WESTINGHOUSE Engineer

JULY 1954

Power for the Home—a growing demand

The long-range curve of electric-power consumption looks like the side of a mountain slope, headed upward. And the curve still shows little sign of leveling off, or even decreasing in slope. This fact was sharply pointed up at the Third Future Power Market Forum, held by Westinghouse earlier this year.

Among the talks given at the Forum was one on the residential market for electric power by J. M. McKibbin, Vice President, Consumer Products, of Westinghouse. The following facts, gleaned from that talk, highlight the increasing influence of residential consumption on the total energy picture, and point out some of the factors that affect this increase, both now and in the future.

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Between 1948 and 1954, the number of households in this country jumped 14 percent, volume of employment 4 percent, disposable personal income over 31 percent, and personal-consumption expenditures for durable goods 33 percent. In that same period over 5¾ million new homes were built to house new appliances.

As the nation grew larger and more prosperous, what effect did this have on residential power consumption? In the same five-year period—1949 to 1954—the number of residential users of electric power rose from 33.5 to almost 42 million—an increase of 25 percent, compared to an increase of about 14 percent in the number of households. This brings to about 94 percent the number of households in the country that are residential consumers.

But that's not the whole story. In the same five-year period in which the number of residential users was increasing so rapidly, the average family consumption also took a giant step—from 1500 to 2300 kwhr, or a gain of 53 percent. These figures all add up to an increase in total residential consumption from 51 billion to nearly 97 billion kwhr, or a gain of 90 percent—all in five years.

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This rapid expansion in residential consumption obviously stems from increased numbers of electric appliances in use. The figures for appliances produced are staggering. In the past five years about 338 million units of electric appliances have been purchased for the homes of America. This includes about 67 million major appliances—ranges, refrigerators, etc.; about 199 million portable appliances; 42 million radios; and almost 29 million television sets. Interestingly, despite the dire prophecies about the effect of television on radio, more radios were purchased in 1953 than in 1949.

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The variety of tasks performed by electric energy is also expanding. In 1930, there were 19 electric appliances useful to the householder. By 1949, engineers had added 24 more to the list. And they didn't stop there. In the past five years alone, 11 more new appliances have been developed, bringing the total to 54. An interesting sidelight is the fact that, as far as can be determined, no single type of electric appliance has been driven from the market by a competitive device.

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With this tremendous volume of electric appliances finding its way into American homes, the obvious question is, how long can it last? Haven't we about reached the limit of what people need or can afford? This brings out a rather surprising fact about the appliance industry. Unlike other industries, the word "saturation" means next to nothing. Perhaps the most outstanding example of this is found in the case of electric irons. Five years ago the saturation of the iron market was 90 percent. Today it is still 90 percent. But, in the interim, people have purchased *35 million* new irons.

In the electric-appliance field as a whole, the degree of saturation is still relatively low, ranging from under 10 percent for such things as broilers and blenders up to 90 percent for refrigerators and irons.

Many factors indicate that electrical conveniences for the home still have a long way to go in easing the householder's tasks. Most homes are still a far cry from the popular-magazine concept of a modern home. Even today, 23 percent of the homes do not have a modern range; and 47 percent don't have central heating. Moreover, a great many homes don't have the basic requirement for additional electrical load—adequate wiring.

But the imagination and ingenuity displayed by designers and engineers in producing new and better electrical household servants show no sign of waning. New improvements, and totally new devices will undoubtedly parallel the increase in power production.

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The pyramiding use of electricity in the home has been an increasingly large factor in total power consumption. And it seems likely this trend will continue. In 1930, residential users accounted for about 15 percent of the total energy sales; by 1940 they were using nearly 20 percent of the total; and as of the end of 1953 they were accounting for 25 percent.

If this same trend continues, residential consumers will account for perhaps 29 percent of the total energy consumption by 1958, or nearly 150 billion kwhr. This would raise the per-customer average from 2300 to 3300 kwhr. And the predictions for 1963 foresee residential consumption as 36 percent of the total, with the possibility that average consumption may well exceed 5000 kwhr annually.

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This adds up to the fact that the residential consumer is becoming a larger and larger influence on the total energy picture. The reasons are many and complex. But certainly one of them can be attributed to the engineers, who have turned their talents to lightening household burdens, and have quietly produced a revolution in home planning and power utilization. RWD

WESTINGHOUSE Engineer

VOLUME FOURTEEN

JULY, 1954

NUMBER FOUR

On the Side

The Cover—High-grade, easy-to-process iron ore is gradually being depleted. As a result, the ores that are more difficult to recover and process—such as taconite—are becoming more and more important. On this month's cover, artist Dick Marsh suggests several stages in ore preparation—mining, shipment, and steel making.

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The principle of using ignitron rectifiers in railway equipment to enable utilization of a-c power transmission and d-c traction motors is now being applied on a large scale. As of the end of May, 27 ignitron-rectifier, multiple-unit railway cars were in operation on the New York, New Haven, and Hartford Railroad. Some had accumulated over 8000 miles of revenue service.

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On the back cover of this issue is pictured the first 330-kv, 25 000-mva Watch-Case circuit breaker ever built, for the atomic energy installation in Ohio. This was shipped in March. By the end of May, four of these huge three-pole breakers had been installed, and by the time this appears in print the total will be 11. Erection time averaged about 5 days.

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Test results on the first inner-cooled generator are outlined in a progress report in this issue. The unit has now been in operation at the Niagara Mohawk Power Corporation for several months, for ratings up to 100 000 kw, 80-percent power factor, and 45-psig gas pressure. Average hydrogen makeup at 45-psig pressure has been in the order of 70 cubic feet per day for relatively long operating periods.

In This Issue

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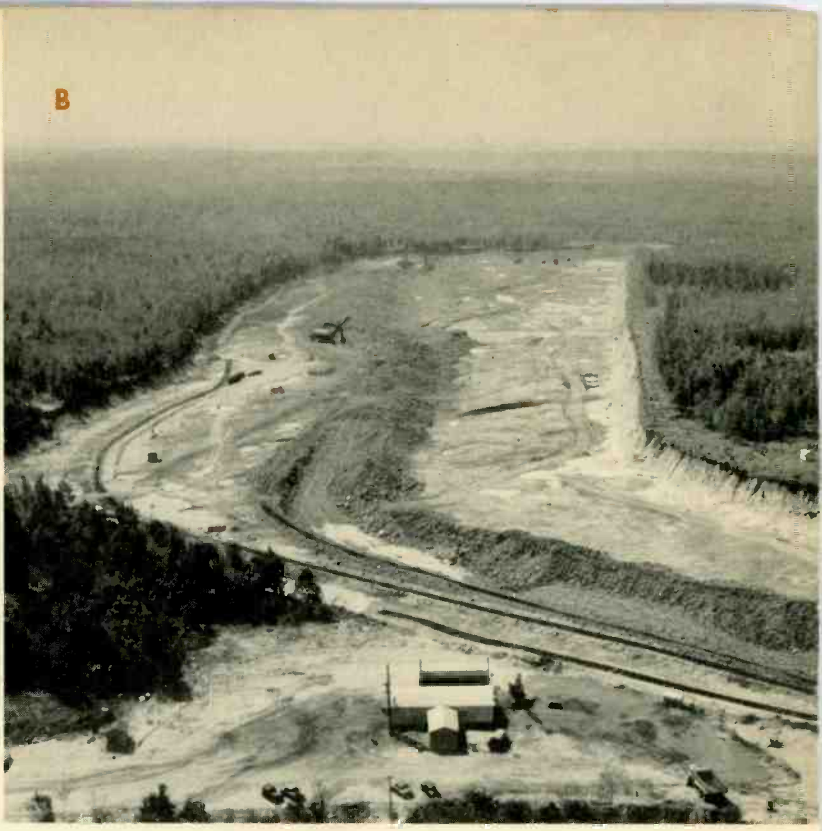
Published bimonthly (January, March, May, July, September, and November) by the Westinghouse Electric Corporation, Pittsburgh, Pa.

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

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

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



All too soon iron ore will no longer be had for the scooping. In anticipation thereof steel companies are starting to make it out of one of the hardest of rocks—taconite.

IRON ORE ...the hard way

A—A jet piercer, by tremendous heat and speed of its flame, drives a hole through hard taconite. B—A representative taconite mine on the Mesabi iron range. C—Nodules are produced from concentrate in a lime-kiln type of plant. D—Pellets, one of three types of end products, ready for shipment. Photos A and D courtesy Reserve Mining Co.; photos B and C, U. S. Steel's Oliver Iron Mining Div.

Mother nature was not stingy when she formed the iron deposits. Furthermore, from one point of view, she was downright thoughtful about how she laid it out for man to use. Take the great deposit of the Mesabi Range, northwest of Duluth, for example. Nearly a billion years ago, when the area now comprising Minnesota, Wisconsin, and Michigan was a large sea, great quantities of iron accumulated in its bed by some unknown technique.

After the tortures of faulting, exposure to intense internal heat, and finally the ice age had passed, the region was left with thick layers of dust-size iron compounds compacted with granites into rock that rates among the world's hardest. This is *taconite*. It contains from 25 to 35 percent recoverable iron.

There are thousands of acres of it. Some of these layers are 600 feet thick and, in the great Mesabi area, are close to the surface, and dip toward Lake Superior at an angle of only 5 to 12 degrees. Elsewhere the layers have been steeply upended or buried under hundreds of feet of glacial debris.

Then, nature—as if she had man's coming in mind—began to soften and enrich some of this harder-than-flint, iron-bearing rock. Sand is only faintly soluble in water. But nature had lots of time. In a few billion years rain and ground water, washing over the taconite, leached out much of the silica in a few comparatively small areas, leaving a crumbly rock rich in iron oxides. This ore averages about 51 percent iron, and is suitable for use in blast furnaces, with no intermediate treatment. Such pockets of naturally enriched and softened rock have furnished the great quantities of "direct-shipping" ore that have comprised about 85 percent of the nation's iron supply to date.

Then, as an additional largess, nature did a partial beneficiation job on other vast quantities of taconite. By fairly simple washing techniques, much of the remaining silica can be washed away, leaving ore comparable or better in quality to direct-shipping ore. About 370 million tons of such wash or gravity concentrates have been produced since 1910. Now

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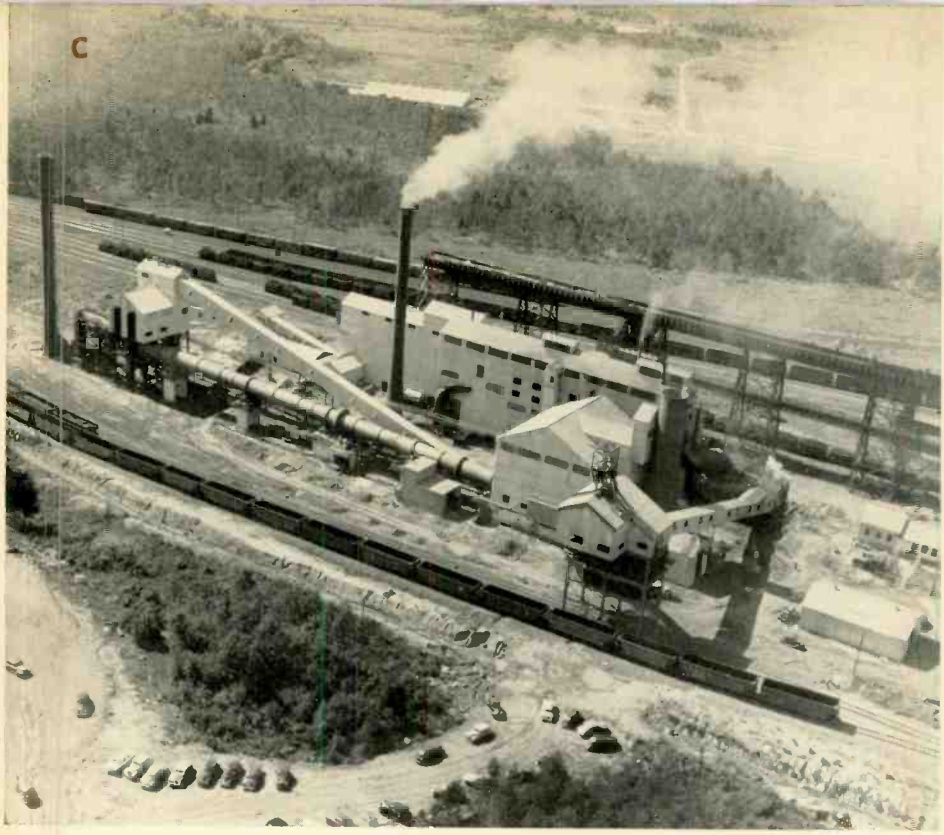
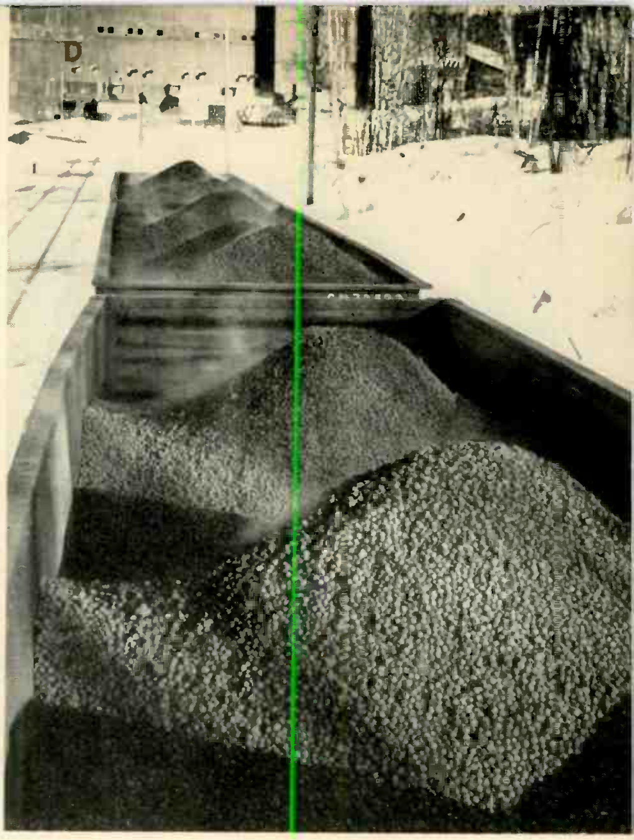
Prepared by Charles A. Scarlott, based on information provided by Oliver Iron Mining Division of the U. S. Steel Corporation, Reserve Mining Company, and other mining organizations, and by Westinghouse.





more than one third of all Minnesota ore receives some treatment before shipment.

Nature, while generous, is also stern. She did the enriching job in what seemed like vast quantities. However, in reality she provided only enough to last while man learned how to do the job himself. He calls it *beneficiation*.

Or, you might say, man came several hundred million years too soon. Possibly by then nature would have finished the job. But we can't wait.

Until War II we thought we had several decades in which to learn how to do in a few hours what nature did in many millions of years, namely, process the hard taconite into an acceptable blast-furnace feed. But the forced-draft of war and the great postwar demand tripled the rate at which the giant shovels scooped the "ready-made" ore from the open Mesabi pits. Depletion of open-pit direct-shipping ore was greatly hastened.

