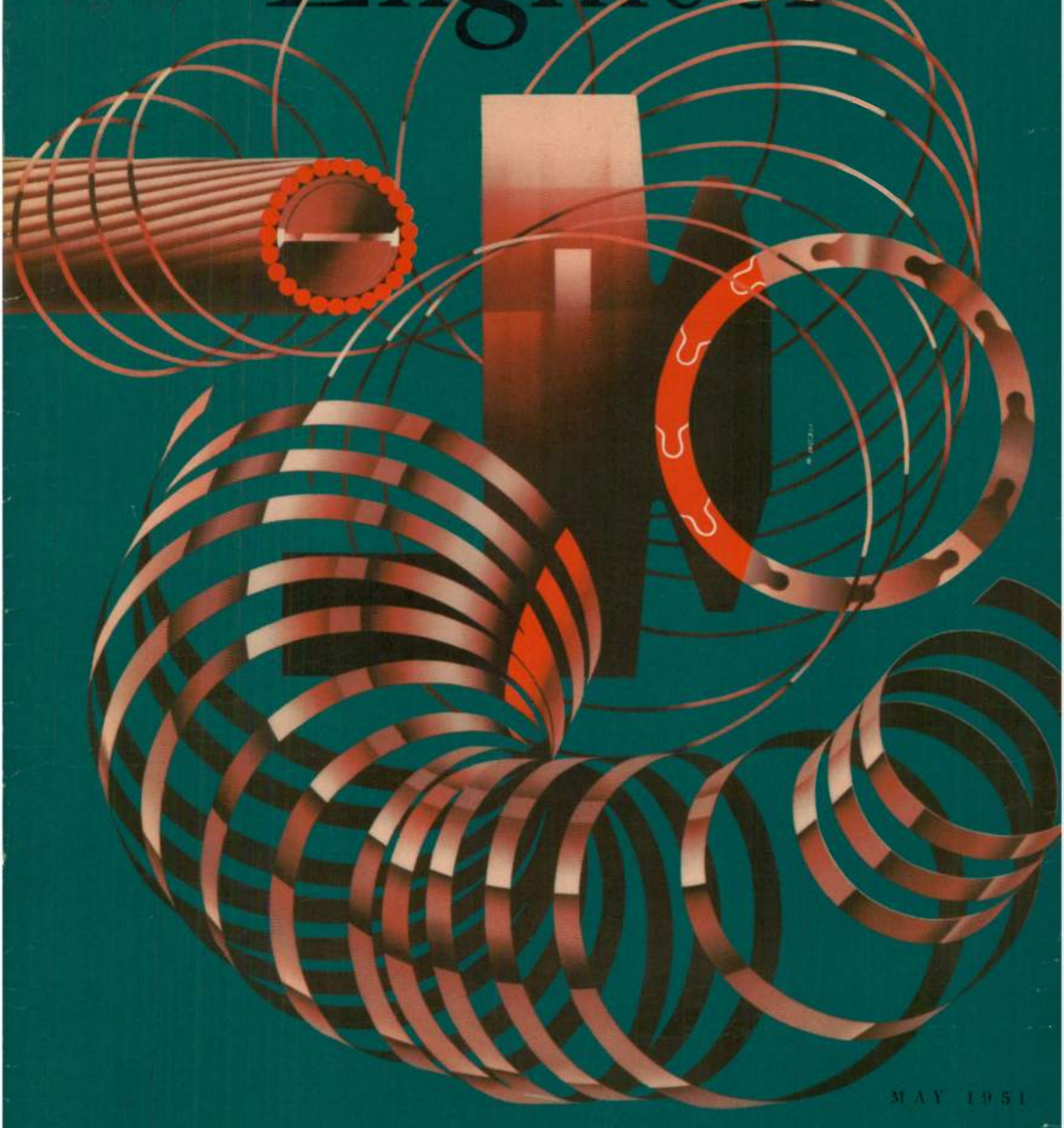
WESTINGHOUSE Engineer



MAY 1951

5 Mph... is too slow

You think traffic jams are a modern malady? Well, they're just about 2650 years old now—give or take a few years. 'Way back in 700 B.C. the Phoenicians built the first system of good stone roads—and struggled with the first great traffic problem. Traffic in downtown Carthage was limited by law. And a little later the Romans had to restrict traffic in Rome. Throughout history—medieval, Elizabethan, Victorian, and modern—restrictions have been the ultimate, effective traffic control. But today we search for a more agreeable way to relieve traffic congestion.

The automobile has given us the greatest system of private transportation the world has known. Motor transport is the life blood of American cities, but now it threatens to destroy the effectiveness of the same cities it has helped to build. We have impressive highways over, under, and through our cities. We have parking garages, parking authorities, and parking laws. But we still don't have enough room for all of the cars that clog our downtown streets during rush hours.

Even if we move or raze buildings to make room for wider downtown streets, we still have to find some place to keep our cars while we work. That requires parking space. Based on the proven average of about 1.75 people per car, we would need, conservatively, 140 square feet of modern garage space for every person who rides to work in an automobile. We learned during the war that car-pooling doesn't raise that average significantly. So for every building full of people who ride to town in cars, we need another building of the same size to house the automobiles they ride in. As we build new parking garages, and new multiple-lane boulevards, they become quickly clogged with more people crowding into town in automobiles.

And those wide, no-intersection freeways do not provide really efficient mass transportation. Hundreds of speeding automobiles blurring by on four, six, or eight lanes of gleaming concrete seem to say movement—big movement. And they do move lots of cars—fast. If automobiles with normal loads were used exclusively on a separated freeway like the Holland Tunnel in New York, 2625 people per hour could be moved past a point along the road. But this is small compared with public transit. If you were to fill the same lane with trolley coaches, about 10 000 people per hour could be moved through each lane; while a lane of streetcars on a regular surface street would carry 13 500 people an hour—five times the capacity of a lane of automobiles on a freeway. Rapid transit, operating on a private right of way, is real mass transportation. A subway or elevated line, with two local and two express tracks, can move 100 000 people per hour in each direction. Rapid transit is expensive, of course, but to move 100 000 people per hour by automobile would require 20 four-lane, separated highways. And these would cost about ten times more than an equivalent rapid-transit system.

Today public transit provides the bulk of transportation that we use in our everyday business and social life. In cities with populations over a million—where 10 percent of us live—the number of daily rides on public carriers is 98 percent of the population of those cities. And the American parade to metropolitan areas continues. Eighty percent of the population increase since 1940 has occurred in communities containing 50 000 or more people. Most of that has been in suburbs on the outskirts of large cities. This only tends to worsen the already serious problem of moving people in and out of the congested business districts of our large cities.

We would rather not be told when and where we can drive our cars, but unless downtown traffic can move faster than the present five miles per hour, we have no alternative. Traffic restriction is an ancient and disagreeable device, but it works. At least it did in Pittsburgh last winter. During the "Big Snow" automobile traffic was hampering the huge job of snow removal, so all nonessential traffic was kept out of the Golden Triangle. As a result, the clean-up was completed faster, public transportation moved freely, and in spite of the poor conditions of the streets, most people managed to get home from work not much later than usual. Ironically, streetcars ran ahead of schedule because the usual crawl through congested areas took only two-thirds as long as it normally does during rush hours.

The rush hours are the big headache—for the transit company as well as the individual driver. In some cities just elimination of street parking and stopping during traffic peaks would get traffic moving. Others would require greater cuts in rush-hour use of automobiles and trucks in congested areas. With proper freeways the automobile is still the most attractive way to travel, and fringe-area parking could take care of the long-haul commuter who prefers to drive most of the way. But public transit from the parking facilities into the congested area would have to be provided. No restriction will work unless there is adequate public transportation available for everyone who must use it.

But we seem determined to make it difficult for the transit industry to operate. A combination of discriminatory and excessive taxes, operating costs that have just about doubled in the last ten years, and declining revenues have squeezed the industry. We levy 40 different *types* of taxes against transit. Our governments—federal, state, and local (which get the lion's share)—take 10 percent of the industry's operating income; and skyrocketing operating costs devour 80 percent. Wages alone take 55 cents of every fare-box dollar.

Income has not kept pace. Each fare increase, which is granted slowly and painfully, alienates some more of the meager affection the public has for public transit. Since the wartime peak in 1946, the number of rides per year on public vehicles has decreased 26 percent, while automobile use has increased. As a result, the transit industry averages less than three percent profit—in a regulated business that is usually limited to a *fair* profit of *six percent* by law.

The greatest need of the transit industry today is to sell itself to government and to the public. We must realize that bigger and faster freeways by themselves cannot solve our rush-hour traffic problems. Public transit—mass transportation—must be the basis for any solution. Large-capacity public vehicles are the only transportation that can move crowds of people in and out of cities efficiently. And many of us, for economic reasons, have to ride public transit. Whether streetcars, buses, trolley coaches, rapid transit or some new form of transportation furnishes a solution, each city must find the blend that best fits its need. There is no universal panacea. Kind and volume of passenger traffic, terrain, money—all these will affect the final decision.

WESTINGHOUSE Engineer

VOLUME ELEVEN | MAY, 1951 | NUMBER THREE

The Cover—We said to Dick Marsh, "Dick, we want our May cover to say—copper." He left with that idea and some samples of products made of copper. He came back with the design you see on this month's cover.

• • •

Westinghouse has added another first to a long list of accomplishments in the development of axial-flow turbojet engines. It is a new, more powerful engine, the J-40, which has passed the grueling ground tests and qualifies for quantity production. Designed especially for high-altitude flying, the J-40 packs more potential speed into less space than any previous rotating engine. Although larger than its predecessor, the J-34, the J-40 uses less fuel per pound of thrust. It is one of the most efficient and most powerful turbojets that has been offered to the armed forces.

• • •

Believe it or not, the ten-year index to the *Westinghouse* ENGINEER is now available. See page 99 for details.

• • •

Ten years ago Westinghouse and the Plantation Pipe Line Company pioneered what was then the largest pipeline for refined petroleum products. Now, Westinghouse motor-starters, switchgear, and ventilating fans—$600 000 worth—serve a huge expansion of the same line. Twenty of the explosion-resisting 600/900-hp motors supplied originally will provide the additional horsepower needed. New 14- and 18-inch lines will up the capacity of the system from 100 000 bbls per day to 167 000 bbls per day, and will increase the potential capacity to a maximum of 221 000 bbls per day.

Editor........CHARLES A. SCARLOTT

Layout and Production...EMMA WEAVER

Editorial Advisers:

R. C. BERGVALL *and* W. W. SPROUL

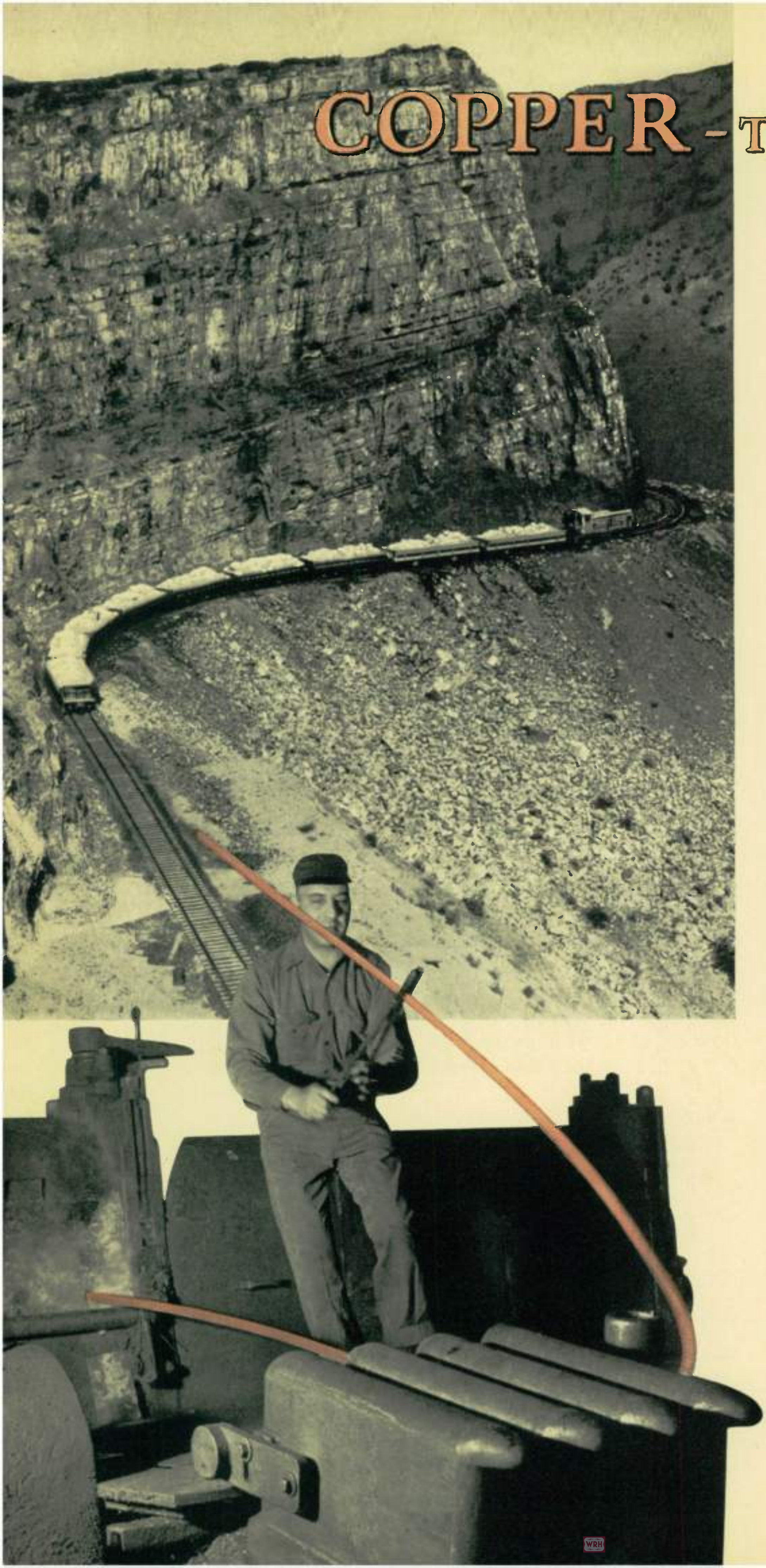
In This Issue

The following terms, which appear in this issue, are trademarks of the Westinghouse Electric Corporation and its subsidiaries: Autovalve, Axiflo, DynAC, Fosterite, Micarta, Motocylinder, Multivane, Precipitron, Watchcase.

The *Westinghouse* ENGINEER is issued six times a year by the Westinghouse Electric Corporation. Dates of publication are January, March, May, July, September, and November. The annual subscription price in the United States and its possessions is $2.00; in Canada, $2.50; and in other countries, $2.25. Price of a single copy is 35c. Address all communications to the *Westinghouse* ENGINEER, 306 Fourth Ave., P.O. Box 1017, Pittsburgh (30), Pa. The contents of the *Westinghouse* ENGINEER are analyzed and indexed in the INDUSTRIAL ARTS INDEX.

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

COPPER - THE PROBLEM



"Can it be true what they say about copper?" A mild uneasiness about the red metal suddenly spread into fast-flying rumors when government restrictive orders appeared five months after the Korean outbreak. As is characteristic of rumors, some about copper are exaggerated. But the hard fact is that, while the United States' mines will produce large quantities of copper for many years, the output does not meet present demand, much less a growing one, and world competition for foreign-produced copper is increasing.

COPPER has had the dubious distinction of being among the first metals endowed with a government limitation order in the present defense repreparation program. On November 29, 1950 the National Production Authority issued order M-12 that limited civilian usage of copper to a percentage of what was used during the first half of 1950. This was followed on December 30 with a supplementary ruling prohibiting the use of copper in certain civilian products considered non-essential, such as specified plumbing fixtures, building materials, and ornamental objects. Production of television and radio sets in 1951 is being limited by, among other things, lack of copper. Full production of some electric-power equipment is no longer possible.

What is the meaning of this? Is the United States running out of copper? Or is there only a temporary inability of productive capacity to keep up with rising demand? Or is government stockpiling making an apparent deficit out of a modest surplus?

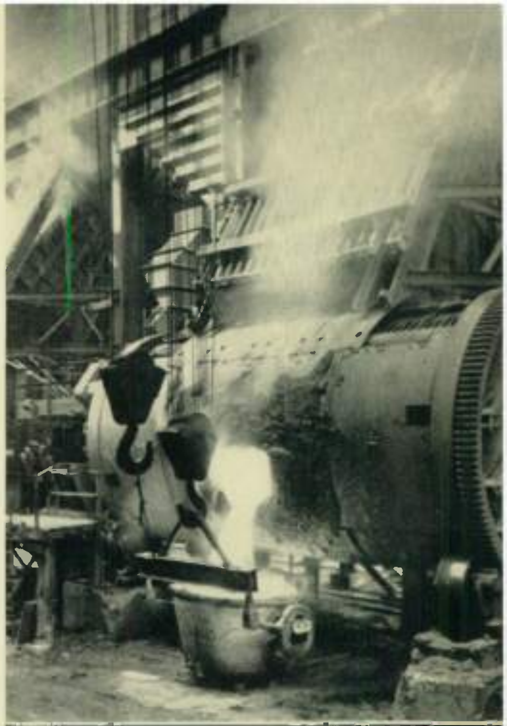
Generalized answers to some of these queries can be given. The United States has not run out of copper nor has it yet entered that inevitable period eventually reached with most minerals when production rate declines. The United States is running out of copper, of course, just as it is exhausting all irreplaceable materials (except such things as magnesium). However, enormous quantities of copper still lie within our

---

Prepared by Charles A. Scarlott from information provided by the staffs of the U.S. Bureau of Mines, U. S. Geological Survey, American Bureau of Metal Statistics, the "Daily Metal Reporter," the Copper and Brass Research Association, American Smelting and Refining Company, American Metal Company, Anaconda Copper Mining Corporation, Kennecott Sales Corporation, Phelps-Dodge Corporation, and Westinghouse.

Above is a picture of copper ore enroute to the concentrator at Morenci, Arizona (courtesy Phelps-Dodge Corp.). The copper-rod picture is from the Anaconda Copper Mining Co.

...AND PROSPECTS



The product of a reverberatory furnace (right) is reduced to blister copper in a converter (Anaconda photo).

mountains and deep in our rocks. This does not say, of course, that costs will remain the same as mines work leaner ores.

As to the ability of our productive capacity to meet demand, our nation first turned from a copper exporter to copper importer 20 years ago and has remained so except for one period of seven years in the 30's. Preceding the Korean affair some members of the industry presented arguments before a Congressional Committee that United States, production had about caught up with the pent-up demand and would then be fully adequate for future requirements. However, it does not now seem likely that this country will ever again have a copper-surplus.

Government stockpiling of copper, obviously, has been an extra load on producers. The amount in the stockpile is not public information but it has been guessed as 500 000 tons. This is equivalent to 10 percent of production over the last five years.

Generalized answers are nice but hazardous. It is better to set forth the essential facts and recent history of the industry from which conclusions and estimates of the future can be more readily formed.

Where Copper Comes From Now

The United States for the last century has been and still is the world's largest producer of copper. Present mine production totals about 900 000 tons per year. Until 1927 it produced more than half of the world supply, but mines in other lands have become increasingly important. Four-fifths of the world's supply of primary copper (this side of the Iron Curtain) comes at present from five countries, United States, Chile, Northern Rhodesia, Canada, and the Belgian Congo, in that order. (Rhodesia copper is not at present available to the United States as it is controlled by and customarily goes to firms in the United Kingdom.) These figures do not take into account Russia, which is believed to produce slightly more than the Belgian Congo, or perhaps one-fifth as much as the United States.

While these five countries are the major producers, copper comes from many places. The widespread occurrence of copper deposits throughout the world is indicated by the fact that the outputs of about 25 other widely scattered nations combine to make up the remaining fifth. Some have been in production for centuries. Copper was being mined on the island of Cyprus when Christ was born. In fact, Cyprus gave the metal its chemical designation, cupreous (*cu*).

About nine-tenths of the world's known copper, believed to amount to approximately 100 million tons, lies in Chile, South Central Africa, Western United States, and Kazakstan (Southern Russia), in that order. In quality the African deposits average best, about three to six percent copper; Chile, two percent; and United States mostly less than one percent. Except for Western United States and the big Chuquicamata pit of Chile, almost all important copper-ore bodies lie too deep for surface mining.

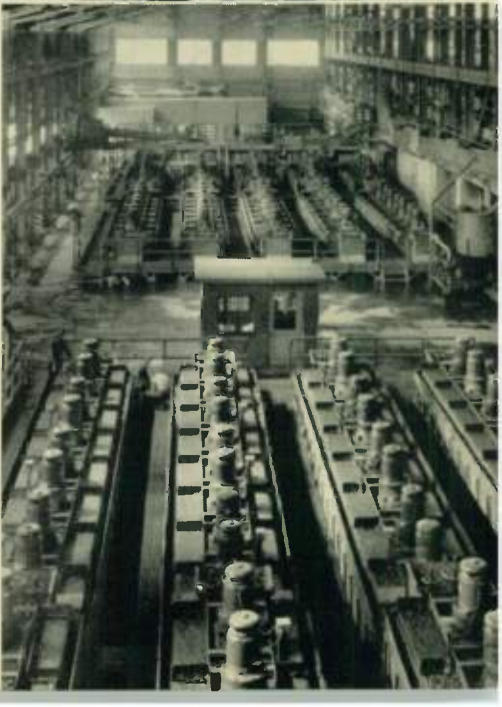
About half of the estimated world reserves (almost all in the United States and in Latin America) is mined by American companies. The British segment—Canada, Australia, and Rhodesia—is about one quarter of the whole, with Belgium controlling about six percent in the Congo.

Copper Production in the United States

In the United States copper comes principally from the Rocky Mountain region. Specifically, in order of rank, Arizona, Utah, Montana, New Mexico, and Nevada. These five account for nearly 93 percent of the total, which in 1950 was 940 000 tons. In fact, Arizona and Utah contribute almost three-fourths of the United States' total. Virtually all other western states produce minor amounts. In 1949 Washington, California, and Idaho combined turned out about 7500 tons, much of which comes about as a by-product of mining other metals, generally gold and silver.

Small amounts of copper come from states east of the Mississippi River. Few realize that Tennessee has long been a producer of copper. Its output, with much smaller amounts from Missouri, Pennsylvania, Vermont, has been a fairly steady 13 000 tons yearly for many years.

The largest producer outside of the western states is Michigan. It has a long history of production. Outcroppings of native, i.e., metallic copper, were discovered by early explorers in the northwest corner of the Upper Peninsula in the 17th century. Actual production began in 1844, very quickly supplanting the few small mines in New England and the eastern seaboard states that had supplied copper to Paul Revere and his fellow colonists. The Michigan ore occurred as masses of pure copper.



Copper-bearing particles are separated from the lighter siliceous material in defiance of gravity by floating them to the surface on air bubbles. The center view is a close-up of a flotation cell (Anaconda photo) and below, a general view of a flotation-cell concentrator.

Some weighed many tons. In recent years more finely disseminated material has been used.

Michigan was by all odds the leading producer until the 1880's when the mines of Arizona and Montana became important. It was surpassed by Montana in 1886. Production in Michigan reached its peak in 1916 with 150 000 tons, and has declined steadily to a level that has averaged, since World War II, about 25 000 tons yearly. The grade of ore now runs about 0.9 percent copper. In about a century of copper mining Michigan has produced a little over 5 million tons, equivalent to less than four years of United States' consumption of new copper at the rate it was used in 1950.

Michigan, however, has prospects of again improving its status as a copper producer. Consideration is being given to developing the large White Pine ore body, where Michigan borders on Lake Superior. Unlike Michigan's previous ores, which have constituted essentially the only United States' native-copper ore, the White Pine ores are sulfide ores. Furthermore, they are low grade—about 1.1 percent copper—and lie far too deep underground for low-cost surface-mining methods, and contain no important by-product minerals. It is estimated that nearly three millon tons of copper can be recovered—equivalent to about two years' present use.

