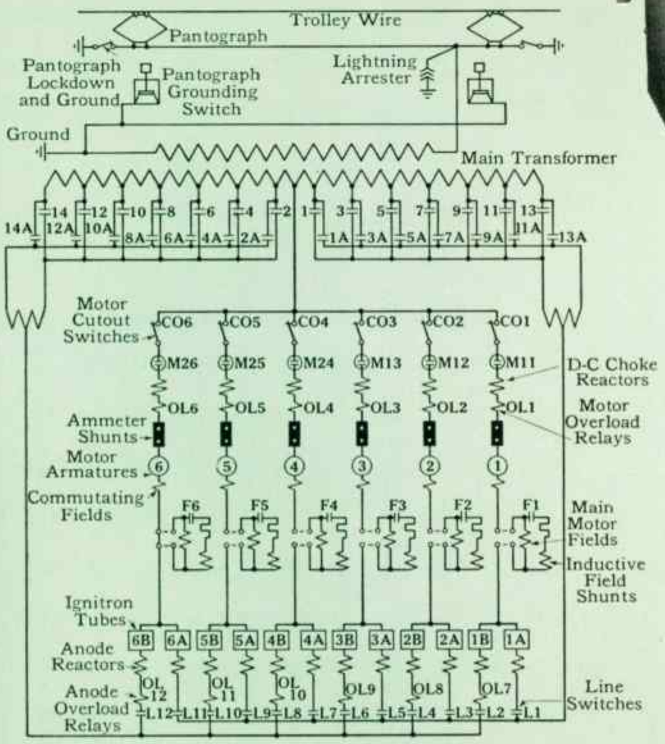
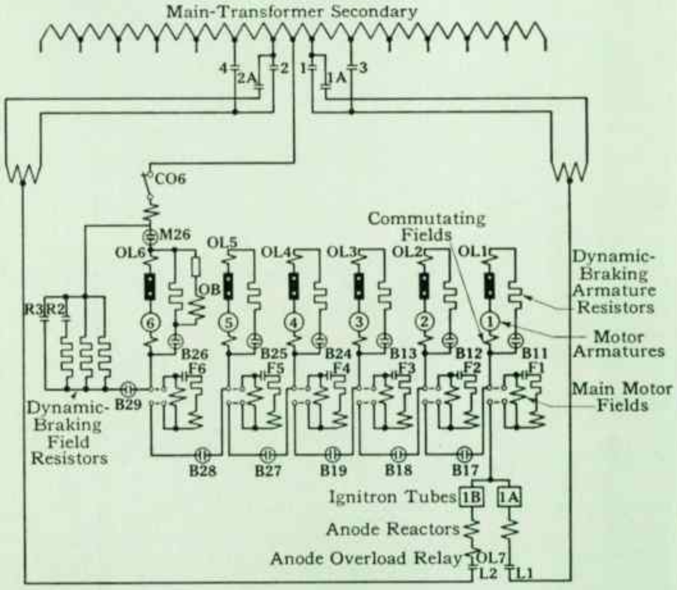


Fig. 5—Circuit connections, dynamic braking.



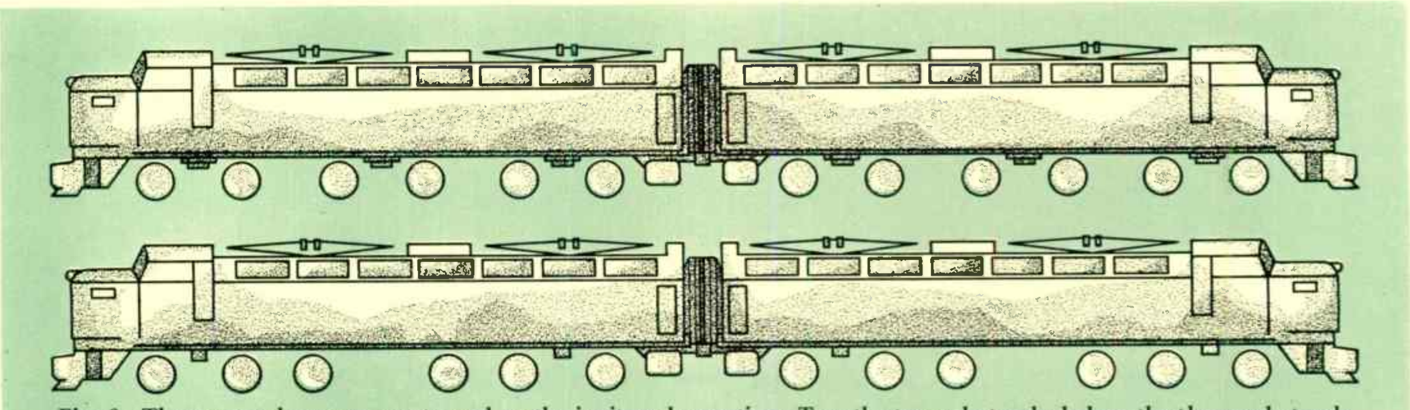


Fig. 6—The two truck arrangements used on the ignitron locomotives. Top, the two-axle truck; below, the three-axle truck.

per cab. This is an entirely new design for six-axle, total-adhesion locomotives (i.e., all axles driven). The advantages include: simplicity and standardization of truck design, greatly improved tracking qualities, better accessibility to motors, and improved motor ventilation.

On the new design the center truck is free to move laterally without restraint. This and extremely soft springs and "no-lift" lateral-motion devices minimize weight shift from truck to truck when the locomotive negotiates curves or vertical irregularities in the track. The lateral motion of the end trucks is spring restrained and thus absorbs the lateral shocks that occur on curves and irregular, tangent track.

When the locomotive passes over any vertical rise in the track, the center truck tends to take more of the load but, because of the soft springs, the increase in load is small and does not greatly affect the axle-to-axle load distribution. The suspension springs, being soft, have a large deflection (7½ inches) when loaded and any incremental increase in deflection causes only a small additional increase in axle load.

Another unique feature of the two-axle truck design is that the entire cab weight is carried by the side bearing pads. The center pin serves only as a swivel bearing and to transmit the tractive effort; it is hollow and is used to transmit cooling air to the motors, with a significant improvement in motor ventilation. Heretofore it has been customary to provide motor ventilation by means of sliding and telescoping air-duct connections to individual motors. These sliding members necessarily cause considerable wear, resulting in loss of ventilating air, thus increasing motor temperature and causing unnecessary maintenance expense.

Running tests up to the present time have shown excellent riding qualities for the 3-truck locomotive cab, even at top speed on relatively rough track. Tests on the second locomotive having two 3-axle trucks are not yet very extensive, but indications are that the tracking qualities will not equal the performance of the first locomotive.

Operating Experience

Any new equipment, particularly such a radical departure from existing equipment as the ignitron locomotive, must result in significant improvements in operation and performance to gain widespread acceptance. And the proof of the performance comes when the equipment is placed in service under actual operating conditions. For the first 60 000 miles of revenue service on the Pennsylvania Railroad, the first two ignitron locomotives have given excellent service.

Arc-backs within the ignitron tube presented the greatest possibility for trouble. This is encountered in some stationary installations of ignitron tubes and was one of the reasons for the failure of the 1914 rectifier railway car. An arc-back is a short circuit caused by the formation of a cathode spot on the anode of a tube. In polyphase installations, when there is a short circuit on one phase, the other phases feed power into it and cause extremely high currents. It is also possible in d-c applications for a load having stored energy in a shunt field to feed power into the short circuit.

This trouble has not been encountered either on the multiple-unit car or on the two locomotives. If an arc-back occurs, it is immediately extinguished at the next zero point on the voltage wave. Since single-phase power is used, there is no other voltage present to reignite the arc. With series-wound d-c motors, there is no possibility of reverse power feeding an arc-back.

The performance of the ignitron locomotive in terms of tractive effort and speed is shown in Fig. 7. A large number of notching curves are provided so that, during an acceleration, the increase in tractive effort between notches is small. This minimizes the possibility of slipping the wheels when the controller is advanced. As a result, a heavy train can be started very smoothly and without imposing excessive stress on draw bars.

The tremendous pulling power of the ignitron locomotive was demonstrated last February. A train made up of 162 cars of coal—a mile and a quarter long—was hauled from the freight yards at Enola, Pennsylvania, to Morrisville, Pennsyl-

TABLE I—PERFORMANCE OF ELECTRIC FREIGHT LOCOMOTIVES IN ROAD TESTS FROM ENOLA TO MORRISVILLE, PA. (130 Miles)

Locomotive Data	Class GG1	Class P5a	Class E2C
Type	A-C	A-C	A-C to D-C
Number of cabs	1	1	2
Continuous rail horsepower	4620	3750	6000
Maximum speed (mph)	90	70	63
Total weight (pounds)	460 000	394 000	740 900
Weight on drivers (pounds)	300 000	229 000	740 900
Overall length (feet)	79.5	62.7	124
Present tonnage ratings			
Enola to Morrisville:			
Adj. tons (factor=20)	6000	6300	16 800
Flat tons, 50-ton cars	4280	4500	12 000
Flat tons, 85-ton cars	4850	5100	13 600
Road Tests			
Date	8-23-46	8-14-46	2-19-52
Rail condition	Dry	Dry	Dry
Number of cars	76	80	162
Adjusted tons	5895	6158	16 588
Flat tons	4375	4558	13 348
Percent of rating	98.2	97.7	98.3
Time in motion	3 hr 28 min	4 hr 50 min	4 hr 20 min
Average speed (mph)	37.4	26.8	30
Gross ton miles	568 750	592 540	1 735 240
Gross ton miles per train running hour	163 905	122 679	400 440

vania, a distance of 130 miles. This run is typical of hard freight service, and contains many curves and crossovers, and frequent grades. The total load on the train was 16 588 adjusted tons.* The run was made at an average speed of 30 miles per hour. Very little sand was applied on this difficult run. On the heaviest grades, it was necessary to use only light sanding in front of the leading truck to prevent slipping.

A good measure of the performance of freight locomotives is gross ton-miles hauled per train running hour. The usefulness of the powerful ignitron locomotive in handling tonnage is well illustrated by the comparison in table I, which gives the performance of the 6000-hp ignitron locomotive (class E2C) and the present electric locomotives (class GG1 and P5a) as determined by road tests over the same route. The gross ton-miles per train running hour for the ignitron locomotive is 400 440, compared with 163 905 and 122 679, respectively, for GG1 and P5a locomotives.

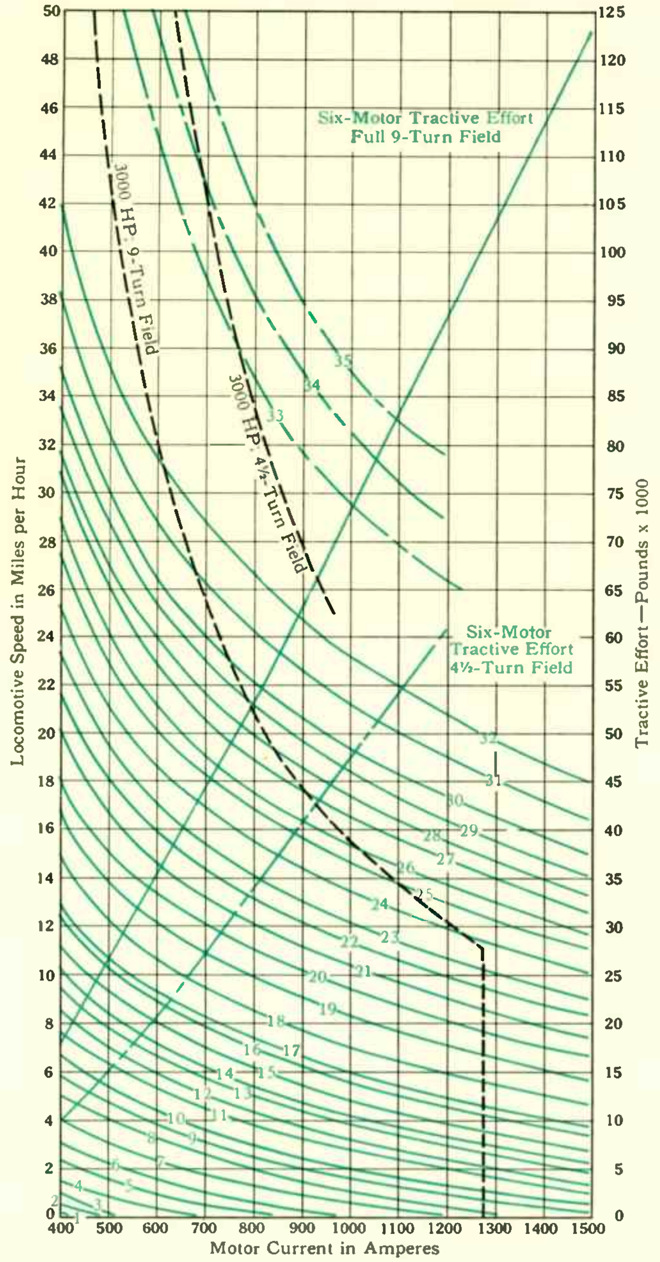


Fig. 7—Performance curves of the ignitron locomotive. Speed for a given motor current is indicated by the solid curves. Three notching curves, for notches 33, 34, and 35, are used with the lower tractive-effort curve. These are obtained with half of the motor field strength. The usual operating range is shown dotted.

During the test run, the minimum speed of the ignitron locomotive up the 21.2-mile, 0.288-percent Smithville grade, hauling a train of 162 cars loaded with coal, was 24 miles per hour.

Extremely smooth, uniform starting is possible with an ignitron locomotive. This minimizes the possibility of breaking a drawbar during starting. As one railroad man states, "This locomotive starts a 150-car freight train with the same ease that the GG1 (conventional a-c locomotive) starts a passenger train."

Another advantage of the ignitron locomotive is its ability to "hang on" at low speeds, i.e., move forward at extremely slow speed without stopping and without overheating the motors. Frequently, this eliminates the necessity of stopping when the train approaches a stop signal—it can creep forward while waiting for the signal to change. This keeps the track behind it clear so that other trains are not held up.

The ignitron locomotive is not "slippery," i.e., it resists slipping of the wheels. This quality is achieved because the weight is equally distributed on all drivers and the d-c motors are operated in parallel. The voltage is the same on all motors and they tend to turn at the same speed. Excessive slipping is also minimized by distributing the weight of the locomotive equally on all axles. Equal distribution of weight is essential on any locomotive.

Easy riding, though not apparently a requirement of freight locomotives, is important in extending the life of equipment and reducing maintenance expense. Men who have ridden the ignitron freight locomotive agree that in ease of riding it excells previous locomotives.

The Future

The experience gained thus far with two ignitron locomotives is convincing evidence that here is a valuable new addition to the motive-power equipment available for electrified railroads. It is a most satisfactory combination of the very great advantages of an a-c trolley system with those of d-c traction motors.

But perhaps the most important feature, considering long-range effects on railroad electrification, is adaptability of the ignitron locomotive to 60-cycle power. All a-c railroad systems in this country operate from 25-cycle power, primarily because the single-phase a-c motor works better at low frequency. However, the ignitron locomotive operates equally well on either 25- or 60-cycle power and makes possible future railroad electrification at commercial frequencies. Locomotive apparatus for operation at 60 cycles will be smaller and weigh less than 25-cycle equipment, and the size and cost as well as the amount of transmission and distribution apparatus can also be reduced if a frequency of 60 cycles is used. Further economies can be realized by increasing trolley voltages above the presently used 11 kv. Also, 60-cycle distribution apparatus is standardized and produced in large quantities, resulting in still further savings. The ignitron locomotive, therefore, is of interest not only because it is a new type of motive power with important advantages in its present application, but also because it may make possible the future extension of railroad electrification. As energy costs rise, this system will become increasingly attractive.