A few numbers help to grasp the iron-ore picture. In 1953, about 120 million tons of iron ore were produced in the United States. Of this, 96 million tons (80 percent) came from the Lake Superior region. Of the Lake Superior ore, about 55 percent is direct-shipping ore (almost entirely from Mesabi pits), 25 percent open-pit concentrate, and roughly 20 percent from underground mines of Minnesota, Wisconsin, and Michigan. Altogether some two billion tons of ore have been taken from Minnesota pits since mining began in 1892.

There is still lots of good ore left in big open pits in Minnesota, and there are sizable amounts underground in Minnesota, Wisconsin, and Michigan. It is estimated as about one billion tons, of which about three fourths is of direct-shipping grade. This ore will be coming out for many, many years. But the salient fact is this: production of direct-shipping ore from the open pits from now on will inevitably decline. One by one pits are being exhausted and closed. Relatively few unopened pits are left. The Mesabi open pits can no longer respond readily to an emergency call for double or triple production. Large quantities of iron-bearing rock susceptible to simple enrichment remain. However, these require treating plants that cannot be built or expanded over night. Production of wash concentrates cannot be stepped up quickly should another emergency arise, as has been the case during war periods with the open-pit operations.

Steel companies must plan their raw-materials supplies decades in advance. For many years the steel makers bordering on the Great Lakes, whose furnaces turn out about four fifths of the nation's total, have been pondering this question: To what source should they look to make up the approaching deficit of iron ore? This search led to the tremendous deposits of iron ore recently discovered in Venezuela and Labrador. These, as is well known, are being exploited. However, managements of the big steel companies don't relish the idea of possible dependence on ores brought across international boundaries or—particularly—across the water. Furthermore, they are good citizens and don't like the national jeopardy such dependence entails.

This situation led to the taconite-beneficiation program, now rapidly taking major physical form. Strictly speaking this program began 32 years ago. A plant was built near the town of Babbitt on the iron range to produce an iron ore from taconite. About one-half million tons of rock were processed. But this venture was born a couple of decades too soon. The hardness of the rock, inadequate equipment, and competition from the low-cost, high-grade natural ore caused the process to be abandoned.

The central figure in the present program of learning how to produce iron ore from taconite has been Professor E. W. Davis, for many years the director of the Mines Experiment Station of the University of Minnesota. He believed that the long-range future of the Lake Superior region lay in finding a practical way of wresting iron particles from taconite rock. That belief he backed with tremendous enthusiasm and determination. He and his staff began a major taconite research program many years ago. Out of this, and programs carried on over the years by other groups, sufficient progress in taconite technology was made to encourage the steel companies to invest millions of dollars in the present sizable pilot plants and the large production plants announced or under various stages of construction.

More than a technically practical process is needed. A favorable tax law is equally important. Iron ore from taconite must stand on its own economic feet. All funds are private capital; no government money is involved.

from rocks *to* dust *to* lumps

Taconite is the general designation for a Minnesota rock through which is dispersed fine particles of iron compounds firmly attached to the surrounding rock material. The proportions vary widely, but a representative specimen may contain iron oxides, 35 percent; iron carbonates, 5 percent; and iron silicates, 20 percent. The remainder, 40 percent, is quartz. To recover the silicates is hopeless; the carbonates practically so. The interest in taconites lies in the oxides.

The oxides are of two forms. Hematite (Fe_2O_3), which is not magnetic, and magnetite (Fe_3O_4), which is. The near-surface taconite that is the Mesabi is a ribbon about 100 miles long and up to five miles wide. At the northeastern end of the area the oxides are almost entirely magnetite. The ratio of magnetite to hematite declines in an irregular fashion as one moves toward the southwestern end where hematite predominates. Because the present concentration process is based on magnetic separation, iron-ore beneficiation operations are located along the magnetite portion of the taconite area.

Regardless of content variations, mining men agree that taconites all have one thing in common. They are rock harder than you know what. Drilling for blasting holes has been an extremely difficult problem. Much of it is so hard that the usual churn drills penetrate only a foot an hour and the cutters have to be changed every four to six inches. Thus a single 35-foot hole requires a lot of bit sharpening. This led to an entirely new method of drilling. This is the jet piercer developed by Linde Air Products Company. Kerosene and gaseous oxygen, under pressure, are burned to create a jet flame with combustion gases moving at 6000 feet a second and at temperatures of 4500 degrees F. Under this attack the rock chips or spalls. The debris is swept away from the surface by a blast of steam formed instantly as water is injected into the hole. The appearance and sound from a distance is of an infuriated monster attempting to devour the earth—which in truth it does, eating an eight-inch hole through the rock at a maximum rate of about 35 feet per hour or an average of about 20, including moving and setup time.

The rock is blasted and loaded into massive trucks or railroad cars for haulage to the crushing plant. Reduction from ton-size boulders to the size of marbles is accomplished in several stages by mechanical crushers of types conventional to the mining industry, except they are made of the hardest steel available to reduce the rate of abrasion. When the rock has been crushed to the size of driveway gravel it is introduced with water into rod mills (rotating drums containing loose iron rods) for grinding to about the size of rock salt.

After rod milling comes the first magnetic separation. Immersed in the slurry from the rod mill is a rubber-covered drum or belt. In the drum is a strong electromagnet or permanent magnet. As the drum turns, the magnetite particles adhere to it and are carried up out of the solution far enough for streams of water to wash them into a flume leading to the final stage of grinding. The sand particles, unaffected by the magnetic action, sink into the outlet below the separator for disposal, after some water recovery, to the tailings dump.

Final grinding of the product from the coarse separator is done in a ball mill, similar to a rod mill except iron balls are used instead of rods. Particles are now reduced to the size of flour and nearly all the iron oxides are freed from the silica. Final separation is made with a series of magnetic separators similar to the first one.

Dewatering is accomplished in a large, rotating filter covered with nylon or other fabric. By suction the water is drawn inside, leaving the desired product forming as a moist black cake of flour-fine magnetite particles adhering to the outside.

Thus we have arrived at the desired concentrate. The separation from sand is remarkably good. The iron concentration runs from 63 to 65 percent (out of a possible 72 percent). In this respect it is superior to direct-shipping ore, which is close to 51 percent (54 percent dry analysis). The extra richness, of course, helps the taconite concentrate overcome its cost handicaps.

The process, however, is not finished. Now, after so much energy and money expended to obtain the dust-size iron particles, something must be done to reform them into lumps. For reasons of shipping and for blast-furnace use, iron-ore concentrate in dust form is undesirable.

The steps leading to concentrate are essentially the same for all producers. As to agglomeration, however, there is no such agreement. Three types of agglomerates are being currently produced—pellets, nodules, and sinter. Each no doubt has its advantages and disadvantages, but if any engineer at this stage knows for sure which is preferable from an overall standpoint, including final metal making, he isn't saying. Comparative costs will undoubtedly decide which, if any, of the three will be the final form. The processes are too new for costs to be known.

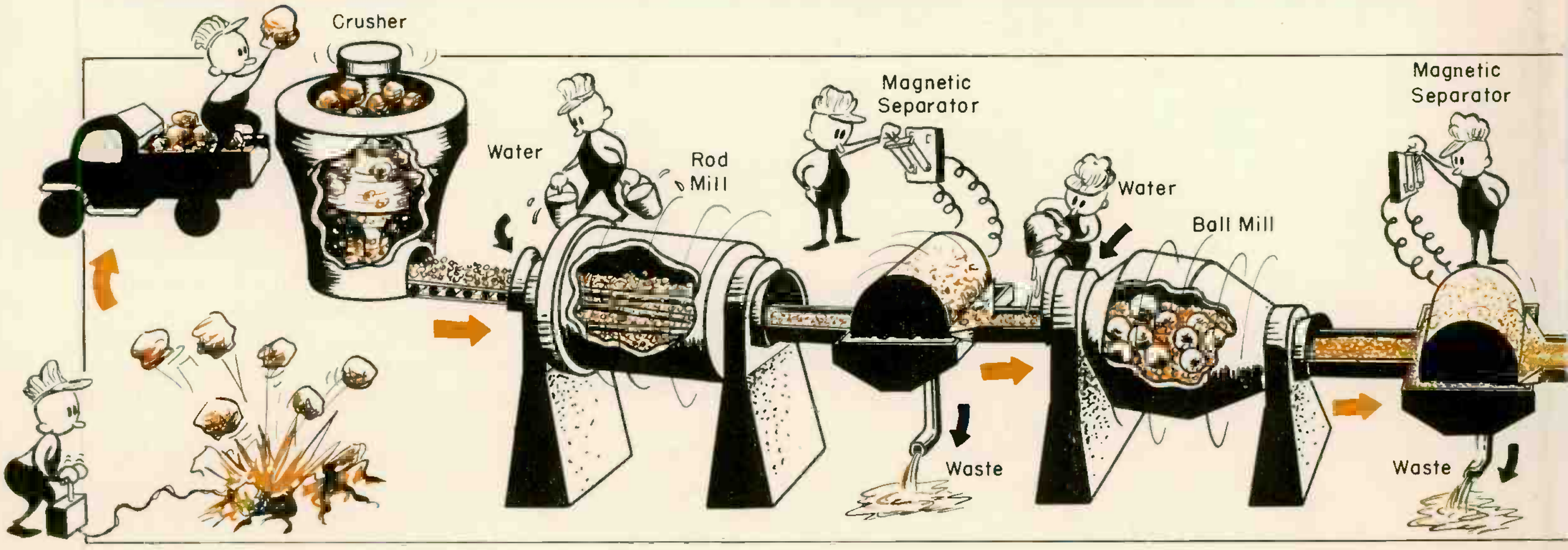
To make pellets, the moist concentrate is mixed with pulverized coal and a small amount of a clay binder. This mixture is fed into a slowly rotating, inclined drum. By snowball action the material forms into small balls or pellets. These run in size from about a half inch to one and a half inches in diameter.

The balling-drum pellets are still soft and friable. They must be hardened by a baking operation. They are conveyed to a furnace where heat of the furnace and from the burning coal in the pellets themselves, plus an excess of air, converts the iron oxide from the magnetite to the hematite form. The final pellets, while hard enough to stand shipping, are porous, which makes them a desirable blast-furnace feed.

Nodules are made by mixing the concentrate with limestone and firing in a kiln of essentially the same type as used to make cement. The moist mixture is fed into the upper end of the slowly turning 350-foot-long inclined kiln. It gradually works its way down hill to the firing end where it spills out as red-hot nodules. These are irregular shaped, hard lumps averaging about an inch in diameter and, to a large degree, still magnetic.

Sinter is produced by feeding a mixture of concentrate and powdered coal onto the long and wide flat bed of a sinter furnace. After it emerges and cools it breaks up into small, hard clinker-like lumps.

Importantly, too, taconite processing is expected to be a year-around operation.



Taconite iron concentrate must carry a heavy investment in physical plant (estimated at 30 to 40 million dollars for each million tons of annual production), and a high consumption of man-hours, fuel, and water. If it is to compete with local ores, as well as ores from Labrador, Venezuela, and Liberia, the tax must be fair. The Minnesota legislature saw the merit of Professor Davis' logic and established a basis for taxing concentrate mainly as it is produced and only slightly on its in-the-ground value.

As matters stand today, three organizations comprising several steel companies and mining companies are already in the Minnesota taconite business: Erie Mining Company, Reserve Mining Company, and Oliver Iron Mining Division of the U. S. Steel Corporation.

Erie, backed by Bethlehem Steel Corporation, Youngstown Sheet and Tube Company, Interlake Iron Corporation, and the Steel Company of Canada, Ltd., was the first to get under way with a pilot plant near Aurora, Minnesota to produce 200 000 tons of pellets yearly. Late in 1953 Erie announced a large-scale project calling for a much larger concentrating plant, and a 75-mile railroad to Two Islands on the shore of Lake Superior, 75 miles above Duluth, where a large harbor will be established. This project is expected to cost more than 300 million dollars and is planned for operation in 1957. It will have an annual production capacity of 7½ million tons of concentrate and can be further expanded.

Reserve Mining Company is owned by Republic Steel Corporation and Armco Steel Corporation. The scene of its concentration activity is the original taconite plant at Babbitt, built 32 years ago, and long since abandoned. Pellets began flowing from Reserve's plant in June, 1952, which now can produce about 300 000 tons per year.

Work is already well along on Reserve's new and much larger plant, to cost about 160 million dollars. The initial unit, planned for completion in 1957, will have an output of 3¾ million tons. Ultimate plans call for expansion to ten million tons, if conditions warrant. This new plant will be built on the edge of Lake Superior instead of at the ore body, as other plants have been. The taconite rock will be given a primary crushing at the mine and then shipped over a new 48-mile railroad to a new and as yet unnamed town near East Beaver Bay, Minnesota, which is about 50 miles above Duluth. Here a concentrate- and pellet-producing plant is being built, along with docking facilities, and a complete new townsite. Operation is scheduled to begin in 1955 for the first sections.

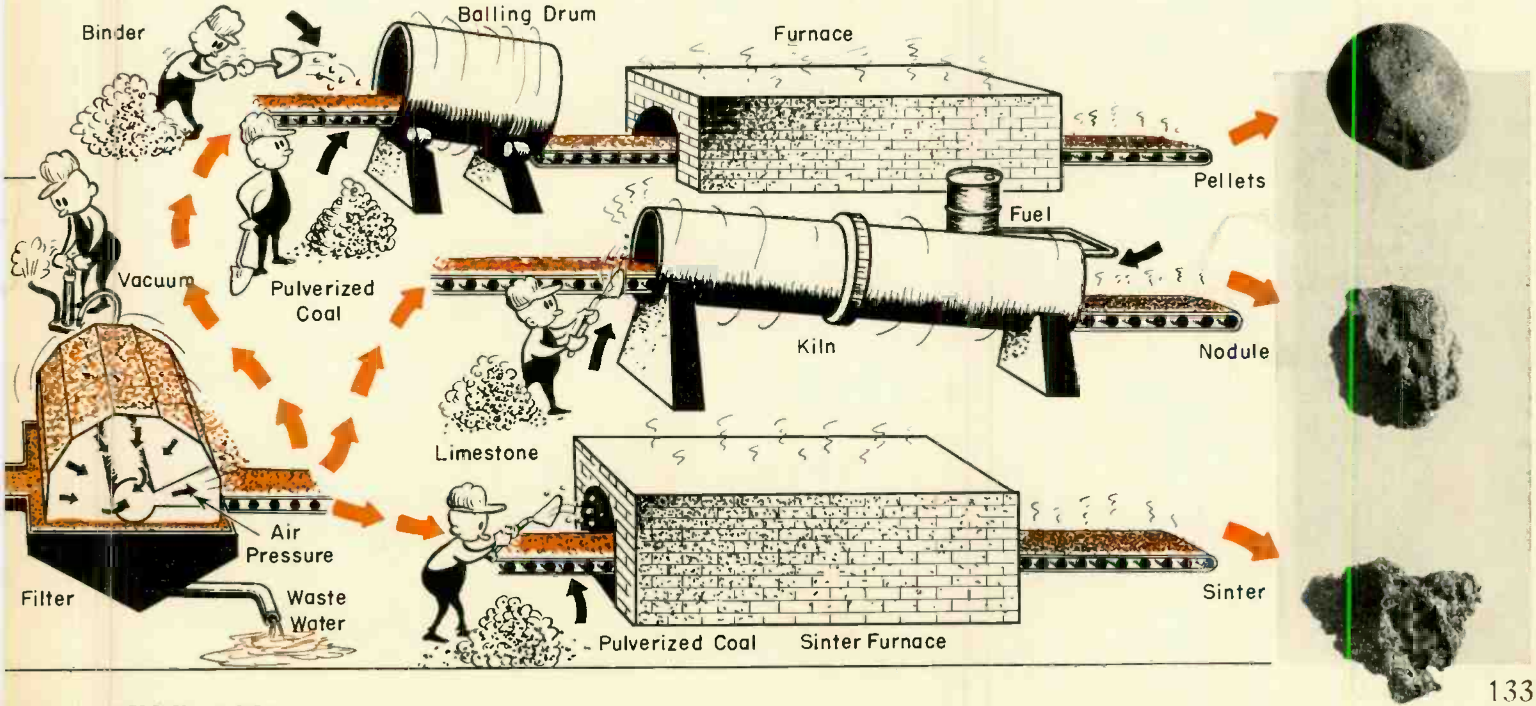
Oliver Iron Mining is the third major factor in taconite processing. This firm has been operating a concentrate-making plant at Mountain Iron. The concentrate is shipped to Virginia, a few miles away, where the firm has facilities for converting it either to nodules or to sinter. Although this operation is experimental, it is sizable—the annual capacity of the finished product is about 500 000 tons.