Consideration is also being given to opening other U.S. deposits. One is the San Manuel underground ore body in Southern Arizona, which geologists estimate as 463 million tons of ore assaying 0.78 percent copper. Another important ore body lies at Yerington, Nevada, believed to contain 50 million tons of one percent ore, recoverable by stripping. The Greater Butte project is also low-grade ore that was not mineable before. It lies above the 3400-foot level in the Butte Hill mines that will be mined under a new plan. This ore body, previously passed over or untouched, is reported to contain about 130 million tons of 1.1 percent ore. At Bisbee, Arizona, a new open-pit mine is planned. All these proposed new mines are sizable low-grade deposits. Other potential sources are being studied.

Copper is a friendly metal. It is willing to combine chemically with many other elements. However, occasionally, as in Northern Michigan, it is found alone. Only about one percent of the world's total is native copper. Occasionally it is found as large lumps—weighing several tons—but mostly fine particles of copper are dispersed throughout hard rock that have averaged about two percent copper, although the grade is much less now. Before the decline of the Michigan mines 35 years ago native copper ores provided the major portion of our copper. But these now account for but a small fraction of the output and are not expected to resume importance, short of an unlikely new discovery.

An appreciable amount of the world's copper—perhaps 15 percent—occurs as oxides, of which there are 17 varieties. Generally these lie on or near the surface because originally they were sulphide ores and have been converted by exposure to oxygen and leaching with water and earth acids. Oxide ores are generally underlain or associated with larger bodies of sulphide ores. The oxide ores average about one or two percent copper, and are finely dispersed throughout hard rock.

Copper's favorite partner is sulphur. Copper sulphides comprise 75 to 80 percent of the world's copper ore. There are at least 30 varieties but chalcocite (copper and sulphur) and chalcopyrite (copper, iron, and sulphur) in about equal amounts account for the bulk of unmined copper ores. The principal remainder consists of combinations of copper with carbon, arsenic, and antimony, although there are others.

Sulphide ores often, if not commonly, occur as disseminated fine particles ranging in size from wheat grain down to micron sizes. The copper minerals usually occupy minute fractures or coat the surfaces of rock particles. In some cases it is necessary to grind the ore to 100 or 200 mesh sizes in order to liberate the copper minerals from the rock.

About 70 percent of the United States' total production of copper comes from open-pit mines, which have obvious great advantages. The outstanding example of this is the fabulous open-pit at Bingham, Utah, operated by Kennecott Copper Corporation. Its history is one of the epics of mining. Although copper deposits in the neighboring area a few miles south of Salt Lake City had been worked by underground methods as early as 1865, the Utah copper deposit was considered worthless by most mining men because of its low average grade—only about 20 pounds per ton (one percent). However, a small group of men, led by Dr. D. C. Jackling, visualized the possibilities of skimming off some hundreds of feet of overburden and taking the ore out in large quantities with shovels. They were bold men, and backed that gamble with millions of dollars. Open-pit operation began in 1906. This technique has made possible the recovery at low cost of about 5 million tons of copper from low-grade ore in addition to important amounts of gold, silver, and molybdenum. In the ten years from 1940 to 1949 inclusive, it has produced almost 2½ million tons of copper, more than 2½ times the next largest United States' mine at Morenci, Arizona, which is also an open-pit operation. Almost one third of the newly mined copper in the United States and one tenth of the world total comes from this one pit at Bingham.

One characteristic common to almost all mining operations is the declining quality of the deposits worked. It is natural that the best deposits be used first. This certainly has been true of copper. A hundred years ago the average "tenor" or grade of copper mined was 20 percent. One bonanza mine in Alaska produced many thousand tons of almost pure chalcocite, which is about 80 percent copper and 20 percent sulphur. That was unique. In the 1914–1930 interval the average of United States' mined ores was 1½ percent. Now our largest copper producers—Bingham (Utah) and Morenci (Arizona)—are running about 0.9 percent. The national average is only slightly above 0.9 percent.

Bigness is another characteristic of copper mining. Of 18 mining areas that, in 1949, produced more than a thousand tons of copper, eight produce more than 20 000 tons of copper per year. Some of the smaller ones produce copper as the by-product. Four fifths of the United States' output of copper in 1949 came from six mines or close-knit regions.

The large scale common to copper mining is inevitable. If the mines weren't enormous they couldn't operate at all on the lean ores now common. The situation goes like this. The initial investment to start any low-grade ore mine is large, running into the millions of dollars. Also the preparation time takes about three years before a pound of metal is recovered. This high initial investment and interval ahead of any return is not justified unless operation for 20 or 30 years is assured. Then, because of the low copper content of the big ore bodies, large volumes of material must be handled to support the large investment. Assuming a price of 20 cents per pound at the refinery and ore running 20 pounds per ton, $4 per ton of ore must cover all mining costs, including stripping or underground development, mining, milling, smelting, freight charges between mine and refinery, sales expense, taxes, profit, and retirement of the investment.

Actually many veins, lodes, and pods of copper ore are scattered throughout the United States, which, because of their small size, are likely to remain mineral curiosities.

Copper, as it occurs in nature, not only is related by marriage to several other elements but also it has many friends. Many of them very "rich" friends. Copper is associated with gold, silver, lead, nickel, zinc, molybdenum, cobalt, and platinum. Combination with arsenic is frequent and undesirable. Even iron and sulphur are sometimes obtained in commercial quantities as a side issue of copper mining. The different combinations of copper and these other metals and the proportions in each case vary all over the lot. In some cases, copper is overshadowed by the other component metal or metals—it can be considered a by-product instead of the basic product of a particular mine. Gold and silver almost always occur with copper ore. In fact they cannot be readily separated from copper but remain with it all the way through to electrolytic refining.

For example, the big open pit in Utah is the second largest producer of gold in the United States. The 76 million tons of ore handled in United States' copper mines in 1949 yielded 436 000 fine ounces of gold and 7 043 000 fine ounces of silver with an aggregate value of $21 million. In most copper-mining operations the worth of the by-product metals is small, but with operating margins close they sometimes represent the difference between profit and loss.

Price of Copper

Selling prices of copper have varied widely, indicating comparative sensitivity to demand. Copper production—all phases of it, mining, smelting, and refining, but particularly mining—cannot be increased or decreased rapidly. Hence the problem of relating world production to demand has been a serious one, with consequent wide swings in price.

To predict the course of future copper prices would be folly, but some influencing factors are apparent. The general demand for copper is increasing—not to mention the superimposed defense-program needs. Copper generally is likely to be in short supply in the foreseeable years ahead. This is true generally for the whole world, not just for the United States. Hence, even removing the present two-cents per pound excise tax would result in little increase, if any, in copper flowing into the United States, which now amounts to about 400 000 tons per year. Production in the United States is not likely to increase much for physical reasons. Even if new ore bodies are made productive—and that takes at least three years—the declining quality of ores will tend to offset the gains. On the other hand, mining technology has always steadily improved, which has the effect of lowering production costs. What government price controls, if any, will be established is another uncertainty. However, rising copper prices, in the long term, seem inevitable.

Consumption of Copper

Copper statistics show two significant facts. Mine productive capacity in the United States has remained substantially constant for the last 30 years. But demand for copper has been generally upward, although it has suffered numerous sharp peaks and valleys.

If production peaks, which occur when the pressure of price or war demand is high, are taken as a rough measure of productive capacity the results come out like this: 955 000 tons in World War I; 1 000 000 tons in 1929; 1 090 000 tons in 1943. Even a curve drawn to approximate average output rises from 550 000 tons in 1910 to only 900 000 tons now.

On the other hand, the total-use curve for new copper, as best it can be approximated allowing for peaks and valleys,

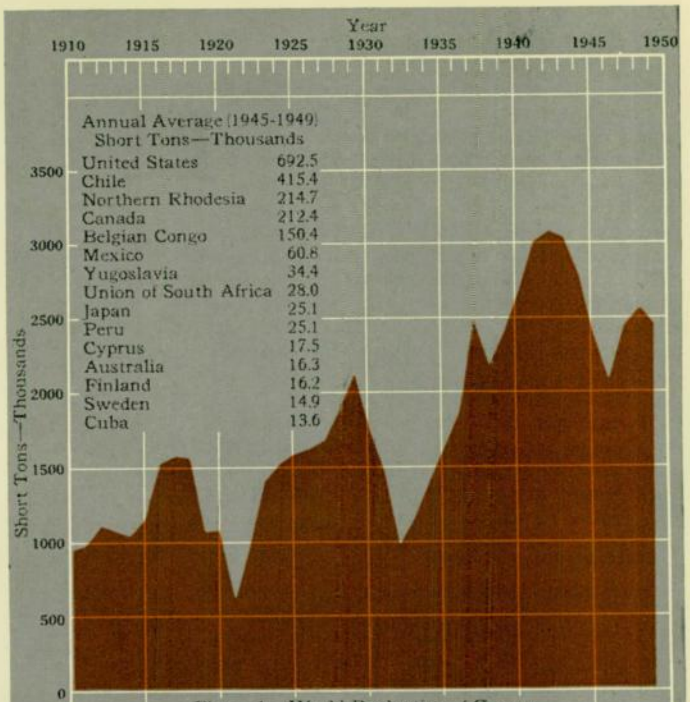


Figure 1—World Production of Copper

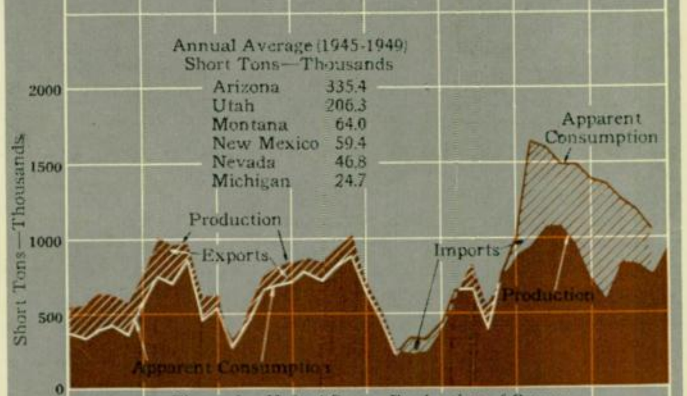


Figure 2—United States Production of Copper

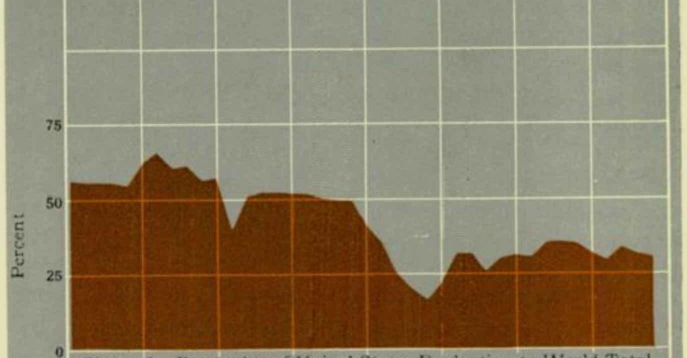


Figure 3—Proportion of United States Production to World Total

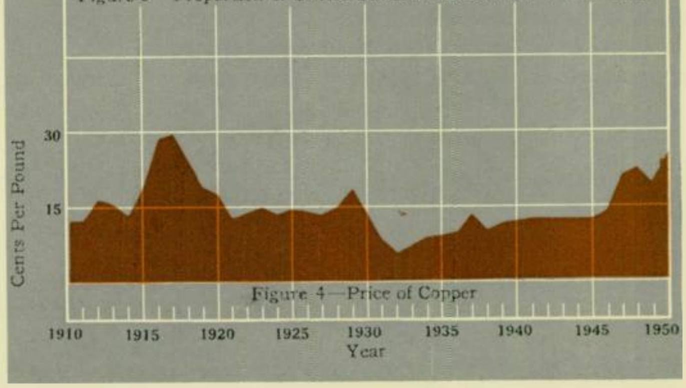


Figure 4—Price of Copper

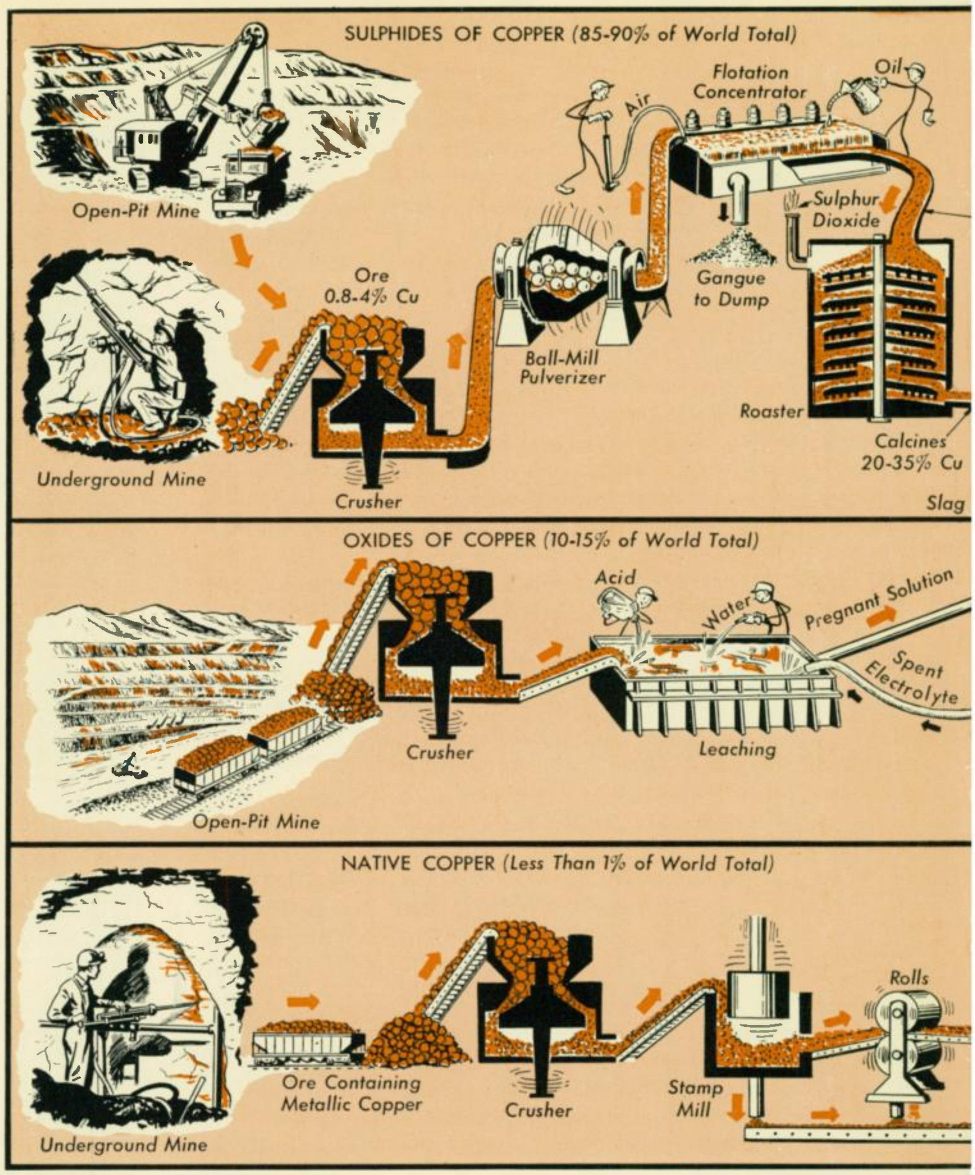
Copper, from Ore to Metal →

Here is how copper is obtained from ore. Only the principal steps are shown, there being many variations, depending on grade and character of ores.

Nearly all copper now being mined, whether open-pit or underground, consists of tiny grains of copper in chemical combination with sulphur or oxygen, widely disseminated through siliceous or quartz material. These are termed porphyry coppers. The first task is to break up the rock so that the copper-bearing particles can be mechanically separated from most of the waste silicates. This is done with various types of crushers and ball mills, depending on the fineness required, which in the case of sulphides going to flotation cells, is about 200 mesh.

Separation of copper compounds from the waste by flotation, introduced in 1912, was one of the great advances in copper mining. In effect it is gravity in reverse. Pulverized sulphide ore is mixed with water and a very small amount of certain oils and air bubbled through the mixture. For some reason, still not clearly understood, the oil adheres to the copper-bearing particles and not to the gangue (waste). These oil-covered particles, although heavier than the silica materials, ride to the surface on the air bubbles and are floated off, leaving the lighter, worthless material to be drawn off at the bottom. The frothy liquid is thickened in settling tanks and vacuum driers to a moist black powder and sent to roasters where surplus sulphur is burned off. The concentrate enters the roaster at the top, falling to the circular hearth where rotating rabbles keep it stirred and work it to the hearth edge or center where it falls onto the hearth below, and so on for perhaps six to eleven hearths. Fuel can be burned in the roaster if the sulphur content of the ore is low, but generally this is not necessary. With some high-grade ores the roasting step is by-passed.

Calcines, the roaster product, plus a flux, such as limestone, are smelted in a reverberatory furnace, in which the large pool of molten material is exposed to



rises from about 375 000 tons in 1910 to 1 441 000 tons (exclusive of stockpile) in 1950. It is difficult to trace the normal growth in demand for copper—because who can say what has been a normal period in the last 20 years? However, a study of five-year averages since 1920, giving weight to the situation in each period, leaves no doubt about the increasing use both in absolute amount and amount per capita (table I). What the demand would be were we not faced with another major military preparation is debatable. In any case it would have exceeded our capacity to produce. But, such reflection is idle. We are in the midst of a huge and probably long-continued military program.

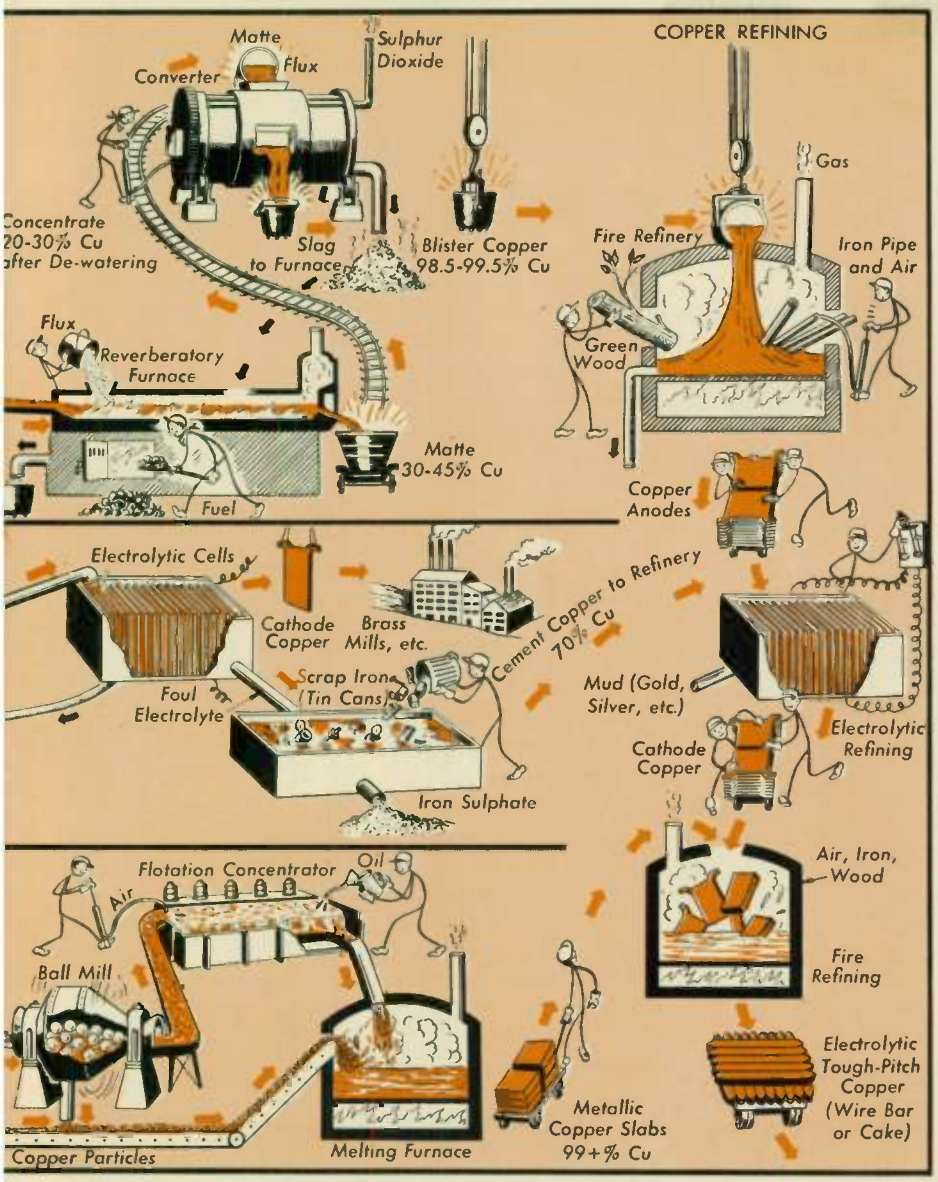
Furthermore, other factors favor a steadily increasing desire for copper. Not only are old standby uses increasing but also in the last several years new copper-consuming uses have appeared. An exact accounting of the end uses of copper is impossible. Even the copper-industry association gave up trying to compile such data several years ago. The best data was compiled by the American Bureau of Metal Statistics for the 1935–1939 period. On this basis the electrical industry (including telephone, telegraph, and radio sets) takes a little more than half (54 percent), of which the manufacture of electric-power apparatus, home appliances, and radio sets takes about half (or 28 percent of the total). The 40 odd million household electrical appliances built in 1950 used 100 000 tons of copper and copper-base alloys. The average refrigerator contains 20 pounds of copper; a vacuum cleaner, 4.5 pounds. The high electrical conductivity of copper (only silver is better) obviously makes it the industry's basic metal.

Automobiles are the next largest user of copper, the amount running to about 13 percent, not counting the electrical system. Automobiles built in 1950 contain 137 000 tons of copper or copper-base alloy. The amount in an automobile lies between 40 and 60 pounds. One small car contains 584 parts made of copper or copper alloy.

The building industry takes a similar percentage. The remaining fifth is divided among many uses including bearings, valves, fittings, wirecloth, ammunition, etc. A World War II tank required 800 pounds of copper; a Superfortress carries aloft three tons. A 37-mm anti-aircraft gun in action expends one hundred pounds of copper each minute.

The amount of copper used by the mint to make pennies varies from 2000 to 7000 tons per year. Thus Uncle Sam buys a ton of copper for $500 and makes approximately 290 000 pennies or $2900. (A penny is 95 percent copper, 5 percent tin and zinc.) Nice work, if you can get it!

In general the things that normally use copper are—aside from war effects—on the increase. Kilowatthours consumed in the United States have, on the average, doubled every decade since 1910 and show every sign of continuing to do so. The saturation level of automobiles is not yet in sight. The building program is still far behind. Taken on any basis, the natural demand for copper can be expected to increase. The limit appears to be price and availability.



long flames and heat. The result is matte and waste slag. Molten matte is passed directly to a converter where with flux, air, and heat the iron combines with the remaining silica to form a slag, which is drawn off and returned to the furnace as it still contains copper. Following this the remaining sulphur in the copper sulphide, with more air, oxidizes to a gas, leaving the copper at last chemically free. It is poured out as a liquid and cast into ingots, called blister copper. Blister contains as "impurities," gold, silver, and perhaps other metals. Blister copper is porous and brittle. Further refinement is necessary to improve the physical properties and to recover associated valuable metals.

Oxide ores, after crushing, are placed in enormous open leaching tanks and slowly circulated for several days with water and sulphuric acid. The result is a liquor known as pregnant solution that is the electrolyte for the electro-deposition cells. The copper plated on cathodes is of high purity, usable as such in brass and other copper and copper-alloy plants. The spent electrolyte still contains some copper, which is recovered by percolating over scrap iron—usually tin cans. The sulphur gives up copper for iron, forming iron sulphate which is dumped. The desirable product is known as cement copper.

Native copper, which is already in almost pure metallic state, goes through several stages of mechanical separation from the quartz particles to which they cling. Flotation affects the final separation. The combined copper pieces and grains are collected and melted in a furnace to provide copper slabs.

Most copper produced is blister copper from sulphide ores. While it is 99+ percent copper it contains valuable minerals and some undesirable impurities. The necessary refining is done as a three-step process consisting of two essentially identical fire-refining operations with an electrolysis operation between them. The electrolysis step is always required if the copper to the refinery contains other minerals of sufficient worth to warrant electrolysis or if bismuth is present—which cannot be removed in a furnace. The second fire-refining step is primarily to give the copper a small oxygen content, necessary for electrical uses.