---

*This was 13 348 actual tons. A locomotive can handle more tons of heavily loaded cars than of lightly-loaded cars. To simplify the dispatching of trains, which include cars of various weights, an adjustment factor is added to the weight of each car to compensate for such differences. The result is called adjusted tons. An adjustment factor of 20 has been established for the Pennsylvania Railroad electrified zones.

Airplane-Type Control for Log Debarking

H. A. Rose
Consulting Application Engineer
Westinghouse Electric Corporation
Seattle, Washington

An airplane pilot's control wheel is used at the Camas, Washington, mill of Crown Zellerbach Corporation to simplify the operator's controls for a Bellingham-type hydraulic barker, with increased production, better-quality output, and less operator fatigue.

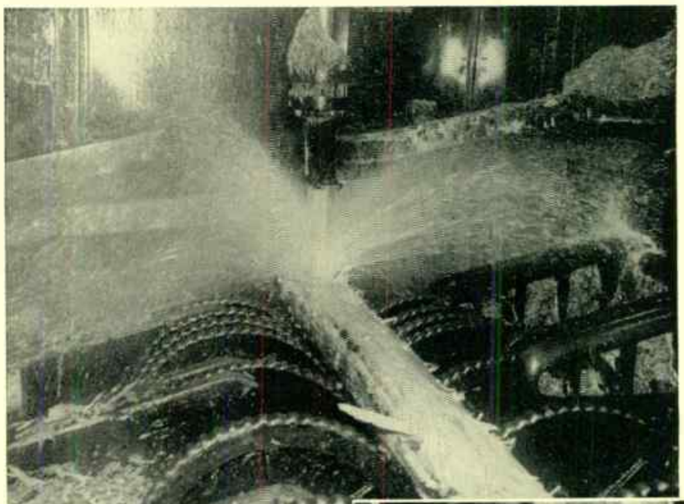
By means of adjustable-speed controls, the operator can rotate a log in either direction, traverse it with a debarking jet of 1400 psig high-pressure water, unload the barker when the log is finished, and load another into the trunnions almost simultaneously with the unloading operation. The operations require much dexterity and skill on the part of the operator. As many as 1500 large logs may be debarked in a single day's operation. Careful watch must be exercised to insure fully debarked and clean logs, so that the quality of the pulp output of the mill will not suffer.

The conventional controls for Bellingham-type hydraulic log barkers use a set of levers, by which the operator controls the various motions required for effectively removing the bark and cleaning out crevices in the log surface. Usually four levers are required with a multiplicity of thumb-operated pushbuttons in the top of the lever handles.

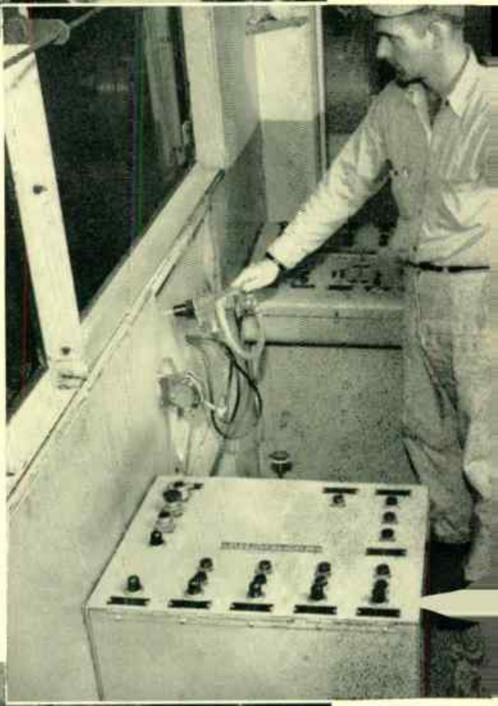
With the new system, Rototrol rotating regulators are used to cause the motors operating the barker to respond quickly to changes in the position of the airplane wheel. Much like flying an airplane, right-hand rotation of the control wheel causes adjustable-speed rotation of the log in the right-hand direction; and left-hand rotation of the wheel produces left-hand adjustable-speed rotation. Pushing the wheel forward causes the barking nozzles to traverse the log away from the barkerman, at a speed proportional to the forward movement of the wheel. Likewise, pulling the wheel back toward the barkerman moves the nozzle in the opposite direction, with speeds proportional to the backward displacement. All four motions, as described, are incorporated on the wheel, in addition to control of loading and unloading operations via two conveniently located, thumb-operated pushbuttons. The airplane wheel, easily operated in all directions of travel, returns all controls to the central or "off" position when the barkerman releases it.

The various motions of the wheel are mechanically associated with cams that drive small push rods on four separate Silverstat contacting resistor elements. The changes in current produced by these Silverstat elements, in turn, produce the required current variations on the pattern fields of the Rototrol exciters. The Rototrols, in turn, excite the main propulsion generators to produce the desired directions and speeds of operation.

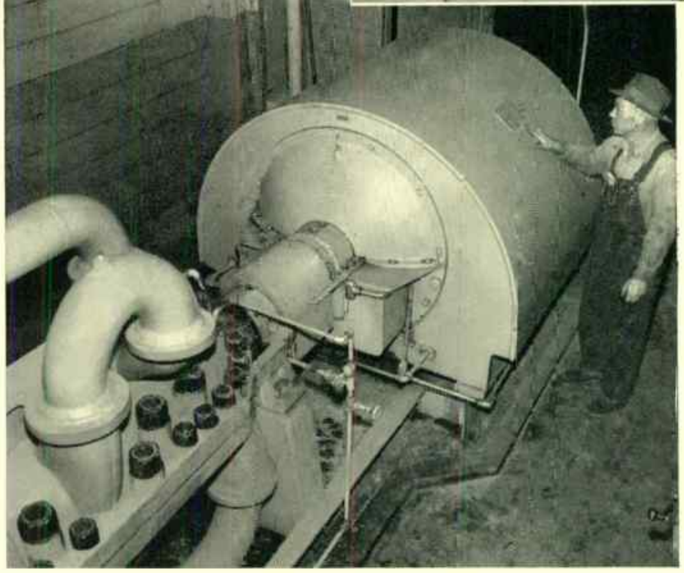
Conceived in basic principle by O. T. DeFieux, Plant Engineer, Crown Zellerbach Corporation, the mechanism and control circuits were designed and built by Westinghouse Electric Corporation. The equipment has been in operation approximately one year. Operating results show that the airplane-wheel type of control can be applied correctly and advantageously to the Bellingham hydraulic log barker.



A hydraulic log debarker in action. A jet of water, at a pressure of 1400 psig, rips the bark off a log in seconds.

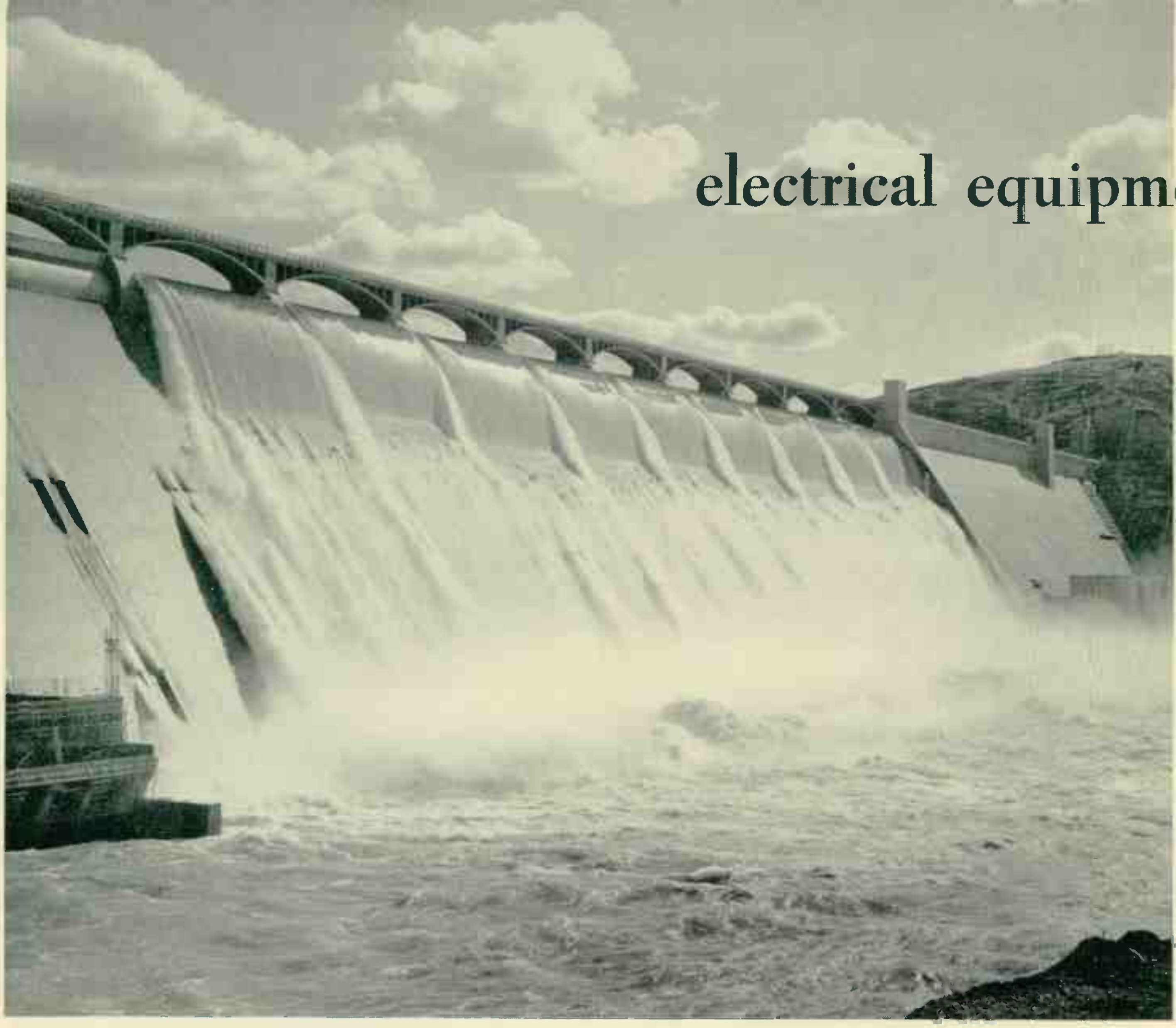


The operator's control room is separated from the debarking room by a glass panel. The airplane-type control wheel replaces four levers and several pushbuttons used on the conventional debarking controls.

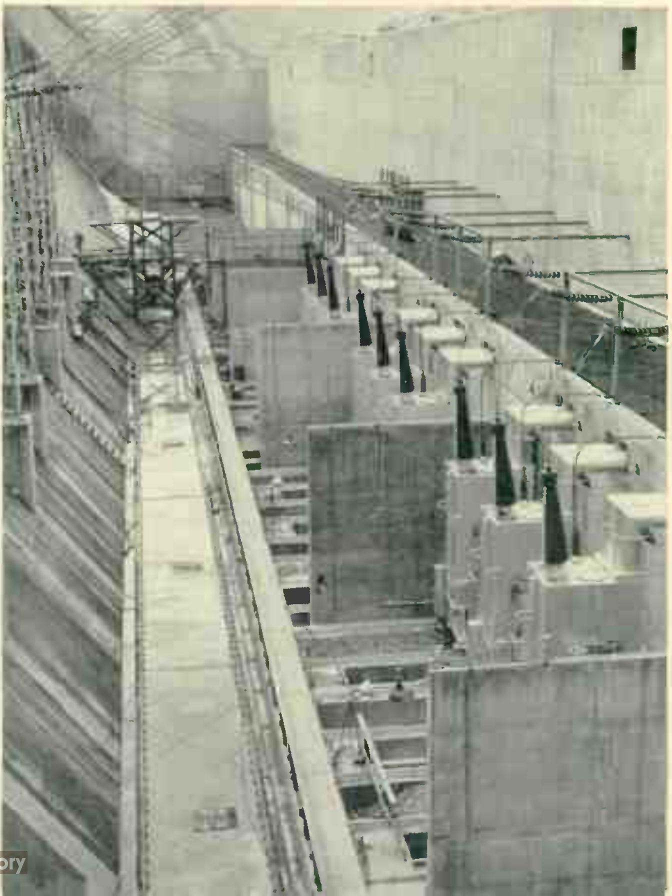


Water for debarking is supplied by a motor-driven centrifugal pump that delivers 1200 cfm at high pressure. Induction motor is rated: 1250 hp, 7000 volts, 60 cycles.

electrical equipment



Grand Coulee Dam is a gravity-type dam that depends on its weight to hold back the waters of the Columbia River. The two powerhouses can be seen at the foot of the dam on either side of the spillway.



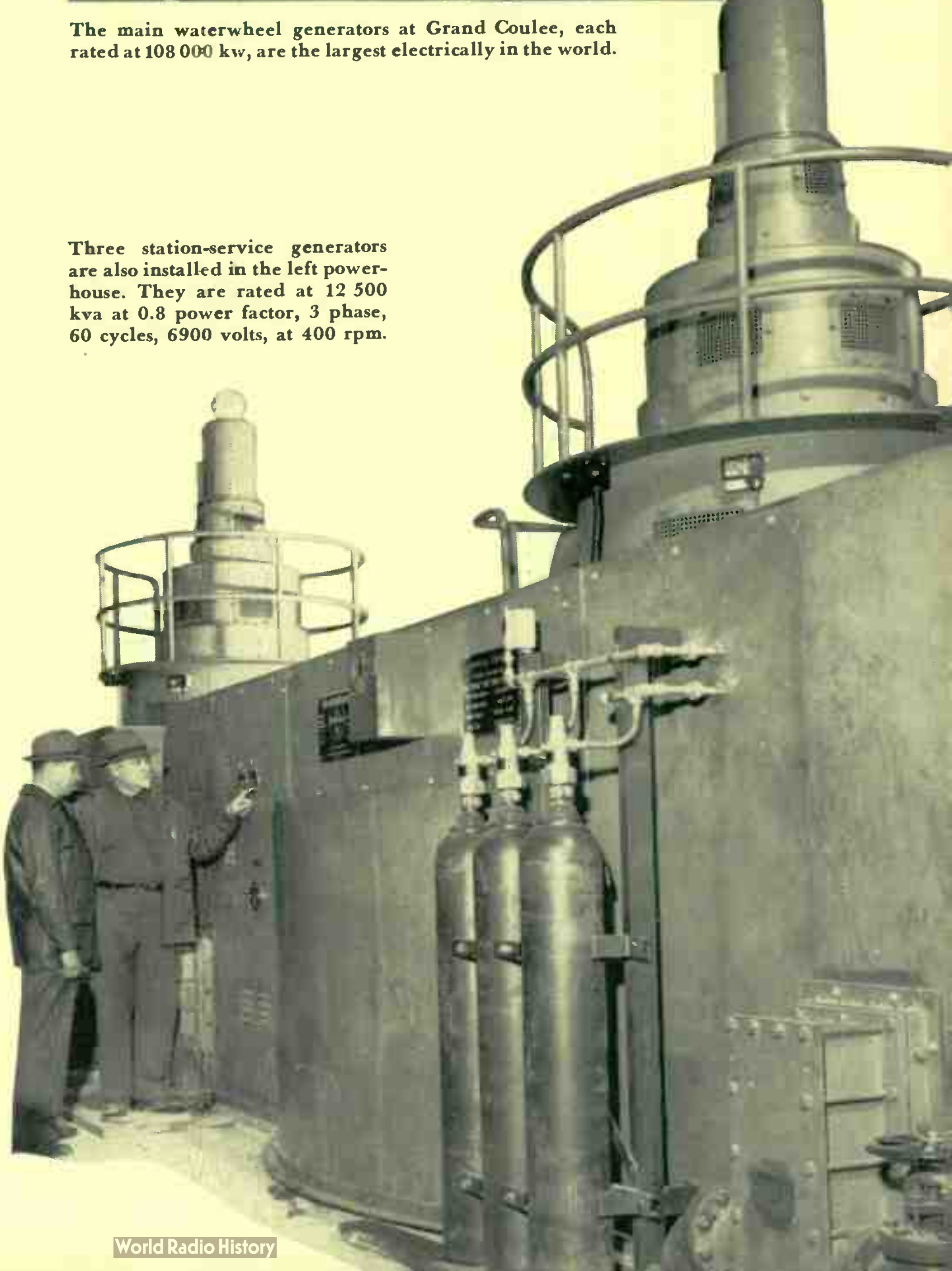
at GRAND COULEE DAM

This year, 19 years after construction of Grand Coulee Dam was started, the first irrigation water, pumped from the reservoir behind the dam, is being distributed to farms on the million-acre Columbia Basin Reclamation Project in central Washington. The synchronous motors driving the pumps, the generators from which power for the pump motors is obtained, and other electrical equipment at Grand Coulee Dam are major accomplishments of the electrical manufacturing industry in the United States.