Oliver has announced no plans for a large-scale plant. It is expected, however, that Oliver will build a large production facility in the area with operations to begin about 1959.

One other and quite different iron-concentrate project is in the picture. This is in upper Michigan. The Humboldt Mining Company, owned jointly by Ford Motor Company and Cleveland-Cliffs Iron Company, has an operation based on extracting iron oxides from a nonmagnetic (hematite) rock called jaspilite, more commonly referred to as jasper. There are sizable bodies of jasper that can be mined by surface methods. While it is nonmagnetic, some of the rock is richer and softer than taconite. Because the iron is in a nonmagnetic form, the separation from sand will depend on a flotation process or on mixing the finely ground rock with a fluid intermediate in density between the iron ore and the silica. Or the two methods may be used jointly. Present plans call for two jasper-concentrating plants. The first will have a capacity of 200 000 tons of concentrate. It will be followed by one of 400 000 tons, and capable of expansion to 1½ million tons.

Aside from problems of high investment, hardness of the rock, and fuel requirements, processing of taconite to an acceptable blast-furnace feed poses two other problems of first-order magnitude of difficulty. These are: a suitable water supply and a place to dump the waste.

Taconite processing takes lots of water. About 40 tons of water are required for each ton of concentrate. Much of this can be recovered for recycling, but the quantity of make-up water is still large. The Mesabi ore body is virtually along the top of the Laurentian Divide. Hence no large streams flow conveniently by. The situation is further complicated



by the fact that waters on one side of the range drain to the Mississippi River. Those on the other side flow across the Canadian border to Hudson Bay. Because an international boundary is involved, water withdrawal and discharge must be planned with care.

The tailings also present a difficult problem, namely, where to put them. For each ton of concentrate produced, a place must be found for three tons of waste material. With eventual production running into many millions of tons yearly, that isn't easy. Aside from geographical considerations there are matters of stream, forest, fish, and game preservation.

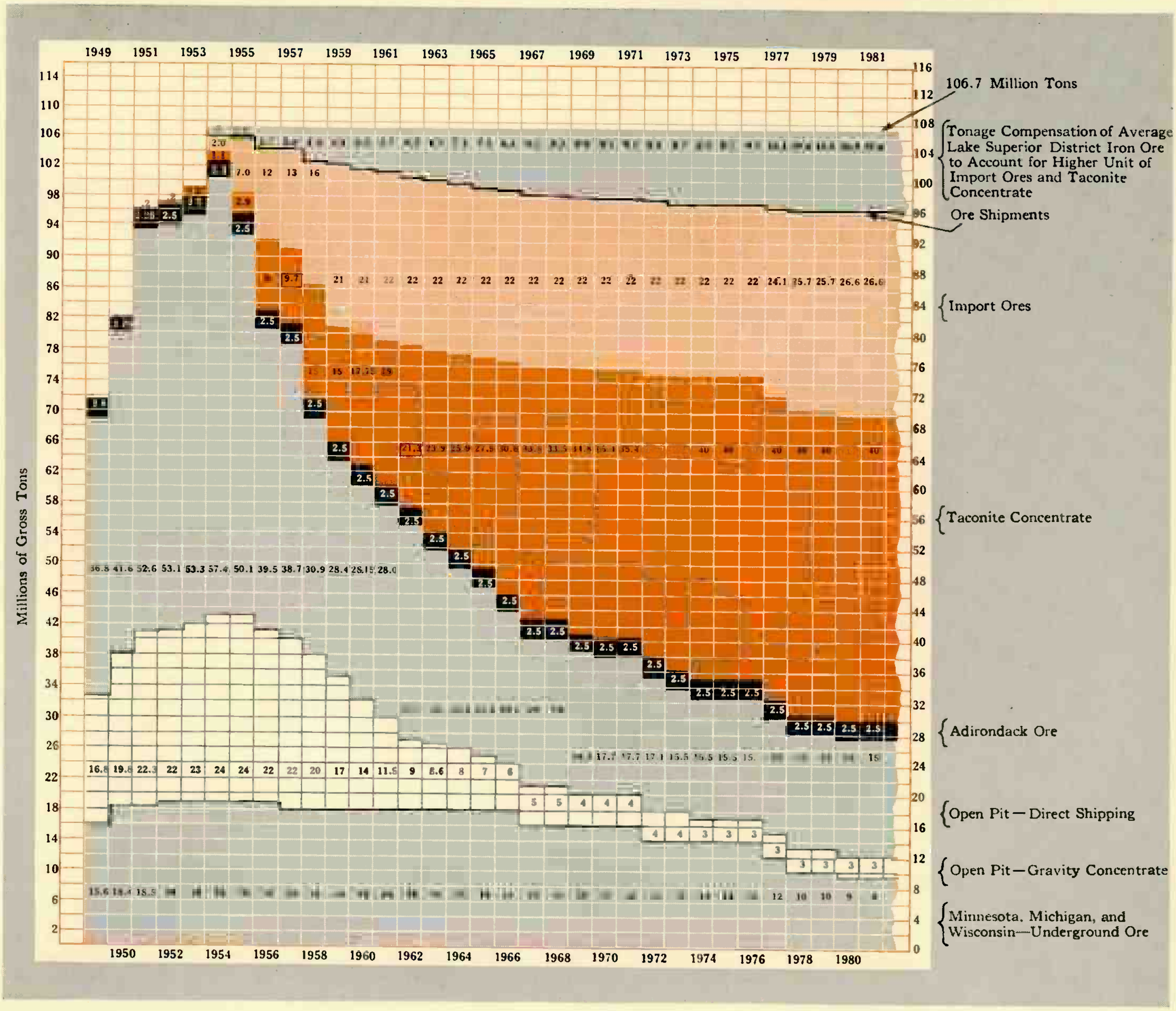
Reserve Mining Company chooses to solve these two knotty problems by building its plant at the lake. The lake will provide a supply of cold water. Also the waste sand, operating on the principle of heavy-density flow, will move along the inclined bottom of the lake to a very deep and very large trough in the lake bottom a few miles offshore.

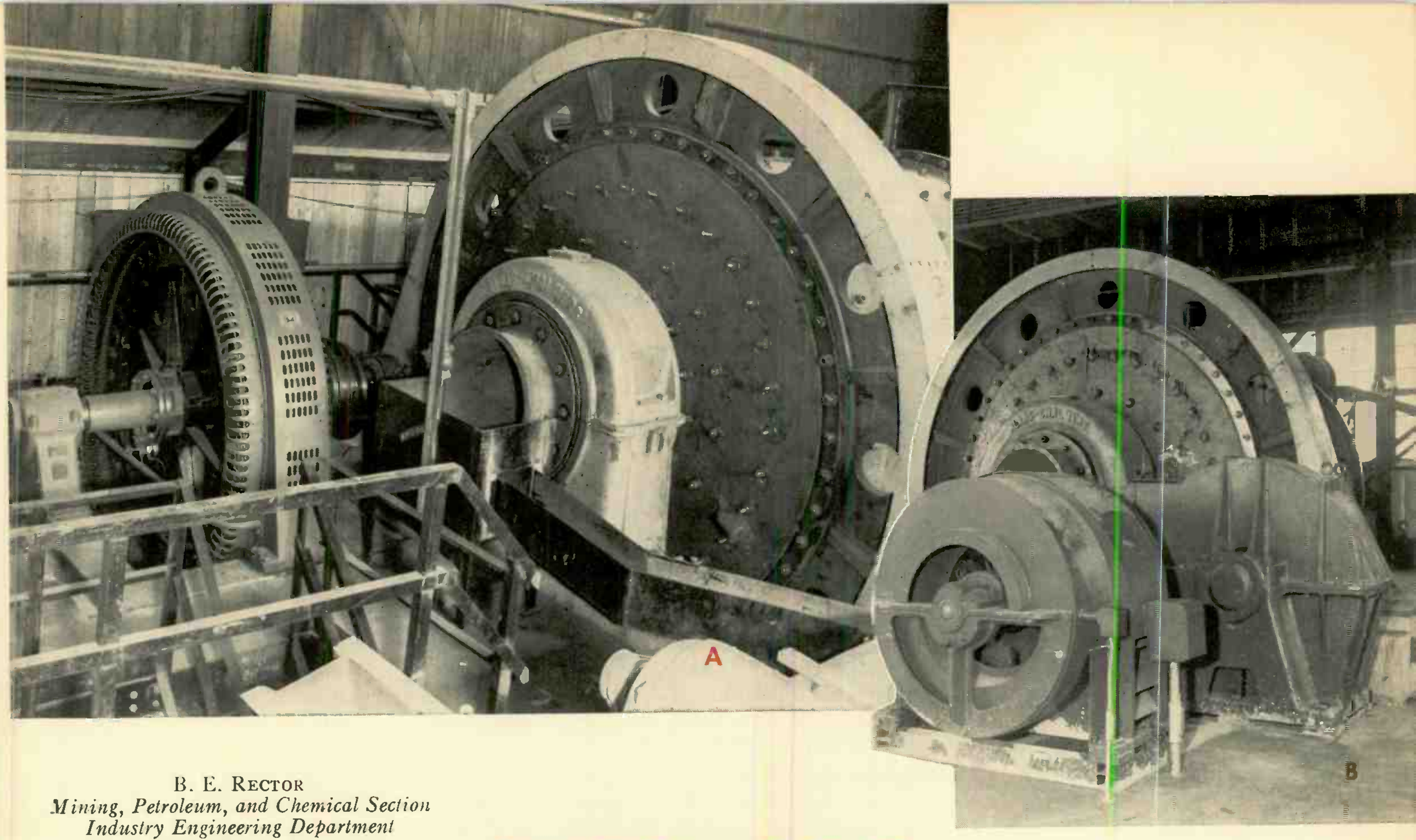
The taconite beneficiation program is entering stage three. Development of a practical process by the University of Minnesota and the mining and steel companies is pretty well concluded. The pilot-plant learning process is in an advanced stage or concluded. Beginnings have been made on the large-scale production plants. These will give a total annual productive capacity for taconite and jasper concentrate of about ten million tons by 1958.

It is estimated that five to six billion tons of open-pit magnetic taconite is available, from which can be obtained about two billion tons of concentrate averaging about 65 percent iron. In addition, several times this amount is underground.

The nation has a new industry—iron-ore beneficiation—with all its connotations: high capital investment by private industry, extensive requirements for massive and sometimes special machinery, large power consumption, and whole new cities and thousands of new jobs. The payoff, of course, is a supply of high-grade iron ore within the nation's boundaries for many decades.

The expected sources of the nation's iron ore for the next three decades, predicated on a constant total requirement beginning with 1954. The figures for 1952 and 1953 were those estimated when the chart was drawn. While the actual totals for those years differ, the ratios are approximately correct. The chart was prepared by V. D. Johnston, of Oglebay-Norton and Co.





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electrical equipment for IRON ORE beneficiation

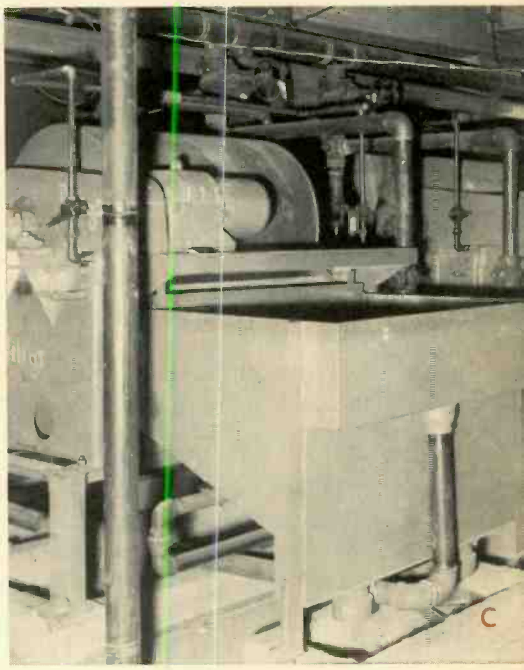
Taconite plants will use many high-horsepower drives. The concentrate is a flour-fine dust that is highly abrasive, magnetic, and conducting. Therein lie several king-size electrical-equipment problems.

THE BLAST-FURNACE skip hoist makes its slow climb up the incline, and, as it reaches the top, spills into the furnace a crumbly, rust-red mass that is iron ore. Not visible is another ingredient—electrical energy. This is of major and steadily rising importance. In 28 years, between 1924 and 1952, the electrical-energy content per ton of hematite ore shipped has increased by 315 percent. In the last ten years of this period it rose from 2.39 kwhr per ton to 5.13.

Most of the rise is the result of the increasing work done in beneficiating the lower grade hematites to the necessary iron content to make them commercial grade. In other words, the figures reflect the decreasing availability of the direct-shipping ores and the necessity of beneficiating greater quantities of the lower grade hematites. These figures are significant of the increasing role that electricity is playing in the iron-ore industry.

But what will the new taconite concentrating industry just getting under way do to the energy consumption totals? The figures are astounding. Taconite mining and beneficiation operations will require between 80 and 100 kwhr to process one ton of concentrate. In other words, to produce a ton of taconite concentrate 15 to 20 times more electrical energy will be consumed than is now used to produce a ton of ore. To use this amount of energy, vast quantities of electrical machinery will be needed. One taconite *pilot* plant alone has over 13 000 hp in connected drives.