Scrap and Reserves

Fortunately most of the copper used is employed structurally. Little is incorporated with other products, as lead is with paint and anti-knock fuel, where it is lost forever. More than three fifths of the copper used is potentially recoverable. The amount actually returned as scrap is extremely variable, being highly responsive to copper selling price and to the labor supply. In general since 1925 output from old scrap (i.e., from discarded materials that have served a useful purpose) has run to over 25 percent of the annual consumption of new and old copper except for the depression years when in one year it hit 49 percent, presumably because of the low cost of labor to collect it. (This does not include secondary copper from new scrap, i.e., from clippings, punchings, etc. produced in the manufacture of copper products.) The amount of previously used copper that will return as scrap will increase, possibly even exceed new copper for limited periods.

When a mineral becomes difficult to obtain, a natural question is: How much reserve do we have? For copper a good, solid, statistical answer is impossible. It wouldn't be worth much anyway. The real pay-off question is: To what extent and for how long can the United States supply its own copper needs? This involves a deal more than dividing an estimate of copper-ore reserves by the annual rate of use to obtain a figure for the number of years before copper bankruptcy.

A definite figure of copper-ore reserves is almost meaningless for several reasons. For one thing, no such figure is published. The nearest approach to such is that compiled by the Federal Trade Commission in 1945 of 29.2 million tons (of copper). To this should be added a few million tons of reserves not included in the 1945 estimate. Since 1945 some 4 million tons of copper have been mined and we are currently producing at almost a million tons per year. If you wish, you may interpret this as 25 to 30 years' worth left. But almost no one—in the industry or out—lays much stock in such a number. As one mining engineer succinctly put it, "Figures for copper reserves have a remarkable habit of remaining substantially constant." (A U. S. Bureau of Mines bulletin in 1938 gave a figure of 26.2 million tons of unmined copper.)

Reserve figures are indefinite for good reasons. For one thing exploration—involving core drilling—is expensive.

But the greatest single factor is the difficulty of deciding today what ore is practicable of mining 20 or 30 years from now. Most copper now comes from workings that mining men rejected 30 or 40 years ago. Mining methods—particularly for the handling of large tonnages—have improved to the point that ores as lean as 16 pounds of copper per ton are profitable. How much further will improved technology carry this trend? Obviously no one can answer with surety. Certainly if ores another point or two lower in richness can be considered workable an enormous quantity would be instantly added to our "reserves."

Furthermore, leanness of ore is not the only factor. The price paid for copper has an obvious direct effect on what can be considered workable reserves. The following statement appeared in a recent copper-company publication:

"Twenty years ago the cut-off point (i.e., where mining even large tonnages becomes unprofitable) was 8/10 of one percent, or 16 pounds of copper per ton of ore. Material containing 16 pounds or more was sent to the mills as ore and material containing less copper had to be placed on the waste dumps. . . . Increased efficiency has permitted a reduction of the cut-off point and has literally turned into ore millions of tons of material that was once waste, thus greatly lengthening the life of the mine. Now, ore containing 4/10 of one percent, or eight pounds of copper per ton, is being mined and shipped to the mills. . . . With such extremely low-grade material, an increase in costs of even a few cents per ton may make it necessary to raise the cut-off point. When this is done, the life of the ore body is shortened."

Location of ore body is also important as it determines the mining method. Depth of overburden, or depth of shaft, and so on, with margins close, may be controlling. Local situations—not enough or too much water—or presence or absence of other minerals have a bearing on whether an ore body can be counted as workable. About all that can be said is that the total copper in lean, uncounted ore bodies in the United States is very large. Copper can be had from them—at a price.

The chances of stepping up the rate of copper production by any large factor to supply the growing demand are not good. Although operations in new ore bodies—such as White Pine, San Manuel, or Yerington—may be opened up, it will be at least three years after the decision is made in each case before any copper results. It is not feasible to step up operations at existing mines by a large factor.

Domestic copper mines have had a strong price incentive to produce at a maximum rate during the last four years. Actual production averaged 860 000 tons. Maximum production during World War II, with incentives very great, exceeded 1 000 000 tons only twice (1 100 000 average for 1942 and 1943). It, therefore, does not seem likely that the industry can produce more than 1 000 000 tons yearly indefinitely.

Can We Do with Less?

When any material becomes hard to get or more costly, or both, engineers are forced to consider a naturally distasteful proposition—substitution. If this happens to copper, what are the prospects in the electrical equipment industry?

Where copper is used for non-magnetic or corrosion reasons the problems are not as serious as when electrical conductivity is involved. The only practically possible substitute for electrical conductors is pure aluminum, which for a given cross section has about 61 percent of the conductivity of copper. Thus for the same current and voltage drop the aluminum member would be (theoretically, not necessarily actually) about 1.5 times larger in dimensions but would weigh only about half as much. The weight ratio of copper to aluminum is about 3 to 1.

If aluminum were freely available—which it isn't—the first relatively easy move the electric-power industry could take would be to substitute aluminum for busbars where space is not critical. Such a change would save a lot of copper, probably several thousand tons yearly. This would involve more than simply using aluminum busses where copper was used before. There are recognized problems of low-drop connections and extra bracing where forces under short circuit are high. But these matters are not insuperable.

But, suppose aluminum had to be used for conductors in rotating machines, transformers, and other devices. What then? It can be done, with an increase in cost and dimensions. Insulation will be a problem. Some work has been done with synthetic and cotton coverings for aluminum wire. However, efforts to enamel aluminum have not been blessed with overwhelming success. Few question that it can be done, but certainly new techniques will be required.

Having obtained suitably insulated aluminum wire, redesign of almost all apparatus using it would be a certainty, because of the size factors. Also soldering and other types of connections pose problems.

Substitutes for copper are being aggressively explored. Some shifts will be necessary, probably long range as well as middle range. It is too early to be more definite about substitution for copper in individual applications except to say that it is on the way in many instances.

However, any conclusion that copper will join the buffalo is not sound. Copper was the first important metal used by man. It can be counted on to be an increasingly useful servant for centuries. There is a lot of copper in the world; but it is not inexhaustible. We must learn to use it wisely. That makes sense anyway—and not only with copper.

Copper anodes in an electrolytic refinery and finished wire bars (Anaconda photos).

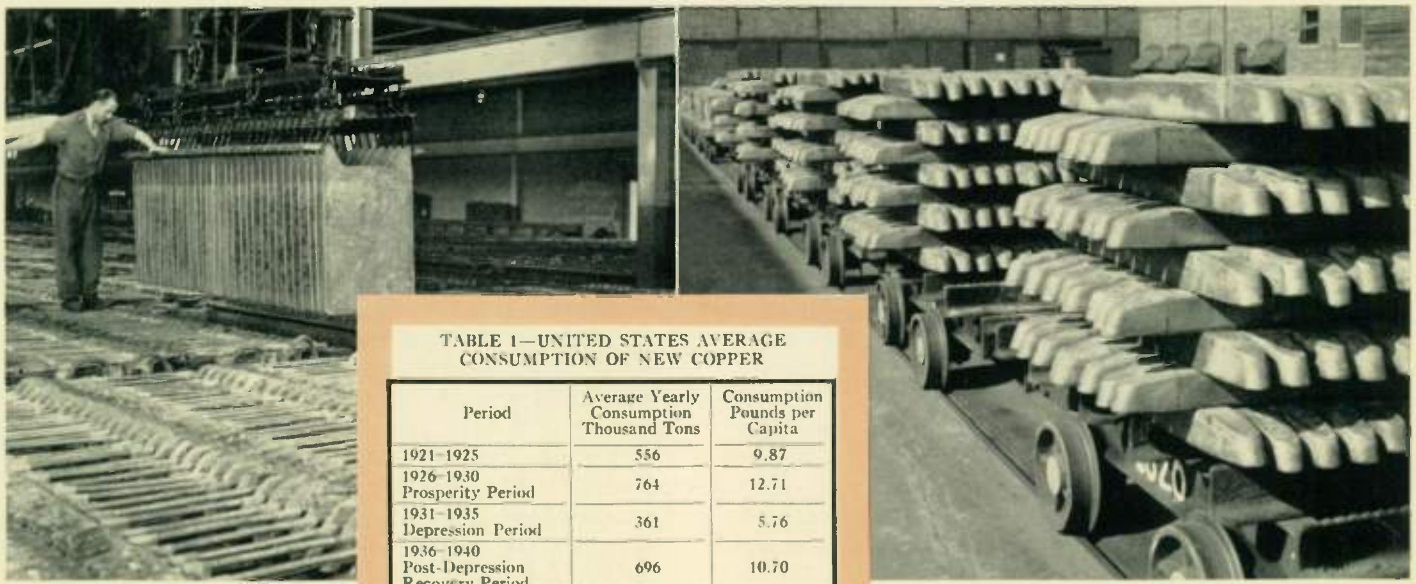
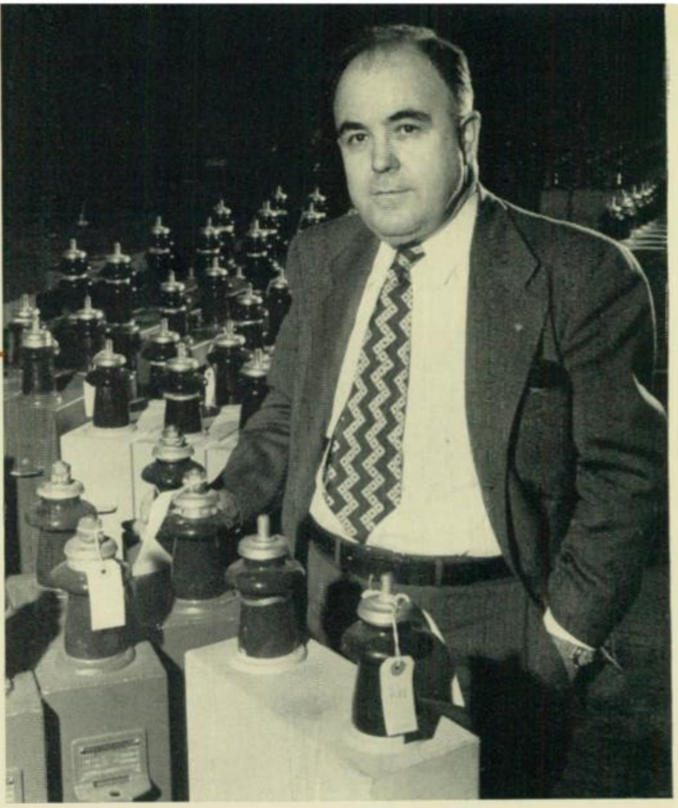


TABLE 1—UNITED STATES AVERAGE CONSUMPTION OF NEW COPPER

Period	Average Yearly Consumption Thousand Tons	Consumption Pounds per Capita
1921–1925	556	9.87
1926–1930 Prosperity Period	764	12.71
1931–1935 Depression Period	361	5.76
1936–1940 Post-Depression Recovery Period	696	10.70
1941–1945 World War II	1226	22.42
1946–1949 Postwar Recovery Period	1192	16.55

Personalities IN ENGINEERING

R. E. MARBURY



A PLOT OF R. E. Marbury's career somewhat resembles a tree. It would have one stout trunk and numerous branches. The trunk would be power capacitors. In their design and application he has established an outstanding position of leadership for many years. The branches—well, let's describe the tree as it developed.

While Marbury was growing up in the small town of Newman, Georgia, his father was engaged in the furniture business. Hauling was then done with horse-drawn drays. Although automotive trucks were still a novelty, young Marbury could see how his dad could use a truck. So he built one—combining the best parts of engine and chassis from a Model-T Ford and a two-cylinder chain-drive Buick.

Marbury still likes to tinker with cars. He has a modern automobile, which he'll admit is a mighty comfortable conveyance, but his pride and joy is a 1934 Packard. When asked why he keeps the 17-year old antique, he replies: "I like to keep a good piece of machinery around." Anticipating difficulty in obtaining repair parts, he bought a spare engine a few years ago, dismantled it, and packed the parts away in grease. He has also added an adjustable thermostat to get better heat control, and an automatic recranking system to his cars.

A second youthful Marbury interest was radio. He made his own spark-gap transmitter in 1914. Although he is no longer active with amateur radio, his interest in the mechanical side of such things remains. Although loath to undertake any rebuilding of his new television set, he did build himself a 50-foot motor-driven antenna tower for it. By a synchro-tie motor system, he can, from his living room, turn the antenna to any position, thus permitting selection of angle to give the best picture with least ghosting regardless of season or weather.

His early interest in radio and automobiles led by a circuitous route to his activity with capacitors, which were required for radio and for ignition equipment. Marbury was half way through the electrical engineering school at Georgia Tech when the United States entered World War I. Too young to join a service or be drafted, he wanted to contribute to the effort. He came to Westinghouse, and after a short period on the Intermediate Student Course, entered the Supply Engineering Department. He was farmed out to Krantz Manufacturing Company, a Westinghouse subsidiary building panelboards. Panelboards were definitely not to his liking, so by a bit of finagling he returned to East Pittsburgh where he helped with lightning-arrester development. However, already audible were the first stirrings of a new industry—radio. Dr. Frank Conrad, as consulting engineer, was experimenting with this new art. Marbury, with his amateur-radio background, naturally gravitated to it. He helped develop radio for communication to and from captive observation balloons. The war over, he assisted Dr. Conrad in making the initial demonstration of radio—i.e., broadcasting phonograph records between East Pittsburgh and Wilkinsburg—that convinced Westinghouse officials to launch the new industry, beginning with KDKA in Pittsburgh. In radio's early growth Marbury was concerned with the development of several of its components, including capacitors. Radio grew so rapidly it soon became a department in itself. But by that time Marbury was well along on a program of developing capacitors for power-circuit use.

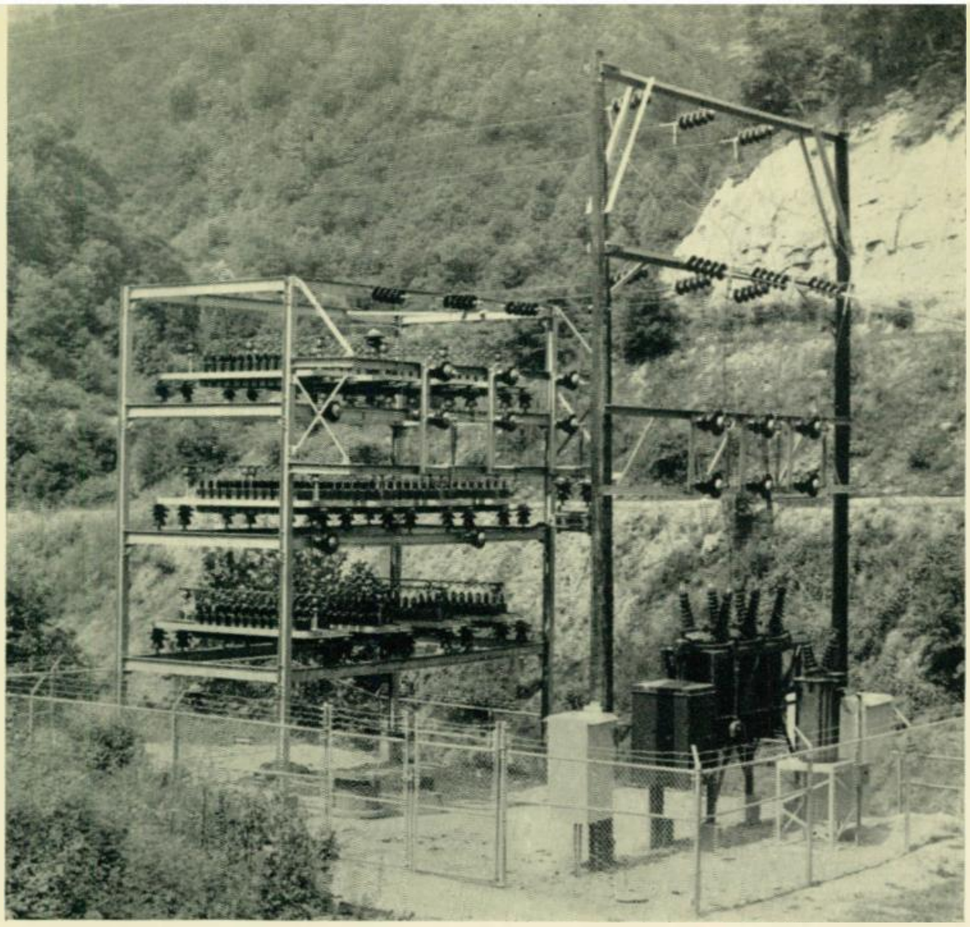
Thus began a long career in this field, interrupted by only one major interlude. In 1930, as manager of Supply Engineering Department, he had charge of several new developments in home appliances such as food mixers, dishwashers, and a practical home Precipitron embodying principles worked out at the Research Department. He designed a garbage-disposal unit—possibly the first, but it was ahead of its day. During this period he supervised the initial activities of Westinghouse in refrigeration for homes and offices, resulting in the first Westinghouse one-ton refrigeration unit for air conditioning. He directed investigations of reverse-cycle refrigeration (now called the heat pump) and supervised the installation of two trial installations in homes.

The depression caused many reorganizational changes and, as a result, Marbury again assumed responsibility for capacitors—which now has several adjuncts, such as bushing-potential devices, wave traps for power-line carrier apparatus, switches and associated equipment for power-factor correction apparatus. In this period much credit goes to Marbury for concepts and features on which the present high state of capacitor development rests. These include the first real analysis of the economics of capacitor design that resulted in the maximum amount of dielectric per dollar of cost, the introduction of welded cases for capacitor cases, solder-sealed bushings, and the development of the outdoor capacitor. With a single debatable exception, Marbury's capacitors have been the first to establish successively higher ratings in a case whose dimensions have remained nearly constant for 25 years. Marbury has long been a believer in the series capacitor and he personally has contributed most of the protective-equipment design principles that are just now bringing the large series capacitor for high-voltage lines to full fruit. (He is now preparing for these pages a discussion of a 15 000-kva series capacitor installed on a transmission line and another 83 000-kva series capacitor now in construction.) He has also promoted many new uses for capacitors, and devised special capacitors to cope with unusual application problems.

Marbury has been a prolific doer. He has been granted an average of one patent every six months since coming to Westinghouse in 1917. These deal with radio components, capacitor designs and applications, home appliances, such as food mixers, dishwashers, refrigeration, protective devices, and control systems.

He has written scores of technical articles, and in 1950 a book by him on capacitors (McGraw-Hill) became a best seller in its field. When at home, and not tinkering with words, he tinkers with things mechanical. A few years ago he devised his own automatic coal-furnace draft control, complete with grate shaker. This heating system is sensitive to outdoor as well as indoor temperature so as to anticipate heating needs imposed by sudden weather changes.

Quite a tree, we'd say, with its roots deep in an unusually sharp engineering imagination, technical curiosity, and mechanical skill.



High-Voltage,

R. E. Marbury
Manager, Capacitor Engineering
Westinghouse Electric Corporation
East Pittsburgh, Pa.

A marked reduction in the cost of large banks of shunt capacitors can be effected by using outdoor units in open racks instead of in metal enclosures. However, several matters of fusing, and correct combinations of units for different sizes of banks and different circuit voltages must be given attention.

When a bank of shunt capacitors is to be located at a substation, the question arises as to whether it should be enclosed in metal or should it be the open type, i.e., the individual units mounted in open structures. Frequently metal-enclosed construction is desirable for safety reasons or for appearance. On the other hand open-type units are entirely practical and require a smaller investment. In fact this construction is increasing in popularity.

An open-type bank consists of a group of outdoor capacitor units suitably supported on a structural-steel rack and elevated a safe distance above the ground. It is usually located in a large substation yard and fenced in to protect personnel. Such an installation is often more economical than a metal-enclosed assembly of capacitor units, especially for voltages

Fig. 1

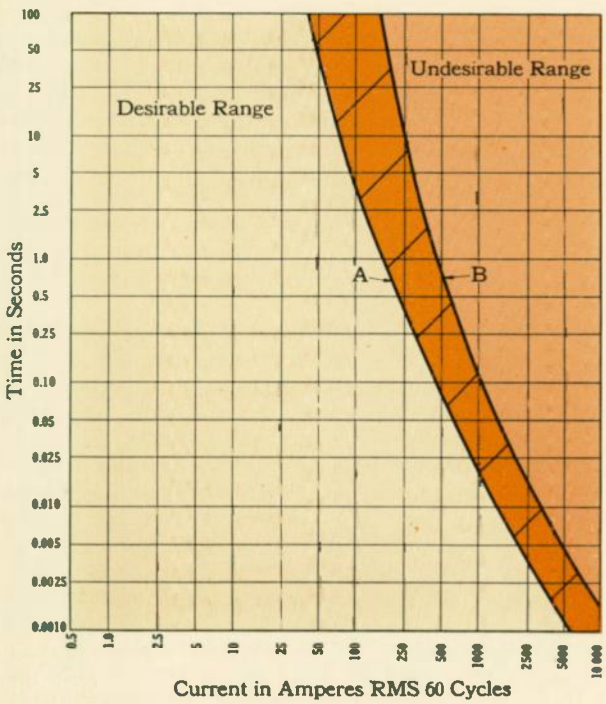
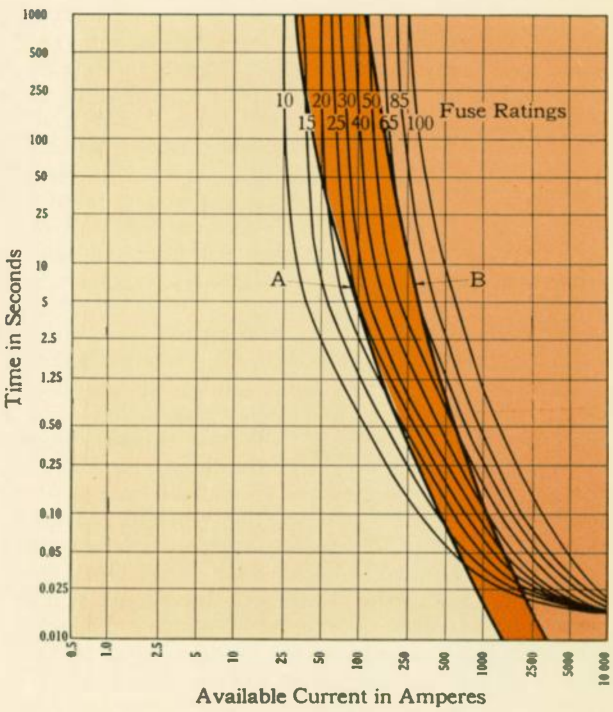


Fig. 2



The picture illustrating the title of this article is a 6600-kvar bank of the Kentucky and West Virginia Power Co., Inc.

Open-Type Capacitor Banks

above 13.8 kv. While most open installations have been for circuit voltages of 24 kv and above, they are entirely practical for lower voltages, provided metal enclosures are not necessary for other reasons.

The Fusing Problem

When an open bank is made of capacitor units rated the same as the phase-to-phase voltage of the circuit, the units must be connected in delta. In this instance it must be recognized that a short-circuited capacitor results in a phase-to-phase fault starting within its metal case. If the fault current is large—3000 amperes or more—it is important to fuse each capacitor unit individually whether the bank is the open type or metal enclosed. The fuse must have sufficient interrupting capacity to limit the duration of the arc within the capacitor. If this is not done the case of the capacitor unit may rupture, and in doing so may damage adjacent units.

A capacitor contains large areas of thin aluminum foil separated by insulation or dielectric material. These aluminum conductors have limited current-carrying capacity, and, like a fuse, will melt on excessive currents. Normally the current is well distributed over the aluminum foil; however, when the dielectric is punctured, current flows directly through the thin foil conductors. The external fuse for each capacitor must be one that blows and disconnects its unit from the circuit before the foil melts. So there is a limit to the size of the individual fuse, and it is highly undesirable to attempt to protect a group of capacitors with only one fuse. The fuse required to handle the current of several units takes too long to operate on high currents, and does not provide sufficient protection for each of the individual capacitors in the groups.

Current-limiting fuses are generally required for delta-connected banks. They should be used on each capacitor unit in the bank so as to take full advantage of the current-limiting properties of such fuses.

The currents required to rupture a capacitor case are shown in Fig. 1, while Figs. 2 and 3 give the current-time characteristic of expulsion and current-limiting fuses superimposed on the curve of Fig. 1.