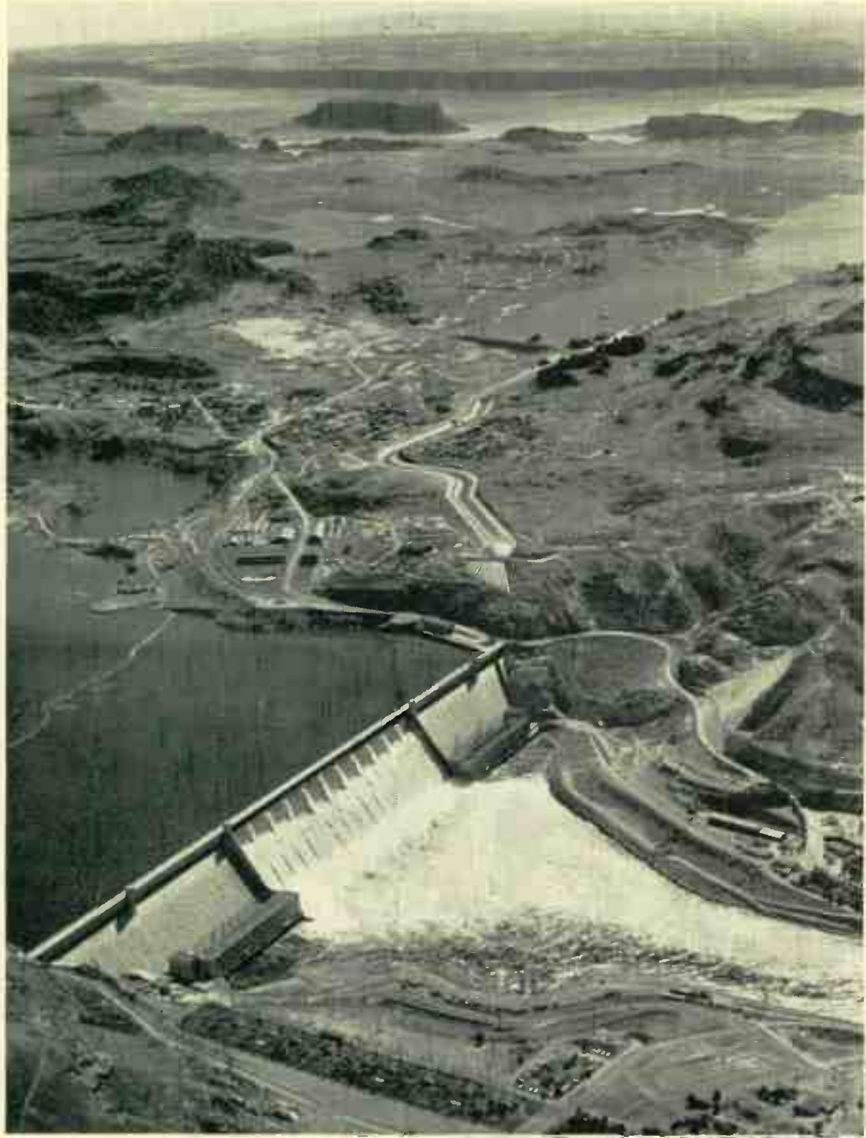
The main waterwheel generators at Grand Coulee, each rated at 108 000 kw, are the largest electrically in the world.

Each Powerhouse at Grand Coulee Dam contains nine waterwheel generators. Each is a vertical, totally enclosed, water-cooled unit rated at 108 000 kw at unity power factor, and 120 rpm. Power is generated at 13 800 volts, 3 phase, 60 cycles. The six nearest generators in the west powerhouse shown were designed especially to supply power for pumping, using secondary energy. They differ from the other main generators only in having separate motor-driven exciters instead of conventional direct-connected exciters. Separate exciters are provided so that at zero speed, full excitation is available to start the 65 000-hp synchronous motors used for pumping. The 12 generators not used for pumping have direct-connected main and direct-connected, self-excited pilot exciters. The rated capacity of the two powerhouses at Grand Coulee, including the three station-service generators, is 1 974 000 kw.

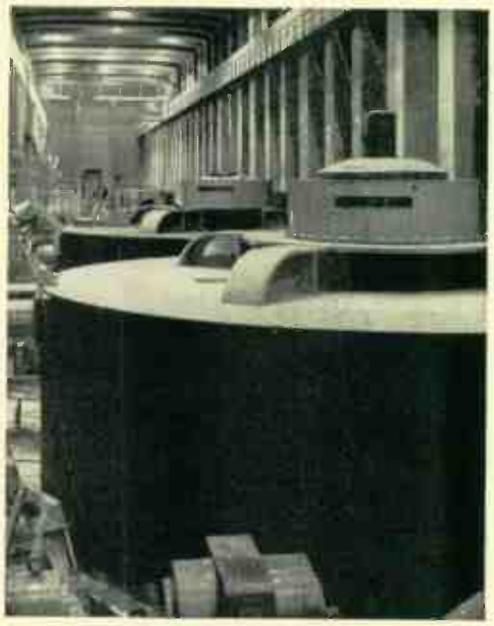
Transformer Banks directly connected to generators step up the generated voltage of 13.8 kv to either 115 or 230 kv for transmission. Nine transformer banks are located between each powerhouse and the dam. Each bank is rated at 108 000 kva, and consists of three 36 000-kva, single-phase, forced-oil, water-cooled transformers. Sixteen banks (seven behind the left powerhouse) have a transformation ratio of 13.6 to 230 kv. One transformer bank has a ratio of 13.6 to 115 kv.



Three station-service generators are also installed in the left powerhouse. They are rated at 12 500 kva at 0.8 power factor, 3 phase, 60 cycles, 6900 volts, at 400 rpm.

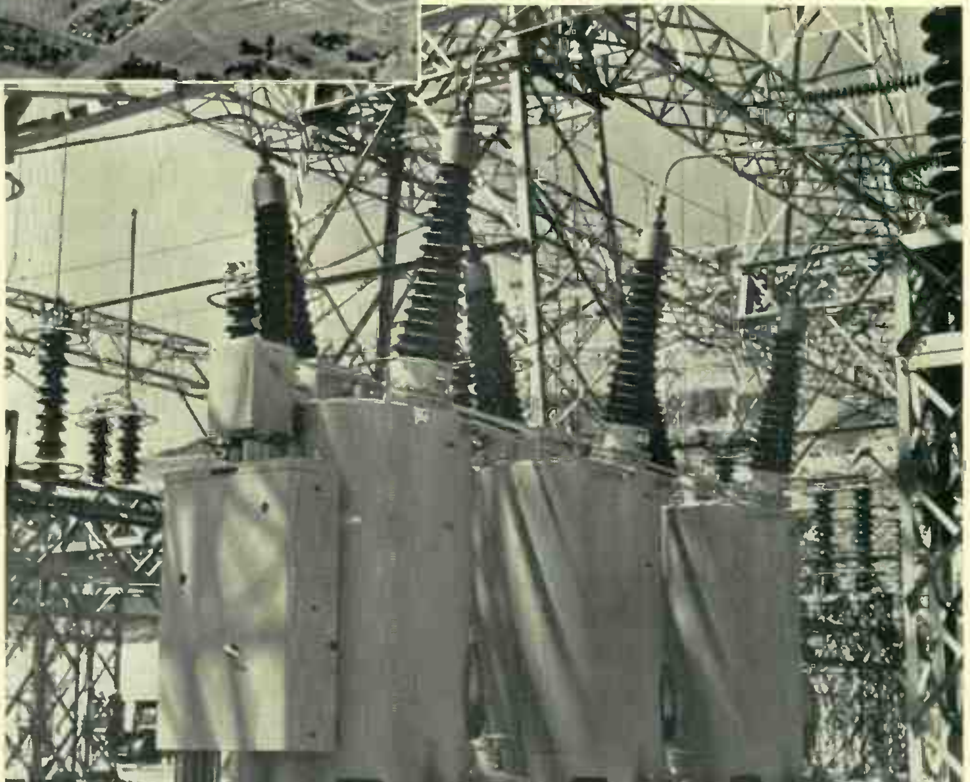


The Pumping Plant is located behind a gravity-type wing dam (center of photo) that runs upstream from the west end of the main dam.



The Pump Motors, one of which is shown in the photo above, are 65 000-hp, 200-rpm synchronous motors rated at 13 600 volts, 3 phase, 60 cycles. They are direct-connected to single-stage, vertical-shaft, centrifugal pumps capable of lifting 700 000 gallons of water per minute.

Oil Circuit Breakers. All switching, except of circuits supplying power to the pump motors, is done at high voltage. The high-voltage switchyard consists of a 230-kv ring bus and sectionalized auxiliary buses. Circuit breakers with an interrupting capacity of 2 500 000 kva at 230 kv isolate the transformer banks from the main bus. All line and bus-tie circuit breakers are rated 10 000 000 kva at 230 kv with three-cycle interrupting time and 20-cycle reclosing. One of these breakers is shown at the right. These breakers were developed in the high-power laboratory at East Pittsburgh, and have been tested to their full rating at Grand Coulee.



Selenium Rectifiers for High-Voltage Power

A block of direct-current energy measuring up to several kilowatts and at voltages between, say, 30 and 100 kv, is hard to come by. Tubes and rotating discs have been the favored devices. Now the selenium rectifier offers advantages in weight, volume, efficiency, quietness, and maintenance.

I. R. Smith, *Manager, Rectifier & Brake Section, Motor and Control Division, Westinghouse Electric Corporation, Buffalo, New York*

Selenium rectifiers are being successfully applied for the production of high-voltage direct current. Units are in use as power supplies for heavy-dust precipitators in the voltage range from 35 to 75 kv, direct current, and with power capacities from 6 to 15 kw, direct current. Several selenium rectifiers, rated at 5 kw at 70 kv, are in service for mist precipitation.

Metallic rectifiers to produce appreciable quantities of power at high voltage are practical because of the development of the 33-volt selenium cell. Although a few attempts have been made to employ copper-oxide rectifiers for precipitator and x-ray applications, their use has not become general, largely because their bulk and cost place them at a disadvantage to electronic tubes and rotating rectifiers.

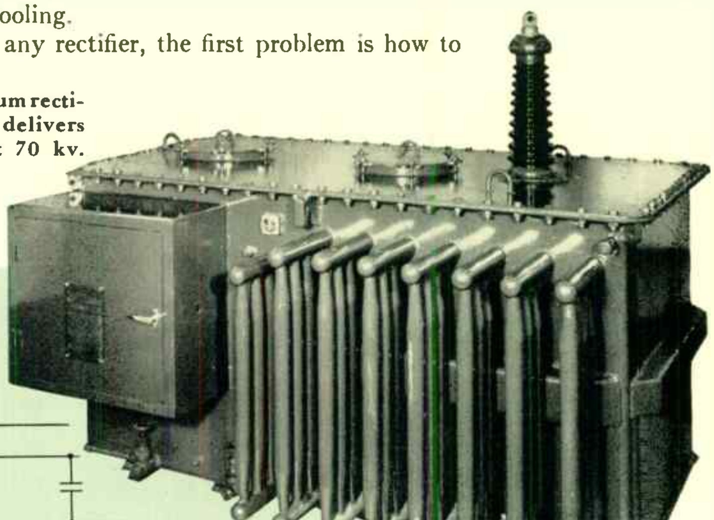
Experience with copper-oxide rectifiers has made it clear that a successful high-voltage unit should be oil-immersed instead of air-cooled. An open-type air-cooled unit collects so much dirt on its own account that it presents a troublesome maintenance problem. If enclosed, insulation clearances make the size excessive. Also, air-cooled units are subject to corona troubles when operating much above 30 kv to ground. This necessitates special measures such as elevated grounds, which increase the cost still further.

Oil immersion, of course, solves the dirt-collection problem, reduces insulation clearances, and suppresses the corona. Disadvantages are: considerable weight, necessity for cooling the oil, and wide installation restrictions that may apply if the unit is mounted indoors.

The selenium rectifier can be operated satisfactorily at temperature rises 2½ times higher than that allowable for the copper-oxide rectifier. Specifically, a temperature rise of 25 to 30 degrees C can be allowed for selenium without sacrifice of long life, whereas the limit for copper oxide is 10 to 12 degrees. As a consequence, container size, oil weight, and volume are much reduced.

By using the new 33-volt selenium elements, the number of cells is cut to nearly one half that required with the 18-volt elements previously available. Also, the open-type construction of the selenium-rectifier stack, with practically the entire cell surface exposed, is ideally suited for oil cooling.

With any rectifier, the first problem is how to



A selenium rectifier that delivers 5 kw at 70 kv.

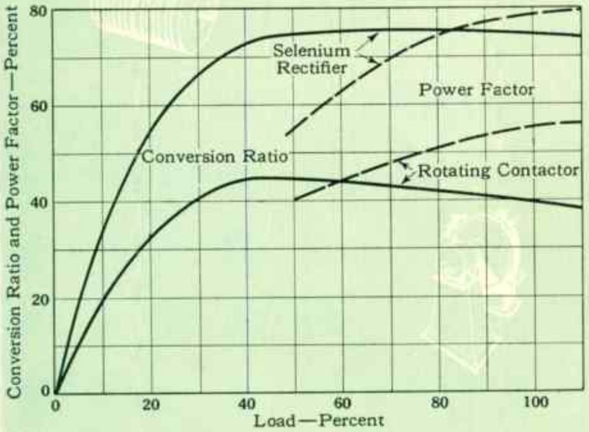


Fig. 1—The conversion ratios and power factor of the selenium rectifier and rotating contactor compared.