In addition to the electrical drive or utilization horsepower required, the corresponding generating capacity must be provided. Electrical power for taconite mining and concentrating cannot be supplied with existing generating facilities. Some of the mining companies will construct their own generating plants to handle these loads. These power plants will use coal, in part because coal can be transported in the ore boats on their return trip



***A* and *B*—Wet-grinding taconite mills driven by direct and geared synchronous motors, respectively. *C*—Drum-type wet magnetic separators are used to make the final isolation of the iron particles.**

from the lower lake ports. Power plants of ultimate capacities of 200 000 kw are under consideration.

To handle and process the tremendous amount of material necessitates motors, control, and other allied electrical equipment in numerous quantities and sizes. These equipments cannot be applied indiscriminately since the design and application engineer must take into account various factors that prevail in this particular industry. The more outstanding conditions are:

1—Presence of extremely fine, highly abrasive, partially conductive and magnetic dust.

2—Need for maintaining a continuous process flow.

3—Extreme climatic conditions.

4—Safety to personnel and equipment with high-capacity rotating equipment.

One of the most troublesome is the dust. Since the dust is magnetic, it is attracted to those components of electrical equipment employing a magnetic circuit. On open-type equipment the dust is held in the air gap of magnetic circuits and may eventually plug them. As dust settles on electric coils it tends to work its way into the insulation between turns, where its abrasive and slightly conductive characteristic promotes insulation failure. Recent developments in insulation materials and techniques have made available methods of resisting this condition. A neoprene emulsion treatment for the coils of motors produces a resilient rubbery surface that resists wear and abrasion and fills the voids. The dust tends to migrate along motor shafts into bearings. If it mixes with bearing grease, a good grinding compound is provided.

All this means the motor must be designed to exclude the dust. Long, precision running fits between motor bracket and shaft and nonmagnetic bearing shields are necessary. For drives of large horsepower used in areas of high dust concentration, totally enclosed, separately ventilated motors are an alternative answer to the dust problem. Clean air is brought from the outside and blown under pressure through the motor. The slightly higher air pressure in the motor forms a positive seal against dust. For motors of smaller ratings, totally enclosed, fan-cooled, or totally enclosed, self-ventilated motors can be used.

It is necessary, of course, that motors be located in the dusty atmosphere of the driven machinery. However, this is not true of motor control, switchgear, and d-c conversion equipment. This equipment can be located in rooms that are physically separated from the areas served. These rooms can be provided with filtered air under slight pressure in an effort to exclude the iron-oxide dust that is highly injurious to electrical equipment.

The pilot plants now in production are more than plants just to investigate the flow diagrams for processing taconite. Their scale is large enough to permit investigation of the most suitable mechanical and electrical equipment on an economical as well as technical basis. An interesting example in regard to electrical equipment is the investigation of the drive equipment for ball and rod mills. The most common practice has been to use a slow-speed motor driving the ball mill through a pinion on the motor shaft, with the pinion driving the ring gear on the mill. With the fairly low speeds at which ball and rod mills operate and with the limited speed reduction of the pinion and mill ring gear, a motor of fairly low speed is required. For a given horsepower the physical size of a motor is roughly inversely proportional to motor speed. Hence a motor of large horsepower and low speeds is large physically. The larger the motor, of course, the more copper and iron in the motor and therefore the greater its price. Also a slow-speed motor is less efficient, requires more excitation power. A high-speed motor with a separate speed reducer for this application is comparable in price to a slow-speed motor without the speed reducer. The higher efficiency of the high-speed motor offsets the losses in the gear, so that efficiency-wise the two systems are about the same. However, the difference in excitation requirements is in favor of the high-speed motor, in the ratio of three to one. The high-speed motor and speed-reducer combination can be physically arranged in less floor space than the slow-speed motor. Also the cost of installing the high-speed drive is less.

On the basis of only a few machines, the gains to be realized with the high-speed machine are not too attractive. However, because the commercial plants will use large numbers of such drives the reduction in excitation energy, decreased building costs, and lower installation costs are substantial. For these reasons both types of drive have been tried in the pilot plants with the final selection to be based on pilot-plant operating experience.

In applying synchronous motors for driving rod and ball mills, it is mandatory that the motors have the proper torque ratings. Due consideration must be given to all factors that can increase future load requirements. Such factors are: future increase of ball or rod charge, addition of mill grates, change in gear and pinion ratio to produce increase in mill speed, and increase of charge as mill liners wear.

The two most important torques to be considered are the starting torque and the pull-in torque. Two factors must be considered when evaluating the starting-torque requirements: first, the actual break-away torque required to start the mill and, second, the peak torque required by the load at the instant the rods or balls start to cascade or roll after being elevated up the side of the mill. The higher of these two values is the predominant consideration in determining the starting torque and for ball and rod mills. In general the peak-load torque is considerably higher than the break-away torque.

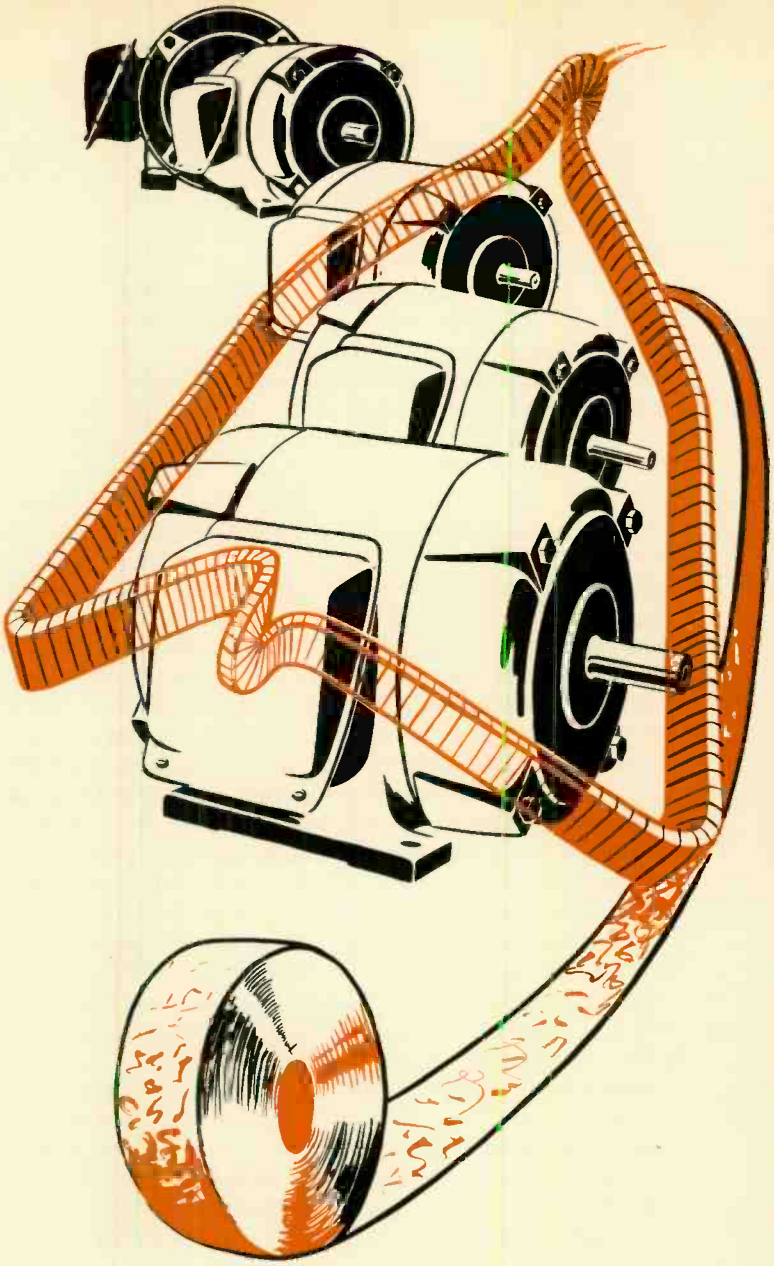
In either ball or rod mills the charge has begun to tumble by the time the motor has reached 95 percent speed, hence the maximum load that occurs at pull-in is the maximum load that the motor must carry in normal operation. It is desirable that the pull-in torque of the motor be specified as low as is consistent with the drive requirements, since this permits the starting inrush to be held to a lower value. This is important in that it helps to reduce starting inrush. A decrease in starting inrush reduces line drop and consequently prevents excessive decrease in starting torque due to unnecessary voltage drop during starting.

The drives for mining, concentrating, and processing phases of taconite production involve no novel equipments. However, these plants have special requirements that demand close attention if good performance and low costs are to be achieved.

• • •

A Transformer Serves As Its Own Oven—Transformer engineers recently reversed a manufacturing process and "put the oven inside the transformer." The problem: how to dry and vacuum treat a giant 100 000-kva, 330-kv transformer that was too big for their largest oven. The solution was to let the transformer serve as its own oven; hot air at 105 degrees C was fed in at the bottom of the transformer and exhausted at the top. Later the transformer tank was sealed off and served as its own pressure container for vacuum treating. The complete air-drying operation took six days. The finished transformer, which weighed over 300 tons, was delivered to the Atomic Energy Commission in April.

The intrinsic insulating ability of a material is but one of many considerations in its application. Whether it can be practically incorporated in a particular machine, the conditions it will operate under, its mechanical and electrical characteristics, and many other factors are vital. For this reason, improvements in insulation can take several directions. The recent advances in insulation for rotating machines show clear evidence of this fact.



Developments in Insulation for Rotating Machinery

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The "chemical revolution" has made possible many new insulation materials and processes that have been significant factors in the redesign of electric machinery. Early electric motors and generators were perforce insulated with materials occurring in nature. Chemists and physicists have contributed a better understanding of why materials insulate, and thus the knowledge leading to better insulations.* Furthermore, they have made these better materials with more closely controlled characteristics, as well as more consistent purity, than was ever possible with natural materials. As a result of this newest industrial revolution, insulation engineers have been active for the past decade providing new insulating materials and systems that are now being used in modern electric machinery.

Insulation Standards and General Considerations

Insulation for rotating machines involves quite different design approaches and application techniques than are employed in the insulation of stationary apparatus. Many problems encountered in rotating machines do not exist in stationary equipment. For example, rotating machines must contend with centrifugal forces. The importance of space and weight in rotating machines, coupled with the greater need for physical support of the coils, requires solid barrier insulation on many parts. This is particularly true on those portions of the winding embedded in the core, where close capacitive coupling exists between winding and magnetic core. Furthermore, a much higher percentage of the winding is closely adjacent to the grounded magnetic core. Therefore, full-voltage insulation is commonly employed between all of the winding and the core.

The design of rotating machines, as well as other electrical equipment, is greatly affected by competition and customer requirements. These emphasize the need for lower cost and increased reliability. Many times a reduction in size means a reduction in cost. Progressive steps have been taken in this direction. Significantly, many of them have been accomplished by reduction in space allowed for insulation, permitting a greater proportion of iron and copper in the machine. Other gains have been made by simplifying or mechanizing insulating processes.

Rotating machines span a wide range of cost, size, and complexity. At one extreme are those of thousands of kva or horsepower; these are largely tailor-made—each is ordered, designed, and manufactured separately and may never be duplicated. Then come those of a few horsepower, and at the other end of the scale the small fractional-horsepower motors;

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*For a discussion of the physics and chemistry of electrical insulation, see "Fundamentals of Electrical Insulation," by Jack Swiss and T. W. Dakin, *Westinghouse* Engineer, May, 1954, p. 114–24.

these are made almost completely by mechanized production lines. The requirements for rotating-machine insulation thus include many widely different problems.

Thermal endurance of insulation is an important limiting factor in electric machine design, and in this field the most obvious gains in electrical insulation have been achieved. The first AIEE standards (established about 1914) classified insulating materials according to their abilities to operate at different temperature levels. This standard outlines the general principles upon which temperature classification of electrical insulation is based. When insulations were first classified as to limiting temperature, the definitions were relatively simple because all the basic components existed in nature. Therefore, the materials fell readily into two classes—organic and inorganic. Temperature limits were selected on the basis of whether organic or inorganic components were used. Subsequently, it was recognized that organic materials fell into two subclasses—those composed entirely of fibrous organic constituents (class O), and those in which the fibrous components were further protected by impregnation with varnishes or immersion in liquid dielectrics (class A). The inorganic class B components described in AIEE Standard No. 1 had obvious uses. Mica was a dielectric barrier. Asbestos and later fiber glass were insulating spacers.

The advent of synthetic insulation materials greatly complicates the problem of classifying insulations according to the original definitions. Compounds can no longer be defined simply as organic or inorganic, nor can the problem be solved by interposing an intermediate class of semi-inorganic materials. Even the truly organic materials have vastly different levels of thermal endurance, as well as differences in physical properties, because some synthesized materials are better than their counterparts in nature.

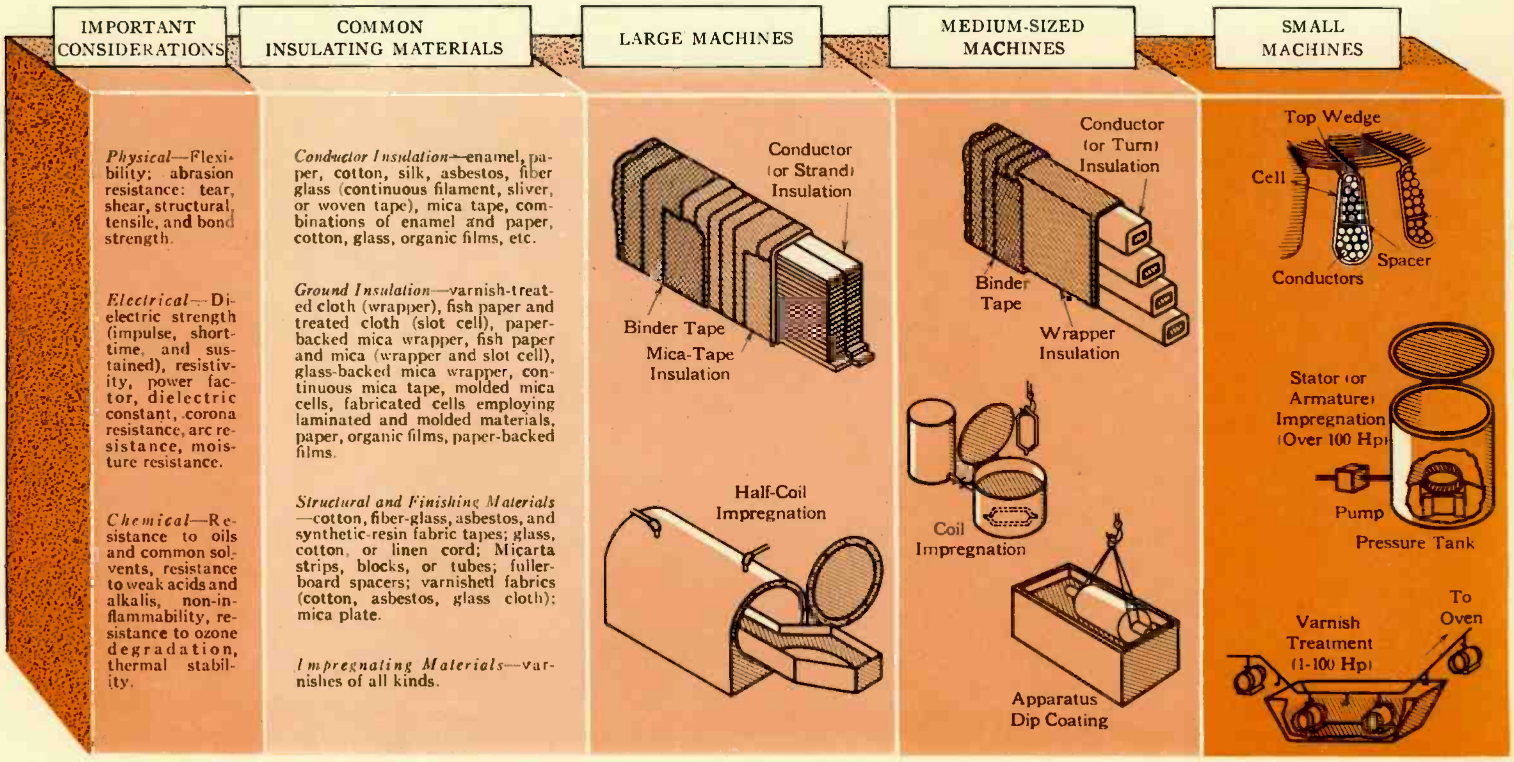
Classifications of insulating materials and systems have been re-examined. Two distinct schools of thought are current. A group of engineers in Europe has proposed (under the sponsorship of the International Electrotechnical Commission) the creation of new classes of insulation intermediate between the now existing classes A and B, and B and H. They further recommend segregation of insulating materials into these classes on the basis of opinions of those who have used them. While many of the opinions underlying this classification are the result of individual tests and experience, no standardized testing procedure or common criteria of insulation evaluation is involved.