Another important factor in large banks is the stored energy released from the capacitors in parallel with the faulty one. This is especially important in banks comprised of capacitors with a voltage rating the same as the circuit phase-to-phase voltage, because of the relatively large number of capacitors connected in parallel. Inasmuch as one third of the units are in parallel, the energy discharged through the short-circuited unit is one third of the total for the bank. In calculating this energy one must assume a transient voltage of about 2½ times normal. Should a capacitor break down while the bank is being switched, energy levels of this value are entirely probable. This matter of stored energy limits the use of conventional-type fuses in banks where each group of parallel units exceeds 1800 kva, and favors the use

Fig. 4—Sometimes, in order to meet reactance and voltage requirements, a capacitor bank must be arranged in groups of parallel units with several groups connected in series in each phase. The schematic diagram illustrates an arrangement of that type.

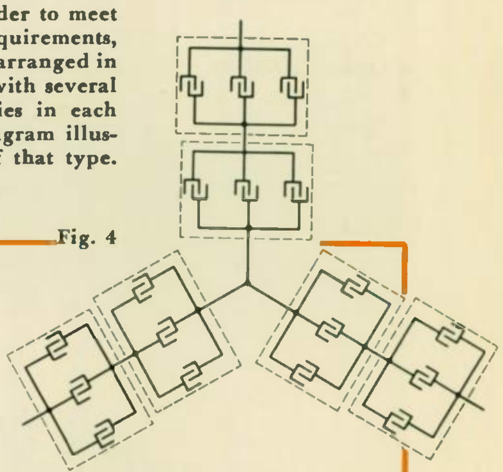


Fig. 4

Fig. 3

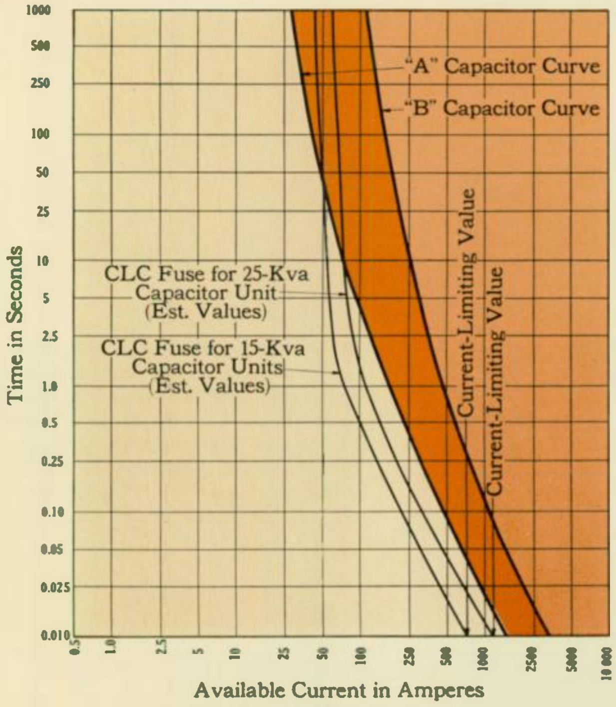
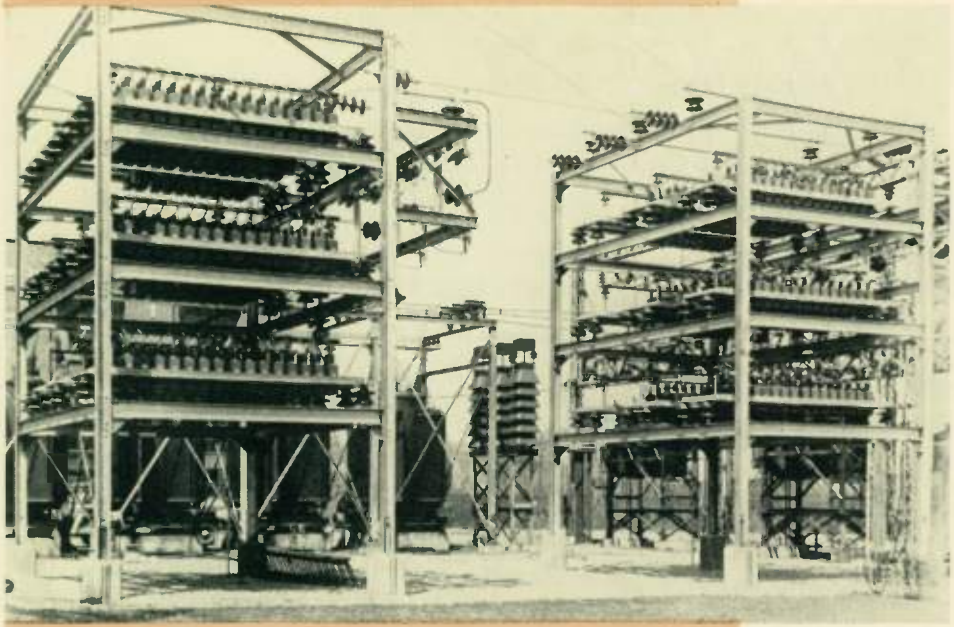


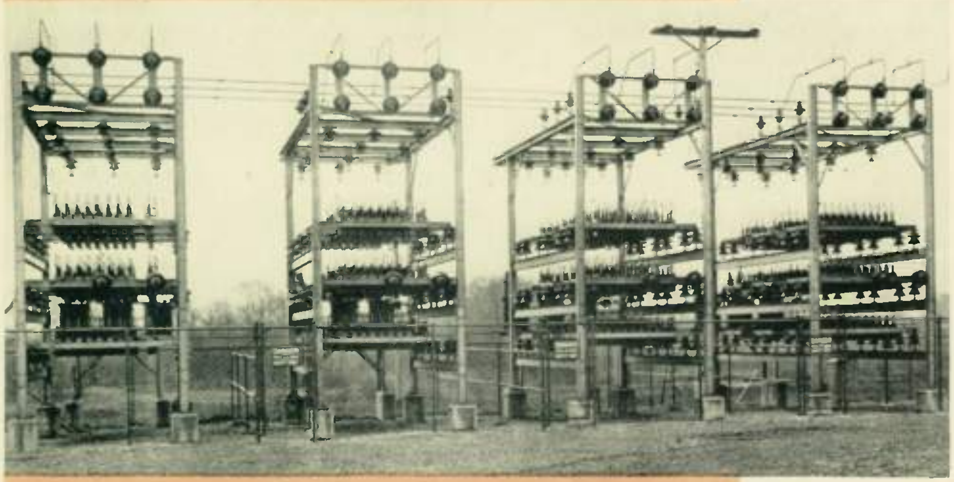
Fig. 1—Here, for 15- or 25-kvar, 60-cycle capacitor units, the short-circuit current is plotted against the estimated time required for the case of a capacitor to rupture due to excessive gas pressure caused by an internal arc. On this and two succeeding curves (Figs. 2 and 3) the area to the left of the curve marked *A* is that range of current-time combinations that is not likely to cause the case to rupture. The area to the right of *B* is an undesirable operating range that may cause an explosion violent enough to damage adjacent units. The values between curves *A* and *B* will sometimes cause the seam of a case to open, but represent a practical operating range on which fuse selection usually can be based.

Fig. 2—Fault-clearing characteristics of type-UT individual expulsion-type fuse links (for 2400- and 7960-volt capacitors) correlated with estimated time required to rupture a capacitor case.

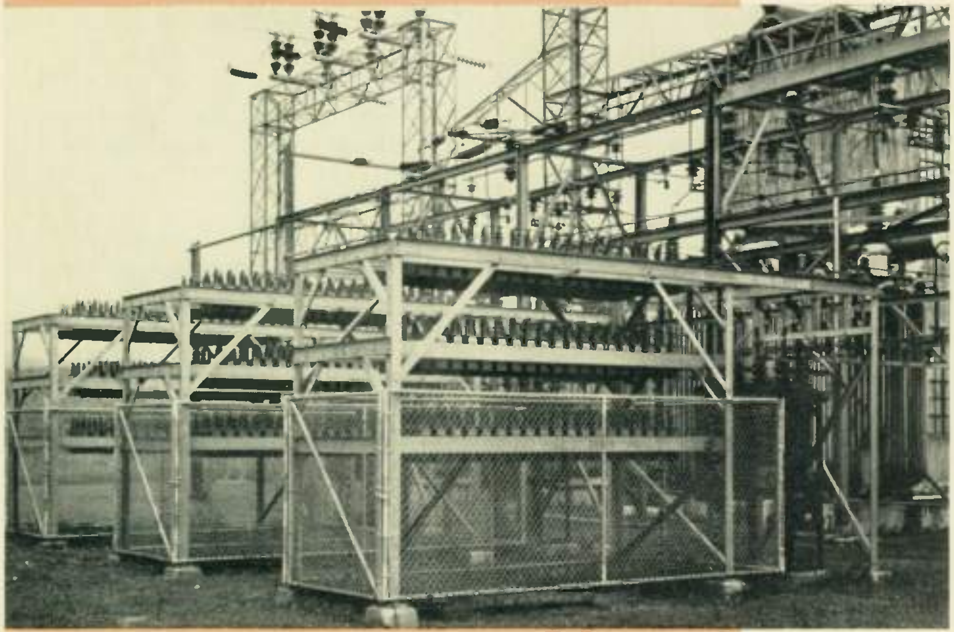
Fig. 3—Fault-clearing time of type-CLC current-limiting fuses (for 2400- and 7960-volt capacitor units) correlated with the estimated time required to rupture the case of a capacitor unit.



Two 6000-kvar, 33.2-kv banks of the Kentucky and West Virginia Power Co., Inc. All units rated 25 kvar. Two of the three series groups in each phase have thirty 7200-volt units in parallel, the third has twenty 4800-volt units.



An open assembly of four 2500-kvar capacitors. This is one of the first installations of open-type capacitors for service at 24 kv and up. Installed seven years ago, it has an excellent performance record.



A typical installation of three 1666-kvar, delta-connected, open-type capacitor banks using 2400-volt units. The cases of all the capacitors are grounded to the steel structure. Individual current-limiting fuses (not shown) were added later for each capacitor.

of an individual current-limiting fuse for each of the units.

When a wye-connected bank is made up of capacitor units rated at the phase-to-neutral voltage, the fuse problem depends on whether the neutral is grounded or isolated. If grounded, the statements made for the delta bank apply. If isolated, the fuses no longer need be ones having high interrupting rating because the fault current is limited. With exceptionally large banks containing large parallel groups of units the stored energy in each phase may be great enough in itself to require current-limiting fuses.

An arc within a capacitor unit can rupture a case even when the current is small. For example, damage can be done by a current of 500 amperes lasting one second, or even 100 amperes lasting 150 seconds. Therefore, trouble may be encountered where fuse-blowing currents are so limited that small current arcs of long duration will be maintained within the case of the capacitor. This would be the result in wye-connected banks with ungrounded neutral and less than four units per phase, or in banks whose phase legs are made up of several groups in series with each group consisting of less than four units in parallel (See Fig. 4).

In some instances wye-connected banks with isolated neutrals and a substantial number of units in each phase have been fused in groups of four to seven units where there are no series groups. Since fault currents are limited, such an arrangement would seem to be satisfactory. However, this practice is not recommended, because it overlooks one important purpose of the individual fuse—accurate determination of the faulty unit when a fuse blows. Group fusing should never be considered where the phases contain groups in series.

Compatible Combinations

High-voltage, open-type banks of capacitors are generally made up by operating groups of capacitor units in series in each phase. Connecting groups of parallel capacitors in series is entirely practical when the cases of individual capacitors are properly insulated from ground, and when certain other precautions are taken. The number of units in parallel must be chosen so that if a unit develops an internal fault the current is sufficient to blow the fuse promptly, and the resulting voltage on the group of capacitors with the blown fuse is not allowed to exceed the maximum permissible operating voltage of the capacitors, which is 110 percent of their rated voltage. The neutral is usually grounded for relaying purposes, but it makes little difference since the current is limited anyway when two or more groups are operated in series.

When a bank is made up of two groups per phase, the smallest number of capacitors recommended is six. This insures positive fuse operation and prevents exceeding by ten percent the rated voltage on the remaining units when one fuse operates. When more groups are connected in series the number of parallel units in each group must also be increased. This sets a lower limit to the size of the bank. With two groups in series and six 25-kvar units in parallel in each group the smallest size of three-phase bank is 900 kvar. This 900-kvar bank can be designed for an 8320-volt circuit if 2400-volt capacitor units are used exclusively, or for a 27 600-volt circuit if 7960-volt units are used throughout.

Table I shows the bank kvar ratings that are possible based on grounded-wye banks using 15- or 25-kvar units, and conforming to the requirements relative to fusing and group sizes. This table assumes that all units in the bank are of the same voltage rating. This is desirable to avoid errors, especially when units are indistinguishable except by the nameplate (as for example 2400- and 4160-volt units).

TABLE I—GROUNDED-WYE BANKS OF CAPACITORS IN OPEN-TYPE STRUCTURES

Unit Connections		Minimum, 3-Phase Bank Kvar[1]		Additional 3-Phase Kvar Steps[1]		Phase-to-Phase Line-Voltage Ratings[2]				
Series Groups	Units Per Group	With 15-kva Units	With 25-kva Units	With 15-kva Units	With 25-kva Units	2400-Volt Units	4160-Volt Units	4800-Volt Units	7200-Volt Units	7960-Volt Units
2	6	540	900	90	150	8 320	14 400	16 700	24 940	27 600
3	8	1030	1 800	135	225	12 480	21 600	25 050	37 410	41 400
4	9	1620	2 700	180	300	16 640	28 800	33 400	49 880	55 200
5	9	2025	3 375	225	375	20 800	36 000	41 750	63 350	69 000
6	9	2430	4 050	270	450	24 960	43 200	50 100	74 820	82 800
7	10	3150	5 250	315	525	29 120	50 400	58 450	87 290	96 600
8	10	3600	6 000	360	600	33 280	57 600	66 800	99 760	110 400
9	11	4455	7 425	405	675	37 440	64 800	75 150	102 230	124 200
10	11	4950	8 250	450	750	41 600	72 000	83 500	124 700	138 000
11	11	5445	9 075	495	825	45 760	79 200	91 800	137 170	
12	11	5940	9 900	540	900	49 920	86 400	100 200		
13	11	6435	10 725	585	975	54 080	93 600	108 550		
14	11	6930	11 550	630	1050	59 240	100 800	116 900		
15	11	7425	12 375	675	1125	62 400	108 000	125 250		
16	11	7920	13 200	720	1200	66 460	115 200	133 600		

[1] The minimum three-phase kvar and additional kvar steps are on the basis of operation at these voltages. When the actual system voltage is less the kvar goes down as the square of the voltage.

[2] The system phase-to-phase voltage should be equal or less than these values.

Cases arise, however, where it is necessary to operate units of different voltage ratings in series groups, for example, where the phase-to-neutral voltage is not a multiple of a standard unit voltage. It is difficult to make up a bank of capacitors for 15 kv using standard units of either 2400, 4160, or 7200 volts, but if the bank is composed of three groups per phase with two groups of 2400-volt units and one group of 4160-volt units in each phase, the phase-to-neutral rated voltage is 2 × 2400 plus 4160 or 8960 volts. This is only slightly above the actual phase-to-neutral voltage of a 15-kv circuit, and the units will actually deliver almost their rated kva. The only alternative is to make all groups with capacitors of non-standard voltage ratings, thus making them alike and able to deliver their full rated kvar.

When capacitors with different voltage ratings are used, the number in parallel with the lowest voltage rating must be at least equal to the total number of series groups, given in column 1 of table I. In addition, the number of parallel units in each group must be adjusted so that each group operates at or below the rated voltage of the units in the group. In some cases units in one group are operated below their rated voltage to avoid operating another group above the rated voltage of the capacitors in the second group.

The number of units required in each group, when all the capacitors in a bank are not of the same voltage rating, can be determined from the following.

$$I = \frac{Kvar \times 10^3 \times N}{E_1} = \frac{Kvar \times 10^3 \times N}{E_2} = \frac{Kvar \times 10^3 \times N}{E_3}$$

Where I = Phase current through series groups.
$Kvar$ = Kvar rating of a single capacitor unit.
N = Number of parallel capacitor units in group.
$E_1 E_2 E_3$ = Rated voltage of the capacitor units in the several groups that are in series in one phase.

Example: Assume that each of the first and second groups contains ten 15-kvar, 2400-volt units. How many 7200-volt units should be used in the third group?

$$\frac{15 \times 10^3 \times 10}{2400} = 62.5 \text{ amperes} = \text{Phase current.}$$

Because the current is the same through all groups in series, the number of units required in the group made up of 7200-volt units is:

$$N = \frac{I \times E}{Kva \times 10^3} = \frac{62.5 \times 7200}{15 \times 10^3} = 30 \text{ units.}$$

In this example the phases are made up of three groups in series, with the first and second group each consisting of ten 15-kvar units in parallel, and the third consisting of thirty 7200-volt, 15-kvar units in parallel. The total kvar per phase is 750 and the phase-to-neutral voltage is 12 000 volts.

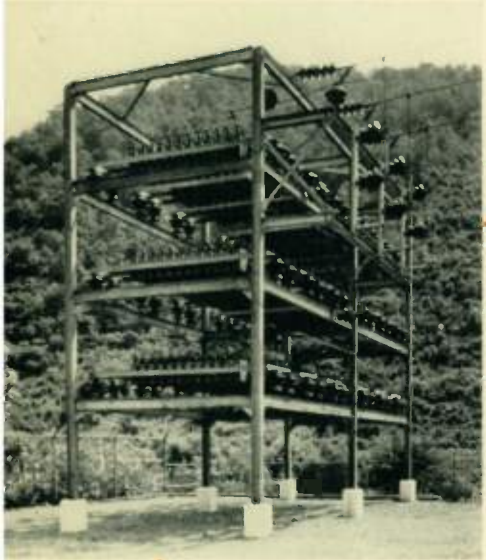
Where the capacitor bank consists of groups of identical capacitor units, removal or addition of units in any one group should be accompanied by a similar change in all groups so as to maintain balanced phases and proper voltage distribution. Where the units are different, as in the example given, the ratio of units as calculated must be maintained when units are added or removed, so that the impedance-voltage relations remain unchanged.

If the bank is made up of series groups, with all units of the same voltage rating but different kvar rating, the kvar of each group should be held the same. For example, suppose a bank contains three groups of 2400-volt units, with the first and second groups made up of fifteen 25-kvar units and the third group made up of twenty-five 15-kvar units. Each group totals 375 kvar. The current is the same for each group because they are connected in series; so the voltage is the same also. If units are added or removed the ratio of different kvar ratings must be alike in all phases to maintain correct voltage distribution and phase balance.

When banks of capacitors are switched one must consider the inrush current and voltage transient. The inrush current usually is not excessive when only one capacitor bank is involved; because line reactance limits the inrush current to values that are quite reasonable, usually not more than 20 or 30 times the normal current of the capacitor. These are shown in Fig. 5 in terms of line-fault current. The breaker used to de-energize a bank should be one that does not permit voltage transients in excess of 2½ times the capacitor rating.

Where several banks of capacitors are located at one point, the inrush currents are much higher when the second bank is switched on. These values depend upon the spacing between capacitor banks, the length and spacing of conductors between banks, and the inductance of lead connections within the capacitor banks. The approximate values to be expected in such cases are given in Fig. 6. Since some banks are switched frequently, and these may be one of a group of capacitors at the same location, these currents can play an important part in determining the switches or breakers to be used with such banks.

Where a capacitor is to be installed on a high-voltage circuit, for example 22 kv or higher, the open-type structure offers a good solution at low cost. For lower voltages the open-type structure makes possible a low-cost installation if space is available; but where the capacitor must be located in close quarters in populated areas the metal-clad construction is still preferred, and has been supplied for voltages up to 34.5 kv.



←

A wye-connected, 45.7-kv, 9900-kvar bank of the Appalachian Electric Power Co. Each phase contains eleven groups in series, and each group has twelve 2400-volt, 25-kvar units in parallel.

Fig. 5—Energizing inrush currents for fully discharged isolated capacitor banks.

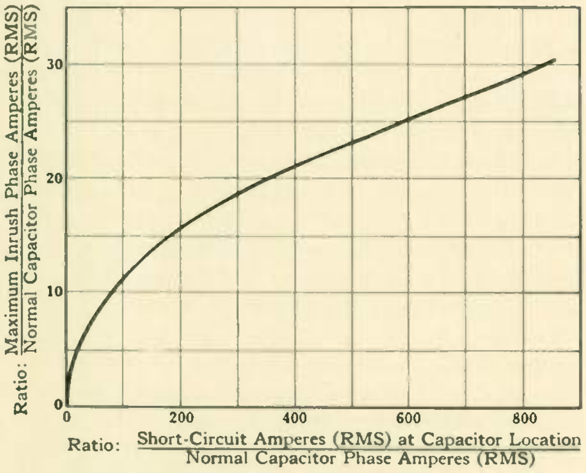
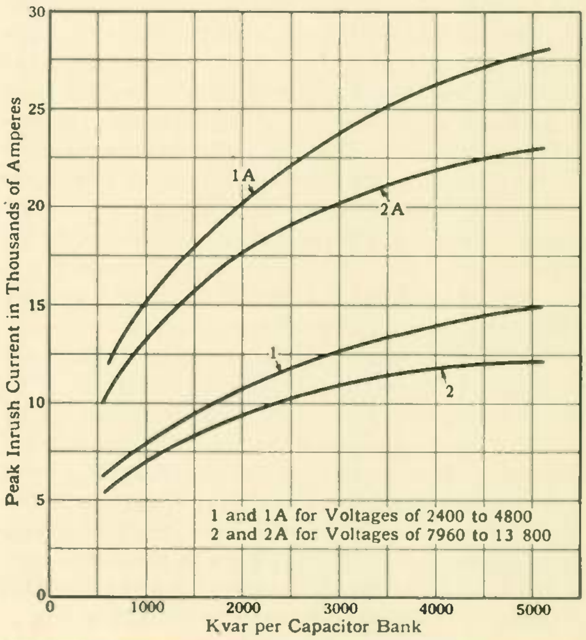


Fig. 6—Energizing inrush currents for capacitor banks located at a point on a circuit where more than one bank is connected. Curves 1 and 2 give current values obtained with one bank already energized; 1*A* and 2*A* give values likely with ten or more banks energized.



A-C Power Plants for Passenger Cars

Alternating current is moving in on another traditional direct-current field—the power supply for railroad passenger cars. With steeply rising electrical loads, the size of storage batteries and the axle-generator drain on the locomotive are getting out of bounds. A separate engine-driven power plant may be the answer. If so, the advantages of alternating current become conspicuous.

I. S. Ritter
Sturtevant Division
Westinghouse Electric Corporation
Hyde Park, Massachusetts

and

H. H. Hanft
Transportation Section
Westinghouse Electric Corporation
East Pittsburgh, Pa.

Many of the devices that figure in the programs of railroads to win and hold a larger proportion of passenger traffic call for additional amounts of energy. Air conditioning—sometimes both heating and cooling within the same run—high levels of lighting, chilled drinking water, dust- and bacteria-free air, radio, television eventually, and facilities for electric shavers, milk warmers, and other personal services, each adds to the electrical load of a passenger car. Where this energy is to come from is a problem that is becoming increasingly important.

Electric power for passenger cars, in the past, has been supplied by axle-driven generators and large 32-volt storage batteries. When the train is at a standstill or running at low speed, the power is supplied from a battery. Of necessity the power is direct current at comparatively low voltage. At higher speeds, the axle-generator voltage becomes enough to assume the load and to charge the battery. However, as the electrical load increases, the inefficiency of the system makes the generator and battery sizes burdensome and places a serious drain on the locomotive. With each kilowatt of added load, approximately two extra horsepower are required and must come from the axle, (i.e., from the locomotive). Some railroads have estimated that the load due to the axle generators has decreased the locomotive effective traction effort such that a normal 14-car train without axle generators must be decreased to 12 cars when axle generators are used. This reduction of cars, from 14 to 12, represents a 15-percent loss of revenue. Also, because of the inefficiency in supplying energy from the locomotive, the fuel cost cannot be ignored. With electrical loads increasing, the weight of the axle generator is beginning to exceed desirable limits.