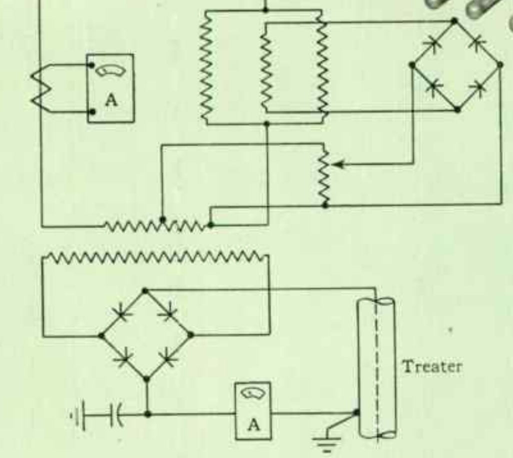


Fig. 2—A saturable-reactor control circuit to permit operation of a dust precipitator at a voltage close to flashover but with assurance of rapid arc extinction.

get rid of the losses. These are generated in the rectifier cells, and must be transmitted to the oil and thence to the case or to some other heat exchanger. Obviously self-cooling is preferable to forced cooling. All Westinghouse high-voltage rectifiers built so far are self-cooled.

Outwardly, a high-voltage rectifier resembles an oil-filled transformer. In fact, the tank design closely follows well-established transformer practice, except that the oil temperature is much lower. Generally the limit of rating for plain tanks is about two kw. Beyond that, to keep size and weight and oil volume within bounds, radiating surface is augmented with radiators, such as employed with transformers.

Although voltages are high—from 30 to 100 kv rms or 140-kv peak—insulation presents no serious problem. Transformer designers have successfully coped with voltages higher than these for years.

One of the principal applications for high-voltage selenium rectifiers is to provide power for electrostatic precipitators. The Cottrell field of rectification has for many years been dominated by the synchronous-commutator type of rectifier, or rotating disc, with some strong competition from tube-type units. As compared to the synchronous commutator, the selenium power pack has a great advantage in operating efficiency, or conversion ratio, i.e., the ratio of d-c volt-ampere output to a-c watt input. This is shown in Fig. 1. The maintenance advantages of the selenium rectifier are obvious. Also the selenium rectifier is free of radio interference, which is very much present with the rotating rectifier.

A further advantage is that the selenium-rectifier power pack can be operated at a higher average voltage than can the rotating disc. A common practice in Cottrell work is to operate with the output voltage just below the point at which too-frequent flashovers occur. The disc-rectifier voltage wave contains high-frequency surges that cause flashover. The average output voltage must be maintained at a lower value than for the smooth output wave of the selenium rectifier for the same degree of freedom from flashover. This in turn means lower efficiency of precipitation.

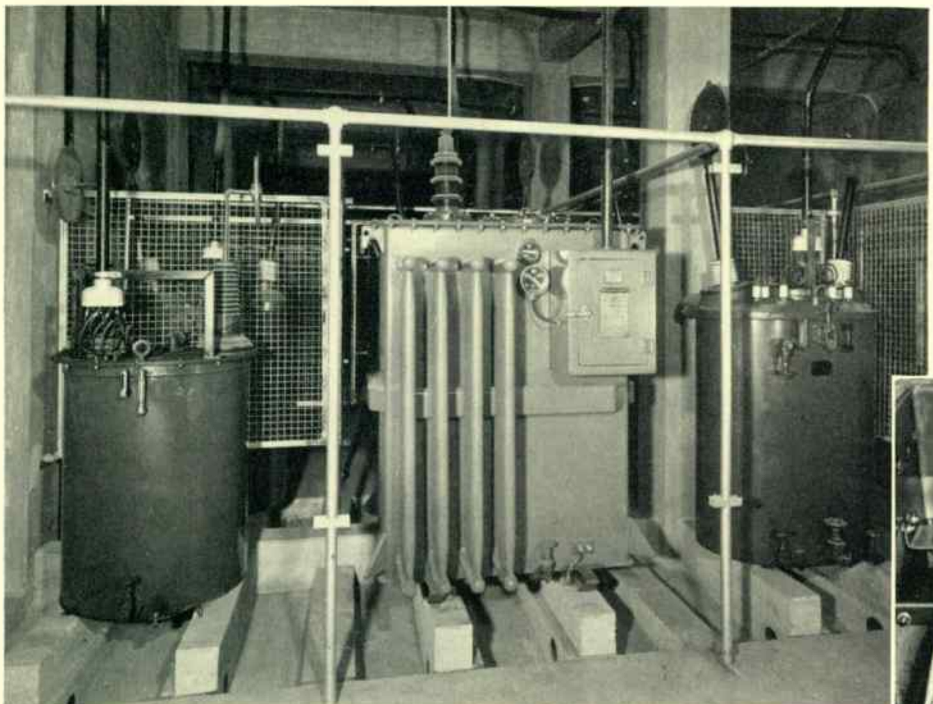
Selenium rectifiers are silent, which is in great contrast to the noise generated by rotating discs. The rectifier power pack, being like a transformer, is easily weatherproofed. It can be mounted outdoors, on the roof or the ground, if indoor space is limited.

The problem of control of a Cottrell rectifier is not simple. Very close voltage adjustment is necessary to get maximum precipitation. One must operate as close below the flashover point as possible—not 5 or 10 kv below it. This means then either an induction regulator, saturable reactor, or variable autotransformer be used to control input voltage. The governing factor is the flashovers that occur because of the build-up of material in the treaters. When flashover occurs an arc is formed. This arc may blow out by itself, with no harm done. If it hangs on it is necessary to snuff it before it can cause damage to the treater or the rectifying equipment by overload. Various methods for doing this have been used. Practice mostly has centered around the use of permanent resistors to drop the voltage on short circuits and put out the arc. This entails a terrific power waste in normal operation. Other schemes have used resistors or reactors cut into the circuit by relay operation only when the short circuit exists.

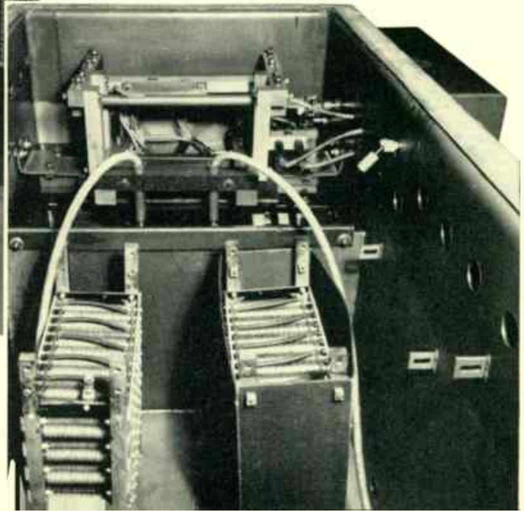
A system of saturable-reactor control, Fig. 2, has been developed for this service. It is extremely simple and yet accomplishes about all a good control should. A saturable reactor is used in the primary circuit. Excitation is taken from the transformer primary voltage, instead of from a separate source, adjustable through a variable autotransformer and a small rectifier. Rectifier-output voltage then is smoothly adjustable to any value desired.

The chief advantage of this control is that when a short circuit occurs, the voltage on the transformer primary collapses, in turn dropping the reactor excitation. Increased reactor impedance is thereby inserted automatically into the circuit. This snuffs the flashover arc effectively without resorting to other devices.

The flexibility of construction, higher operating temperature, and high voltage per cell of the selenium rectifier make it well suited to handling high-voltage, direct-current applications. It also has great maintenance appeal.



A selenium rectifier supplying power to a Cottrell precipitator for collecting heavy dusts in one of the world's largest copper smelters. Looking into the tank (below) of an oil-immersed high-voltage selenium with two banks of selenium cells; in the rear section, the transformer.



A trolley coach must provide passengers with comfort, a smooth ride, and fast transportation. The transit company, too, needs fast acceleration to maintain schedules; but it also needs equipment that is simple and sturdy and that requires minimum attention. A new trolley-coach motor and control fulfill these requirements.

Fig. 1—Fifty-three new trolley coaches like the one shown above were placed in service in Boston recently. The electrical equipment in these coaches includes Super-Series d-c traction motors (inset) and Electrocam controllers.

W. F. Bowers
Transportation Engineer
Industry Engineering Department
Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania

New Motor New Control for Trolley Coaches

The modern trolley coach was introduced in America in 1928. Its use has steadily increased since then, especially during the years immediately preceding and following World War II. Since 1945, this trend has increased. The success of the trolley coach is closely related to the excellent performance obtained from the electrical drive and control equipment. Thirteen years ago the 40-passenger, single-motored trolley coach, provided with dynamic braking, was introduced in this country. As with all equipment, however, changes and improvements have been needed to keep it in step with new developments and more exacting service requirements. The most recent improvements were introduced a little less than two years ago.

In the fall of 1950, five new trolley-coach electrical equipments were placed in service in Boston and Chicago. The motors and controls in these coaches are of new design and the first of their kind to be used in transit service. The motors, shown in Fig. 1, are termed Super Series. This motor, instead of operating at all times as a series motor, has both a series and a shunt winding. During motoring, it is operated as a straight series motor, the shunt winding being disconnected. During braking, only the shunt field is used. The motor then operates as a shunt generator, and provides dynamic braking. The control, also new, has fewer switches and interlocks than its predecessor and requires less maintenance. It is designated the Electrocam.

The service experience provided by these first five equipments has since led to the installation of 103 trolley coaches with the new traction motors and controllers in transit service in Boston and Cleveland. Fifty have been operating in Cleveland since last October. An additional 53 went into service in Boston about the first of this year. At this writing a total of approximately 2 million miles of successful operating experience has been obtained in Boston and Cleveland.

The Super-Series Motor

Modern trolley coaches, because of street widths, turning requirements, loading zones, etc., are generally limited in physical dimensions, and weigh between 17 000 and 21 000 pounds. It has been found possible to develop a single motor that meets the various operating conditions of trolley-coach service. A single motor has the advantage of quantity production resulting from standardization. For universal application, the motor rating and characteristic must provide adequate capacity for the severe grades encountered in cities like San Francisco, Seattle, and Birmingham; for high-speed operation required in Chicago and Cleveland; and frequent-stop, congested operation in cities like Providence, Brooklyn, and Boston.

To meet these varied requirements the d-c traction motor (type 1442-N-1) is rated at 140 hp, 194 amperes, 1700 rpm, 600 volts. During acceleration and motoring it operates as a series-wound d-c motor. Series motors are particularly adapted for traction service because speed drops rapidly as the torque demanded by the load is increased. This can be seen in Fig. 2. Transportation service requires reasonably high speed on the level, and development of high torque for starting and for operation on grades. Armature current should be as small as practicable. The d-c series motor meets these requirements; and its superior commutation, freedom from flashing, power economy, and low maintenance are also inherent advantages.

The series motor has one disadvantage: dynamic braking of a single motor is difficult to control in order to secure smooth braking. For that reason, the new motor is provided with a separate field for braking, connected so that the motor

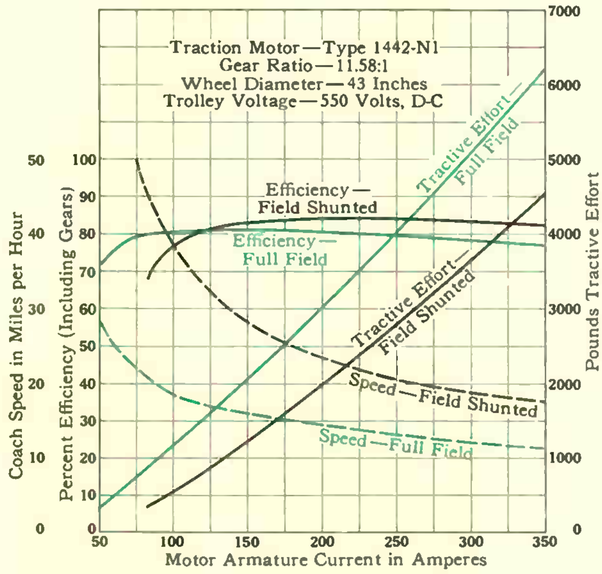


Fig. 2—The curves indicate the performance of the Super-Series motor. Those shown in color are with full motor series field effective. Those in black are obtained with 65 percent of the series field winding shunted.

acts as a shunt generator, the series field being disconnected. By this means, smooth, notchless dynamic braking is obtained. The average braking effort is sufficient to provide a deceleration rate of two miles per hour per second for average seated load conditions of the coach (25 000 pounds total).

Circuit Operation

The Super-Series motor has a supplemental advantage. It makes possible a simpler control that is reliable and easy to maintain. The simplicity of the Electrocam control is illustrated in Figs. 3 and 4, which show the fundamental circuits for motoring and braking.

Operation during motoring consists of progressively cutting out resistance in series with the motor armature. This is accomplished by closing cam switches, which short-circuit part of the series resistance. These switches (*R*1 through *R*7 in Fig. 3) with two field-shunting switches (*FS*2 and *FS*3) provide a total of 14 power notches for motoring—11 with series resistance, one with full field and no series resistance, and two with the series field shunted and no series resistance. The coach operator can select any accelerating rate between the minimum and maximum settings of the control, and the equipment maintains that rate automatically. This automatic acceleration is obtained by means of a quick-acting current-limit relay. As the pedal is depressed, the current permitted by the limit relay becomes higher and acceleration increases until the desired rate is attained.

The circuit connections for braking are shown in Fig. 4. The shunt field is excited through a portion of the resistor that is carrying armature current. Any tendency of the armature current to rise causes a larger drop in the common resistor, which causes a reduction of shunt-field current and limits the rise in braking current. The circuit is established with only residual voltage on the motor and the braking current builds up smoothly and quickly as the shunt field builds up. Since the motor field excitation is minimum when electric braking begins, no high initial rise in current, which would cause peak braking effort, is obtained. The build-up of braking is uniform and retarding effort is smooth and nearly constant over a wide speed range.

The Electrocam Controller

The control for propulsion and dynamic braking consists essentially of two assemblies: a main control panel (which includes a cam controller, master controller, line breaker, four shunt-field contactors, overload relay, shunt-field relay, and silicone carbide disc), and a pair of resistor panels. The main control panel is shown in Fig. 5.

The cam controller—an assembly of nine spring-closed cam switches, two cam interlocks, and a power-brake changeover switch—cuts out resistance in series with the traction motor and controls two steps of field shunting during acceleration and motoring. The simplicity of construction effects a material reduction in space requirements and increases mechanical reliability. No sequence interlocking is required because the closing sequence of the controller is fixed mechanically by the cam-shaft assembly.

The cam controller is operated by air pressure. Two piston heads that move in a vertical cylinder are connected by a rack that engages a pinion at one end of the controller shaft. The rotation of this shaft determines the closing sequence of

Fig. 3—The motor circuit for acceleration and motoring.

↓

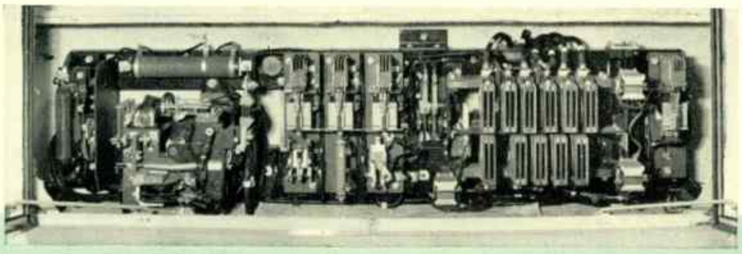
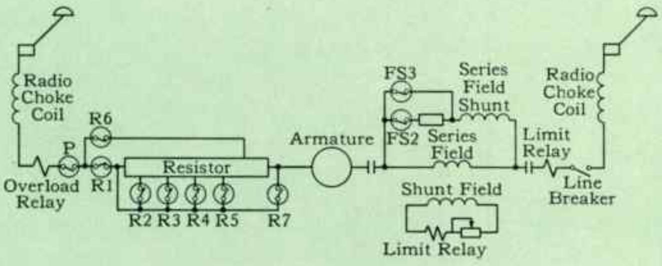
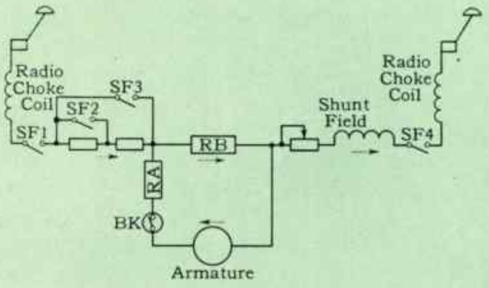


Fig. 5—This photo of the Electrocam controller illustrates the compact arrangement of the equipment. The traction motor is underneath this control panel.