The second group is composed of electrical engineers in the United States working under the sponsorship of the AIEE. The objective is standardization of test methods and criteria whereby not only insulating materials, but complete insulation systems can be evaluated in terms of time and temperature to failure. This group has developed a functional evaluation program with proposed standard test methods resulting in measurable end points of insulation life. Many manufacturers and users are now evaluating different insulation systems by the use of model motors under standard methods. The program of this group is ultimately to adopt definitive test methods for determining the heat endurance of insulating materials.

Westinghouse has experimented for over 15 years in evaluating insulation on models of motors and parts of motors, as well as on complete small integral-horsepower motors. This has convinced engineers following these tests that standardized test methods and agreed criteria form the only sound basis for classifying both insulating materials and systems.

New Insulating Materials

Fibrous glass has grown from a laboratory novelty to an essential component of every large high-voltage generator and is being used on many small integral-horsepower machines. Its use is still growing. Fibrous glass meets the "inorganic" requirement of class B and H insulation, but is also being used in class A insulated apparatus, because of its desirable qualities and its drastically reduced cost. The outstanding physical strength of fibrous glass, the immunity of the fibers to thermal aging, and inertness to attack by chemicals and moisture have led to its use wherever justified economically.



IMPORTANT CONSIDERATIONS

Physical—Flexibility; abrasion resistance: tear, shear, structural, tensile, and bond strength.

Electrical—Dielectric strength (impulse, short-time, and sustained), resistivity, power factor, dielectric constant, corona resistance, arc resistance, moisture resistance.

Chemical—Resistance to oils and common solvents, resistance to weak acids and alkalis, non-inflammability, resistance to ozone degradation, thermal stability.

COMMON INSULATING MATERIALS

Conductor Insulation—enamel, paper, cotton, silk, asbestos, fiber glass (continuous filament, sliver, or woven tape), mica tape, combinations of enamel and paper, cotton, glass, organic films, etc.

Ground Insulation—varnish-treated cloth (wrapper), fish paper and treated cloth (slot cell), paper-backed mica wrapper, fish paper and mica (wrapper and slot cell), glass-backed mica wrapper, continuous mica tape, molded mica cells, fabricated cells employing laminated and molded materials, paper, organic films, paper-backed films.

Structural and Finishing Materials—cotton, fiber-glass, asbestos, and synthetic-resin fabric tapes; glass, cotton, or linen cord; Micarta strips, blocks, or tubes; fullerboard spacers; varnished fabrics (cotton, asbestos, glass cloth); mica plate.

Impregnating Materials—varnishes of all kinds.

Wire enamels have also improved significantly. A new resin for this purpose, developed at the Research Laboratories, is applied to wire for the new Life-Line A motor. Called Bondar, this resin enamel has excellent thermal endurance—at least two to three times that of previous enamels, as established by wire tests and tests on complete motors. It also exhibits superior resistance to refrigerants, such as Freon 12 and Freon 22, and has high dielectric strength.

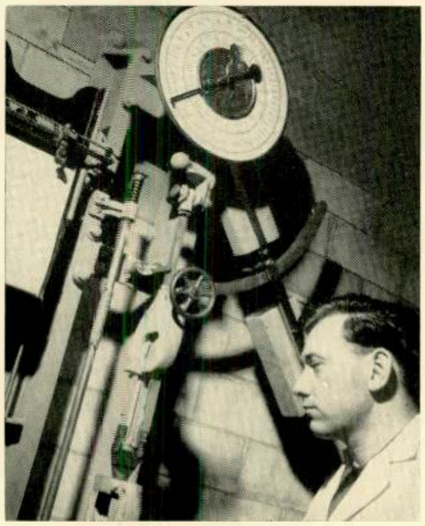
The progress in wire enamels has made it possible to insert the windings of fractional-horsepower motors completely by special winding machines. Also, many of the space-consuming barriers and similar insulation materials have been eliminated on single-phase fractional-horsepower motors as a result of the improved insulation on the wire. The development of wire enamel having good resistance to thermal shock makes it possible to wind fractional-horsepower split-phase motors for severe starting applications without cotton covering or other space-occupying material on the starting winding wire.

The contributions of resin chemists to electrical insulation are extremely important. New synthetics have been created that serve as varnishes for impregnation of insulation, for bonding structural parts, and for finish coating surfaces of both insulation and metal. Silicone resins and their tremendous thermal stability are intriguing and an outstanding development, but the conventional organic resins must not be overlooked; they provide strong, and sometimes resilient bonds for insulation and fill the insulation interstices to an essentially void-free condition.

Silicones—Silicone varnishes and class H insulation have overcome severe operating problems where equipment is overloaded or operated in high ambient temperatures. Silicone rubber is a promising new material that provides dielectric barrier action. It has good dielectric strength on short-time tests, and excellent voltage endurance. Rubbery materials have a degree of fatigue resistance plus flexibility, resilience, and an ability to endure shock, which fits them to withstand prolonged mechanical vibrations and repetitive elongation and contraction. However, organic rubbers have too short a thermal life to permit their use as a major insulation in important electrical machinery. Silicone rubber, however, possesses the essential characteristics of organic rubbers plus outstanding thermal endurance. In addition, silicone rubber has outstanding chemical properties. Absorbed water does not materially affect power factor, dielectric constant, or dielectric strength, as is the case with well-known organic materials. The weathering and corona resistance of silicone rubber are also unique among rubber materials. This opens the way for its use as insulation ground wall. Considering all of its characteristics, silicone rubber some day will probably find use as a ground insulation on important electrical machinery, but more work is needed to solve application problems.

Silicone resins are being used as enamel to coat bare wire and for treating glass-covered magnet wire. Mica products are available with silicone-resin bonds; these products include permanently flexible types and the hard molded plate and complex shapes. Certain silicone resins are useful for impregnating coils and windings. These high-temperature resins are used to coat fiber-glass cloths, as well as to coat coil surfaces, and as a finish for assembled electric machinery. In general, silicone resins do similar jobs to their organic counterparts with improved thermal endurance and moisture resistance.

The outstanding thermal endurance and excellent moisture resistance of silicone resins have resulted in ever-increasing usage. These resins have been employed in electrical machinery for more than ten years in connection with mica and fiber-glass insulation components. The composite insulation has been classified in AIEE standards as class H insulation with a permissible hot-spot allowance of 180 degrees C. The U. S. Navy has recognized this class of insulation as capable of continuous operation at hot-spot temperatures up to 200 degrees C. Much equipment with class H insulation has been in service for five years or more with an excellent operating record. Accelerated tests have been made at temperatures up to 300 degrees C, indicating that 200 degrees C hot spot is a satisfactory value for reasonable life. Motors in this test program, operating since 1943 at 240 degrees C, have accumulated 40 000 hours without trouble.

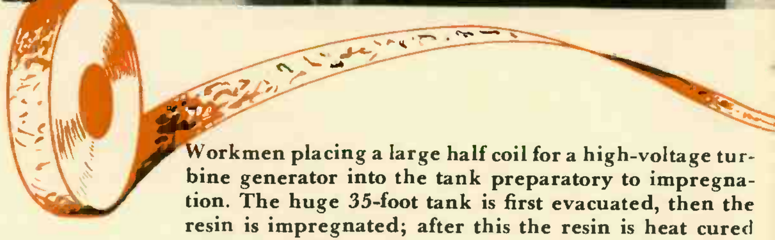


In addition to high dielectric strength, Mylar polyester film is also mechanically strong. Here a sample of 0.005-inch-thick Mylar and 0.005-inch paper—the same combination used in the new Life-Line A motor—withstands 360 pounds before it finally tears.

In conventional class H equipment, wherein silicone resins are substituted for organic resins in connection with mica and fiber glass, experience with class B insulation can be extrapolated to the class H temperature range. Laboratory tests and field experience correlate so that silicone insulation can now be applied to most types of electrical machinery where some economic advantage can be derived from it. Newer and more radical class H insulations in which resin films are substituted for the mica-flake dielectric barrier are being evaluated. These resins are either coated onto fiber-glass cloth or impregnated into the interstices of inorganic paper-like structures, some of which are made from pulverized mica particles. In evaluating new materials of this sort, engineers should not presume that an insulation fits into a class whose characteristics have been proved merely because it contains particles of the same basic constituents. To be consistent, these materials should be subjected to the same functional evaluation tests recommended for other new classes of electrical insulation.

In the case of fractional-horsepower motors the silicones have not resulted, as yet, in the same advantages as for larger machines. This is brought about by parts other than the winding insulation being adversely affected by elevated temperatures. In these motors small temperature gradients exist between the winding and the mechanical parts of the motor. Also, the relatively long low-temperature curing cycles prior to the final setting bake of silicone varnishes are not adaptable to the high-production methods of fractional-horsepower motor manufacture. Recent changes show promise of improvement in this respect.

Improved Organic Resins—New organic resins with vastly improved physical, electrical, and fabricating characteristics



Workmen placing a large half coil for a high-voltage turbine generator into the tank preparatory to impregnation. The huge 35-foot tank is first evacuated, then the resin is impregnated; after this the resin is heat cured while the coil is molded, to insure accurate dimensions.

have made possible tremendous advances in the insulation of some kinds of electrical machinery. Several new resins have been developed which have excellent film-forming properties and provide great dielectric-barrier strength. Examples of these are Mylar, Teflon, nylon, and cellulose acetate, as well as many polyvinyl resins. Some have limitations in thermal endurance, others have poor voltage endurance; therefore a more complete evaluation is necessary to determine their full value. Some resins are ruled out because they flow under concentrated pressure.

Many synthetic resins can be formed into large sheets of thin, hole-free films. This can be an important advantage. Many appear to hold great promise for use as the main insulation in low-voltage, low-temperature classes. These are being studied and their position evaluated, but mica is still the most reliable high-voltage insulation for important machines. Mica may, in turn, be better applied when supported on some of these new films.

Mylar polyester film, one of the newest of these resins, has quickly developed into an important item in the insulation engineer's material list. It has extremely high dielectric strength. Its tear strength, particularly without an incident notch, is exceptionally good (p. 139). These, together with other qualities, make it suitable for slot insulation, requiring less than half the space of previously used materials of similar qualities. Thermal-endurance tests indicate that Mylar retains these qualities, and has a useful life at temperatures somewhat above the 105 degree C maximum value allowed for class A insulation.

Mylar film has already found its way into small integral-horsepower motors. In the new Life-Line A motor it is used in combination with rag paper as slot-cell insulation. This combination has about twice the tear resistance, and half the thickness of the material it replaces, for the same dielectric strength. This film is also being used as a wrapper on small d-c motor coils. In fractional-horsepower motors this thinner slot-cell insulation will allow further winding reductions by permitting better utilization of copper and iron within the motor enclosure. In some designs this would allow the use of aluminum wire in place of copper, where desirable, because of material availability.

The wound stators of the new Life-Line A motor are dipped in an organic varnish that provides many improved characteristics. Called Bondite, the new varnish has a life at elevated temperatures of 170 percent that of the previous varnish. It has excellent resistance to oils, solvents, acids, and alkalies. Fortification with silicone has also provided greater water repellency, an important factor in many applications.

Another important resin development is the solventless heat-reactive resin impregnant. One class of these solventless impregnants brought to reality the insulation engineer's dream of "complete impregnation." Since insulation impregnation was first attempted, engineers have been striving towards the complete fill of the internal voids of an insulation to improve its electrical and physical properties. Unfortunately, they had only two types of materials—one was the varnish employing a solvent, and the other was the plastic semiliquid asphalt-like bitumen materials. The solvent type was used in most impregnation work because of its ability to penetrate the deep-seated insulation interstices. But evaporation of the solvent left voids that could not be filled. The thermoplastic bitumen material was so viscous and of such great molecular size that it could not be thoroughly forced into most insulation structures even at the highest practical impregnating temperatures. Therefore, the creation of a low-viscosity solventless material that reacts completely when heated, without the evolution of gases or solvents, was an important step.

Thermalastic insulation is an outstanding example of achieving optimum physical, electrical, and thermal properties in such an insulation without sacrificing any of the known characteristics of mica. The solventless synthetic-resin varnish employed for impregnating Thermalastic insulation is one of the most valuable contributions of research to the insulation art. Because of its low viscosity before reaction it penetrates deeply into interstices of complex insulation structures with simple processing. When cured, its resilience, physical strength, excellent electrical properties, thermal stability, and water resistance have opened up new vistas of insulation potentialities still under development. Its ability to fill voids completely has made it a "natural" for high-voltage machine insulation.

This insulation had its inception in the Westinghouse Research Laboratories in 1940. It was first used commercially on large turbine-generator stator windings in 1949, and has since become the standard insulation for all electric-utility turbine generators built by Westinghouse. Also, it has been applied to all armature coils for large salient-pole generators, such as water-wheel generators. A modified form of Thermalastic insulation is being supplied on nearly all synchronous and induction motors of 200 hp or more. Among its outstanding properties are: (a) higher dielectric strength and greater voltage endurance (Fig. 1); (b) fewer internal voids, with better heat transfer and reduced internal ionization; (c) resilient insulation system with great physical strength to withstand thermal cycling forces in very long coils; (d) low power factor, less affected by voltage and temperature (Fig. 2); (e) chemical inertness; (f) outstanding moisture resistance; (g) greater thermal endurance and longer life.

Other Insulation Trends

In addition to new materials, other factors affecting insulation and its application have appeared in recent years. New concepts of construction and increasing demands for higher power output have a definite effect on insulation.