One answer to this is to provide each car with a self-contained power plant. This makes the car independent of the locomotive and remainder of the train as far as its own functions are concerned. Such a power plant is a diesel-driven, 3-phase, 60-cycle, 220-volt, 30-kva alternator.

Advantages of A-C Power

The a-c system offers several important advantages. Many stem from using standard 110-volt, 60-cycle motors, lamps, and other electrical devices. This is particularly true of fluorescent lamps. Use of alternating current eliminates brush mechanisms with their need for more frequent servicing. The initial cost of a-c motor-powered devices is less than for direct current. Fluorescent lamps work better on a-c.

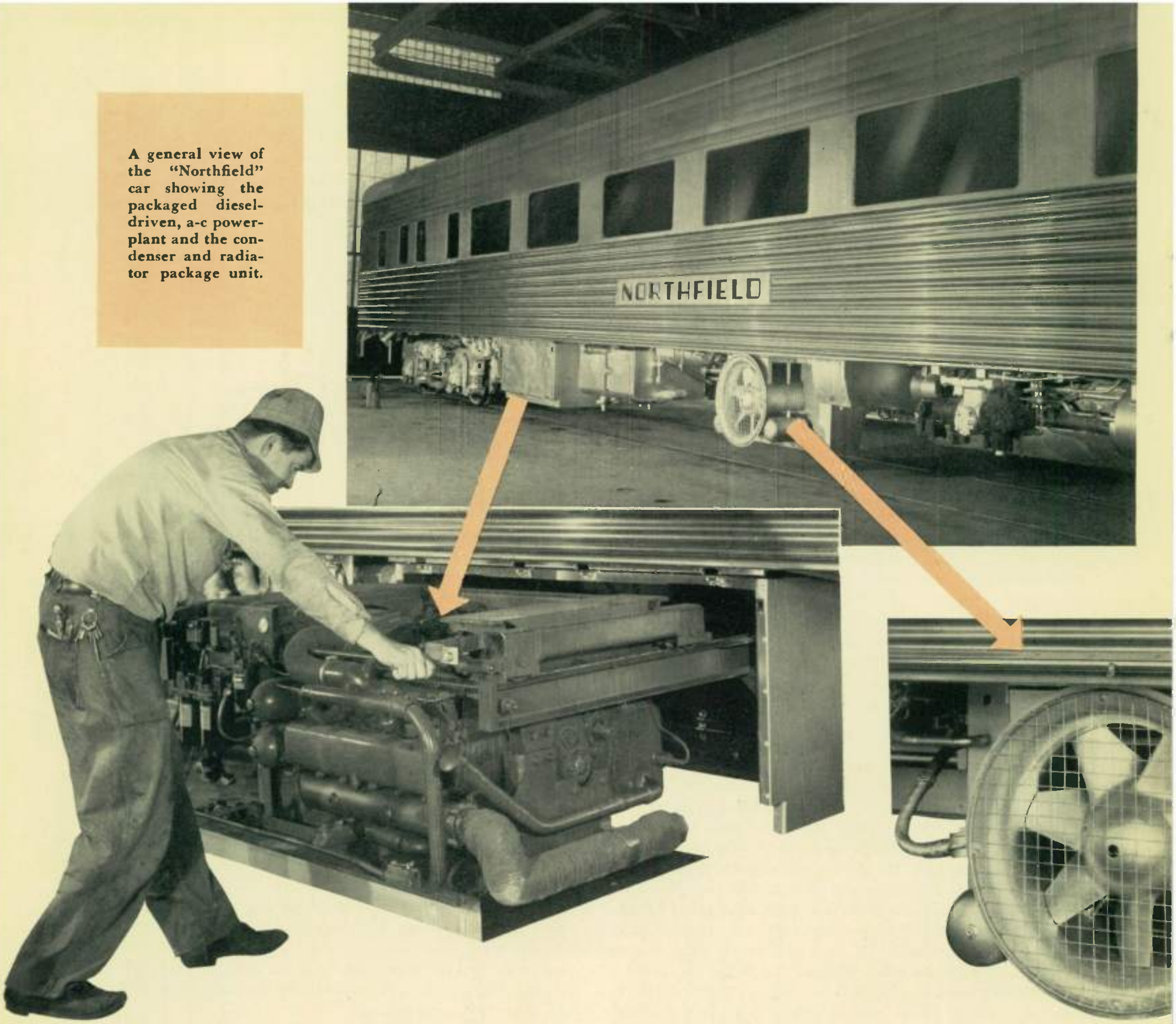
With a power plant that runs continuously, i.e., one that is independent of train movement, the size of battery required is greatly reduced. With the proposed system the only battery needed is for emergency service and this can be one of 284 ampere-hour capacity at 32 volts, weighing 1128 pounds. Batteries for passenger cars, but with smaller loads than contemplated for future cars, have been rated up to 550 ampere-hour capacity, 110 volts, and weigh up to 10 400 pounds. Batteries also are costly initially and to service. The space saved by the smaller batteries is very important.

Perhaps the most significant result of an a-c power supply on a passenger car, because the motor has no brushes, is that it is possible to use hermetically sealed compressors for the air-conditioning system. It is impossible to seal hermetically a d-c motor into a freon system. Consequently service expense is larger with a d-c system because of seal leaks. A hermetically sealed compressor, with its complete elimination of all external moving parts, properly installed with tight joints and a clean, dry system is spared the frequent servicing normally resulting from the infiltration of dust and moisture. Many years of operation without service is not unusual for this type of machine. The hermetically sealed compressor unit, in which the motor is contained within the same enclosure as the compressor, has been the greatest single factor contributing to the success of modern domestic refrigerators and air-conditioning systems.

With each passenger car possessing its own power plant, in severe weather it makes no difference whether the car is the first or last on the train. The system is not dependent on locomotive steam for the heating of the space. Ample heat is available from the electric heaters and from the diesel engine waste heat.

Two power plants of this engine type are sufficient to supply an all-electric diner—air cooling or heating as well as all cooking loads. This eliminates wasteful and generally unpleasant fuel-fired stoves, and thus adds considerable passenger appeal.

A trial installation with equipment of this type was made late in 1948 on the car "Northfield" of the Chicago Rock Island and Pacific Railroad. The car was first put in service between Chicago and Des Moines on the *Des Moines Rocket*. In order to obtain information on a north-south run with its extremes in temperature, the car was transferred to the *Twin Star Rocket* running between Minneapolis and Houston, Texas, in February, 1949. It remained in this service regularly until November, 1949, when it went into its present run between Denver and Chicago on the *Rocky Mountain Rocket*.



A general view of the "Northfield" car showing the packaged diesel-driven, a-c power-plant and the condenser and radiator package unit.

The Power-Plant Package

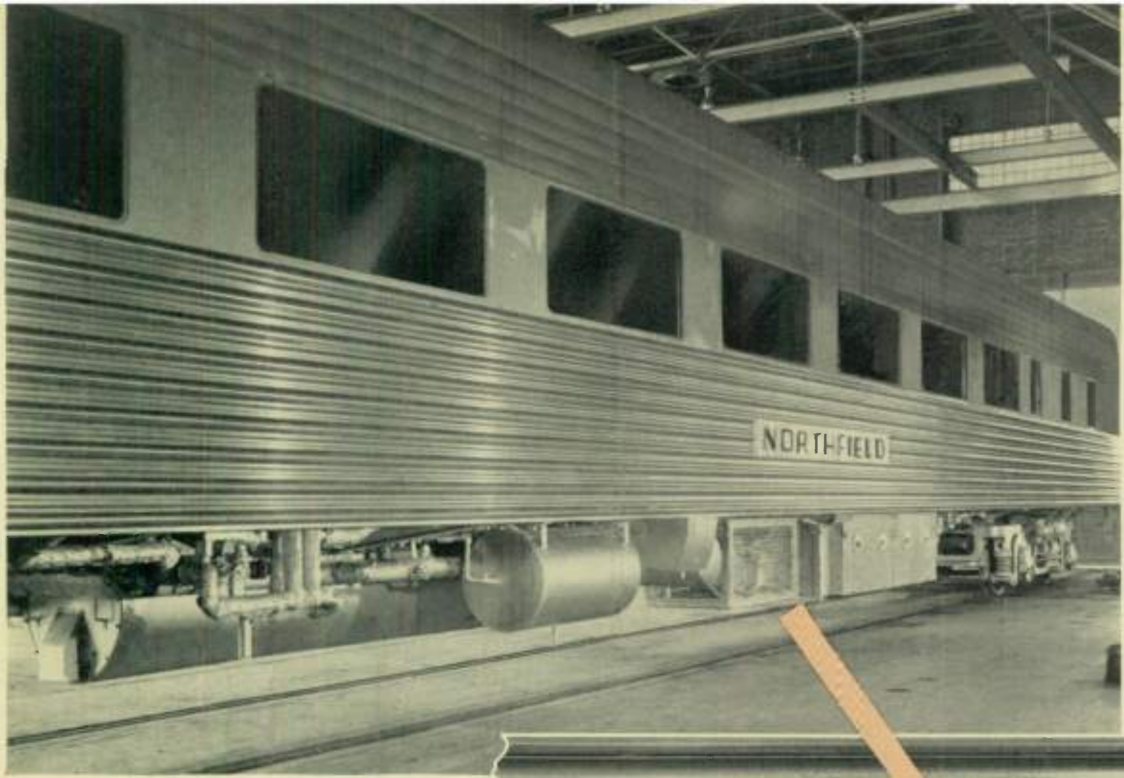
The heart of the entire system is a power-plant package, resiliently mounted under the car, containing a diesel engine and alternator. The complete removable power plant weighs 3000 pounds. The engine used is a Hercules diesel, type DJXHF. This is a horizontal engine specially developed to meet the exacting clearances required where the equipment must be mounted under railroad cars.

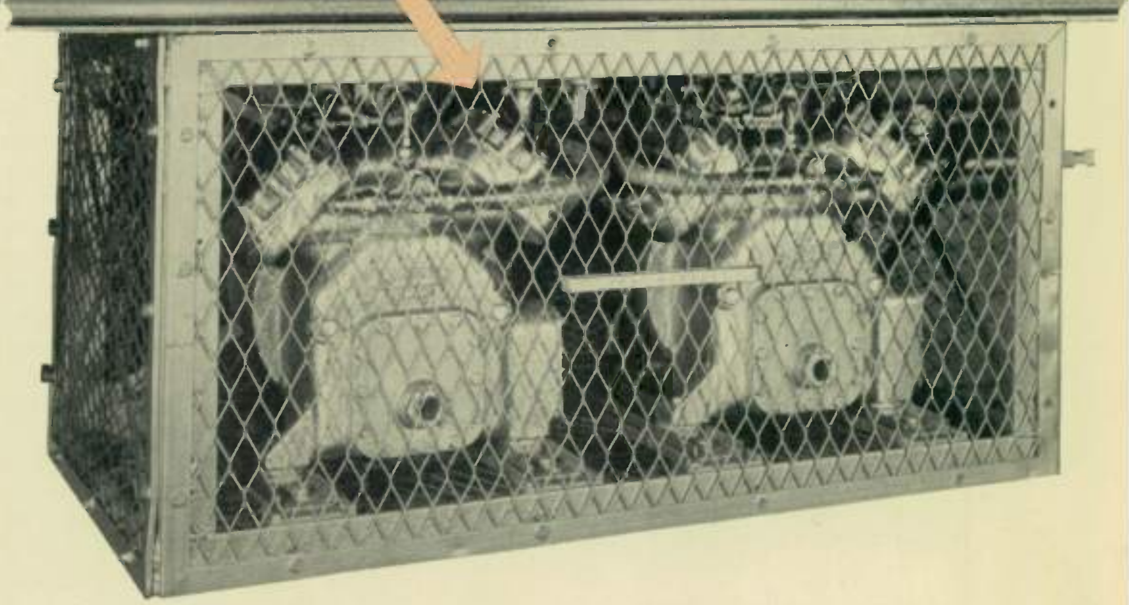
This engine is a six-cylinder unit with 298 cubic inches displacement and a rating of 79 hp at 1800 rpm at sea-level altitude and normal temperature. When the engine is derated for altitude and temperature, it is rated at a little more than two hp per kw of generator rating. Operation of the engine at light loading tends to reduce maintenance requirements and costs, but still keeps the engine in a loading range that gives economical operation.

Coupled directly to the engine is a Westinghouse 3-phase alternator. It delivers 30 kva at 0.8 power factor, 220 volts, 60 cycles. The excitation system has no moving parts, which saves a great deal on service work and gives better regulation. The rotating main field is excited through the car emergency-lighting battery. The second or auxiliary field is excited to maintain constant voltage at varying generator loads. It is connected across a selenium rectifier that is served by three current transformers in the main-generator leads. Any increase in generator load increases current in the rectifier, thus raising the field current to maintain a constant voltage. Response to load changes is extremely rapid, as no inertia of moving parts is involved. Excellent regulation is obtained.

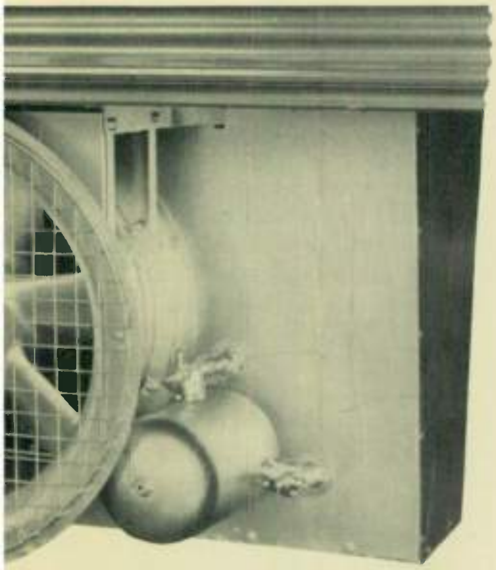
The engine and alternator are packaged so that all routine servicing of the engine can be accomplished without moving it. Lubricating-oil filters, fuel filters, air cleaner, lubricating-oil drains, and filler pipe are all located at the front of the unit. When it is necessary for other servicing or to replace the power plant with a spare, the entire unit is rolled out on slide rails after disconnecting sealed water and fuel couplings and electrical plugs. Removal and replacement of a power plant have been accomplished in five minutes.

To furnish the engine with as clean combustion air as possible, 250 cubic feet per minute of conditioned air is drawn





Mounted underneath the other side of the car are hermetically sealed air-conditioning compressors, also supplied as single units.



from within the car. This air first passes through the generator and then divides. Part goes to the engine air intake through its air filter. The remainder spills into the power-plant package, building up a slight pressure that helps keep dirt out. This clean air serves to reduce maintenance and insures against engine damage should the engine air filter not be properly maintained.

To facilitate starting in cold weather, a loop is connected to the train steam line and run through the power-plant package. When outdoor temperature drops to 40 degrees F and the engine is shut down, steam is supplied to the loop, keeping the engine warm.

During a typical period, which covers both winter and summer operation, the average loading of the unit was 13.7 kwhr. The fuel consumption was 6.73 kwhr per gallon of fuel oil, and lubricating oil, 72.8 kwhr per quart.

Air-Conditioning System

The air-conditioning system is designed to use two standard Westinghouse hermetically sealed compressors. Each compressor is driven by a 5-hp, 3-phase, 60-cycle, 220-volt, 1750-rpm motor built integral with the compressor. Freon-12 refrigerant vapor passes over the motor windings to cool them. The compressors are connected to two entirely separate air-conditioning systems and have a total cooling capacity of from eight to nine tons.

The outstanding advantage of the two separate systems over the single-compressor system is the fact that one unit can ordinarily carry the load. The second unit is required on only a few high-temperature days, in case of a breakdown of one compressor, or should a leak develop in one system. In the single-compressor system, a failure of this type would mean a hot car for the remainder of the run, which might be as much as 60 hours.

For ease in servicing—a matter of great importance to railroads—each compressor is also mounted in a package on movable slides. Lines to each are sealed by a set of valves while the compressor itself is sealed by another set. Closing these valves and unbolting two flanges allows the compressor to be removed and another fully charged one slid into its place. The compressor-package, like the engine-generator package, is an under-car installation.

The method of controlling the air-conditioning system provides the railroad passenger with comfort far greater than conventional systems. The essential difference is the removal of moisture from the car air when the outdoor temperature range is between 60 and 75 degrees F and then reheating the air to the desired car temperature. One compressor system is controlled only by outdoor temperature and operates continuously when the temperature is 60 degrees F or above. At this point, car cooling is not needed, but the evaporator cools the air in order to remove moisture from it. This moisture is removed in sufficient quantity to insure a satisfactory effective temperature without dependence on a humidistat. Humidistats in general are erratic. After some moisture has been removed the air is reheated electrically to maintain the car temperature at 75 degrees F.

The second compressor and its system are controlled only by the temperature within the car. It operates only when the first system is not able to keep the car down to 75 degrees F or at any time when the car temperature is above its 75-degree setting. In this manner, car conditions of 75 degrees F and below 55 percent relative humidity are maintained during all warm-weather periods.

Future installations of this system will provide for the use of the engine waste heat in heating the car, thus making the car completely independent of the locomotive for heating, cooling, and power. This was purposely not done with the experimental installation to simplify the gathering of performance data. With this additional utilization of equipment, part of the 55- to 65-percent loss in heat energy from the fuel will be utilized, making an extremely efficient system.

It is expected that when complete trains are equipped with this system, operation in multiple will be desired. This can be done in several ways. Power units can be completely independent of each other with a manual control for handling half load on each of two cars when there is a breakdown on one. Power units can be independent with automatic half loading between cars. Or all power units can be paralleled in the train with each car taking the power it requires.

The Air-Conditioning Condenser

The condenser is also quite different in arrangement from most condensers. This one is air cooled, but it is aided by atomizing sprays of water controlled by discharge pressure. The condenser can carry an 8-ton load, without any water, until the outdoor temperature exceeds 90 degrees F. If the temperature is above 90 degrees F, the discharge from the compressor in service rises sufficiently to bring the sprays into operation. Each compressor has its own condensing coil and subcooling coil. The condensing coils and subcooling coils are built into one assembly and receive their cooling air from one Axiflo fan. Liquid receivers for the two systems are also mounted on the package.

To save duplication in parts such as motor, fan, and casing, the engine radiator coil is mounted in front of the condenser coil as part of the condenser package, using the condenser fan and housing. This method also insures that a separate radiator cannot be located under the car to blow hot air over the condenser coil, which would reduce its capacity.

The mounting of the radiator coil with the condenser poses a problem in winter. It is necessary to operate the fan at all times for engine cooling, but during the winter with the condenser not operating, snow could block the condenser coil and prevent air from reaching the radiator. By automatically reversing the rotation of the motor-driven fan, when the outdoor temperature drops to 40 degrees, the air is then brought in through the hot radiator coil, which insures against coil blockage. At 60 degrees the fan again reverses to its normal rotation. Any water in the spray system is also automatically dumped at this same 40-degree temperature to prevent freezing and damaging the apparatus.

The Air-Conditioning Evaporator

The system evaporator is an overhead type located in the roof of the car. The evaporator is made up as a packaged unit, which includes two separate system coils, a fan section, an emergency steam coil, and a bank of electric strip heaters for use on reheat and car heating. Two single-inlet Multivane fans supply air to the evaporator. Two thirds (1600 cfm) of the air is recirculated; one third (800 cfm) is outdoor air. The evaporator coil for each system covers the full face of the package so that all air must pass over a refrigerated surface, even with one compressor shut down. On the leaving end of the evaporator is mounted an 18-kw bank of electric strip heaters that are used to reheat air leaving the evaporator after dehumidification and for car heating in cold weather.

The Control System

A novel and effective method is used in controlling the overhead bank of electric heaters. Three 7½-kva saturable-core reactors control the power input to the heaters. The a-c coil of each reactor is placed in a leg of the three-phase circuit. The current in the heater circuit is then controlled by superimposing d-c excitation upon the regular a-c excitation on the core. The d-c excitation is varied through a motor-operated rheostat which is, in turn, controlled by the car-temperature system. Excellent modulated control of the overhead electric heat is obtained by virtue of the large number of heating power steps inherent in the rheostat. Furthermore, this method of control eliminates the contactors that would be needed if heat control were obtained by cutting resistance heating elements into and out of the power circuit.

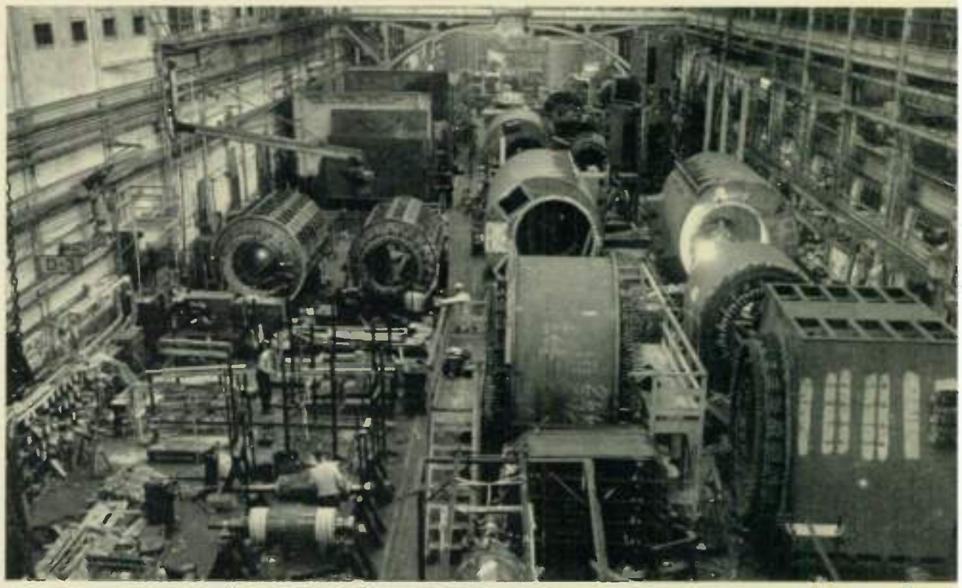
Controls for the air-conditioning and generating equipment are relatively simple. All controls for air-conditioning equipment are placed on a Micarta panel. Equipment on this panel includes contactors for each compressor and evaporator fan. Panelboard-type breakers are used for each of these pieces of equipment as well as the electric-heating circuit. The remaining item on the panel is a timer that prevents the compressors from starting at the same time. The timer is necessary to prevent light flicker at temperature conditions that would place the two compressors on the line simultaneously. The second compressor is thus delayed from starting until 15 seconds after the first one starts. Controls for the power plant are placed on a Micarta panel also, and include the main line contactor and breaker along with two control contactors. The equipment is fully automatic, one pushbutton being pressed to start the entire electrical and air-conditioning system in operation and another to stop it.

The Rock Island car "Northfield" had been previously equipped with 32-volt, d-c lighting. It was decided to leave these lamps in and operate them on 32 volts alternating current through a 220/32-volt transformer.

Experience gained thus far from this installation has already proved valuable to us, to the railroads, and to equipment builders in showing what is practical at this time as well as suggesting new horizons for the future. It is certain that railway air conditioning will continue to improve and demonstrate its essential value.

Since 1910 consumption of electricity in the United States on the average doubles every ten years. The electricity production curve looks like one arm of a parabola. The natural consequence is that power companies continually require more machines and bigger ones. To keep up with this, very much expanded and modernized manufacturing facilities are being provided at East Pittsburgh.

From D-aisle to D-aisle



The D-Aisle as it looked in 1903 (top view) and in 1941 (below).

When George Westinghouse built the main aisles of the East Pittsburgh manufacturing plant in 1899 he planned well. One aisle he made big. Known as the D-aisle, it was 66 feet wide, and almost 1200 feet long. For several years it held the record as the world's longest manufacturing aisle until one only a few feet longer was built almost adjoining it.

Building such a manufacturing aisle a half-century ago was a bold step. The electric power industry was in its infancy and the giant machines of today could not have been imagined. The first central-station steam turbine had not yet been built. (The rights to build steam turbines were brought to this country from Parsons of England by George Westinghouse only three years before.)

The machines built during the early years of the new shop were small in rating. But that doesn't mean some of them weren't big. In 1905 the engine-driven generators for the Manhattan plant in New York were built here. These 6000-kw giants—which established the high-water mark in engine-driven units—were 40 feet high. (The 108 000-kw Grand Coulee generators, which came 40 years later, were but 31 feet high from floor to pilot exciter.) The one-quarter sections of the stators for those Manhattan generators are seen in the foreground of the picture of the aisle taken in 1903.