Fig. 4—Schematic diagram of the motor circuit for dynamic braking.

↓





the cam switches. Air pressure is normally applied equally to both pistons. A quick-acting current-limit relay controls a valve, which alternately vents and recharges one end of the cylinder to move and stop the cam shaft.

Included in the cam-controller assembly, but functioning independently, is the power-brake changeover switch. It consists of two cam switches, a control interlock, and an operating cylinder that is air applied and spring returned. One cam switch applies power to one side of the motor circuit during motoring. The other cam switch connects the braking resistor across the motor armature during braking. The power-brake-changeover interlock stops shunt-field contactors from closing until the braking resistor is connected across the armature.

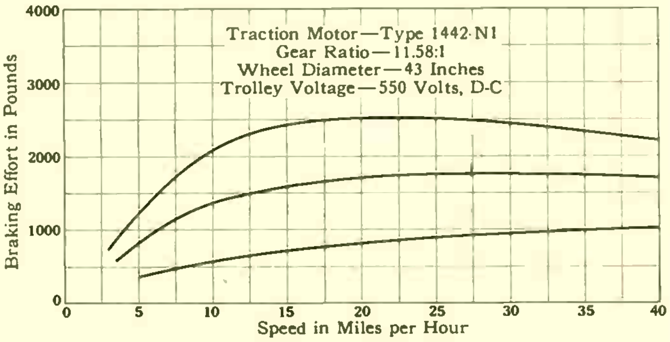


Fig. 6—Typical dynamic braking curves for the traction motor. Three braking rates are available.

The master controller includes a power controller, brake controller, reverser, and limit relay. The power and brake controllers are operated by the operator's foot pedals.

The power controller has two selective operating positions, determined by how far the operator's foot pedal is depressed. The first position is for slow-speed operation. In the second position acceleration is controlled by the limit relay, and progresses automatically unless stopped by the operator.

The brake controller has three selective operating positions, determined by the amount the operator's foot pedal is depressed. These provide the operator with three rates of dynamic braking. The first portion of the pedal travel controls the application of the dynamic brake while the remainder of the travel controls the air brake. The dynamic brake is fully effective throughout the electric-braking cycle regardless of the amount of air brake used.

As shown in Fig. 6, dynamic braking effort is uniform over the greater part of the braking cycle. It decreases at low coach speed, and is automatically cut off at a low speed by a shunt-field relay, which opens the shunt-field circuit shortly before the coach stops.

Automatic acceleration is controlled by the limit relay, which includes a series coil that carries main-motor current, a shunt coil energized by transformer action from the motor field to provide faster action in charging and venting the cam controller valves, and a steel armature on which is mounted a set of contacts. When the current in the relay series coil exceeds the relay setting, the contacts open and acceleration is stopped. The relay setting is governed by a spring, whose tension is varied by the movement of the power controller.

Conclusions

In this motor, the excellent accelerating characteristics of the d-c series-wound motor are supplemented by the advantages of smooth, notchless dynamic braking, and the number of operations required of the cam controller is reduced. The controller is simpler and requires fewer contactors and interlocks than previous controllers. It is easily accessible for inspection or maintenance and occupies a minimum of space. The equipment has been satisfactory in about 2 million miles of operation in heavy service in Cleveland, Boston, and Chicago, and promises to increase further the utility of the trolley coach by furnishing improved performance and reducing maintenance expense.

Role of the Trolley Coach in Public Transit

Since its introduction in 1928, the convenience and performance of the trolley coach has been improved steadily. Today it is a key vehicle in the transit plans of many American cities.

Trolley coaches serve well as replacement of streetcars. When major track reconstruction and procurement of new rolling stock becomes necessary, installation of trolley coaches frequently is more desirable than renovation of streetcar lines. The trolley coach not only satisfies the transit-riding public's desire for comfort, safety, and convenience, but also provides the transit company with a less expensive means of expanding or rebuilding. Expensive track systems are not necessary and expenditures for street paving are reduced or eliminated. In addition, overhead lines intended for streetcar operation are easily modified to accommodate trolley coaches, and the same substation equipment and other fixed investments can be utilized.

There was a marked increase in the use of trolley coaches just before World War II. During 1939, '40, and '41 the number of trolley coaches placed in operation equalled 95 percent of all the trolley coaches installed in the previous ten-year period. This trend continued when the war was over.

Although early applications of trolley coaches were in cities with populations of less than 500 000, they are also well suited to service in larger cities and are being used extensively in large metropolitan areas. In January of this year 37 percent of the trolley coaches in operation were in metropolitan areas of more than 1 000 000 population. Cities with populations of less than 500 000 accounted for 44 percent; and those between 500 000 and 1 000 000 had 19 percent.

In large cities, trolley coaches can be used to provide the necessary service between rapid-transit station stops and between individual rapid-transit lines. One type of traffic plan utilizes high-speed lines that operate in subways in congested areas, and on surface, private right of ways in less congested areas. At the outer ends of these lines, parking areas are provided for those who drive from home to the rapid-transit line by automobile. In addition, a number of trolley-coach lines fan out from the rapid-transit line and provide service throughout the suburban business and residential districts. These lines also can serve parking areas farther away from the rapid-transit line.

This is not the only use of trolley coaches. They can also be applied in crosstown service with heavy traffic transfer between the trolley-coach lines and between trolley-coach and rapid-transit lines.

Although transit problems in small and medium-sized cities differ from those of large cities, mounting traffic congestion in downtown business districts and a desire to make these areas more accessible are common to most cities, regardless of size. Programs for relieving traffic congestion usually include modernization of the transit system. The trolley coach can be a key item in such programs.

Thoriated-tungsten filaments with high output and long life; 1000-kw power r-f tubes; tubes delivering pulses of thousands of kilowatts at thousands of megacycles; x-ray movie tubes; high-reliability rectifiers. These are but some of the vacuum-tube developments that have taken place since World War II.

A Decade of Progress in Electron Tubes

H. J. Dailey
Section Engineer, Radio Tube Section
Electronics Engineering Department
Westinghouse Electric Corporation
Bloomfield, New Jersey

1

Electron tubes can be divided roughly into two groups—high-vacuum and gas-filled. High-vacuum tubes are primarily concerned with the generation or reception of high-frequency energy such as radio transmitters, radio receivers, induction- and dielectric-heating oscillators, and radar equipment. High-vacuum tubes include triodes, tetrodes, pentodes, magnetrons, klystrons, traveling-wave tubes, resnatrons, diodes, electrometer tubes, and others. Gas-filled tubes generally apply to much lower frequencies, such as rectifiers, controlled rectifiers for battery chargers, d-c power supplies, and similar uses. This group of tubes includes mercury- or gas-filled diodes, triodes, tetrodes, pentodes, and ignitrons.

Use of electron tubes in industry has been greatly facilitated by steady improvement. These improvements, which have contributed materially to tube reliability, concerned cathodes, grid materials, vacuum envelopes, electron optics, and dissipation capabilities of anodes.

Cathodes

The cathode in all tubes must supply the needed electrons; the grid or grids must control the electrons in the desired manner; and the anode must collect electrons passed through or by the grid or grids, and must dissipate the energy released by the electrons on striking the anode.

High-power transmitting tubes of about 1940 were mostly triodes utilizing pure tungsten filaments as the electron source. At that time the maximum power obtainable from the largest commercially available tube in this country was about 100 kw. The emission efficiency of this cathode type is low. The power to heat the cathode is about one twelfth of the radio-frequency power output. A 100-kw tube required about 8 kw of cathode power.

Thoriated-tungsten filaments were used in low-power transmitting tubes until about 1940 for power outputs up to about 1 kw of CW (continuous wave) power applications. The tube in the radar set that detected the approach of Japanese planes on that fateful day at Pearl Harbor in 1941 had a cathode requiring about 800 watts and was capable of supplying about 80 amperes of emission current in pulsed service. Another tube (WL-530 special), used in pulsed service only, had a thoriated-tungsten filament requiring 4000 watts of heating power and could supply up to 400 amperes of electron emission current. This type was used to generate 1000 kw of peak power in pulsed service. A pure tungsten filament to supply this much emission would require about 40 000 watts of filament power for a reasonable tube life.

Thoriated-tungsten filaments can be used under severe continuous-wave conditions if the ratio of peak available electron emission to actual electron emission used is about 3 or 4 to 1. The same ratio for pure-tungsten cathodes is about 1.1 or 1.2 to 1. Even with this high difference in ratios, the thoriated-tungsten filament saves about 65 percent of the cathode power. The present-day practical limit for good tube life on emission from thoriated-tungsten filaments is about 1.5 amperes per square centimeter of filament area under continuous-wave conditions. Under pulsed conditions this figure may become approximately 6 amperes per square centimeter. The thoriated filament requires a balanced selection of minimum acceptable tube life, tube cost, and operating temperature of the filament, and filament-power cost.

Early magnetron cathodes were coated with barium, strontium, and calcium oxides. This coated heater, while satisfactory for some purposes, has many limitations. Flaking of the coating often occurs, with high susceptibility to sparking during high-current pulses of long duration. During short-time pulses, current densities are many times greater than during steady-state emission. Back bombardment of the cathode in magnetrons and other high-frequency applications gives rise to secondary emission and, in some cases, excessive cathode temperature. Various cathode types have been developed not so susceptible to the flashing and excessive sparking common with earlier types. Some of these are:

1—A solid cathode of sintered thorium oxide that can supply longer current pulses without excessive or destructive sparking. It is, however, fragile and difficult to fabricate.

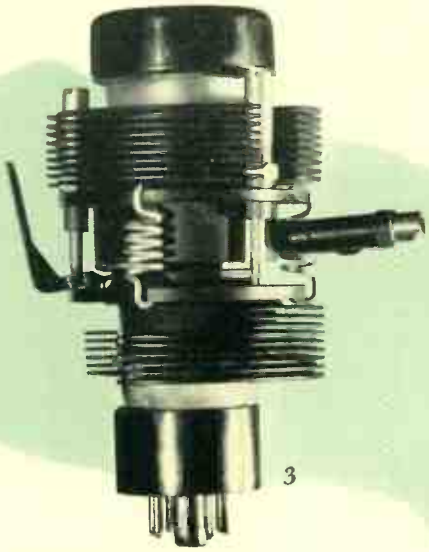
2—A mesh screen over a metallic base, if impregnated with oxide powders of barium and strontium, can supply relatively long pulses of high current density without excessive sparking. It is not as fragile or difficult to fabricate as other types of cathodes.

3—A sintered molybdenum and thoria powder or thoria, tungsten, and molybdenum powder combination is being used for both continuous-wave and pulsed operation with considerable success.

4—A porous tungsten sleeve or button over a source of barium shows promise of being an excellent magnetron cathode. This type appears to be satisfactory for both continuous and pulsed service.

Since 1940 the power level for transmitting types has increased more than fivefold with the present power level ap-


2


3


4

proaching 1000 kw for continuous power output. Some of the higher power tubes use pure tungsten and others thoriated-tungsten cathodes. Economic factors appear to be the only limit to power output obtainable with present-day know-how. A tube could probably be built to deliver 100 000 kw if there were a need for it.

What such power levels could be used for is highly conjectural. One of the highest power levels used is in an induction heating installation in a steel mill in West Virginia. About 2000 kw of radio-frequency power is used to soften and flow electroplated tin on steel strip at a 2000-feet-per-minute speed to obtain a denser coating.

Grids

Grid materials used in transmitting tubes with thoriated filaments have been materially improved within the last decade. Thorium is evaporated from the filament during normal operation, a portion of which lands on the grid, thus giving rise to undesired emission from the grid. The materials now employed permit higher grid-input power and more cathode power. Platinum, a material with a high "work function" (a measure of the difficulty with which electrons are released from a material) is the base of numerous emission-inhibiting grid materials.

Lens Systems

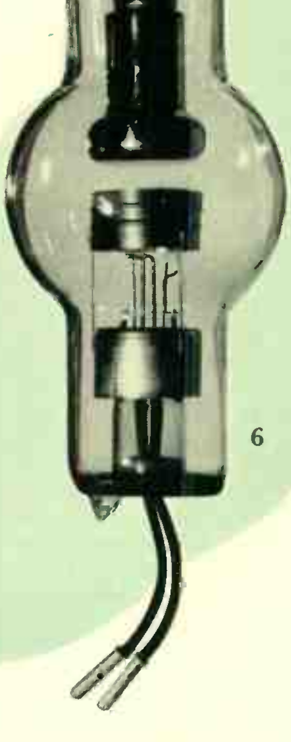
Electrostatic lens systems have also been developed that prevent many electrons from striking the grid or grids. The electron path can be controlled in a manner similar to the control of light rays by lenses as in cameras or picture-projection equipment. These systems shape the electrostatic potential lines so that the electrons are caused to converge or diverge as desired. Inasmuch as electrons emerge normal to a cathode surface, the shape of the cathode itself aids in forming the required lens system. A tube delivering approximately 500 kw has been built incorporating such a lens system. In this case about 3 kw of energy is required to control 500 kw of output, or a power gain of about 166.

Vacuum Seals

High-power transmitting tubes usually have external anodes of copper. Vacuum seals between copper and glass have been made by thinning the copper to about 0.008 inch where it enters the glass. This thinning is necessary due to the difference in the expansion coefficient of copper and glass.

Electron tubes for industry take a variety of forms: 1—One of the historic WL 530 tubes in the radar set used at Pearl Harbor, December 7, 1941; 2—A high-power air-cooled r-f heating tube; 3—A klystron; 4—A sealed ignitron; 5—A modern thyratron; 6—A kenotron rectifier; 7—A transmit-receive tube used to protect radar receivers.


5


6


7

The thin copper, being soft, can deform sufficiently to make up the difference in expansion coefficient between the two materials, which is in the ratio of about 4 to 1. This feathered seal is comparatively fragile and is easily damaged. Many seals are now being made with Kovar, which is an iron-nickel-cobalt alloy having an expansion coefficient that matches several hard glasses. Since the expansion characteristics of the metal and glass are essentially equal, the metal does not have to be thinned out to give strong, rugged permanent seals.

Anode Dissipation

Anode dissipation per unit area has been increasing steadily. Higher coolant film velocities, both water and air, have raised the heat-dissipating abilities from several hundred watts to several kilowatts. The result has been higher power outputs from smaller tubes.