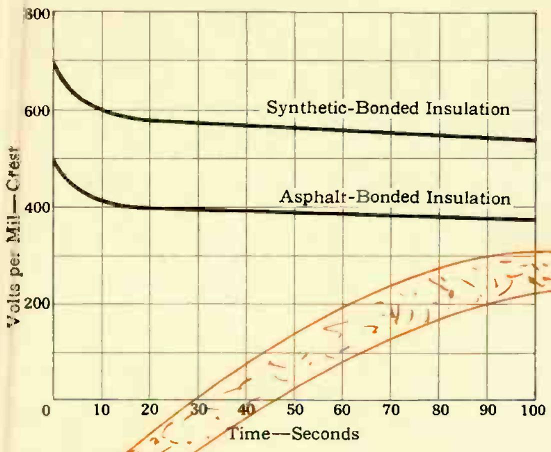


Fig. 1—Improvement in dielectric strength of identical mica splittings—due to Thermalastic bonds, impregnant, and processing—is more than 40 percent in volts per mil or 1000 times longer to failure at the same value of dielectric stress.

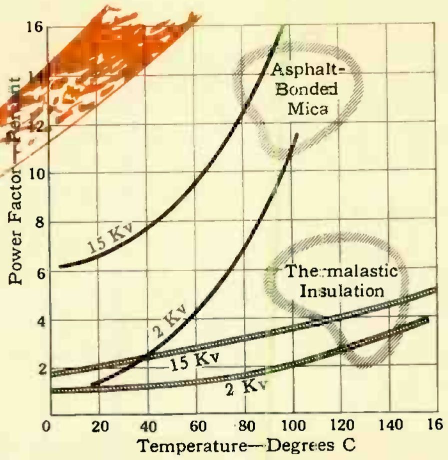


Fig. 2—Power factor versus temperature for asphalt-bond and Thermalastic insulations.

Higher Voltage Machines—The economics of generating electrical energy have dictated larger and larger concentrations of power in a single unit. Machine designs have now reached the physical size where increased ratings must be achieved by higher operating voltages. This imposes newer and more difficult problems on the insulation designer. Fortunately, new materials already developed for machines in the 15-kv insulation class, such as Thermalastic insulation, are readily adaptable to the higher voltages. The high dielectric strength of this insulation provides protection and reliability without excessive insulating wall thickness. Many machines are being built for at least 20 kv, and several for 24 kv (rated at 250 000 kw). Machines with voltage ratings up to 30 kv are in sight, and several studies are being made toward higher voltages.

Inner Cooling—Inner cooling of high-voltage generator coils is a major advance in cooling techniques, and requires but minimum changes in insulation design and manufacturing methods. In most respects insulation for inner-cooled stator coils conforms to the best practices on conventional machines. Conductor strands are individually glass-covered. Turn insulation is no problem, as these large generators employ single-turn half coils. Thermalastic insulation employing solventless-resin-impregnated mica tape provides the insulation ground wall. The outer binder is a lapped fiber-glass tape, applied before the resin impregnation of the ground wall. It is, therefore, solidly bonded thereto.

One new element of the inner-cooled stator coils requires insulation, namely, the metal tubes that carry cooling gas within the stator coils. These tubes are placed between two halves of the transposed conductor strands. The outside of these metal tubes, therefore, must be electrically insulated from the conductor strands, although they are in intimate thermal contact. The fiber-glass covering on the strands is supplemented by wrapping the individual gas-conducting metal tube with a fiber-glass tape. Thus, each tube is individually insulated from the adjacent tubes and each of the strands of conductor with the equivalent of conventional strand insulation. The metal tubes assume the voltage level of the adjacent conductors by a capacitive coupling, and therefore do not require major insulation. The relatively light electrical insulation between vent tubes and conductors offers low thermal resistance to heat flow from the conductor into the cooling gas. From this it is evident that within the slot and in the main part of the end windings the insulation on an inner-cooled generator does not differ from normal practice on conventional machines.

Only at points where cooling gas enters and leaves the stator core do new insulating problems arise. On the inner-cooled stator coils the ventilation is straight through the coils from end to end, which simplifies insulation problems. At the extreme ends of half coils, where the slot-to-slot connection must be made, a new insulation problem was created by the existence of the ventilating openings through the main ground insulation. At the extreme ends of the half coils the gas-conducting tubes must leave the conductor. The conductors and coils are connected to each other in a conventional manner and the cooling tubes must have access to cooling gas. The opening in the ground wall for entrance of cooling gas to the tubes changes the insulation from a dielectric barrier to a creepage surface at that point. Exhaustive studies have demonstrated the adequacy of the creepage spacing and striking distance allowances on these end windings. Modern windings employed by Westinghouse are designed to be corona-free under operating conditions and under conditions of impulse within the limits of their surge-protection equipment. Considering that in a high-voltage winding of this type more than 90 percent of the voltage of the copper appears on the surface of the insulation in the end winding, conventional windings that have complete barrier insulation on the end turns are remarkably corona-free. Reasonable additions to the creepage distances and to the striking distances give adequate margin of safety at the point where the metal tubes leave the conductor. The addition of a molded cap of silicone rubber at this point gives added safety, although the design is such that this addition need not be depended upon.

In the Future

Although much progress has been made in insulation development in the past decade, the accomplishments also emphasize the potentialities that remain. For example, in the large-machine field, mica is not likely to be supplanted as the basic ground insulation within the foreseeable future; however, as Thermalastic insulation proves, there may well be better ways to utilize it in combination with other materials. The chemical field has already produced many new insulating materials, but the surface seems hardly to have been scratched.

The improvements to come can take many avenues. Machine designers would like to use less space for insulation, to have higher dielectric strength, lower dielectric losses, greater voltage endurance, longer thermal life, higher operating voltages and temperatures, reduced variability, improved resistance to contamination and damage, greater reliability, and a whole host of other improvements.

An Engineering Personality

A. C. Monteith

When the average person moves up to a new position, his interest in and knowledge of the previous activity fades. This cannot be said of the new president of the AIEE. One of his close associates summed it up this way: "'Monty' can keep more balls in the air at one time than anyone I know."

A. C. Monteith has taken many upward steps since coming to Westinghouse in 1923 after graduation from Queen's University in Kingston, Ontario. He has moved steadily from engineering apprentice, to a central-station engineer, to managership of Central-Station Engineering, to manager of Industry Engineering, to manager of Headquarters Engineering, and finally to the engineering vice presidency of the Company. With each new position he has had to delegate more and more of the engineering to others. In fact one of his major complaints is that he no longer has time for engineering. In spite of all this Monteith retains a lively interest in the kinds of functions he has been active in. This perennial interest, along with a prodigious memory, gives him a fund of knowledge that continually surprises his associates.

His first major assignment after joining the Central Station Engineering Department in 1924 was to become expert in matters of powerhouse auxiliaries. Although it has been almost 25 years since he has had much to do firsthand with powerhouse auxiliaries, he is still considered one of the best informed men on the subject in this country.

In the late 20's Monteith was assigned to help with the fast-growing problems of high-voltage transmission. This brought him into daily working contact with C. L. Fortescue. Genius though Fortescue was, he always had difficulty making his work understood by others and in reducing it to usable form. Monteith was one of those who helped "translate" Fortescue. In doing so he became an acknowledged expert in matters pertaining to high-voltage lines. During this time he developed sets of curves that are still used by transmission engineers. Fifteen years later, in 1948, when studies of lines of voltages up to 500 kv were being contemplated, Monteith saw their need and potentialities and marshaled the forces of Westinghouse to make it the leading manufacturer participant. Now that the tests are almost concluded, Monteith can in a few minutes give a clear but complete summary of what was learned.

When conflict began in Korea, Monteith anticipated the vast shortage of technical manpower facing not only Westinghouse but also every defense-important industry in the country. Others saw it too, but Monteith was one of a small group that took vigorous action to focus national attention on this critical problem and promote remedial action, such as helping sell the merits of technical education to high-school students, and making better use of engineers' time. He was one of the principals in the Engineering Council for Professional Development and later the Engineering Joint Council, which took vigorous action leading toward better use of available engineering talent and to helping sell engineering as a profession to high-school graduates.

This is but one phase of his interest in technical education generally. At Westinghouse Monteith has provided aggressive leadership for the Graduate Student Training program, has helped establish graduate-study arrangements for all employes with nearby universities, and guides the Company's scholarship and fellowship programs. He is, characteristically, chairman of the Westinghouse Educational Foundation, which administers the trust funds provided by the Company. Also Monteith personally had much to do with the planning of the Educational Center for graduate students.

His election to the presidency of the AIEE comes as a natural consequence of 30 years of active participation in the association. He believes strongly in the worth of technical societies and in the importance to the individual of working therein. He backs up this preachment with practice of such vigor that there can be no doubt about it. No one gave more support and personal effort, for example, to the program of steam-turbine standardization than Monteith. He has, in fact, been a strong advocate of most of the recent standardization programs. Although his career has been primarily that of an electrical engineer, he was recently signally honored by the ASME by being elected an honorary member.

Such a career of multitudinous technical activities would seem to leave little opportunity for hobbies and pastimes. But here the pattern of his life follows that at the office. If he didn't leave the office at night with a full briefcase under his arm, he would feel off balance. And his associates can testify that this is no mere show. But somehow he finds time for a wide variety of projects. These include tending a small orchard, raising prize roses, dahlias, and gladioli. He is particularly proud of his asparagus garden. When the weather doesn't permit outdoor activities, he and Mrs. Monteith engage in the hobby of etching on brass, or—as of the moment—helping his sons rewire an electric organ for chimes, which they built themselves. He is rewiring the house so high-fidelity records can be heard at several locations at will. Monteith gave up golf some time ago. Too time consuming! Goes in for skeet shooting instead (has had the perfect score of 25 out of 25). Loves to hunt, particularly for small game in the north woods of his native Ontario. Monteith is no television fan; doesn't like to sit still that long.

For all the swift pace of his life, Monteith gives no outward appearance of nervousness. Endowed with a big frame, a strong physique, broad interests, and a liking for people, he exudes confidence and unconsciously invests associates with his own enthusiasm.

spent going up to about 2300 degrees F, the remainder coming down. The cycle for the smaller pieces in the continuous kiln is about five days; here the clay ware passes through increasingly hotter zones in the tunnel until the maximum temperature is reached, then proceeds through decreasing zones to the exit.

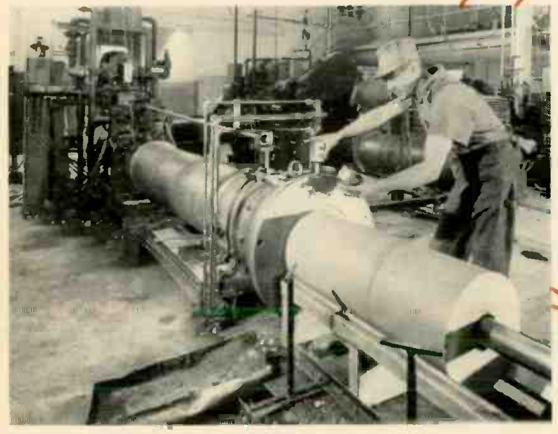
Success or failure of the entire porcelain-making process depends upon proper firing. Therefore, the operation is performed with extreme care, utilizing precise control of temperature. Too rapid change of temperature may well result in warping or cracking.

After firing, the casting is tested electrically (photo G), and inspected (photo H).

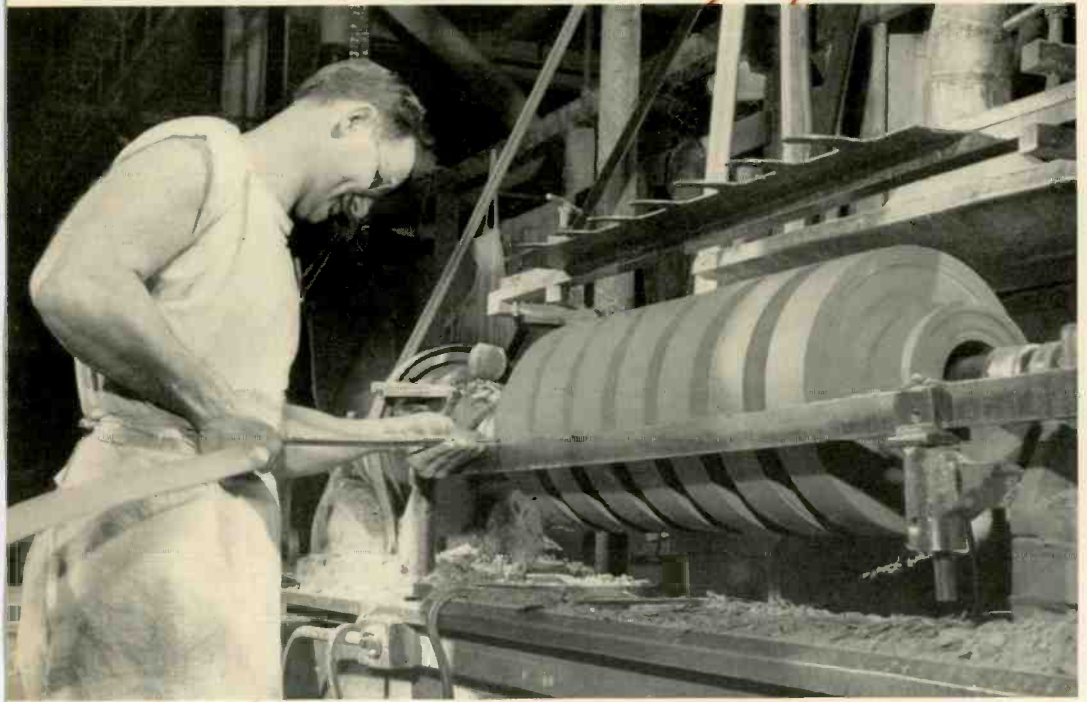
Tube Turning—Insulators that can be readily machined from a tubular or cylindrical shape are manufactured by tube turning. The preparation of clay slip is similar to that for casting, except that a large blunging mill is used instead of the ball mill. This is merely a large tank containing rotating mixing paddles.

Because clay tubes are handled and machined semi-wet, or green, a larger proportion of ball clay is added for strength.

The clay slip is fed into filter presses, where nearly half of the moisture is removed, producing a flat, plastic pancake. These cakes are fed into a pug mill, which shreds them into fine pieces and mixes them thoroughly into a dense homogeneous mass. This is forced through a die into a cylindrical shape. The soft clay tube is dried at about 90 degrees F until it reaches the stage where it can be handled without deforming, but is still soft enough to be readily machined; this is commonly called the "leather-hard" state. The cylinders are then machined on more or less conventional lathes, or other machine tools.



porcelain tube turning



After machining, the remaining moisture is removed in driers at 150 degrees F. The glaze is applied by dipping or spraying, and the piece goes to the kiln.

Hot Pressing—Hot pressing lends itself best to forming of circular, dish-shaped insulators, such as the suspension type. Here the material comes from the same pug mill used in tube manufacture. Chunks of soft clay are placed in a plaster of Paris mold, and a rotating, gas-flame-heated plunger forced down into the mold. The plaster mold shapes one side of the porcelain and the rotating plunger the other. A layer of steam is formed between the clay and the hot tool, preventing sticking and providing a smooth surface.