The original plan served its purpose well. Although the massive engine-driven generators—like the dinosaurs—became a relic of the past, turbine generators began to grow to ratings undreamed of when the cornerstone was laid. By 1920 generators of 20 000 kw and 20 feet long were being erected. And in 1934 the largest single-shaft generator ever built was completed in this aisle. This was the 165 000-kw, 1800-rpm machine for Richmond Station of the Philadelphia Electric Company.

About this same time, the designers of the giant 200-inch Mt. Palomar telescope were looking for a factory with machines and space big enough to construct the telescope mount. The D-aisle was one of the few with space and boring mills big enough to do the job.

Meanwhile another newcomer appeared on the power-plant horizon to bring a second temporary halt to the growing dimensions of generators. This was the 3600-rpm generator, which in 1930 was only 15 000 kw. By 1937, the size had crept up to 50 000 kw. By 1941 to 65 000 kw. The war stopped large generator construction, but the war's end released an enormous pent-up demand for electrical energy that quickly swept high-speed turbine generators to unheard-of numbers and sizes. In 1951 over three million kw of generators will pass through D-aisle portals. This is more than three times the total United States installed generating capacity when the aisle was completed. Machine sizes now exceed 150 000 kw.

Yes, George Westinghouse planned well. But progress of a half century has caught up with his plan. While the giant aisle can still cope with the largest machine any central-station needs at present, the combination of size and numbers is crowding its capacity as an efficient manufacturing space.

As a result a new aisle is under construction for use late in 1952. The present aisle will remain, but beside and paralleling it will be another of essentially the same length but half again as wide—about 100 feet. It will have higher head room. The 93 feet from floor to roof is equal to a seven-story building. Particularly important will be larger cranes. To make the heavy lifts at present sometimes requires four cranes acting as a team with a double-tree lifting mechanism. This is cumbersome and a production deterrent. The new facility will have two decks of cranes, those in the upper deck being capable of lifting loads as heavy as 350 tons. (The heaviest piece of any machine now under construction weighs 200 tons.) The general flow of materials will be improved to expedite delivery time.

The planners for the enlarged construction, like their predecessor of a little more than a half century ago, have tried to look long into the future. Working in coordination with the existing D-aisle, which will continue large generator manufacture, the new aisle will make it possible to take care of a much larger volume of machines and extremely big machines with least waste motion and time. The new aisle is planned to accommodate not just the biggest machine designers of power plants can foresee now, but one 25 percent larger than that.

Overvoltage During

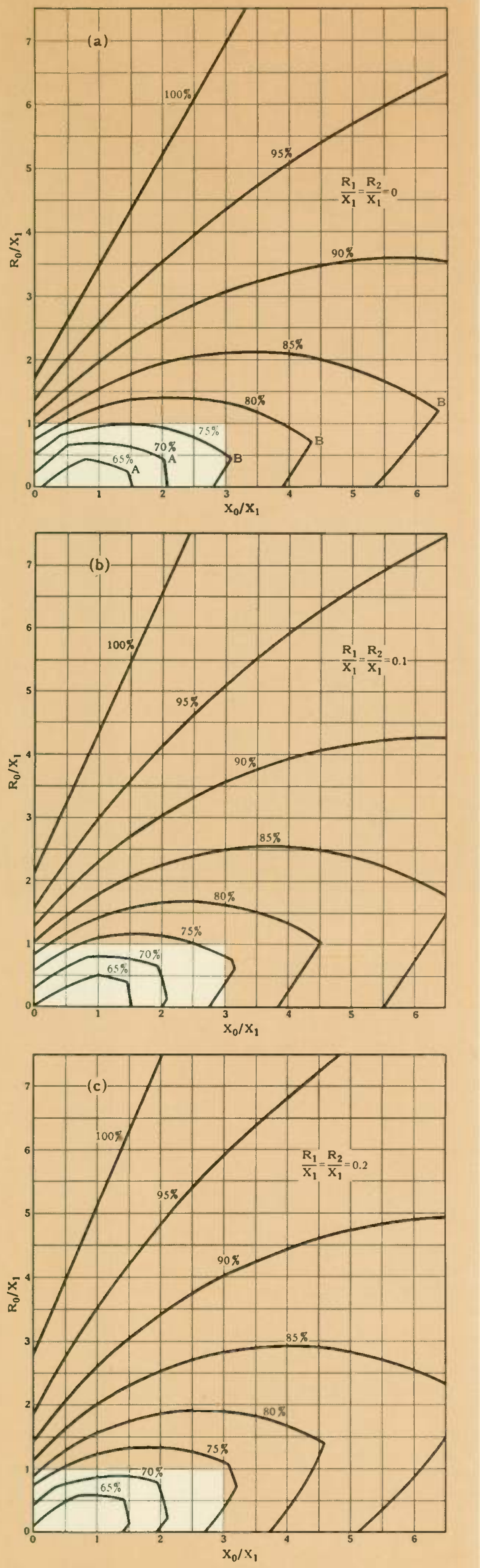
An important factor in lightning-arrester application is the determination of the maximum dynamic or power-frequency voltage that may exist across an arrester during fault conditions. Lightning arresters must be chosen so that their rating is greater than the maximum dynamic voltage that can exist across the arrester for any type or location of fault. Thus, the maximum possible dynamic voltage at a given location determines the minimum allowable arrester rating and, together with the surge characteristics of the arrester, sets the lower limit to the surge protective level attained by applying an arrester at a given location.

Under normal conditions the line-to-ground voltage is 57 percent $(1/\sqrt{3})$ of the system line-to-line voltage. Current in the neutral impedance and coupling between the faulted and unfaulted phases causes the line-to-ground voltage on an unfaulted phase to increase during some fault conditions. Thus, because an arrester might have to operate during a fault on another phase, its rating must be greater than the maximum rms voltage across the lightning arrester during any fault condition.

To simplify the task of lightning-arrester application, Evans and Beck[1] presented a method for estimating maximum dynamic voltage from curves based on the ratios of system impedances. Their curves, shown in Fig. 1(a), give the maximum line-to-ground voltage as a percent of the base line-to-line voltage in terms of the ratio of R_0 (zero-sequence resistance) to X_1 (positive-sequence reactance) and the ratio X_0 (zero-sequence reactance) to X_1 for a system with no positive- or negative-sequence resistance. All of these quantities are the equivalent impedances seen when looking into the system from the point of fault. The base voltage is usually taken to be 1.05 times the normal line-to-line voltage to allow for emergency operation.

At each point in Fig. 1(a) the type of fault and amount of fault resistance that will give maximum voltage is used to determine the voltage for given system impedance ratios. The curves from the points labeled A to the X_0/X_1 axis are determined by the phase-*a* voltage during a double-line-to-ground fault on phases *b* and *c*. From point B to the X_0/X_1 axis, the phase-*b* voltage during a single-line-to-ground fault on phase *a* determines the curve. The remaining parts of the curves are determined by the phase-*c* voltage during a single-line-to-ground fault on phase *a*. In applying the curves, any phase can be designated as phase *a* so long as a positive-sequence phase rotation is maintained.

Because an actual power system has positive- and negative-sequence resistance, their effect on dynamic overvoltage must be considered. Two curves that show the addition of equal amounts of positive- and negative-sequence resistance—



←

Fig. 1—Line-to-ground voltage charts for grounded systems with dynamic voltage as a percentage of the base line-to-line voltage. The unshaded areas are the usual values that can be expected on effectively grounded systems. The curves at (a) are for a system with no positive- or negative-sequence resistance. Those at (b) are for systems with positive- and negative-sequence resistance equal to $0.1X_1$; those at (c) are for sequence resistance equal to $0.2X_1$.

Power-System Faults

The choice of a lightning arrester for a particular application involves many factors. Determination of the maximum dynamic voltage has been facilitated by the development of some new curves.

R. W. Ferguson, *Central Station Engineering, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania*

0.1 X_1 in Fig. 1(b) and 0.2 X_1 in Fig. 1(c)—have been designed to supplement the original.[1] This positive- and negative-sequence resistance causes the maximum voltage to decrease for those portions of the curve determined by the phase-*c* voltage. The voltage increases slightly on those portions of the curves determined by the phase-*b* voltage and decreases slightly on the portions of the curve determined by the phase-*a* voltage.

When using these curves with long high-voltage lines, the effect of line capacitance must be considered. By use of Thevenin's theorem the curves can be applied directly to these systems. The base voltage for the curves is the maximum voltage at no load at the arrester location; this will usually be greater than the source voltage. As before, five percent should be added to take care of emergency operating conditions. Line capacitance is taken into account by including it in the calculation of impedance ratios for the system as they appear at the arrester location.

The curves of Fig. 1 give the maximum voltage across the arrester for any fault to true ground at the arrester location. But some consideration must be given to the possibility of a fault at another location or a fault to arrester ground. Under certain system conditions, either of these may cause a higher voltage across the arrester than is indicated by the curves.

A different fault location can give a higher voltage when a higher R_0/X_1 and/or X_0/X_1 exist at another point in the system, or by the voltage-multiplying effect of an unloaded transmission line. By checking the system impedance ratios around the arrester location the possibility of a higher voltage from a higher impedance ratio can be determined. The maximum error in the curves due to the voltage-multiplying effect of a transmission line occurs when arresters are connected to ungrounded transformer banks at the end of a radial high-voltage line with a fault near the source end of the line. The curve of Fig. 2 gives an indication of the increase in voltage that can occur over that indicated in Fig. 1 at the fault location in terms of the length of line between the arrester location and the fault in miles for an X_0/X_1 ratio of three and R_0/X_1 ratio of one at the fault location. The increase in voltage on an actual system is less than this because the effect of loads and transformer magnetizing current is neglected in Fig. 2. For these cases, where X_0/X_1 is less than three at the fault location, the values from the curve of Fig. 2 are too high.

The sequence connections for a fault-to-arrester ground are indicated in Fig. 3(a). It is assumed that no ground wires of incoming transmission lines are connected to station ground. In Fig. 3, R_1, R_2, X_1 and X_2 are the impedances measured by looking back into the system from the fault point. X_{0T} represents the zero-sequence impedance of any transformer banks that are connected to the arrester ground as illustrated in Fig. 3(b). By adding three times the arrester ground impedance, $3R_A$, to the system impedance, $R_{0S}+jX_{0S}$, and paralleling this new impedance with X_{0T}, an equivalent zero-sequence impedance, R_0+jX_0, can be found.

$$R_0+jX_0=\frac{(3R_A+R_{0S}+jX_{0S})(jX_{0T})}{3R_A+R_{0S}+jX_{0S}+jX_{0T}}$$

This impedance should be used to compute the R_0/X_1 and X_0/X_1 ratios to use with the curves of Fig. 1 in finding the maximum voltage across the arrester during a fault to arrester ground. If no transformer neutrals are connected to the arrester ground jX_{0T} becomes infinite, and R_0+jX_0 is equal to $3R_A+R_{0S}+jX_{0S}$.

If ground wires of incoming lines are connected to station ground, the zero-sequence impedance to be paralleled with X_{0T} is a complex combination of arrester ground resistance and the zero-sequence impedance of the line. Since this impedance is usually less than a simple series combination of arrester ground resistance and system zero-sequence impedance, results obtained by the method outlined in the preceding paragraph give a greater arrester voltage than is actually present and can be used in arrester application.

These curves should serve as a guide in the application of arresters to grounded systems. Some margin should be included to take care of the possibility of greater voltage for other fault locations in line with the above discussion. A system is said to be effectively grounded if the X_0/X_1 ratio is not greater than three and the R_0/X_1 ratio is not greater than one. This range, unshaded areas in Fig. 1, is always within the 80-percent curve with the exception of a small area at low values of X_0/X_1. Thus, the curves justify the present practice of applying arresters rated at approximately 84 percent (1.05 times 80 percent) of normal line-to-neutral voltage to effectively grounded systems.

REFERENCES

1. "Selection of Lightning-Arrester Voltage Ratings," by R. D. Evans and Edward Beck, *Westinghouse* ENGINEER, February, 1942, p. 7.
2. "Symmetrical Components," by C. F. Wagner and R. D. Evans, McGraw-Hill Book Co., 1933.

Fig. 2

Voltage increases at various fault locations, due to the effect of unloaded transmission line, for impedance ratios of $X_0/X_1=3$ and $R_0/X_1=1$.

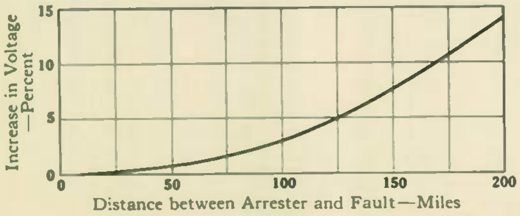
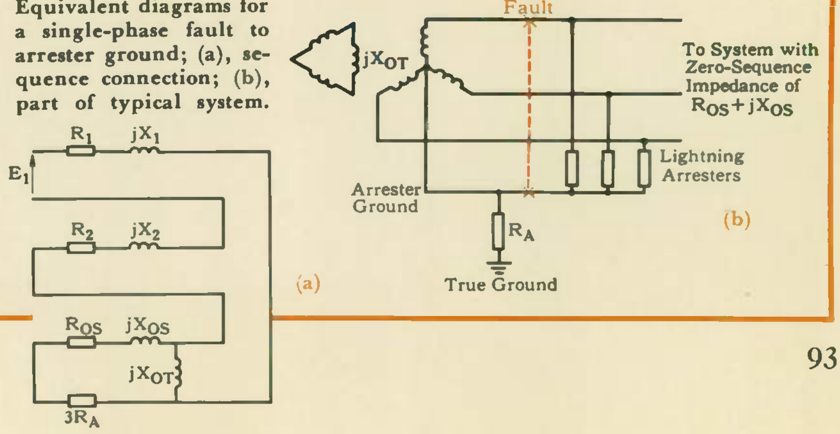


Fig. 3

Equivalent diagrams for a single-phase fault to arrester ground; (a), sequence connection; (b), part of typical system.



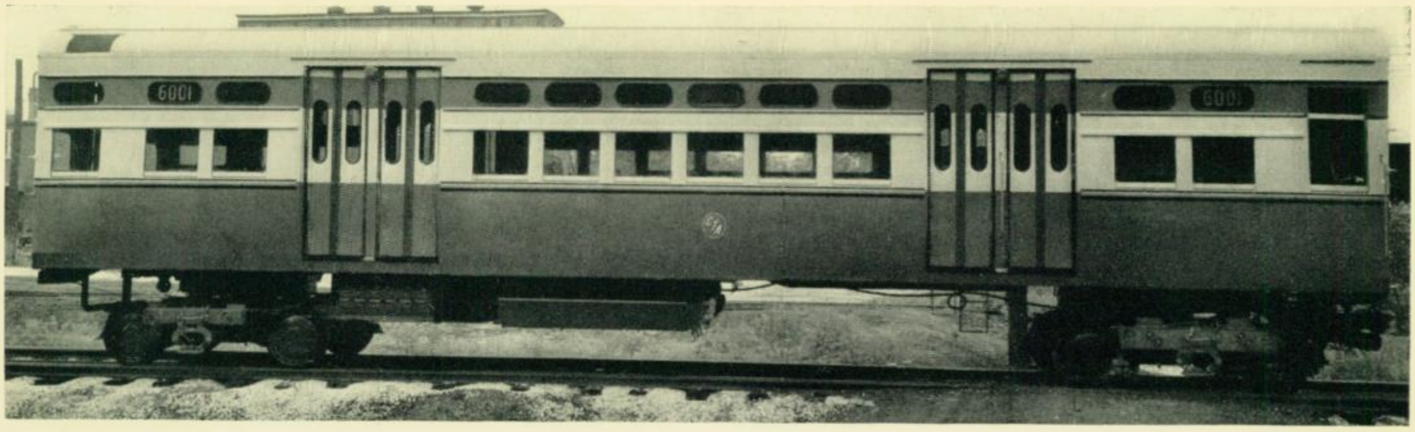


Fig. 1—The lightweight rapid-transit car gives the rider comfort, speed, and safety; the operator gets efficient, economical operation.

Rapid Transit Gets a New Car

Multiple-lane, high-speed thoroughfares have failed to provide a solution to the congested downtown traffic problem. Rapid-transit systems are the answer for many large cities now devoid of such facilities. Lower initial investment, reduction in operating and maintenance costs, and a car designed for fast, comfortable, safe service increase the financial attractiveness of such systems. A new lightweight rapid-transit car, modeled after the PCC streamlined streetcar, is a vehicle that satisfies those requirements.

M. L. Sloman, *Transportation Engineer, Industry Engineering Dept., Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania*

Twenty years ago a radical departure was made in the design of surface streetcars when the Presidents' Conference Committee, composed of the presidents of the major city transportation companies, decided that they needed a better trolley car. The result was the PCC streamlined streetcar for city transit service. Now this car has played an important role in the development of a new vehicle for rapid-transit service. The new, lightweight rapid-transit car, developed through the combined efforts of the American Transit Association, the Transit Research Corporation, and interested manufacturers, retains the basic features and equipment of the PCC car. Modifications were made only where conditions peculiar to rapid-transit service required them.

The structural elements of the standard PCC car that reduce weight and lower first cost by making volume production possible, are retained. One change necessary in the rapid-

Fig. 2

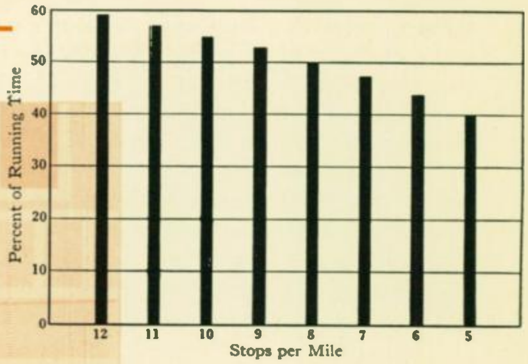
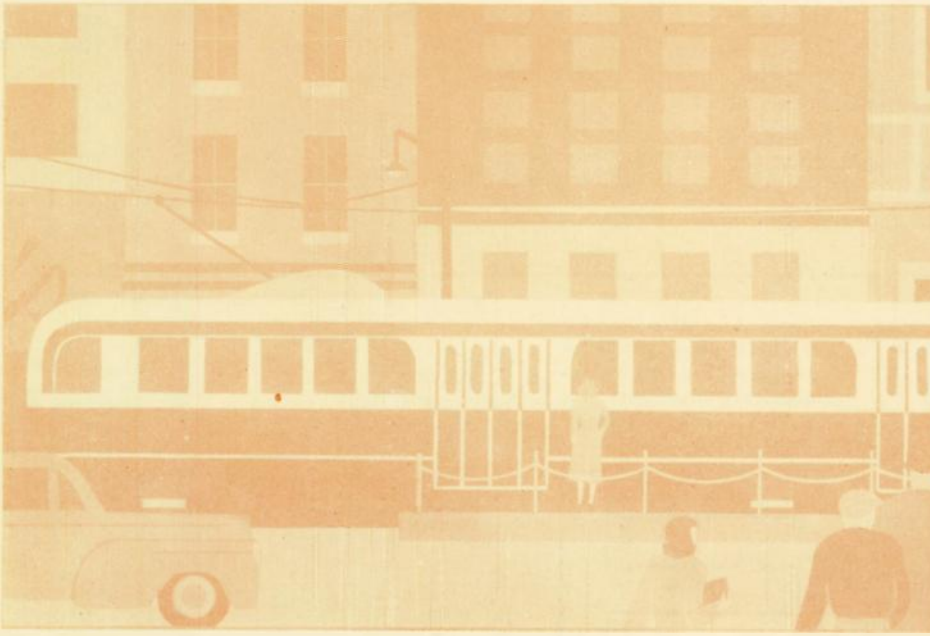


Fig. 2—The time required by the PCC streetcar for accelerating and stopping in normal surface operation is expressed here as a percentage of the running time.



transit version of the PCC car is provision for high-level platform loading. Two or three large doors on each side of the car hold the loading and unloading times to a minimum. And the maximum capacity of the car is increased to 180 passengers, 44 percent more than the standard car, while the number of seats is decreased by a longitudinal arrangement to 46, only 15 percent less than the standard car. The car is mounted on two 4-wheel trucks, which can be modified to accommodate the brake system necessary for the application. The wheels are either 26 or 28 inches in diameter, and may be all-steel or the resilient type used on the standard surface car. The rapid-transit car is 48 feet long and is equipped for multiple-unit operation. It weighs approximately 45 000 pounds empty. Seated load and maximum load are 52 000 and 70 000 pounds, respectively. Corresponding weights for the PCC car are: 36 000 pounds empty, 43 500 pounds seated, and 52 800 pounds maximum load. A profile view of the new car is shown in Fig. 1. These cars can be connected back to back to form a semi-permanently connected two-car unit. Units can be operated alone, or combined to make up trains of four, six, eight, or ten cars when traffic demands larger trains.

Propulsion Equipment

Most existing rapid-transit lines operate on 600-volt d-c power taken from a third rail, because height restrictions make the use of trolleys impractical in subway operations. However, Westinghouse developed a special lightweight pantograph trolley to be used on the new cars when they operate from an overhead trolley on a surface right of way. When the cars operate underground, this trolley folds down on the roof so that it will not foul tunnel ceilings.

The propulsion equipment consists of four traction motors (type 1432), each rated at 55 hp and driving through the same hypoid gear unit that is used on the standard PCC trolley car. This gives the new car a high ratio of horsepower per ton weight for both empty and maximum load conditions. With the standard gear ratio of 7.17 to 1 and 26-inch wheels, a two-car train is capable of attaining a free running speed of 46 mph with average passenger load on level tangent track.

Nature of Service

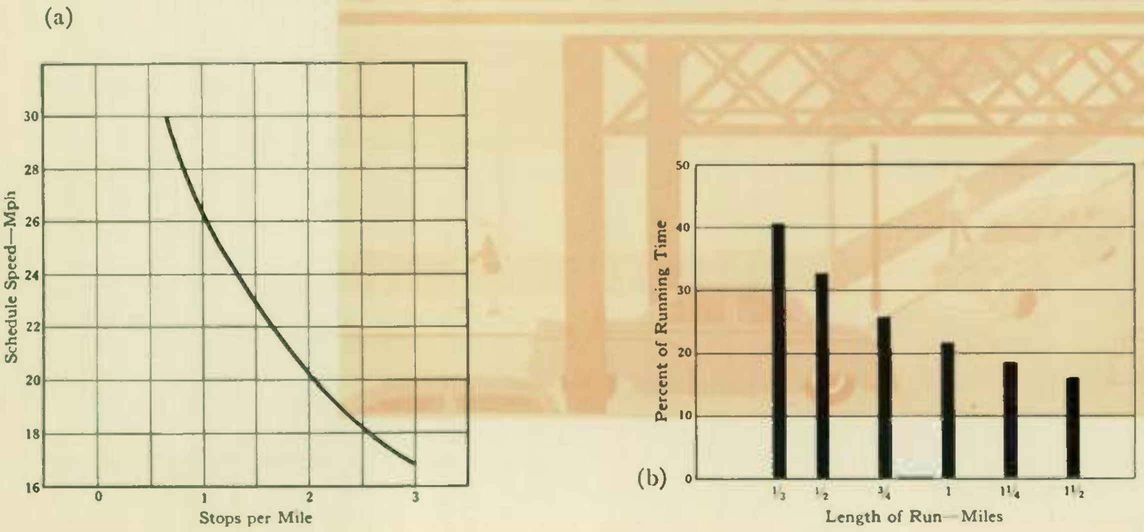
It may seem strange that the same traction motor is used in both the PCC car and the lightweight rapid-transit car, which carries much heavier loads usually. However, it's a matter of the kind of service required. For city-transit service the standard PCC car has maximum accelerating and dynamic braking rates of 4.75 miles per hour per second, although the average accelerating rate in service is closer to 3.5 mphps. These high rates were necessary to maintain the car's position with respect to other street traffic and to increase schedule speeds over those obtained with older models replaced by the PCC car. On heavy-traffic lines, where streetcars are the most economical vehicle to operate, the number of stops per mile may vary from 5 to 12. This makes the average length of run so short that much of the running time is consumed in accelerating and braking. This is shown graphically in Fig. 2. The only way schedule speed could be increased was to provide enough motor capacity to obtain the highest practicable accelerating and braking rates.