Magnetron

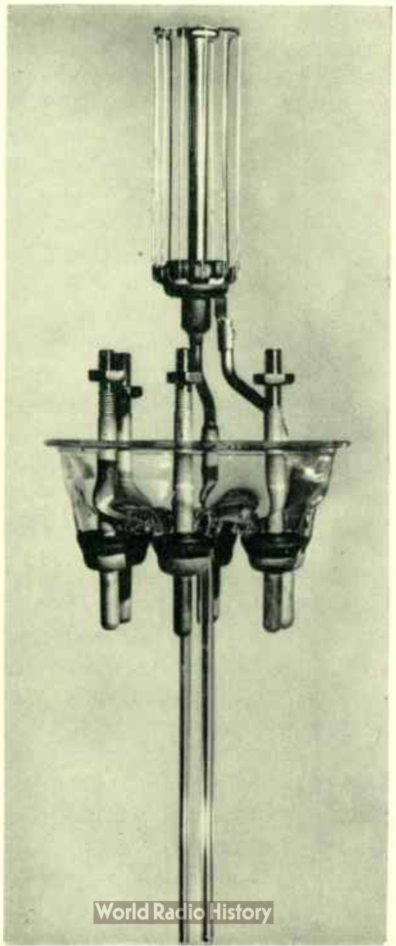
Generation of alternating current at very high frequencies has made tremendous strides within the last ten years. The magnetron principle was discovered in the early 1920's, with various refinements being developed up to about 1940. At that time the multi-cavity magnetron was invented, giving a tremendous impetus to the development of this tube type for radar and similar pulsed applications. The lower practical frequency for this tube type appears to be at about 600 megacycles per second and extends to about 75 000 megacycles. The power range lies between a few watts, continuous, to several thousand kilowatts of power in pulsed service.

The development of the magnetron has been highlighted by several significant discoveries and improvements.

One shortcoming of earlier multi-cavity resnatrons was called modiness. While designed to operate at a frequency determined primarily by the inductance and capacitance of the cavities, the frequency would often jump to another frequency, usually near the design frequency. This frequency jumping often resulted in lower circuit efficiency and decreased the reliability of the tube for radar service. It was discovered that if alternate anodes or poles were electrically connected the tendency to shift frequency was eliminated or greatly reduced. Another method of minimizing unwanted modes consists of slotting pole or anode faces so that anode-to-cathode capacitance is minimized. In this way the capacitance and inductance for other than the desired mode is reduced.

Resnatron

The resnatron type of high-frequency generator has become an excellent source of radio-frequency power in the last decade. The name resnatron was applied to this type as the resonant circuit was built within the vacuum envelope in early models. This tube type is usually built as a four-element tube or tetrode. As in all negative-grid tubes used at high frequencies, electron transit time in the resnatron must be kept as short as possible. Electron transit time is partly licked by brute strength. A high voltage is applied to the screen grid so electron transit time between cathode and screen grid is maintained small compared with a complete cycle, i.e., 180 electrical degrees or less. Energy is then extracted from the electrons by causing them to slow down in the space between screen grid and anode. An average power of 80 kw at 500 megacycles has been obtained with the promise of many times this figure possible in the future. A power output of thousands of kilowatts may be feasible.



→

A thoriated-tungsten triode filament.

As in most electronic tubes, the cathode in the resnatron presents the principal problems to tube designers. An electrostatic lens system, of which the cathode is a part, must reduce electron interception by the grid or grids to a small fraction of the total number of electrons emitted by the cathode in order to obtain high efficiency.

The Klystron

Electron transit time, a serious drawback in conventional tubes operated at high frequency, is utilized to an advantage in a tube type that has been highly developed within the last ten years. The klystron utilizes the time required for an electron to move from one spot in the tube to another to generate high-frequency energy. Some electrons are retarded while others are accelerated in passing through the tube. The resulting bunches of electrons pass through a resonant cavity in such phase relation that energy is extracted from them to maintain oscillations within the cavity. By adjusting cavity dimensions and applied voltages, the frequency can be shifted over a considerable range. Klystron efficiency is usually quite low and its application has usually been restricted to applications requiring only a few watts of power in the hundreds and thousands megacycle ranges. It can be modulated easily and is used in high-frequency radio, telephone, and television circuits. The power range is being expanded to the kilowatts power level and efficiencies of 25 to 30 percent are being realized regularly.

In radar receivers a sensitive crystal detector is used for rectifying the reflected radio wave. While the outgoing signal may be hundreds of kilowatts, the power in the reflected wave may be microwatts. Since the same antenna is commonly used for transmitting and receiving, a means is necessary to isolate the sensitive crystal detector from the powerful transmitted signal. This need resulted in a tiny gas-filled device known as a T-R tube (transmitting-receiving). This is a resonant-cavity, gas-filled device that, under high-power excitation at its resonant frequency, breaks down into a gaseous discharge and holds the power passing through to the receiver crystal to a low value. Following passage of the sending signal, ionization ceases quickly so that the tube is ready to pass a weak received signal through directly to the receiver. For powerful transmitters sometimes a circuit employing two T-R tubes is necessary to protect the crystal rectifier.

Construction of tubes to operate at high frequencies, i.e., thousands of megacycles, calls for almost unbelievable accuracy, particularly in magnetrons. Ordinary machining methods when applied to copper failed to give the required accuracy. By making a hob in the reverse of the pole pattern needed and using a steel that maintains its strength at elevated temperatures, the complicated but precise shapes required for magnetron bodies have been possible. The copper and hob are maintained at the desired temperature and the hob is forced under great pressure into the copper. The copper flows under the tremendous pressure into the hob cavities, which, when withdrawn, leaves the desired magnetron pole faces. By this method the desired accuracy is obtained.

One of the best materials known for use in magnetron cathodes and cathode assemblies is molybdenum. It is highly refractory, has a low vapor pressure at elevated temperatures, and can be produced relatively gas-free. Previous to the past decade little was known as to how to make molybdenum in large sections that could be fabricated to intricate shapes. The know-how has since been acquired and molybdenum can be made to almost any desired size and can be readily machined to the desired shape. Molybdenum can be produced in sheet form to wide widths. These can be drawn and spun to shapes heretofore impossible.

X-ray Fluoroscopy

Fluoroscopic examination of patients is preferred to x-ray photography by many radiologists, because of the time factor and because some performance of body functions can be observed over a cycle. Low light intensity from the fluoroscopic screen has been a great handicap to use of this type of physiological examination.

The image-intensifier tube was developed to rectify this situation. X-rays, after passing through the patient, fall on a composite cathode screen similar to that of an ordinary fluoroscope, which emits electrons over its entire surface in proportion to the x-ray intensity. These electrons are accelerated by high voltages, and are focused by an electrostatic lens system on a screen similar to a television picture screen. The original x-ray image is therefore transformed into an intense light image. By means of an optical lens system the radiologist can observe the image closely. Minute particles in the human body, such as a needle or pin, ordinarily indistinguishable on a conventional fluoroscopic screen, can be readily observed with the image-intensifier tube. The x-ray intensity on the patient can also be readily maintained at a safe tolerance dosage.

X-ray Tubes

The conversion to Kovar seals in x-ray tubes made a notable improvement in their ruggedness and reliability. X-ray tube anodes are usually quite massive and the thin-edged copper seals deform easily. Most manufacturers of x-ray tubes have incorporated Kovar seals in their designs.

The extremely high voltages used in x-ray tubes require extra-low gas pressure within the tube to obtain stable operation. Vacuum pumps now available can pump to extremely low gas pressures but normal usage may release some gas in the sealed-off tube. Devices known as getters, capable of absorbing the remaining gas molecules, have been incorporated in tubes to lower the remaining gas pressure left by the vacuum pump and to keep it low during tube life. The result has been shown in greater stability, fewer internal flashes and longer tube life.

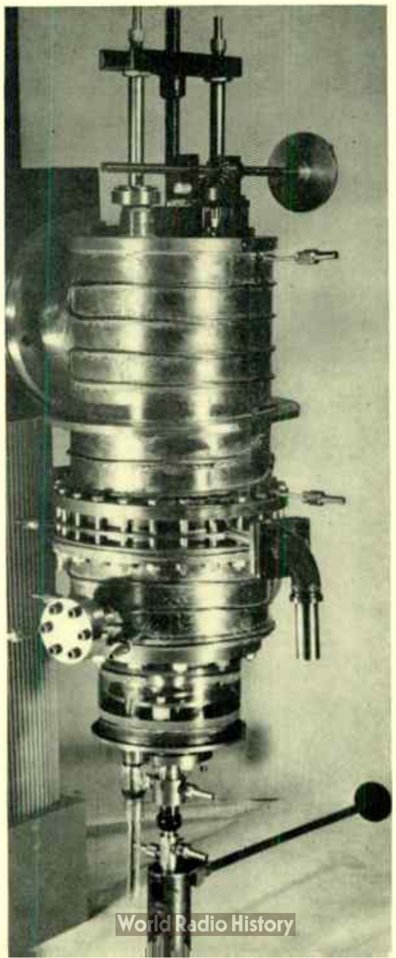
A need has long existed for an x-ray tube capable of taking pictures in approximately a millionth of a second. A tube developed to fill this need has been of tremendous value for military research and industrial applications. It is rated at 360 kv and its cold cathode is capable of supplying approximately 1000 amperes during the x-ray pulse. This gives the enormous value of 360 000 000 watts during the pulse.

Rectifiers used in x-ray service are subjected to instantaneous currents far in excess of their permissible average current ratings. Such high currents have often resulted in unstable operation in past tube designs. Solid anodes of high thermal capacity have been introduced in several Westinghouse tube types. These tubes have anodes specially processed to obtain surfaces that are extremely stable when operating under high voltage and high peak current. In normal operation the anodes remain quite cool due to their large mass and high thermal conductivity. The heat is conducted to the oil cooling medium surrounding the tube.

X-ray tube performance is better if the voltage across it is maintained constant. This type of service is particularly severe on the x-ray tube as the potential across the tube is maintained constant by a condenser connected directly across the tube. In case of a gas flash within the tube, the charge on the condenser is discharged through the tube. Previous constant-potential types had been limited to 220 kv because of this factor. One Westinghouse tube type is rated for constant-potential service up to 250 kv. Operation at this potential is made possible by extreme care in processing and streamlining to a high degree. A resistor between the tube and its constant potential source limits surge currents to a safe value for the tube and minimizes the possibility of damage to circuit components.

X-ray movies are emerging from the novelty stage to many practical uses. While movie cameras have been used to photograph the x-ray image on a standard fluoroscopic screen, such movies are necessarily short for safe human exposures, as the x-ray tube must be energized continuously during the exposure. The light output of the screen is also low.

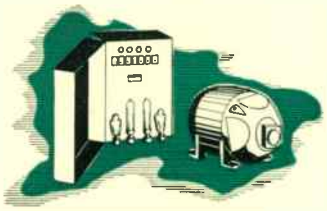
A new x-ray tube can be triggered on and off so that high-intensity x-ray pulses can be used with safety to the patient. The camera shutter can be synchronized



←

High-capacity tube of the resnatron type.

with x-ray pulses to obtain the x-ray movie or a shutterless camera can be used if in total darkness. The tube filament has a low thermal capacity. A condenser discharge circuit pulses the cathode of the tube at the rate desired. This filament is extremely well braced and anchored to withstand the stresses of repeated high current discharges.



The Ignitron Rectifier

One of the most versatile workhorses of the electronic age—the ignitron—has made its widespread commercial appearance in this decade. The ignitron principle was discovered in the 1930's and by the 1940's it had been generally applied to difficult welding, rectifying, and kindred applications. Virtually an entire industry has built up around the ignitron.

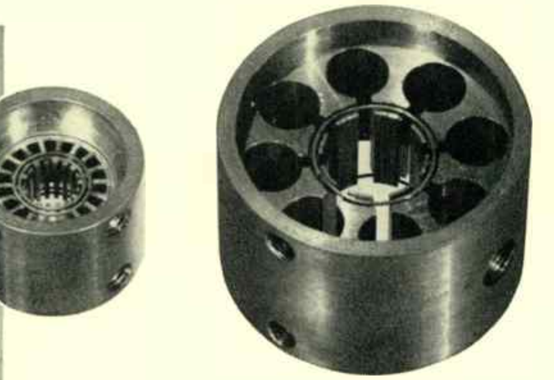
This tube type is used for precisely timed welding requiring thousands of amperes, which had not been possible previously. It has largely supplanted motor-generator sets for producing low-voltage, high-current direct current for mining and other applications; it is a mainstay in production of aluminum and other metals by the electrolytic process, and it is being used to rectify alternating current for use on locomotives. One of its newer uses is for high-voltage, high-current d-c supplies for generation of radio-frequency power at high power levels for induction- and dielectric-heating service.

This growth in usage has been paralleled by many developments that have made this tube type so reliable as to provide very acceptable life. Steels had to be found that would not permit hydrogen from the cooling water supply to seep into the tube. Resistance welders, using ignitrons, have been developed to make vacuum-tight welds 9999 times out of each 10 000 welds. Ignitors (which are immersed in the mercury-pool cathodes) are built with closely controlled initial characteristics and maintain those characteristics for the millions of starts required. In modern tubes, shielding between anode and cathode minimizes arc-backs. Ignitor firing circuits are 100 percent reliable. Not only do they always fire when desired but do not fire when not required. Firing circuits can be "phased-back" so that when it is desired the ignitron can be fired for less than a half cycle. Means have been devised for outgassing the massive graphite anodes. The anodes are vacuum fired at about 1800 degrees C before installation in the ignitron and are processed to minimize the production of graphite dust from the anode.

Thyratrons

Closely allied with the phenomenal growth of ignitron application has been that of the thyratron. In this tube a grid functions similarly to the ignitor in an ignitron. A hot cathode is used instead of a mercury pool and the grid can start current passing through the tube at any portion of the cycle where the anode is positive with respect to the cathode. The tube is gas-filled and the grid cannot interrupt current flow while the anode is positive.

Thyratrons have become widely used to control motor speeds, for variable high-voltage d-c supplies, and for high-speed circuit breakers on d-c supplies. Voltage ratings of this tube type have increased to approximately 15 000 volts for industrial service and to higher values for certain special applications. While mercury vapor is used for filling most tubes of this type, inert gases are becoming popular due to their relative independence of ambient temperature. In the inert gas-filled types, gas "clean-up" occurs so the type gradually becomes a "high-vacuum" type. When this clean-up progresses to a certain point the tube becomes inoperative. This clean-up rate is held to a minimum by careful design considerations, one of these being to keep the volume of the ionized gas to a minimum. When means are discovered to eliminate clean-up, then inert gas-filled types will virtually eliminate mercury-filled types, which are highly sensitive to ambient temperature.



Left—An image-amplifier tube and, right, typical multicavity magnetron anodes.

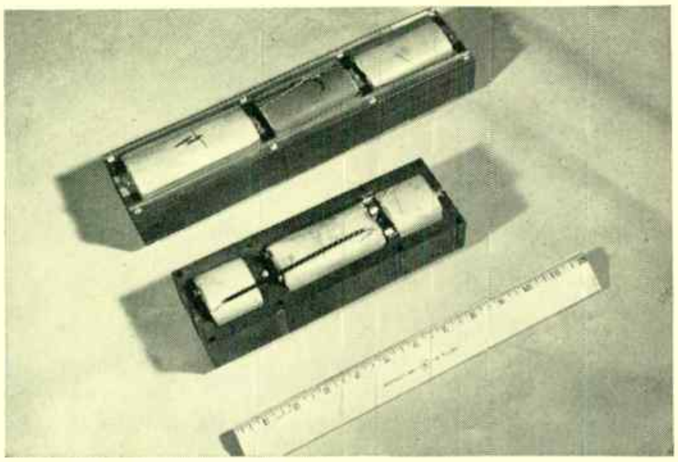
The decade 1940–1950 in electronic-tube development has been fruitful. The use of electronic tubes has expanded beyond the fondest dreams of the most ardent tube or equipment designer. As a result of this development, we have more power at lower cost; many more people are employed; we travel safer; we see over long distances; and we have better materials at a lower price. It is a bright story of continuous technical progress contributing to our standard of living.