Next, the mold is heated, drying and shrinking the clay enough that the molded piece can be easily removed; it is then trimmed to specification, dried, glazed, and kiln fired.

Dry Pressing—Small, intricate shapes from the size of a quarter to several inches in length and width are usually formed by dry pressing. The dry mix for this process is prepared in a large steel tank containing heavy steel rollers, which grind and mix the constituents. Moisture is added to make the resultant clay mix about 16 percent water. The mixture at this stage is somewhat lumpy; it is thus fed into a "dust mill," which breaks up lumps to obtain the proper grain size.

The moist granular clay is placed in a steel die cavity and pressed between two steel dies machined to the desired contours. Pressures used vary from 1000 pounds per square inch down to about 500 pounds, depending upon the physical shape of the piece being pressed. The Prestite process of dry forming, developed by Westinghouse, makes use of slightly higher pressures, combined with vacuum in the pressing chamber, to give a much more dense fired material. In either case the pressed clay configuration is then dried, trimmed, the glaze applied, and kiln fired.

The Finished Product—The porcelain insulators that come from these processes are hard, tough materials. The hardness of rocks and minerals is usually expressed in terms of Moh hardness numbers, which run from one (talc) to ten (diamond). On this basis electrical porcelains approximate a hardness of seven or eight.

The finished porcelain rates high on strength, being stronger in compression and tension than, for example, granite or marble. Electrically, porcelains have high resistivity (10^{12} to 10^{15} ohm-cm), good dielectric strength (about 250 volts per mil), and a dielectric constant of about seven at 60 cycles. The combination of these characteristics, plus the fact that porcelain does not char or track during flashover, gives a material that is unexcelled for many insulating applications.

ELECTRICAL PORCELAIN

Materials and Processes

Electrical porcelain manufacture, although an offshoot of an ancient art, utilizes modern techniques to produce a material with qualities old-time craftsmen wouldn't recognize.

The process of turning clay into objects useful to man is undoubtedly one of the oldest surviving crafts in the world. Primitive men knew the art, and numerous peoples down through the centuries have contributed new ideas and processes. Considered in this light, electrical porcelain is a johnny-come-lately—it had its beginnings with the electrical industry but a few decades ago. Actually, however, electrical porcelain is a highly specialized version of the product turned out by early pottery makers, although accomplished with considerably more precision, and with characteristics and purposes ancient craftsmen could hardly have foreseen.

By comparison with older methods the manufacture of modern electrical porcelain is a highly mechanized, high-production industry. While it is hardly in the realm of the mass-production industries like automobile manufacturing, technical improvements have vastly enhanced the quality and consistency of the product through constant engineering development and more precise control of manufacturing processes.

From a manufacturing standpoint, the major aim in making electrical porcelain is to achieve a perfect vitrified substance, i.e., one with no internal voids to encourage electrical breakdown. Producing a nonporous material, however, is a tricky process and requires careful regulation of every step in the operation.

A major consideration in porcelain making is shrinkage. From the time the clay is first formed into the desired shape until it emerges from the kiln it may shrink by 10 or 15 percent, depending upon the process. Also, this means that the initial clay shape must be made a precise amount larger than the desired final dimensions.

The Raw Materials—The ingredients that go into electrical porcelain are basically the same as used in other high-grade porcelains—namely, clay, feldspar, and flint (quartz). These come from scattered locations—china clay from England, Georgia, and Florida; ball clay from Kentucky and Tennessee; feldspar from New Hampshire, North Carolina, Maine, and Virginia; and the flint from Pennsylvania and Virginia.

In most electrical porcelains, clay represents about half of the dry mixture, flint about a fifth, and feldspar about a third. The clays and feldspar react chemically during the firing operation, while the flint is relatively inert. In the fired porcelain, the flint is analogous to the human skeleton, in that it produces rigidity and stiffness. By the same analogy, the combination of clays and feldspar produces the flesh or meat of the body.

Flint and feldspar portions of the mixture remain fairly constant, regardless of the type of porcelain or the manufacturing process used. The respective proportions of ball and china clay are changed according to the manufacturing method. In the wet state, ball clay is much stronger and more plastic than china clay; thus its content is increased where the clay ware is to be machined or worked while green. China clay is used mainly to limit the shrinkage to a reasonable degree.

The other prime ingredient of the starting mixture is water. It is essential in manufacture, undesirable in the finished product; in fact, its presence in the final product would be catastrophic. In mixing the raw materials, enough water is added to constitute about 25 percent of the clay-feldspar-flint "slip." After firing, the water content is zero.

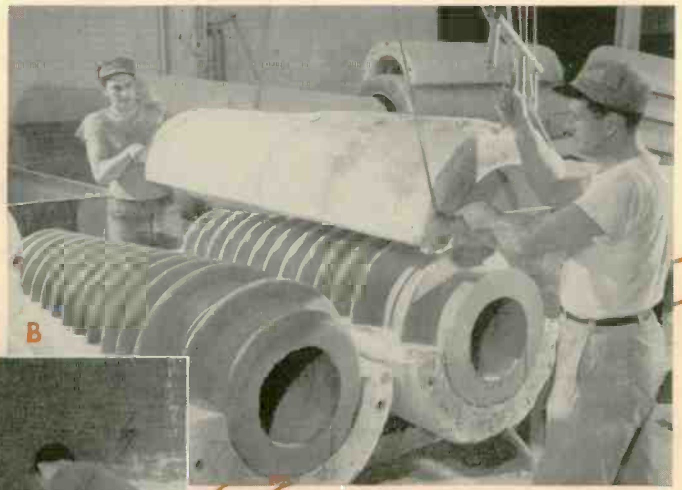
Actually, the constituents are not quite as simple as they seem. Feldspar is a combination of the oxides of sodium-potassium, aluminum, and silicon; flint is essentially silicon dioxide; clays are complex alumina silicates. Thus the firing process is not merely a drying action, but also brings about the chemical changes that produce the resultant hard, glassy, nonporous material.

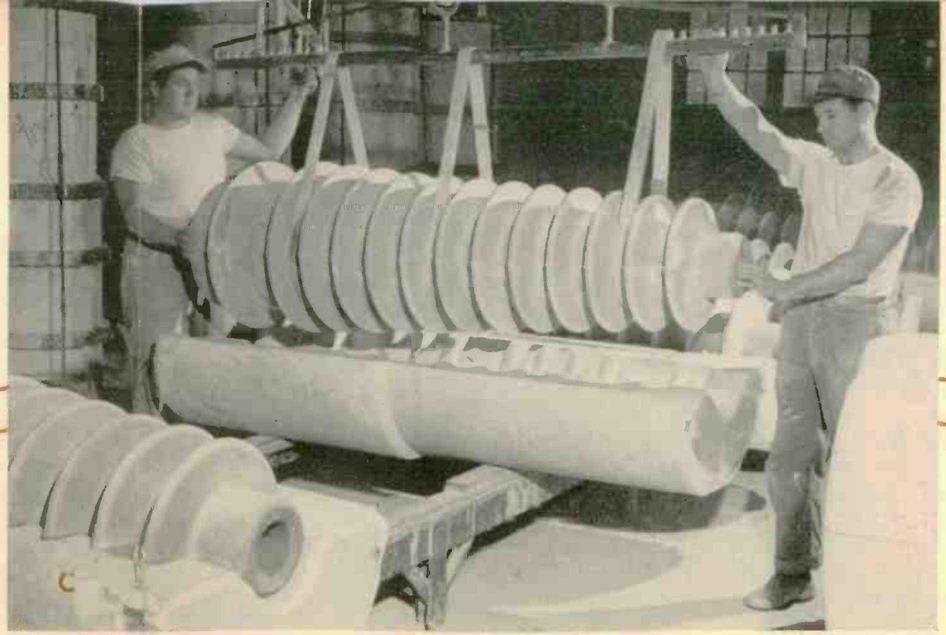
Other ingredients are sometimes used to produce special properties. Zircon, for example, is used in one type of porcelain insulator to produce exceptionally high strength as well as different electrical properties.

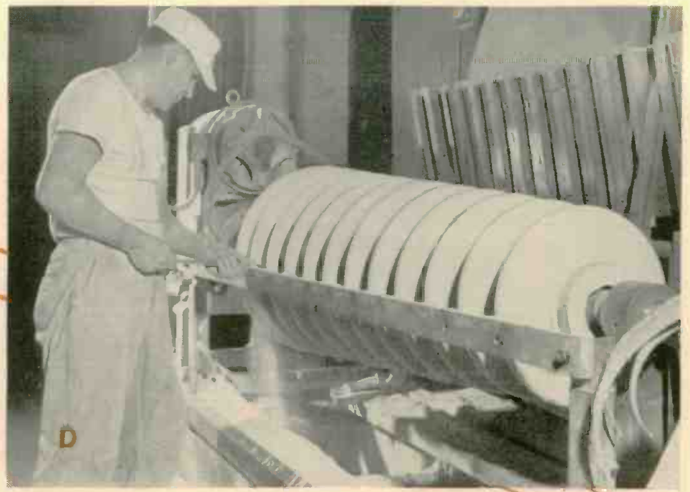
The Processes—Electrical porcelain is commonly made in one of four different ways. These are casting, turning, hot pressing, or dry pressing. Manufacturing considerations largely determine the process used. Large, heavy pieces with tapering shape and some smaller, irregular shapes are cast, because of the difficulty of using any other method. Smaller, cylindrical-shaped insulators are turned in a lathe in the plastic state. Round, pie-shaped porcelains are formed by the hot-press method; and small intricately shaped insulators are formed by dry pressing.

This article was written by Richard W. Dodge, based on information and assistance furnished by H. S. Glenny, Engineering Department, Westinghouse Porcelain Department.

. . . porcelain casting



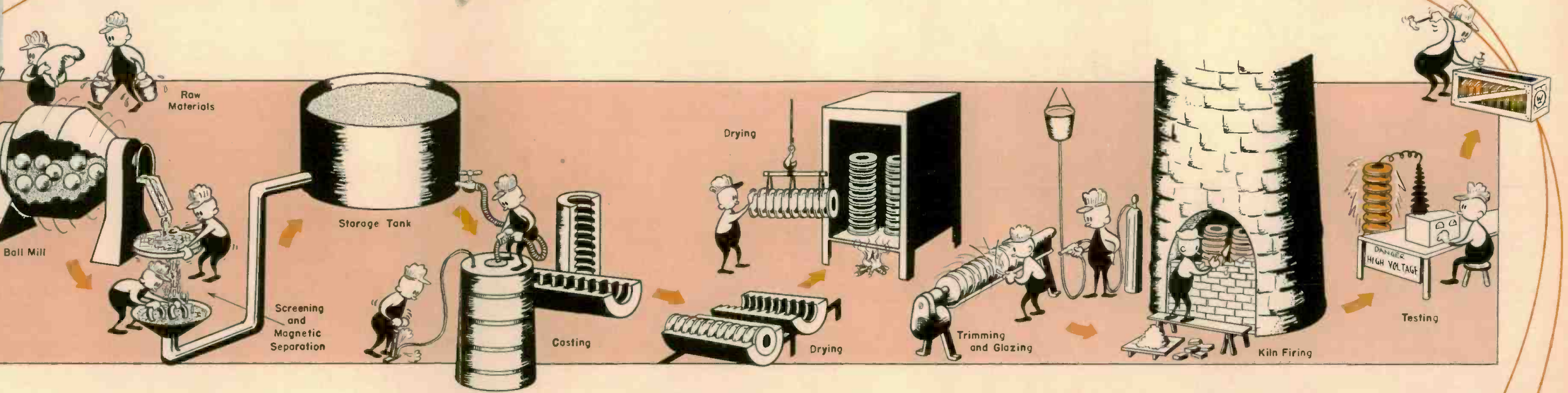




The porcelain-making process consists of five principal steps—mixing of materials, forming into the required shape, drying, applying a glaze (in most cases), and kiln firing.

Casting—Unusually large porcelain insulators—such as the six-foot long, two-foot diameter upper porcelain housing for the 330-kv circuit breakers—are invariably made by the casting process. Because of their size, shape, and weight (this 330-kv housing weighs 700 pounds) such pieces could not be readily manufactured by other methods.

The raw materials (photo A), with water added, are mixed and ground in a ball mill, a rotating horizontal cylinder partially filled with stones. After mixing, the clay slip is passed over fine-mesh shaker screens to remove any foreign particles or lumps, and over magnetic separators that remove metallic particles. It is then pumped to storage cisterns.