On the other hand, rapid-transit service normally averages only one to three stops per mile. The longer runs permit more high-speed operation, and the accelerating and braking rates may be lower than for surface cars, since only a small percentage of time is consumed in these operations. This is shown in Fig. 3(b). These two conditions, lower accelerating and braking rates, and longer runs, have made it possible to use the standard PCC motor on the heavier cars and loads common to rapid-transit service without exceeding the motor's margin of safety.

The true measure of a car's performance is its ability to maintain high schedule speeds. This is doubly important in rapid-transit service, for with proper headways and signal systems the car is on its own, unhampered by traffic jams and traffic lights encountered in surface operation. The new lightweight car maintains the fast schedules that are requisite to rapid-transit service, as shown in Fig. 3(a).

Fig. 3 (a) & (b)

Fig. 3(a)—Typical schedule speeds of a two-car train made up of lightweight rapid-transit cars with average load on level track. This shows clearly how the number of stops per mile affects schedule-speed performance. (b)—Accelerating and braking time, expressed as a percentage of the running time, for a two-car train operating with average load. Length of a run is the distance between stops.



Control Equipment

The control scheme is similar to that used on the standard PCC car, although some of the electrical apparatus had to be redesigned to meet the special operating conditions required in rapid-transit service. A larger accelerator is used, with 135 resistance steps instead of 99, because smooth, high-speed dynamic braking calls for a resistance 50 percent greater than that normally used on the PCC car. A special line relay is used to compensate for the effect of frequent third-rail gaps, which momentarily cut off power to the car. The relay has a very fast opening time and a delayed pick-up that gives the control equipment time to adjust so that the reapplication of power is smooth and unnoticeable.

A train of lightweight rapid-transit cars in Chicago's Loop, where the new car was first tried out. Two hundred of these cars are being built for the Chicago Transit Authority to replace older cars.

In a long train the motor-generator set on the lead car normally must supply a heavy train-line control load. So that a standard motor-generator set could be used, this load has been held to a minimum by installing special operating coils on all train-line contactors, and by using relays to actuate the reverser. Thus, full operating coil current is not carried by the train-line wires.

Because rapid-transit trains are made up of two to ten cars, a defective car in a long train may go undetected and build up braking currents during acceleration. To prevent this, a loop contactor is placed in series with one pair of motors to open the dynamic-braking circuit when a reverser fails to operate correctly. It closes when the line breaker closes and remains closed through the accelerating and braking cycle until the car stops. Thus, on each run, beginning with the first application of power, the equipment is checked for proper operation. A failure automatically eliminates power from a faulty unit, and allows it to be pulled freely.

Foot-pedal operation of the PCC car has been replaced by hand-operated controls on the rapid-transit car, since the motorman is freed of fare-collection duties. The car is controlled by a combined power and brake controller operated by a single handle. Although two accelerating rates are adequate for rapid-transit service, the equipment may have three rates of approximately one, two, and three miles per hour per second. Since the rates must be changed electrically in multiple-unit operation, limiting them to two or three reduces the number of train-line wires required.

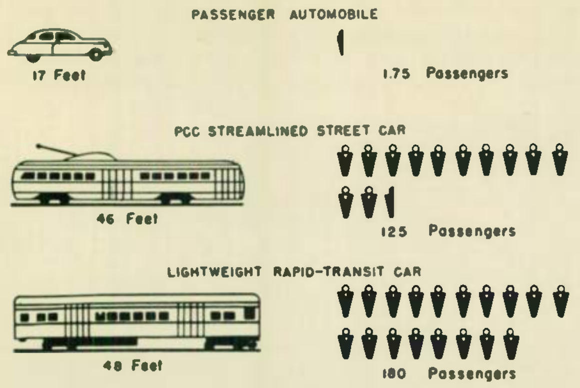
Two types of braking systems are available; however, in both systems the majority of all normal service braking is obtained dynamically by operating the traction motors as generators. On the all-electric car, three dynamic-braking rates are provided. For emergency applications, the maximum dynamic-braking rate is augmented by an electrically actuated drum-type friction brake, which is used normally to stop and hold the car when the dynamic brake fades out at a very low speed. On cars equipped with pneumatic devices, the dynamic brake is augmented by air-actuated tread brakes. Fifteen normal service braking rates are obtained by varying the straight air-pipe pressure, which actuates a rheostat in series with a loading coil on the limit relay. This changes the calibration of the relay to produce the desired dynamic-braking rate. The air-brake application is delayed by a lockout relay until the dynamic brake fades out, whereupon air-operated tread brakes are applied to the wheel to complete the stop. These brakes also supplement the dynamic brake when the dynamic-braking rate alone is insufficient due to extreme load and grade conditions.

Additional Advantages

In addition to its exceptional performance characteristics, this car has even more to offer. It is the lightest weight rapid-transit car ever built, and it has the lowest first cost due to standardized production of the various components that are used on both the standard and rapid-transit cars. Based on 16 years' experience with city-transit operation of PCC cars, it is expected that this car will produce real savings in operating and maintenance costs. To managements operating large fleets of PCC cars in surface transportation, the rapid-transit version of the PCC car offers obvious advantages. Spare parts' inventory can be kept to a minimum, since many of the parts are interchangeable. Maintenance practices are already established and maintenance tools and equipment are available. Skilled mechanics and electricians, trained in the maintenance of PCC equipment, need no additional training, because the new car is equipped with identical traction motors and many of the same mechanical features, as well as the same general control scheme and equipment used on the standard car.

With intense competition among various means of transportation, passenger comfort and safety have become almost as important as speed in attracting the public. This lightweight car includes many features that promote passenger appeal and goodwill. Smooth accelerations and decelerations and a good spring-suspension system combine to produce an exceptionally easy-riding car. One seating arrangement using transverse seats provides comfortable facilities for all passengers during the normal traffic periods at a sacrifice in full-load capacity during the rush-hour traffic peaks. A longitudi-

Mass Transportation . . . . the Movement of People



Capacity. Schedule speed. They are the reasons more cities are turning to rapid transit for relief from traffic woes. The sketch illustrates the great difference between the load-carrying capacity of the automobile, the streetcar, and the lightweight rapid-transit car. Assuming the average load of 1.75 people, it would take 71.5 automobiles stretched out along 1215 feet of single-lane street space to carry the 125 passengers that one streamlined streetcar can carry in 46 feet. Automobile capacity does not even compare with rapid transit. There, cars are operated in trains on private right of ways, and are not stymied by traffic bottlenecks that tie up surface traffic in many of our large cities.

nal seating plan provides fewer seats but allows more space for standing passengers, and therefore is preferable for heavy routes and lines with frequent interchange points. An automatically controlled heating and ventilating system maintains proper car temperatures within the normal temperature range regardless of load. A d-c incandescent lighting system using diffusion-type, non-glare fixtures provides good seeability for reading. Small high-level windows aid standing passengers to identify each station. All these features are either inadequate or nonexistent on the old rapid-transit cars that are still in service.

Applications

Up to January 1, 1951, neglecting a few experimental equipments, 240 lightweight rapid-transit cars had been purchased—all equipped with the apparatus outlined above. Two hundred of these cars are being built for the Chicago Transit Authority, which is in the midst of an extensive modernization program. These cars will be used on the rapid-transit division to replace existing cars that have been in service for approximately 40 years.

Forty cars are being built for the Metropolitan Transit Authority of Boston for use on its East Boston Tunnel route. The mile-and-a-half-long tunnel connecting Boston with East Boston was constructed early in this century under Boston Harbor to provide fast transportation for the thousands of commuters who used the many streetcar lines that terminated at East Boston. In 1924 the line was modernized with 48 rapid-transit cars, and the stations were rebuilt with high-level platforms to speed up the service. This year a 2¼-mile extension of this line will be opened. It will be a combination surface and depressed open-cut type of construction using an overhead trolley wire. Several new trolley-coach routes will be used as feeders to serve a vast new area from rapid-transit stations. A long-range transit program calls for eventual extension of this rapid-transit line to Lynn, Massachusetts.

Other cities are planning rapid-transit systems and are giving consideration to this new type of car. The City of Toronto, Canada, is constructing a 4½-mile subway line through the heart of the city. Cleveland is planning the construction of a rapid-transit line extending through the city in an east-west direction and using the Cleveland Union Terminal for a station at the Public Square. Financing has been arranged and consulting engineering firms are working on detailed plans for the system. The lightweight rapid-transit car is designed to meet the anticipated service conditions in both of these large cities.

This car provides the transit industry with a new tool to supply fast, comfortable, efficient service with a minimum investment in new rolling stock.

• • •

So Who's Buck Rogers?

Even Buck Rogers, in the 25th century, didn't have radioactive photographs. But our no-less-spectacular 20th century science has a new photographic technique that uses induced atomic radiation to print pictures. The new process doesn't threaten any revolution in the art of making pictures, however. It was developed by Dr. Kuan-Han Sun of the Westinghouse Research Laboratories "purely as a research experiment." Although it has no apparent commercial possibilities it may find applications in the recording of secret papers for intelligence work or business transactions.

Dr. Sun's process is an extension of one used in medical and metallurgical studies to record radioactivity on film, but this marks the first time the technique has been applied to pictorial photography. The first step in the new application is to make a positive film from a negative. Then, when prints of the picture are wanted, the positive is bombarded with neutrons which knock nuclear particles out of the silver coating. This makes the atoms radioactive, and when a sheet of photographic paper is exposed to the resulting radiation, the picture is printed on the paper. The same effect can be obtained with a glossy photograph.

This process could conceivably be used to record secret documents. The information to be recorded would be written with a mixture of invisible ink and a substance that becomes radioactive when bombarded with neutrons. Then the hidden message would be revealed only when the film or photographic paper were exposed to it. Silver, of course, could be used, but some other compound would be preferred—one that is potentially radioactive but at the same time hard to detect. The rare earths—dysprosium, thulium, and europium—have the essential qualities and could be used instead of silver.

This whole process is completely safe, because the intensity of atomic radiation needed is low enough to permit safe handling of the print or film.

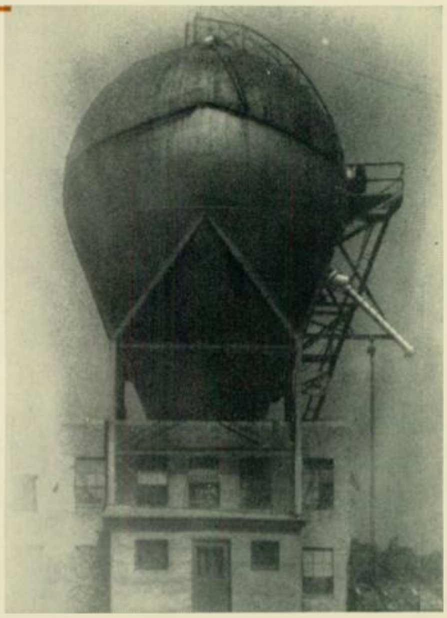


TABLE I—STANDARD BUSHING CURRENT TRANSFORMER RATINGS AND ACCURACIES*

Standard Current Transformer Ratios	Generator Bushing Ratings—Amperes		
	2000	4000	6000
1200-5	X		
1500-5	X		
2000-5	X	X	
3000-5	X	X	
4000-5	X	X	X
5000-5	X	X	X
6000-5		X	X
7500-5			X

*All of these current transformers meet the following ASA Accuracy Classifications: Relaying Accuracy of 10-L-400; Metering Accuracy of 0.3 for all ASA Standard secondary burdens up to and including the B-2 burden.

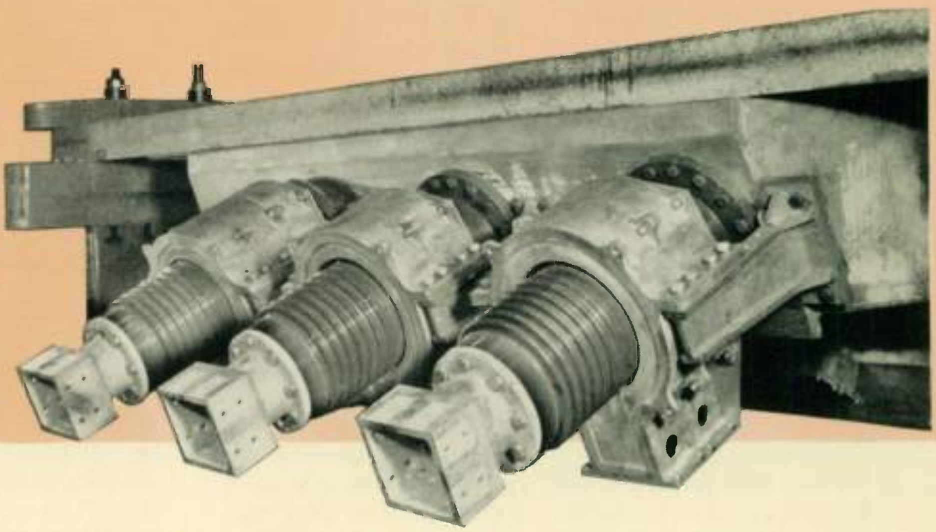


Fig. 1—A 6000-ampere assembly with bushing adapters suitable for bus running in line with the bushings. With adapters, the main bus can be run from the machine in any desired direction. Each bushing can accommodate a total of three transformers on line and neutral ends.

New *Transformers* Over Generator Bushings

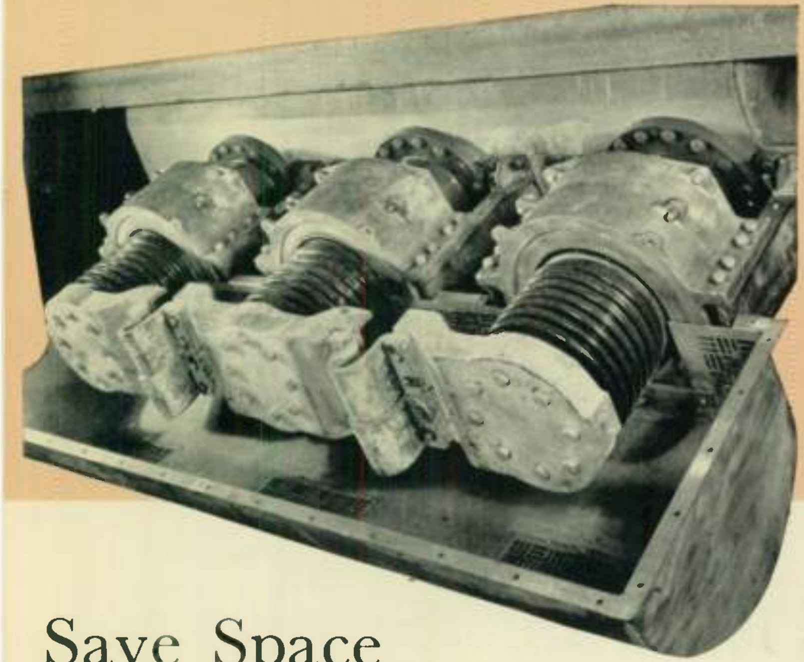
C. C. Sterrett, *A-C Engineering, and* C. A. Woods, *Circuit Breaker Eng'g., Westinghouse Elec. Corp., East Pittsburgh, Pa.*

Fig. 3—The light weight (casing is aluminum) and individual assembly make bushing-type current transformers easy to install or remove.

Large three-phase turbine generators require from 12 to 18 current transformers to energize differential and back-up relays, meters, and instruments. Bushing current transformers installed around new condenser bushings, and neutral connections installed in an aluminum enclosure, have eliminated the problem of finding space for this equipment under hydrogen-cooled machines. Installed as an integral part of the generator, they provide an economical, compact terminal arrangement.

Structural Details

Bushing current transformers are especially suited where heavy currents and strong, stray magnetic fields are encountered under short-circuit conditions, because their toroidal construction prevents stray or leakage flux from impairing their accuracy. In this new application, the transformers are mounted over the condenser bushings to take advantage of the insulation inherent in the termination of the machine windings. Each transformer, embedded in moisture-resistant, thermosetting Fosterite compound is enclosed in a cast-aluminum case, which permits connecting any kind of bus on the line end. The secondary leads terminate in a compartment integral with this case. A typical assembly is shown in Fig. 1, and Fig. 3 shows a transformer being installed. The construction of these transformers gives excellent protection against moisture, high temperature, and vibration during shipment and installation, as well as in service.



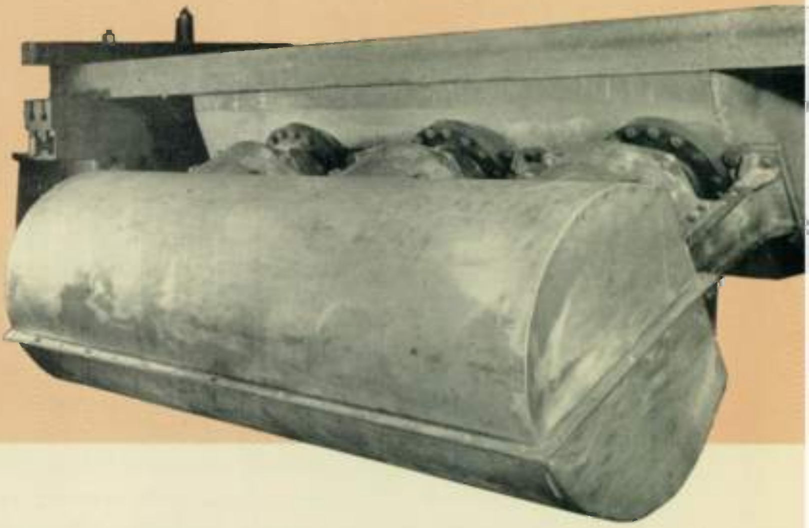


Fig. 2—The neutral connection under the generator now is enclosed in an aluminum case which fits as closely as proper ground clearances will permit. With the top half of the enclosure removed (shown at left) the shunts between bushings can be seen. They are made of leaf copper, so that stresses caused by large fault currents or differential expansion do not stress the bushings.

Save Space

The problem of placing a lot of equipment in the space under turbine-generator units is not new. However, a solution to part of the problem is to install bushing-type current transformers at the generator terminals.

The first of the three possible units on each bushing is installed adjacent to the external end of the bushing, so that any unused positions are between the first unit and the frame of the machine. This provides a symmetrical arrangement with smooth faces that makes it possible to connect isolated-phase bus or the aluminum-enclosed neutral connection without subjecting the transformer core and windings to mechanical strains. The neutral connection, shown in Fig. 2, is designed to keep fault-current stresses on the generator bushings to a minimum.

A removable cover plate on the bottom of the lead chamber gives easy access to the connections between the bushings and the generator windings, and a bushing can be removed from the assembly without disturbing the generator rotor or end-bearing brackets. A handling tool is available for the larger size bushings to facilitate their installation or removal.

Choosing the Proper Transformer Ratio

Almost any arrangement of current transformers necessary to meet metering and relaying requirements is available. Various standard ratios of bushing current transformers are listed in table I for each bushing size. To determine the desired transformer ratio for generator metering and protection, multiply the generator current rating for a hydrogen pressure of 0.5 psig by four-thirds. Then use the transformer with the next larger primary current rating, as listed in the table under the appropriate bushing rating. This assures a transformer with a ratio great enough to handle the larger currents obtained with increased hydrogen pressure.

Relay Coordination

With duplicate line and neutral bushing current transformers, maximum sensitivity is obtained on the generator differential protective relaying, and the possibility of incorrect tripping on through faults due to d-c saturation is minimized. To simplify still further the design of differential and over-current relaying schemes, the ratios and relaying accuracies of these transformers have been coordinated with those furnished in Westinghouse station-type cubicle switchgear. Proper relay-zone overlap and coordination are thus obtained with minimum effort. Linear-coupler bushing transformers can be furnished where this type of bus relay protection is used.

Power-plant engineers can specify these bushing transformers and neutral connectors as part of the turbine generator to obtain a neat, space-saving installation that reduces costs, and that is properly coordinated with switchgear and relaying equipment.

Just One Place . . . .

. . . to look for anything that has been published in the *Westinghouse* ENGINEER. A 10-year cumulative index, which locates all articles that have appeared between May, 1941 and November, 1950 is now available and will be sent without charge to readers on request.

Bound Volume—Bindings of the 1949–1950 issues of the *Westinghouse* ENGINEER, with index, are now available. The price, $6.00 postpaid. Or, send in your copies (12 issues for 1949 and 1950) of the *Westinghouse* ENGINEER. We will place these in an attractive permanent binding, with cumulative index, and bill you $3.75, plus 35c for each missing copy supplied.

Westinghouse ENGINEER
306 Fourth Avenue
Pittsburgh 22, Pa.

Control of *Lightning Arrester* Quality

T. L. Dyer
Engineer

Edward Beck
Manager

Lightning Arrester Design Section
Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania

A lightning arrester, unlike most machines, cannot be given any adjustment or trial run after installation. It must be ready when lightning strikes the first time. To make sure they are ready, Autovalve arrester elements are given their first surge in the factory. Each element is checked under simulated service conditions with surge tests more severe than present standards require.

Fig. 1—This revolving surge-testing table is being loaded with station-type lightning-arrester blocks. The surges are introduced to the specimen blocks at the back of the machine through the contacts that can be seen on top, above each cubicle. The series gaps are inside the white rings seen above each test cubicle.

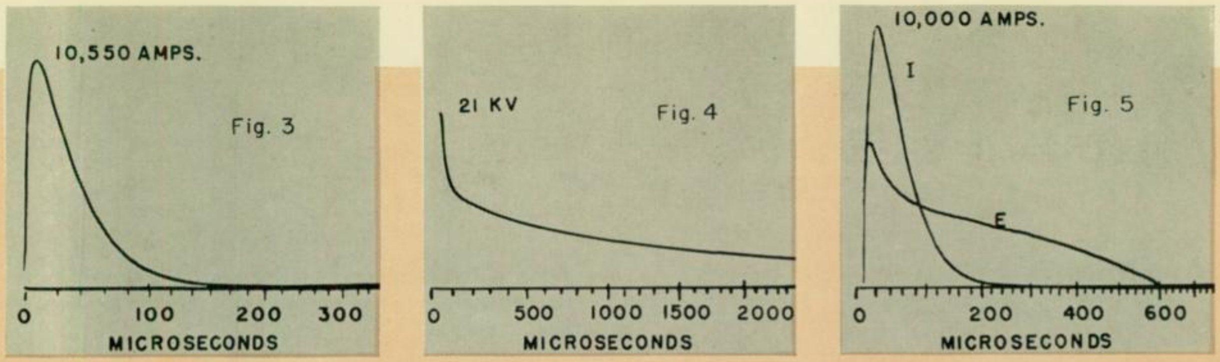
Fig. 2—This test checks the ability of lightning-arrester elements to protect adjacent equipment. It consists of surging an arrester block and checking the volt-ampere characteristic on the oscilloscope. The surge takes place behind the screen to the right of the operator. He feeds the blocks into the surge machine one at a time on a small tray which swings behind the wire mesh.

Lightning arresters are assigned a twofold duty. First, they must divert surge currents, thereby limiting surge voltages to magnitudes that do not endanger adjacent apparatus. Furthermore, they must accomplish this without any disturbance to service. This means that after the surge current through the arrester has ceased, they must quickly reestablish themselves as insulators by interrupting power-follow current at the earliest possible instant. Ability to interrupt power-follow current is the essence of a lightning arrester—which in fact is not a lightning arrester at all, but a lightning *diverter*. It is, however, a *power-follow* arrester. A device that does not arrest power-follow current over a wide range of surge-discharge conditions cannot, by the accepted definition, be called a lightning arrester.

These considerations led to the present practice of applying routine surge and power-follow tests on all valve elements manufactured for use in station, line, and distribution types of Autovalve lightning arresters. Quality-control testing of the elements has been practiced for more than 20 years, but before 1938 the criteria were in accordance with existing AIEE standards. In 1938 the practice described here was adopted for station-type Autovalve elements. And in 1940 it was applied also to line and distribution types. Field data on arrester discharges indicate that the test surge used is representative of severe service duty; and operating experience with arresters built of elements controlled with these tests has been excellent.

Power-Follow Tests

In 1936 a survey was made of the meager field data on the magnitudes and wave shapes of currents discharged by lightning through arresters in service. This, plus experience with arrester designs that are now obsolete, indicated that for power-follow tests the discharge current should have moderate crest magnitude and be of relatively long duration. The current wave chosen for these tests rises to crest magnitude in 10



The oscillogram in Fig. 3 shows the current surge with no transformer in the test circuit, and in Fig. 4, the corresponding voltage wave. The voltage and current waves obtained with the power transformer connected are shown in Fig. 5.

microseconds and decays to half value in about 50 microseconds. The low-current tail lasts more than 4000 microseconds when no power transformer is connected in the circuit.