What's NEW! . . . . in Engineering

The Lead-Lag Fluorescent Ballast Makes a Comeback

Sometimes devices, long popular, wane in favor and seemingly disappear, only to return improved and more vigorous than before. The lead-lag type of ballast for fluorescent lamps has gone through such a cycle.

This type of ballast, old in principle, was adapted to the instant-start Slimline fluorescent lamps introduced in 1946. Later a new type of circuit, called the series-sequence-start circuit, was introduced and by 1950 had become generally applied in various forms in the industry. This circuit was arranged so that one lamp started ahead of the other (i.e., in sequence) after which they were operated in series. It had the considerable advantage that amounts of iron and copper in the ballast were much reduced; in addition, the watts loss was lower and the size and weight reduced. It did not provide the stroboscopic correcting effect of the old lead-lag circuit, which puts the light output of the two lamps out of phase. Also, with this circuit, if one lamp failed the other lamp either went out or operated at very low current.



The series-sequence circuit brought with it another weakness not apparent for some time. Because it did not allow adequate energy at starting, there was a long time for transition from cold-to-hot-cathode operation, causing the electrodes to deteriorate. Lamp life was seriously reduced. Although some improvements have been made in this circuit, this deficiency has not been completely removed.

Last year Westinghouse lighting-equipment engineers decided to return to the original lead-lag circuit, which had none of these fundamental weaknesses, to determine if it could not be overhauled to provide the advantages of the series ballast with none of its faults.

Their efforts met with success. The new ballast with lead-lag circuit for two-lamp instant-start fixtures weighs about the same as the series-sequence-start unit and saves about one third of the copper and one third of the electrical iron of the old lead-lag ballasts. Its losses are also reduced by about one third. Because it is physically smaller, less space is required for it. At the same time it provides the desirable stroboscopic correction feature of the old lead-lag system.

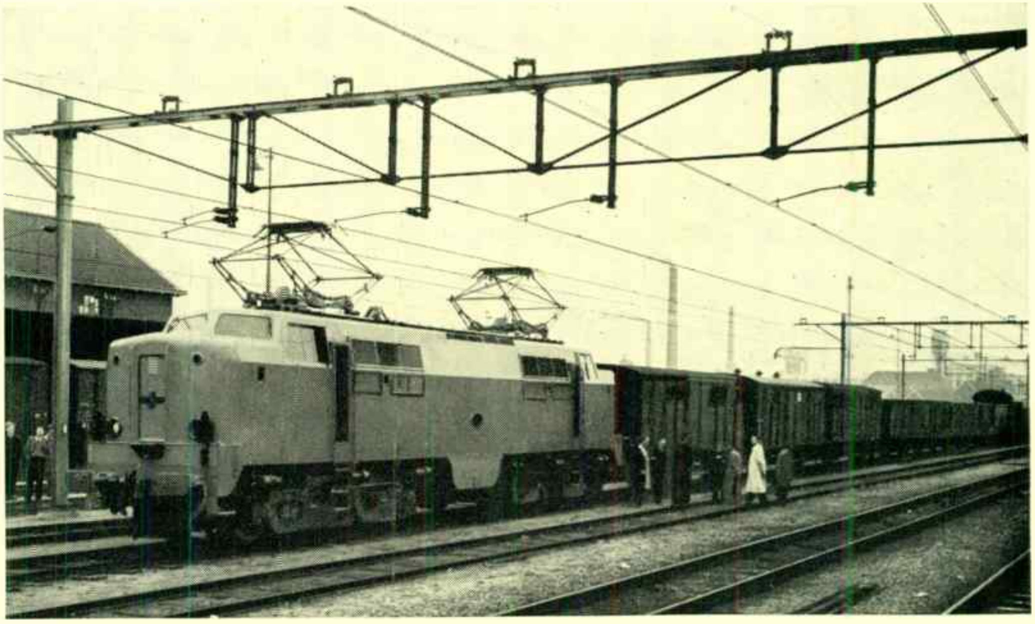
This improvement comes about from an entirely new mechanical arrangement of the core and coils and by a change in the electrical circuit. As an additional improvement the punchings of the magnetic core are now held together by welding instead of clamping. This reduces the tendency to create noise and, by eliminating one human element in assembly, provides greater uniformity of product.

Automatic Operation of Cooling Fans on Dry-Type Transformers

A thermal relay (type TRA), which protects dry-type transformers from thermal overloads, is now being used to control automatically the starting of cooling fans on dry-type power transformers. When the transformer loading increases to a value that causes the winding temperature to approach the maximum safe limit, a contact on the thermal relay closes. By means of an auxiliary relay and a contactor, the closing of this contact causes the fans to start. A second contact on the thermal relay is set for a somewhat higher coil temperature. If the fans fail to start, the second contact closes and operates a signal light and a switch-

American Designs Emigrate

This is one of 25 locomotives being built in Holland for the Netherlands Railways according to American designs and using some American-made parts. This marks the first time a fleet of European locomotives has been built to American standards. The locomotives will operate on a 1500-volt d-c system and develop 3000 hp. The locomotive construction follows closely designs well established in electric-locomotive practice.



board signal. Or, it can be wired so that a circuit breaker opens to remove the load.

Operation of the relay contacts is controlled by a bimetallic element placed in the path of the air leaving the transformer cooling ducts. This bimetal is also heated by an electric current proportional to the transformer load current. The two relay contacts can be independently set to close at predetermined winding temperatures.

Once started, the fans are under the control of a current relay. As soon as the first contact on the thermal relay closes, an auxiliary relay locks out the thermal relay. Fan operation is then controlled by a current relay (type SC), the contacts of which are set at the rated current of the transformer winding. The cooling fans continue to run until the load drops to from 90 to 100 percent of the transformer rating. At this point the contacts on the current relay open, the fans are stopped, and the control circuit is restored to its original condition.

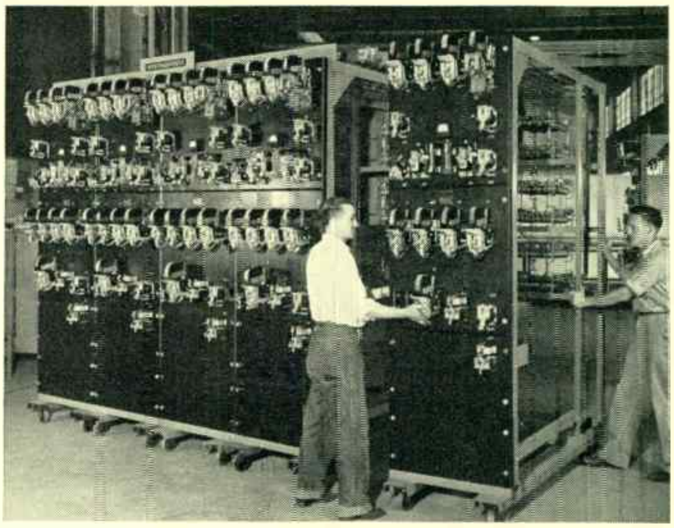
A small thermal breaker is provided for protection of the fans, and fuses protect the control circuit. A switch is provided so that fans can be operated manually if that is desired.

Arc Furnaces for Phosphate Production

As the demand for elemental phosphorus increases, so does the size of arc furnaces for its production. Until recently such three-phase furnaces were 6000 to 15 000 kva. Recently three have been installed in Idaho, each rated at about 17 000 kva. But these will hold the record only briefly. Another for the same installation is now being constructed that will draw 27 000 kva.

Factory-Assembled Constant-Voltage Controllers

Flexibility in the application and installation of constant-voltage controllers for steel-mill auxiliary service is made possible by a new type of frame construction. Instead of cutting and welding frames to accommodate a number of controllers, each control panel is mounted on an individual frame. Several of these frames are then bolted together to form factory-assembled shipping sections. The sections are installed in groups at the mill. Shipping sections are usually installed in the mill side by side, with the supply buses of adjacent sections connected with splice plates. The only other work needed to place the controllers in operation is to connect a power feeder to the bus, and motor and control leads to terminal boards on the panels.

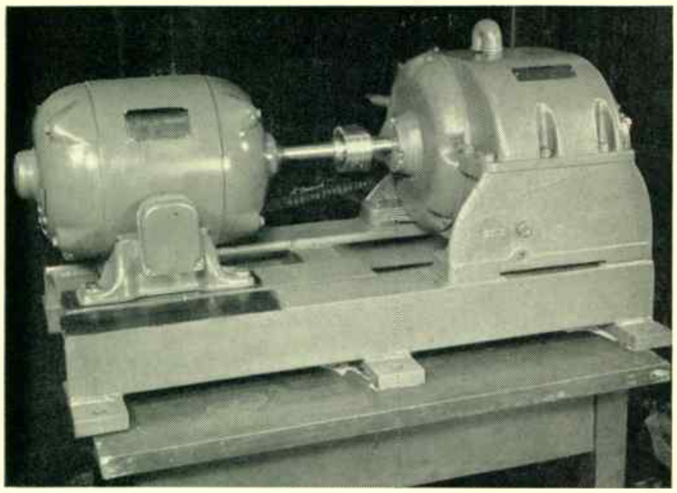


This method of building controllers has other important advantages. In the past, details of the mill layout were required before controllers could be assembled. Now, the design and manufacture of controllers can proceed without a detailed floor plan of the installation. Individual units can be shipped, then assembled in the mill as desired, if the layout is not known before shipment. In addition, changes in mill layout can be made at any time since rearrangement of the controllers is relatively easy and inexpensive, and does not require much time. For the same reason, the mill can be revamped at any time and the controllers rearranged or moved to a new location.

. . . . in Products

New Line of Speed Reducers

Conservation of space is highly important in every modern industrial plant. The constant endeavor of every geared-drive manufacturer is to reduce the size of his product as far as is practical and yet maintain sound design principles. The gearmotor, with its integral construction of electric motor and particularly compact "in-line" speed-reduction parts, probably represents the ultimate in space saving.



At the same time, it is necessary for some industries to maintain a higher than normal degree of flexibility in their drives. Electric motors are purchased in large quantities from several different manufacturers and carried in stock, and the number of different ratings kept to a minimum. Final drive speeds may vary over a rather wide range so that taking full advantage of the compactness of gearmotors may be impractical. Consequently, the solution to the problem may dictate the use of separately coupled speed reducers.

The new Westinghouse type DB speed reducer is particularly designed to satisfy the conditions of this problem of coupled motor and gear drive and at the same time provide an appreciable amount of compactness with resultant saving in space. The mechanical parts (gearing, housing, etc.) of type C and type E gearmotors have been adapted to speed-reducer construction by simple substitution of a bracket with necessary additional pinion shaft and bearings for the normally "built-in" motor used in gearmotor construction.

Eight sizes of units are available providing gear ratios from 6.25 to 58.3 to 1 and ratings from approximately ½ to 150 hp, depending upon the particular gear ratio and motor speed required. Standardized fabricated steel bedplates to support motor and gear unit, as well as the necessary flexible couplings, are available for each size.

Above, two 30-kw constant-current regulators. At right is the new type CPH; at left the older type CP. Note the new horizontal through-tank bushing on the new regulator in cutaway view.

Constant-Current Regulators Reduce and Improve

THE ADVANTAGES of using Hipersil magnetic alloy in the cores of transformers are well known. Now the magic of Hipersil magnetic alloy has been utilized again to improve further a previously well-accepted product. In a new line of pole-type constant-current regulators (type CPH), cores made of Hipersil, and a new bushing combine to give a smaller, yet more efficient and mechanically stronger regulator for street lighting.

The usual improvements that come with Hipersil core iron are found in the new type CPH regulator. Physical size and weight for given kilowatt rating have been reduced and efficiency has been increased. The difference in size between a new and an old 30-kw regulator can be seen at left. Weight for the 30-kw unit has been reduced from 1430 pounds, for the CP, to 1170 pounds in the type CPH. Tank diameter for this same rating is reduced three inches to 24¼ inches, with a reduction from 74 to 54 gallons in the quantity of oil required. And efficiency has been increased—from 96.3 percent to 97 percent at full load. These improvements are typical of this whole line of regulators.

The improvements resulting from the use of a new bushing are also impressive. The bushing on the type CPH regulator will be a through-tank type and will project horizontally from the tank case, as shown at left. The bushing can be seen in detail in the photograph. A nonbreakable Enrup clamping knob on the end of the bushing is used to connect the leads, which can be inserted from either of two directions. Since the insulated knob is hand operated, connections are made without tools.

The bushing assembly is made much more rugged than the pocket type. Where the bushing enters the tank wall the size of the porcelain has been increased; and a heavier clamping bracket has been added. As a result, the horizontal tank-type bushing has more than twice the mechanical strength of the pocket type. And the electrical characteristics are also improved.

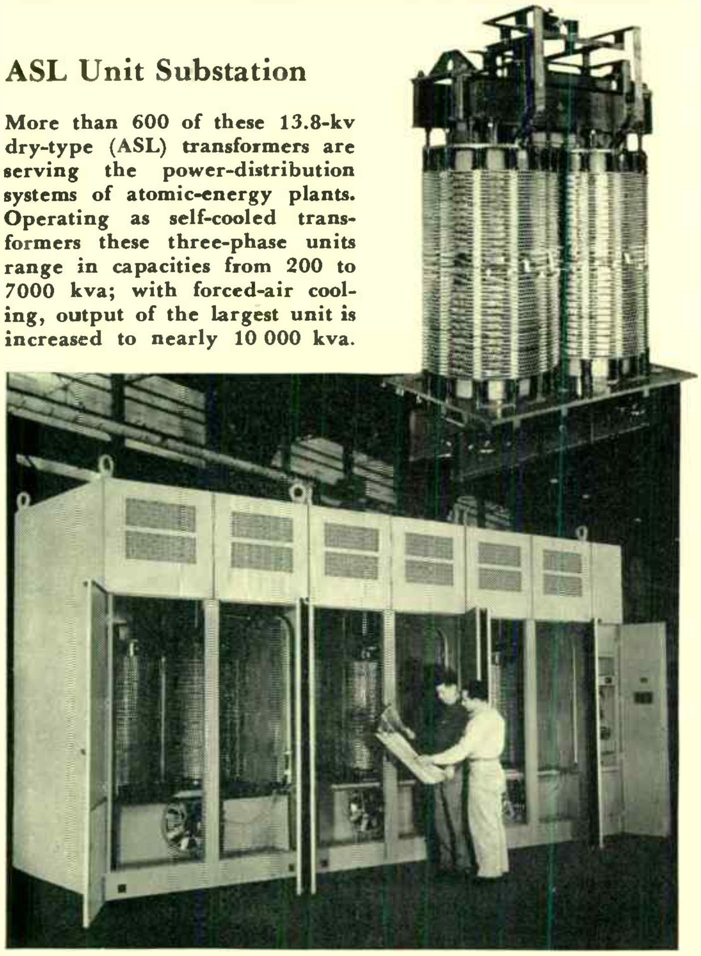
The type CPH constant-current regulator is now available in ratings from 5 to 30 kw. It can be supplied for service at 2400, 4800, or 7200 volts.

All models of this new regulator have round tanks made of copper-bearing steel. For corrosion protection they are bonderized and finished with the new, very successful Coastal Finish paint system.

Hipersil magnetic alloy now is being used in other types of constant-current regulators. These include the packaged types having built-in protective devices (type CSPH) and the subway variety (type CMH).

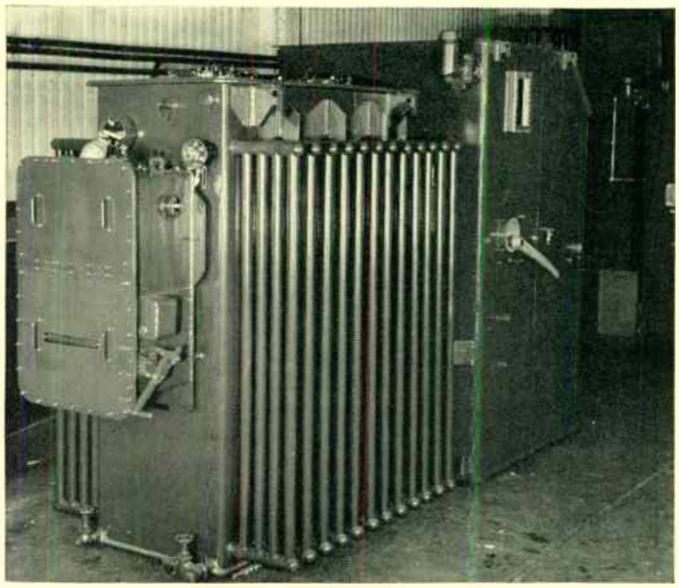
ASL Unit Substation

More than 600 of these 13.8-kv dry-type (ASL) transformers are serving the power-distribution systems of atomic-energy plants. Operating as self-cooled transformers these three-phase units range in capacities from 200 to 7000 kva; with forced-air cooling, output of the largest unit is increased to nearly 10 000 kva.



Submersible CSP Transformers

Four of these CSP units, made completely watertight, will be placed in vaults beneath a large building in Nashville. Each is a 1000-kva, 13 200/2400-volt, 3-phase unit and will feed the spot network supplying the building. In addition to manual disconnecting switches, units have air circuit breakers that trip on overcurrent or reverse current. The breaker can be tripped locally by an inspector but can be reclosed only by the central dispatcher.



A 16-Step Voltage Regulator

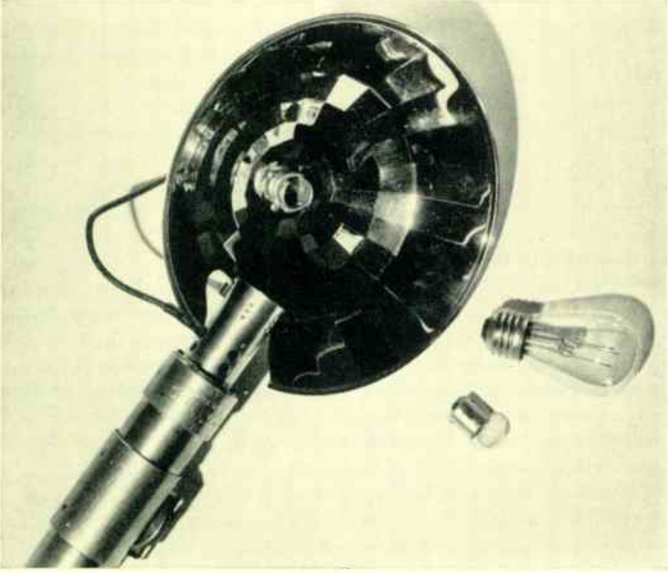
You can get ±10 percent regulation on distribution lines with the latest addition to the URL line of voltage regulators. The new 16-step URL-16, now in full-scale production, provides an answer to the problem of economic voltage regulation, especially on rural feeders or at small substations. It gives 10 percent regulation, raise or lower, in sixteen 1¼-percent steps. It is lightweight for pole mounting and is intended for use where the 10-percent range provided by the URL-8 is not sufficient.

The URL-16 is a simple tap changer with direct motor drive. Separate oil immersion, to prevent contamination of oil surrounding the transformer windings, assures positive arc interruption and minimum voltage variation during the tap-changing period. A reversing switch makes possible the ±10 percent regulation on either side of the regulator neutral setting.

The URL-16 retains all the outstanding features of the URL line. It has cover-mounted bushings; and coordinated surge protection is provided by externally mounted De-ion lightning arresters. A numbered position indicator is mounted on the tank wall in such a position that it is readable from the ground.

The controls are the same as those of the URL-8 except that the range of line-drop compensation has been increased to correspond to the increased regulating range. The line-drop compensator is arranged for separate adjustment of resistance and reactance drop and provides rated line-drop compensation even if the load on the regulator drops to only 67 percent of rated load. A CJ-1 voltage-regulating relay and auxiliary relays are mounted in a Flexitest case that can be removed easily for repair or test.

The URL-16 is available in ratings from 12.5 to 76.2 kva single phase, and at standard voltages up to 7620 volts.



At left, type PT-1 Flash-Chek, and beside it, the PT-2.

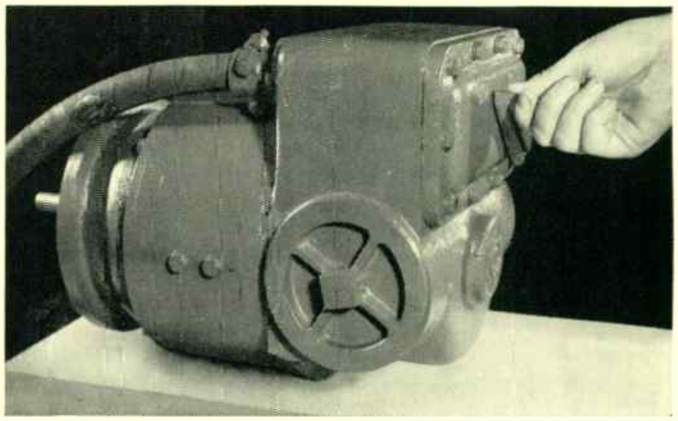
Inexpensive Photoflash Test Lamp

If you do much flash photography, you have probably experienced the disappointment of having your flashgun fail to operate just when the picture—subject, expression, pose—was perfect. And you can readily appreciate the need for an inexpensive test lamp for checking photoflash equipment; thus, saving waste of both flashbulbs and film. The Flash-Chek test lamp is just that—a simple, inexpensive means of checking photoflash synchronizers.

The Flash-Chek indicates the condition of batteries by its brightness. If the batteries are known to be in good condition, operation of the synchronizing circuit can be checked with the test lamp. A Flash-Chek test lamp gives at least 2 700 000 tests during its rated life.

The lamps have other potential uses, too. For example, they can be used to check synchronization of shutter and lamp. Or to check the position of reflectors.

Flash-Chek lamps cost only one third as much as previous test lamps. Costs were reduced by eliminating complicated adapter sockets. The lamps come in two sizes, each with standard bases. One, the PT-1, for use in small flash holders, has a bayonet base. The PT-2, for use in large flash holders, has a standard screw-type base. List price of the PT-1 is 22 cents, the PT-2, 25 cents.



Explosion-Proof Motor with Built-In Starter

Motors for fans, pumps, and other service facilities in mines should provide safe, reliable operation with minimum attention. In a new line of Life-Line explosion-proof motors (type SK), these features are provided by installing a fuse, thermal overload protection, and a start-stop switch within the motor housing itself.

Protection against prolonged overloads is provided by a start-stop switch (Motor Sentinel) with built-in bimetallic overload protection. If the motor becomes overloaded, the thermal switch shuts off power to the motor before the armature becomes seriously overheated.

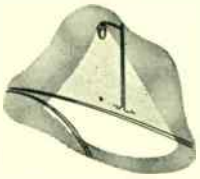
After a stoppage caused by an overload, the motor is easily started by moving the switch handle to the "off" position, then back to the "on" position.

A heater is used in the switch to introduce a time delay in the operation of the overload protection. Proper selection of the heater prevents starting current from inadvertently causing the motor to shut down.

Additional space to house the fuse and switch is provided by a specially designed end bracket. This increases the overall height about three inches over the height of a standard explosion-proof motor. All other construction details are the same as standard explosion-proof motors.

This motor is approved by the United States Bureau of Mines and is especially applicable for driving mine equipment, such as pumps or fans. The motor shown in the picture is a ¾-hp, 230-volt, 1750-rpm pump motor; but it can be supplied in standard ratings up to 3 hp.

What's NEW! .... in Literature



Street Lighting Engineering Guide—Got a street lighting problem? Here are the complete answers. This 84-page book discusses not only the subject of selecting luminaires and a lighting source, but also pays special attention to the problem of street-lighting layout. This book is intended as an aid to engineers who plan—or direct the planning of—street-lighting installations. Booklet B-5460.

To obtain literature, write to Westinghouse Electric Corporation, P. O. Box 2099, Pittsburgh 30, Pa.

Personality Profiles

Hampton ("Ham") J. Dailey, one of the country's top-flight designers of electron tubes, was first an electrician. For five years before he entered Virginia Polytechnic Institute in 1930 he worked in that capacity for the Jefferson Electrical Company of Roanoke, Virginia. He was graduated from V.P.I. in 1935 with a degree of B.S. in E.E., which he topped with an M.S. the following year. He joined Westinghouse that same summer. In 1943 he was made head of the section charged with the development and design of radio power tubes and vacuum rectifier tubes.

During this time he developed the type "Z" fin radiator for the more efficient forced-air cooling of power tubes. He also developed an automatic self-aligning chuck, automatic pulser exhaust circuit, getter coating for tube anodes, filament supporting means for large power tubes, improvements in electrometer tubes, and developed several new types of large power tubes for broadcasting and industrial uses.

• • •

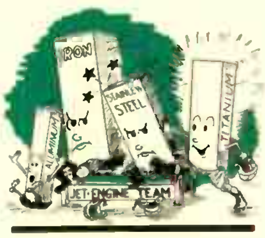
H. A. Rose, of Kansas origin and education, is an acknowledged expert on paper- and lumber-mill electrification problems in the Pacific Northwest. The route between these areas has been devious.

After obtaining B.S. in E.E. and B.S. in M.E. degrees from Kansas State in 1924 and 1925, he came to Westinghouse, quite early thereafter joining the Switchgear Division. The activity was automatic switchgear and control. Two years there were followed by four in general engineering application work, on such matters as power systems for railroads, street-railway systems, mines, and manufacturing plants. In 1931 the work leading to the development of the ignitron rectifier was under way and Rose was asked to help with that. He wound up in 1936 as section engineer in the Research Department on ignitron developments. In 1937 he was asked to go to New York as application engineer for railway, marine, and industrial equipment. By 1940 war clouds began to gather and the need for aluminum and ignitrons to produce it was skyrocketing. Herb had to return to Pittsburgh to assist with this rectifier activity and to help with special rectifier designs and the development of special vacuum pumps. Meanwhile the atomic bomb was taking shape. Rose's experience with vacuum pumps caused him to be "requisitioned" by the Kellex Corporation, deeply involved with the Manhattan Project.

The war over, Herb had his own ideas about what he wanted to do next. He asked for and got a post as Westinghouse consulting and application engineer in Seattle. The fact that he is a skilled and enthusiastic fisherman and hunter, and that the Seattle country is unequaled in opportunities for such avocation had nothing to do with his decision—maybe. Anyway, Herb, his wife, son, and daughter—the "Four Roses"—moved to Seattle in 1945, where he is now widely known by the industries of the region for his broad engineering skill—and doubtless by the wild life of the region for his prowess with rod and gun.

• • •

W. S. Hazelton started his undergraduate college education at the University of Minnesota in 1934. As he had money enough for only one year of college he was not able to complete it until 1949. This was followed by periods of working, to assist with family financial matters, and brief periods at school. By the time the Army called him in 1941, to become an Air Corps pilot, he had accumulated two years of college credits.



The war over, he had opportunity to approach college on a more consistent basis, and emerged in 1949 with a B.S. in Metallurgy. While in school Hazelton proved himself a hot man on the trumpet and a high man in pole-vault events.

With his degree in metals he hied himself to DeHuff's gas-turbine metallurgical section, then being formed (see page 121). He has been there since, whittling out for himself a reputation in the solution of titanium application problems and in developing high-temperature test methods for jet-engine alloys.

• • •

W. F. Bowers graduated from Michigan College of Mining and Technology in 1930. His engineering career began with Pickands-Mather as a mining engineer. From there he went back to his alma mater to do research work in the beneficiation of iron ores.

Bowers left this work in 1934 and spent the next ten years in various engineering capacities in construction work. The large jobs he worked on include the air bases built in Newfoundland just before the war and the U.S. air bases built above the Arctic circle. When he returned from the Arctic to his home in Michigan he heard that Westinghouse was looking for engineers. He applied. The resulting job offer looked good to him and in May of 1944 he headed for East Pittsburgh, where he has contributed to the engineering of electrical equipment for both heavy- and light-traction equipment. Much of his work has been for the Westinghouse International Company on traction equipment for South America and Europe.

• • •

C. C. Whittaker became interested in electricity while he was in high school, and later went to Sheffield Scientific School of Yale University to study electrical engineering. Upon graduating in 1911, he came to Westinghouse to, as he puts it, "learn everything about electric-railway locomotives. But after 40 years of work on electric-railway equipment, I still don't know all there is to know, so I'm still here." During those 40 years Whittaker has worked on equipment for most of the important railway electrifications in this country.

After two years on the student course at East Pittsburgh, he joined the Railway Engineering Department.

His first big assignment was design work on locomotives for the New Haven Railroad. In 1914, Whittaker worked on equipment for the Norfolk and Western, and, in 1918, on the first 3000-volt a-c electrification for the Chicago, Milwaukee, St. Paul and Pacific. He later played an important part in the development of equipment for the Pennsylvania electrification. He has worked closely with the Pennsylvania on the improvement of a-c electric railway equipment and the development of the ignitron locomotive.

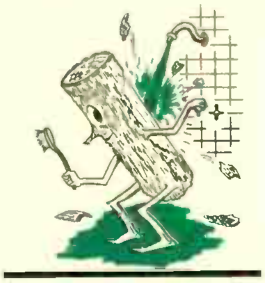
In his 40 years with Westinghouse Whittaker has received 70 patents, the majority of them covering control equipment for electric locomotives.

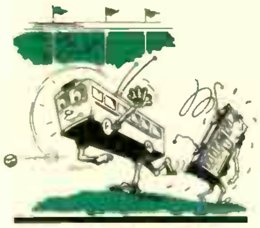
• • •

W. M. Hutchison decided even before graduating from Penn State College that he wanted to work on electric-railway equipment. When he graduated in 1915, he came to Westinghouse and went through the Student Training Course, after which he joined the Railway Engineering Control Department.

Hutchison's experience with electric railways began with the design of control equipment for both the New York subway and the Chicago elevated lines. His introduction to application engineering came in 1924, when he went to the Netherlands to supervise the installation and testing of multiple-unit electric cars on the Netherlands State Railway.

When he returned to the United States, he continued to design control equipment and in 1929 became manager of the control design section for heavy-traction equipment, and later for all traction equipment. From 1936 until 1943, Hutchison's principal activities were concerned with the design of equipment for the Pennsylvania Railroad. In 1943, he left design work to join the Transportation Section of Industry Engineering. In this position, he is responsible for the application of equipment on heavy-traction locomotives for the Pennsylvania, Virginian, and New Haven Railroads.





Coal Unloading at 600 Tons per Hour — This movable coal unloading tower handles a five-ton bucket on a 30-second cycle. The operator's cab (at right and above) is mounted on a telescoping boom and can be moved out over the ship, as shown, to increase the operator's visibility. Other features include automatic dumping of coal into hopper; a-c rail-clamp drives with d-c dynamic braking; also simplified tower travel and apron-hoist drives.