The surge and power-follow tests applied to Autovalve elements are in two parts. The first part, called the two-shot test, ferrets out those blocks that have defects such as cracks, inclusion of foreign material, or other structural defects. It is applied to every Autovalve block used in station-, line-, and distribution-type arresters. The second part is a sampling test of greater severity.

For the routine two-shot test, completed valve elements are stacked in pairs on a revolving table and are electrically connected to a circuit containing series gaps, a 60-cycle power supply, and a surge generator. The two blocks and the series gaps comprise an actual 6-kv lightning arrester ready for test under simulated service conditions. A setup for station-type blocks is shown in Fig. 1. With a 60-cycle voltage slightly greater than 6000 volts rms applied, two separate surges are applied. Two surges are applied to every pair of production elements because past experience has shown that two surges are required to disclose any structural defects present in the blocks. The current surge is timed to occur between zero and 15 degrees ahead of the crest of the 60-cycle voltage wave having the same polarity as the surge. The shape of the surge wave is approximately the same for all types of Autovalve blocks, but for station-type arrester blocks the current peak is 10 000 amperes, whereas for the line and distribution units the peak is 5000 amperes.

If the Autovalve elements perform satisfactorily the testing table indexes to the next position automatically. But if any element fails, the resulting short circuit causes a circuit breaker in the 60-cycle power supply to trip and shut down all the equipment automatically.

The more severe sampling test checks the general quality of each batch of blocks. (A batch is the group of blocks made from a particular load in the mixing machine.) For this test the operator chooses at random four to five percent of the elements from each batch and makes test specimens like those used in the two-shot tests. These specimens are subjected to 30 or more discharges under the same conditions as the two-shot test. Line and distribution types are given 30 discharges, station types, 50. If all the blocks from a batch perform properly the entire batch is accepted; but if any two or more test specimens do not, the entire batch is rejected. A sequential-sampling process is used if only one specimen is damaged. The blocks that have been exposed to this durability test are scrapped, because they have been subjected to severe service conditions under which their life is not unlimited, although blocks that pass this test will continue to perform satisfactorily for many more discharges.

Impulse-Characteristics Controlled

An additional routine impulse test is made on all Autovalve elements. The purpose of this test is to control impulse characteristics. It consists of discharging through the individual elements a current whose crest is 1500 amperes and which rises to crest in 10 microseconds and falls to half value in 20. During this discharge the volt-ampere characteristic is observed on the screen of a cathode-ray oscilloscope constructed especially for this purpose, Fig. 2. Limits are set up within which these characteristics must fall; otherwise the elements are rejected by the tester.

Effect of Transformer on Wave Shape

The wave shape of the surge current discharged through the test specimen in the power-follow tests is of considerable interest, because the power transformer in parallel with the arrester modifies the arrester current.* The effect of the transformer is illustrated by the oscillograms of Figs. 3, 4, and 5. The arrester discharge current with no power transformer in the circuit is shown in Fig. 3. The test circuit consists only of the surge generator, the arrester specimen, and the measuring equipment. After about 200 microseconds the current becomes so small that it is hardly readable on the oscillogram because of the extremely large 10 000-ampere crest. The voltage oscillogram produced when the current of Fig. 3 is discharged through the element is shown in Fig. 4. There is voltage across, and therefore some current through the arrester elements for well over 2500 microseconds. Other oscillograms* show it lasting longer than 4000 microseconds.

A similar oscillogram with the power-transformer secondary connected to the arrester and its primary short circuited to simulate connection to a large energized power system is shown in Fig. 5. The voltage corresponding to the current is quite different from that of Fig. 4 and illustrates how the transformer influences the current through the arrester if the generated surge lasts very long. It shows that the current through the arrester ceases at about 600 microseconds. This time is influenced by the inductance and resistance of the power-follow circuit. The larger the kva of the 60-cycle source and the lower its reactance, the shorter the total duration of the current.

More Rigorous Than Standards

These tests have been used for 12 years, and arresters built with tested blocks have excellent service records. They represent conditions likely to be met in the field, and are more exacting criteria of Autovalve lightning-arrester quality than tests now recommended in American standards.

---

*"Lightning and Lightning Protection on Distribution Systems," by R. C. Bergvall and E. W. Beck. Trans. AIEE, Vol. 59. 1950, p. 442-9.

What's NEW . . . . in Products

Decorative Micarta

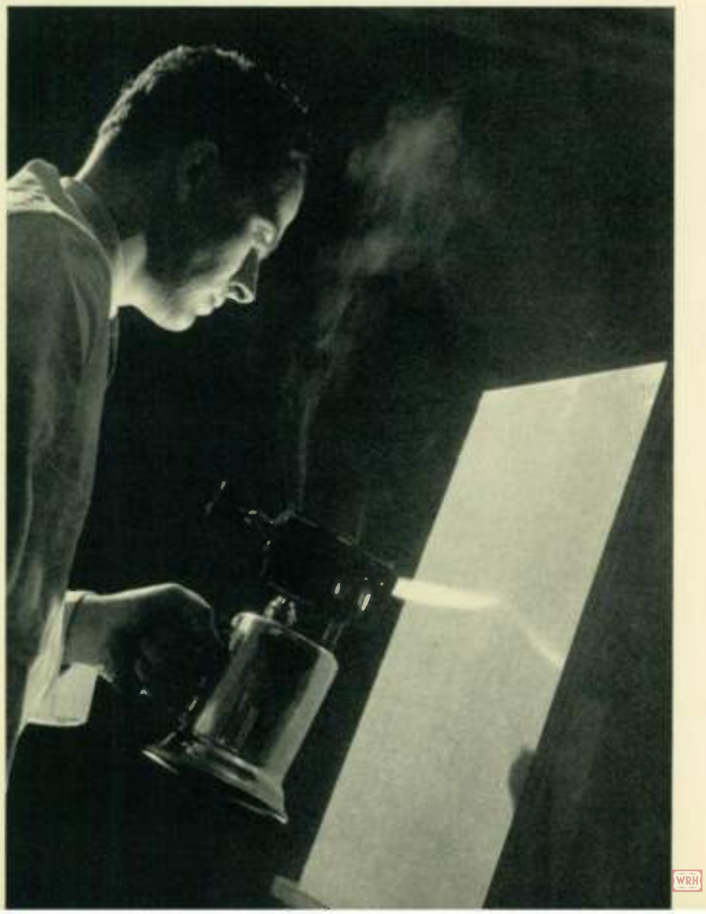
Fire prevention, a sometimes overlooked precaution for the landlubber, is a must for the seafarer. On passenger ships, where the comforts of home are boasted of, such things as furniture, bedding, and pretty wall panels are a potential danger. For the new, completely fireproof superliner *United States*, a fireproof, decorative Micarta has been developed. This material consists of 1/16-inch aluminum sheet sandwiched between layers of melamine plastic bonded to the aluminum with a phenolic resin.

The thermal coefficients of expansion of aluminum and the melamine plastic differ greatly; therefore, the amounts of expansion for a change in temperature will be different. Reconciling this existence of different expansion coefficients with the necessity for obtaining a firm and lasting bond has been an almost insoluble problem. However, a layer of phenolic resin about equal in thickness with the decorative melamine layer gives a positive bond that does not break. This Micarta sheet has been cycled through extremes of temperature (36 to 130 degrees F) and subjected to 100 percent humidity at 98 degrees F without breaking the bond between the metal and plastic.

This material is formed during a single process; the plastic-to-metal bonds are made simultaneously with the pressure forming of the outer decorative melamine layer. Many colors and wood-grain or textile finishes can be made in wide variety to suit the most exacting of decorators' requirements.

Safety from a fire standpoint is obtained by the heat-conducting aluminum and the nature of the melamine coating. The foundation aluminum sheet disperses any heat from a point source, such as hot food containers or cigarette butts, to eliminate danger of fire. Although the melamine outer layer will burn when heat is applied, it will not sustain combustion. And because there is as much of this material as of the phenolic, the melamine serves to quench any combustion supported by this phenolic resin. Thus a tough new fireproof wall paneling is born and should find many uses in places such as elevator cabs where fireproofness is mandatory.

This man is wasting his time—that's fireproof Micarta.



Limitation to Small Banks of Switched Shunt Capacitors Removed

Shunt capacitors should be as close to the load as possible. For high-voltage (2.4- to 15-kv) distribution systems, this has not been economically obtainable because of the absence of a suitable contactor of low cost. The cost of providing switching in a substation housing has deterred use of small banks of switched shunt capacitors on high-voltage distribution circuits. This deficiency was removed last year by the development of an oil switch for this specific purpose. It is a single-pole, electrically or manually operated switch that resembles a recloser. Special features include compactness and weatherproof design. The light weight of 54 pounds enables three of them and a large number of capacitors to be mounted on a single pole. Thus an economical capacitor application near the load is possible.

Stopping Tap Changer with Precision

The motor that drives the load tap changer of a transformer must stop suddenly and precisely—i.e., with no overrun or underrun. One way is to apply direct current to the a-c motor windings. But that requires a source of direct current, such as a disk-type rectifier. Or the motor can be stopped by plugging action, i.e., switching the capacitor from one winding to the other. This introduces the problem of disconnecting the circuit at exactly the right instant or the motor reverses direction.

A new brake, called the DynAC, does this with a novel scheme of reconnecting the windings of the single-phase, split-phase capacitor motor in such a manner that there is no reversing torque after the motor has stopped. It is able to achieve a stop in not more than six revolutions (about six cycles) with no hunting.

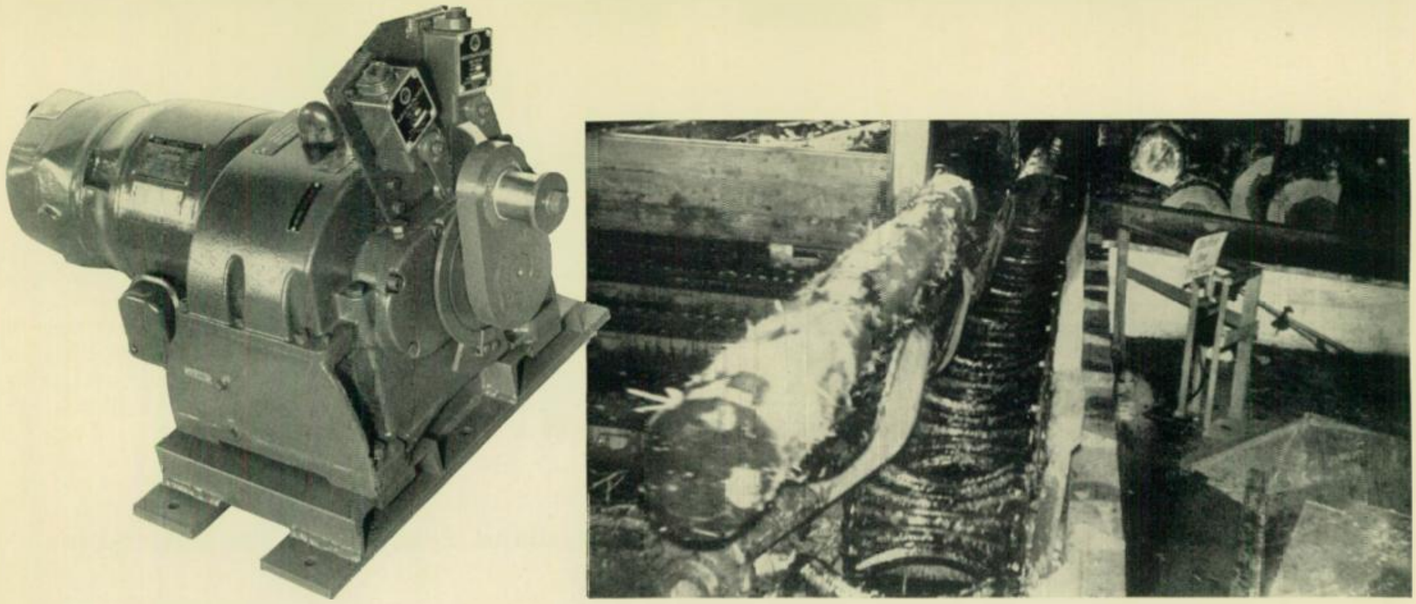
Motocylinders

Although the steam turbine long since, and the electric motor more recently, has replaced the majority of industrial reciprocating drives, there are still many applications, large and small, where reciprocating power is supreme. One such important place is in a sawmill where a large percentage of timber-handling equipment requires reciprocating motion. Now a geared electric-motor drive has been built to replace the more-or-less inefficient and costly steam, air, or water cylinders that are common.

This electric drive—called the Motocylinder—is a gearmotor with a short crankarm on the output shaft that supplies the reciprocating motion when the output shaft is rotated. The geared crankarm can be connected directly or through a connecting rod to the driven device or, where it is desired that the crankarm be on the driven machinery, power is transmitted through a heavy-duty chain (these are called off-set Motocylinders).

Previous reciprocating drives—steam, air, or water engines—were wasteful of their fluid medium, were difficult to keep properly lubricated, and required considerable extra equipment for supplying the working fluid. Also, they "froze up" in the low temperatures prevalent in the logging areas in winter. And these conventional cylinder drives subjected the driven machinery to excessive shocks, causing considerable wear and tear.

The new electric-drive Motocylinder provides a smooth sinusoidal motion, the motor torque, fortunately, being incapable of giving sudden shocks. Fast-acting electric limit switches are



Direct-acting Motocylinders (left) are used to drive roll case unloaders in sawmills (right). Motocylinder is located below unloader

set to start and stop the motor at definite stroke positions. An electric brake on the motor shaft defines the "stop" positions to give precise placement at the end of the stroke. Standard three-phase, squirrel-cage induction motors matched to an adequate gear unit—usually class III AGMA gearing—are generally used. These motors are either totally enclosed, non-ventilated or fan-cooled (taking air from a clean air source) to prevent introduction of the sawmill's dirt and water to the windings.

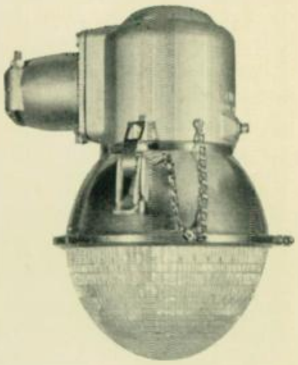
Various types of control, pushbutton or switch, can provide start, stop, inch, hold, reverse, and lock-out operation. Such things as master switches, electric eye and automatic sequencing controllers, or any of a multitude of types of electric control can also be used. Hence the flexibility of the electric Motocylinder is unlimited. And it is proving a useful tool in sawmills, providing the high efficiency of more completely electric equipment.

AK-6 Suburban Luminaire

THE OLD open street light, whose reflector swings with the vagaries of the wind to flash a gleaming light into nearby windows, is doomed. A new, small luminaire, the AK-6, has been designed to bring comfortable and controlled lighting to those areas, such as small towns and suburban areas, where the open light is most often encountered. This small, lightweight luminaire, which can be used on existing poles and wires, provides more efficient light distribution—and inexpensively.

This luminaire can be fitted with either a 1000-lumen or a 2500-lumen lamp to give the desired light intensity. Also it can be fitted to provide any one of three different light distribution patterns. A symmetric pattern for center lighting of intersections (IES type V) and a narrow asymmetric pattern for mounting at the side of the street (IES type II) are provided. In addition there is another pattern (designated type II-A) for more efficient illumination of street intersections. This provides light on all approaches to the intersection as well as on the intersection proper; the pattern is in the form of a cross, one arm of the cross for each of the street approaches.

The luminaire is made exclusively from noncorrosive materials—stainless steel, spun aluminum and aluminum castings, and nickel and copper alloys—that make for easy maintenance even after considerable time in service. Relamping is accomplished by unfastening two latches that hold the reflector assembly to the luminaire head, lowering the reflector assembly, and replacing the lamp. The reflector assembly is suspended during relamping from a non-corroding chain.



To fit the wide variety of system conditions in existence, the luminaire can be provided with either a side-mounting or top-mounting head, for internal or external wiring. Also for the communities where expansion and changing traffic conditions may require greater light outputs, the universal metal head can be used to permit a change to a larger luminaire such as the AK-10 at some future date. The AK-6 is attached to the universal metal head by means of a reflector ring that is removed when the larger luminaire is to be attached.

. . . . in Engineering

Lindsay-Strathmore Pumping Control

IRRIGATION projects are not all as simple as the old-world style large channels feeding many little channels lower down on the hillside. Most now require that water be pumped initially from a canal or river to a series of lesser irrigation ditches or that some other more-or-less complex function be accomplished to maintain the overall system equilibrium. Such is the case at the pumping station for the Lindsay-Strathmore Irrigation District in Southern California. Here, to live up to water-treaty requirements, it is required that this district get 24 percent (no more, no less) of the total water flowing through a primary canal carrying water diverted from the Colorado River.

This is further complicated by the fact that the amount of water flowing in this main canal varies from day to day and season to season. Thus the amount of water diverted must vary accordingly. The canal flow is metered automatically and the 24 percent is diverted into a sump from where it is pumped into the secondary irrigation system. This is accomplished by the water-hydraulic system alone.

Electrically driven pumps are required to remove water from the sump and deliver it into the irrigation ditches at the same rate it is diverted from the main canal. Completely electric control of several pumps of different capacity governs the rate at which water is removed to correspond with the rate at which it is diverted. A float in the sump indicates the water level, hence the amount of water being diverted from the main canal. Four squirrel-cage induction motors having ratings of 15-, 30-, 40-, and 50-hp are controlled in sequence and in combination to deliver the precise volume of water being diverted. In addition to controlling the pumping capacity at any one time, the sump float controls a throttling valve in the pump-discharge line. If the pumps deliver more water than is being diverted into the sump, the float goes down. This closes the throttling valve slightly, increasing the back pressure on the pump which reduces the discharge to conform to the incoming flow. Coordination of the pumping motors with the hydraulic system to meet these special requirements provides automatic and accurate discharge into the irrigation system, without necessitating an uneconomical round-the-clock human attendant.

King-Size Faucet

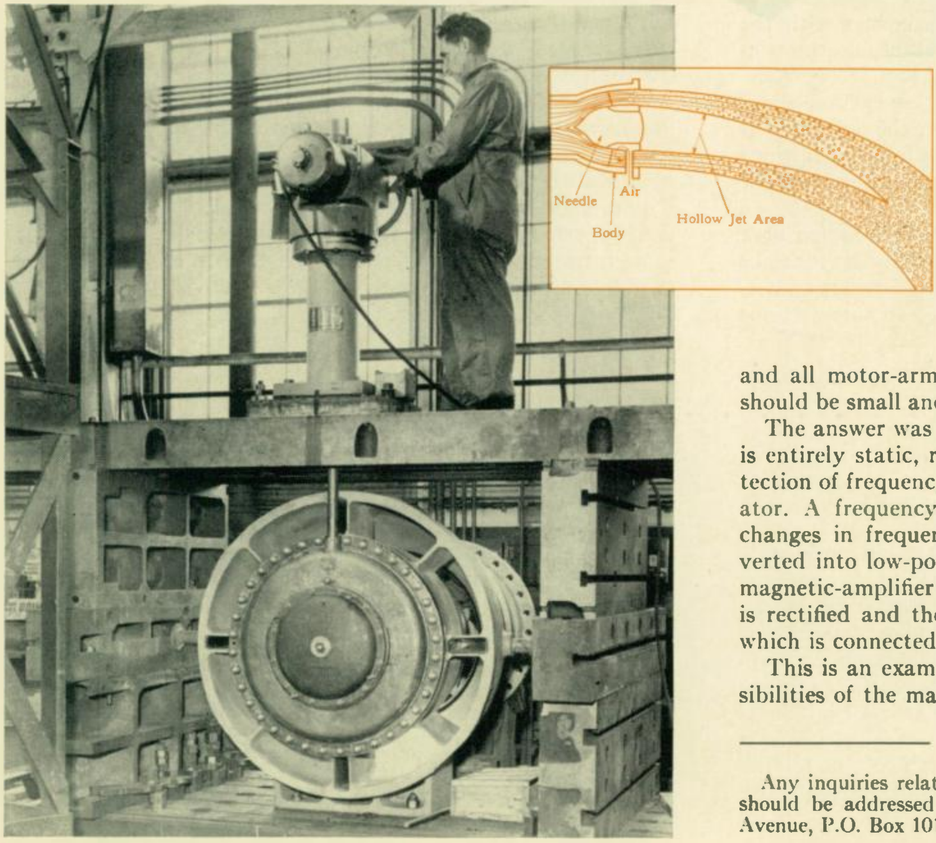
The Westinghouse Staats-Hornsby hollow-jet valve is like the new-style kitchen-sink spigot in that it discharges an axial stream of aerated water. But it is unlike it in most every other respect, including its rate of discharge—sometimes as high as 4000 cubic feet of water per second. This relatively new valve is used at dams and hydroelectric projects to discharge excess water when the water level is too high, or, perhaps, to by-pass a stopped turbine runner.

This needle-type valve is free from cavitation, vibration, and slamming. The outside diameter of the water stream is constant regardless of the pressure head or degree of valve opening. Air from outside the valve is drawn through pipes and passes through splitters (the hollow vane-like braces on the discharge side of the valve) to aerate the water stream. This gives a negligible spray or mist, an important feature when it is necessary to discharge large volumes of water near electrical installations, highways, and bridges, etc.

The valve can be built for mechanical or hydraulic operation, as necessary. The needle (see sketch), or movable part of the valve, is balanced when in the closed position. When designed for mechanical operation, holes in the valve face admit water to balance the upstream pressure; hydraulically operated, this pressure is balanced by an enclosed fluid under pressure. In hydraulic operation this counter pressure is reduced slightly to open the valve, and whether opened by a motor, by hand, or hydraulically, the needle is nearly balanced and little force is needed to close it.

The largest of these to date is 8½ feet in diameter and will discharge 4000 cubic feet per second under an effective head of 155 feet. Many other sizes for various pressures and rates of discharge have been built for numerous hydraulic projects in this country as well as South and Central America.

A 30-inch hollow-jet valve being checked at the factory. The sketch at right shows the operation of these valves.



Narrow-Band Telegraph-Type Power-Line Carrier

Frequency shift is the latest addition to the power-line carrier family. The equipment provides narrow-band carrier channels suitable for telegraphic or keyed-type functions such as telemetering, supervisory control, and remote tripping. The rate, duration or coded sequence at which the carrier frequency is shifted is utilized to transmit the intelligence from one station to others via the power lines. Crystals are used, operating in the 90- to 200-kc band, and these are shifted from the normal frequency by 0.06 percent of that frequency.

Many channels can be stacked side by side and operated through common coupling and tuning equipment. As a result, a small portion of the available frequency spectrum is used. This is an important feature with the large number of carrier frequencies required for the many carrier services.

Each transmitter and receiver forming a channel can be operated independently from the other channels. This is an important feature in maintenance and service. In addition, the several transmitters in the same band of frequencies can be located at different stations, each sending signals to a central control point. The receiver employs a crystal filter and discriminator that permits operation through high attenuation with low transmitted power. This communication system also provides high discrimination against interfering signals and noise with wide changes in circuit attenuation.

Magnetic Amplifier Solves Unusual Regulation Problem

A 75-kva motor-generator set supplying 3-phase, 60-cycle power obtains its energy from a d-c power source whose voltage can vary over a two-to-one range. However, it is necessary to hold the frequency at 60 cycles for all loads and all motor-armature voltages. Furthermore, the regulator should be small and have no moving parts.

The answer was obtained with a magnetic amplifier. The unit is entirely static, receiving control power for operation and detection of frequency directly from the terminals of the a-c generator. A frequency-responsive circuit is used for detection of changes in frequency. These variations in frequency are converted into low-power d-c signals that control a self-saturating magnetic-amplifier circuit. The output of the magnetic amplifier is rectified and then fed into a control field on the d-c motor, which is connected differentially to the main shunt winding.

This is an example of the versatility and almost endless possibilities of the magnetic amplifier.

Any inquiries relating to specific products mentioned in this section should be addressed to the Westinghouse ENGINEER, 306 Fourth Avenue, P.O. Box 1017, Pittsburgh 30, Pa.