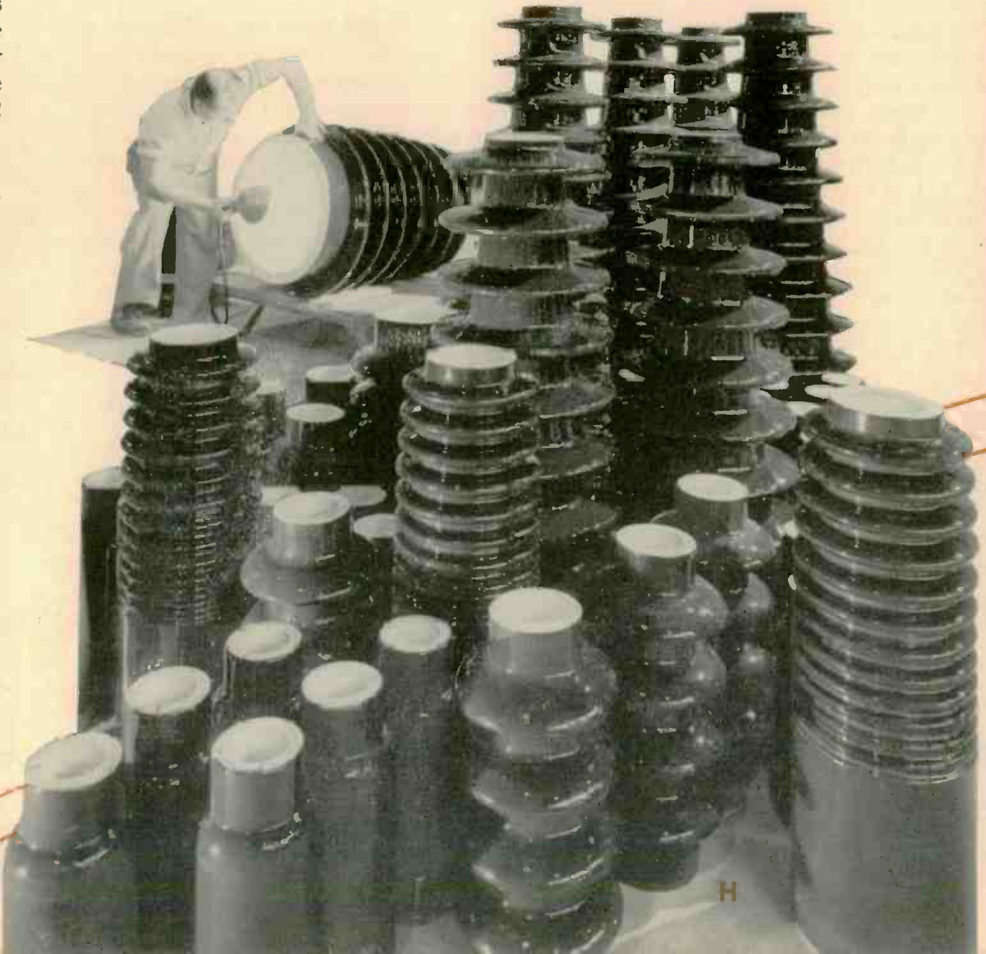


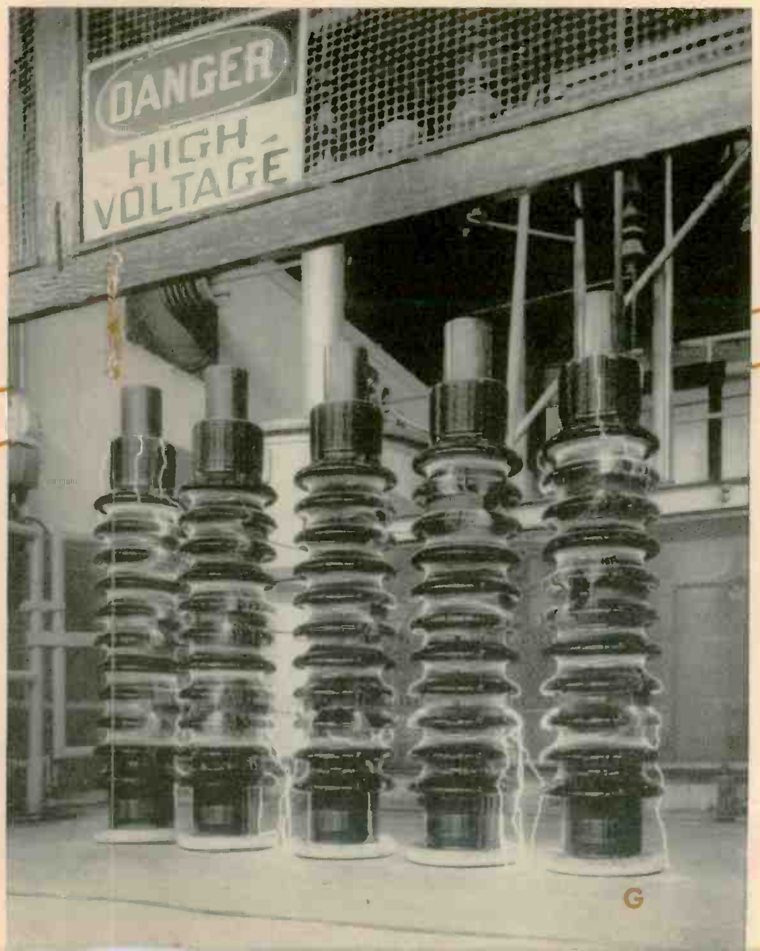
The molds used for casting porcelain (photo B) are plaster of Paris (reinforced with steel rods), made from a master die of aluminum. Initially, the mold is filled completely with clay slip pumped from the cisterns. Because the mold is porous, its walls absorb moisture from the clay, gradually building up a layer of solid clay on the inside surface. This is allowed to continue until the necessary wall thickness is built up, then excess liquid clay is drained from the center. Often the rate of casting is accelerated by applying air pressure during the casting period. The cast piece is left in the mold for 6 to 12 hours, depending upon its size, then placed in a drying mold (photo C) for anywhere from a matter of hours to several days, depending again upon size. At this point moisture content has decreased from 25 percent to about 15. The remaining moisture is removed in a drier.

The casting is now hard enough to withstand machining to shape and size (photo D). Machining is done with hand tools, tipped with high-speed steel, utilizing templates to guide the tool.

The glaze coat is sprayed on (photo E) or, in the case of smaller pieces, applied by dipping. The glaze is primarily feldspar (44 percent) and flint (31 percent), with coloring (9 percent) and clay (16 percent) added. The insulator is ready for the final step—kiln firing.

Two types of kiln are used—an upright version for the unusually large, thick pieces (photo F), and a continuous kiln for all others. Insulators remain in the upright kiln for 11 or 12 days, half of which is





Control of Radiant Heat *by* Surface Finish

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A clear lacquer film, but 30 millionths of an inch thick, on aluminum increases its ability to absorb or emit radiant heat by a factor of about ten. Similar, or even more unusual effects, can be produced by other coatings, and on other materials. Potential applications of such surface finishes are innumerable.

THE RADIANT heat absorbed or emitted by any object can be controlled to a remarkable degree by the proper choice of a surface finish. One common example is the use of white clothing in the summer to "reflect" the radiant heat from the sun, thereby helping to keep the body cooler. A lesser known fact is that the white cloth is a poor reflector of body heat, thus increasing the cooling effect. There are also many misconceptions as to radiant heat from surfaces; one common one is that a dark-colored surface is a better absorber or emitter than a light-colored finish under all conditions.

Control of heat absorption and emission is used to good advantage in the electrical industry, by proper choice of surface finish. For example, a newly designed waffle iron reaches cooking temperature 30 percent faster than its predecessor because the bottom of the grill, i.e., the surface facing the heating element, is coated with a gray material that increases its ability to absorb radiant heat. Other devices where heat absorbing or reflecting surfaces are important include thermal control elements, transformers, capacitors, jet engines, and electronic-tube components.

The Principles Involved

Heat transfer by radiation is one of a family of three (conduction, convection, radiation) and in most applications more than one of them is involved. When studying practical applications, therefore, it should be kept in mind that any one of the above mechanisms of heat transfer may overshadow the others. Even when considering radiation alone, other factors must be taken into account, such as the continuous transfer of radiant energy from a body to and from its surroundings. For example, the feeder pipes to a domestic hot-water heating system radiate heat to the walls of a basement. Although the walls are at a lower temperature than the pipe, they also radiate heat, a certain portion of which is absorbed by the feeder pipes. Calculation of the net loss in heat by radiation,[1] therefore, requires consideration of the temperatures of both the wall and the pipe as well as the emissivity and absorptivity of their respective surfaces.

Surface absorptivity is a measure of the ability of a material to absorb radiant heat. A theoretical "black body" absorbs all incident radiation at all wavelengths and reflects none (Fig. 1a). Although a perfect black body does not exist, some surfaces—such as a coating of lampblack—reflect such a minute portion of any incident radiation that they approach ideal black-body conditions. A good heat-absorbing surface is simultaneously a good emitter of heat energy (loss of heat by outgoing radiation) at the same wavelength. The term used to define the ability of a surface to emit radiant heat is emissivity. By definition, the emissivity of a given surface is the ratio of the intensity of radiation emitted by that surface to that emitted by a black body under the same conditions of wavelength and temperature. For example, a surface of lampblack mixed in water

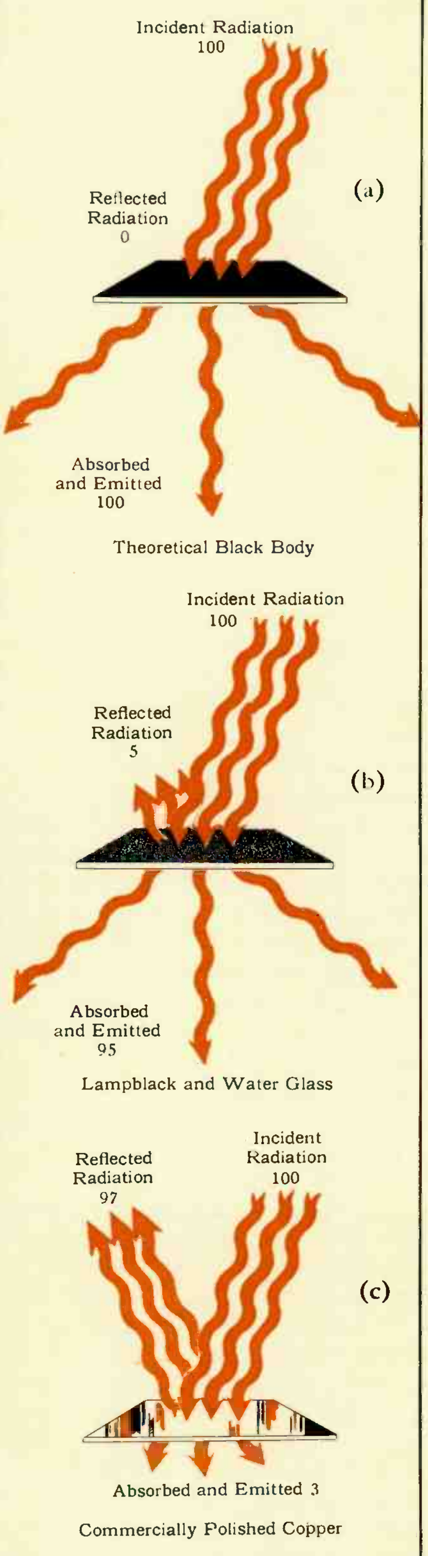

Fig. 1—(*a*) A theoretical black body reflects none of the incident radiation, absorbs and emits all of it; (*b*) a surface of lampblack and water glass approaches a black body, reflecting but a small percentage of the radiation; (*c*) polished copper, on the other hand, has a low emissivity, reflecting nearly all of the incident radiation. Absorbed heat radiates from all surfaces, rather than from one as shown in this simplification.

This article is based in part on information supplied by Westinghouse operating divisions and Research Laboratories, as well as pertinent literature.

TABLE I—EMISSIVITY OF VARIOUS MATERIALS

Material	Temperature (Degrees F)	Emissivity (Percent)
Metals		
Brass —Rolled plate	72	6
—Rubbed with emery	72	20
Copper —Commercially polished	66	3
—Oxidized by prolonged heating	77	78
Cast iron—Newly turned	72	43.5
Nickel, electroplated on iron		
—Not polished	68	11
—Polished	74	4.5
Lead —Grey oxidized	75	2.8
Silver —Polished	100	2.2
Non-Metals		
Asbestos-board	74	96
Glass —Smooth	72	94
Wood —Planed oak	70	90
Rubber —Hard glossy plate	74	95
Lampblack and water glass	70	95

glass has an emissivity of approximately 95 percent of a perfect black body (Fig. 1b). In contrast, a commercially polished copper surface at about the same temperature has an emissivity of approximately 3 percent of a perfect black body (Fig. 1c). Some other examples are given in Table I.

The intensity of radiation of any surface varies with wavelength and temperature. A few black-body radiation distribution curves for different temperatures are shown in Fig. 2. The area under each curve represents total spectral energy emitted at a given temperature. Increasing the temperature causes an increase in the intensity of radiation at any given wavelength and a decrease in the wavelength at which maximum energy emission occurs. Lampblack gives similar curves. In general, the emission curve for any practical surface lies below that for a black body at the same temperature.

However, some materials have quite different emission characteristics. Such materials are termed selective emitters, and their emissivities vary widely at different wavelengths. White cloth is a poor absorber of radiation from the sun (low emissivity at short wavelengths) and at the same time is a good emitter of body heat (high emissivity at long wavelengths). The coolness of white clothing in the summer, therefore, can be ascribed to its high reflectivity for solar radiation and its low reflectivity for the heat generated by the human body.

Zinc oxide is also a selective emitter as shown in Table II. Its emissivity is 97 percent at a temperature of 125 degrees F (corresponding to a wavelength of 8.8 microns) and is only 14 percent at 5000 degrees F (0.95 micron) while its emissivity is 18 percent at solar temperatures (0.60 micron). (The term emissivity commonly denotes the ability of a body either to emit or to absorb radiant heat. An emissivity value at a given temperature does not necessarily mean that the body itself is at that temperature; instead it may indicate the ability of the body to absorb radiant heat from a second body operating at that temperature.)

Two important considerations in dealing with radiant-heat absorption and emission problems are: (a) for most solids, absorption (or emission) is a surface phenomenon; and (b) the color of a surface is not a measure of its ability to absorb or radiate heat. For example, bright copper has an emissivity of approximately 7 percent at 200 degrees F and an emissivity of 44 percent if the surface is tarnished (see Fig. 3). These same curves show that the emissivity of bright copper can be increased from 7 to 37 percent merely by applying a thin coat of clear lacquer. The effect of various thicknesses of lacquer films on the emissivity of aluminum is shown in Fig. 4. Experiments have shown that the emissivity of polished iron (0–100 degrees F) can be increased to as high as 83 percent by applying a very thick layer of oil. This data[2] shows that a 0.0008-inch thick layer of oil results in an emissivity of 22 percent and that a 0.008-inch layer of oil increases the emissivity to 81 percent. A thin coating of aluminum oxide on aluminum can change the emissivity from 3 percent to a value as high as 80 percent, as shown in Fig. 4. Note that the thickness of the oxide coating becomes less effective after a value of approximately 70 percent is attained. Curves indicating emissivity versus temperature are shown in Fig. 5 for samples of Nichrome V. The same curves[10] show the effect of preoxidizing the samples prior to testing.

TABLE II—EMISSIVITY OF A FEW PIGMENTS[3]

	Emissivity—Percent				
Wavelength—microns→	24	8.8 (125°F)	4.4 (750°F)	0.95 (5000°F)	0.60 (Solar)
Camphor soot	94	98	99		99
Lampblack		94.5	94.5		
Black (CuO)	96		85	76	
Yellow (PbO)	90	74	49		48
White ($PbCO_3$)	93	89	71	8	12
White (Al_2O_3)	94	98	79	12	16
White (ZnO)	95	97	91	14	18

Dead black, black, dark green, white, black enamel and white enamel paints all have practically the same emission characteristics when coated on a body operating at about 100 degrees C.[3] This is the reason that the efficiency of a steam radiator painted with conventional household paints is equally good regardless of the color. However, when considering such finishes as aluminum and bronze-colored metallic-pigmented paints, lacquers, etc., the situation is somewhat different. Since most metallic-pigmented finishes have emissivity values considerably lower than standard household paints, a household hot-water or steam radiator painted with aluminum paint might be expected to be less efficient than one painted with enamel. Actually, the net difference in efficiency may be negligible, or in some instances in favor of the lower emissivity finish. Approximately 70 percent of the heat dissipated[4] from a two-column radiator of thirteen sections is transferred to the room by convection whereas 30 percent is dissipated by radiation. Radiant heat is useful mainly to the object upon which it impinges and is generally lost to the walls, ceiling, etc. A low emissivity finish on the radiator could, therefore, decrease the amount of heat radiated directly to the walls and in turn conducted to the cooler outside wall. Another variable is that the emissivity of metallic paints can be varied by the degree of leafing (arrangement of particles), which is dependent, among other things, on the physical size and shape of the metallic particle as well as the composition of the vehicle used to carry the metal. For example, an aluminum paint* consisting of aluminum powder and a low-solids-content varnish might have an emissivity as low as 25 percent; on the other hand an aluminum paint with an emissivity as high as 60 percent can be made with aluminum paste (extremely fine powder mixed with liquid) and a suitable varnish. An excess of resin or an extra coat of clear resin or lacquer on the surface further increases the emissivity.

The curves in Fig. 4 substantiate the fact that color is not a criterion for predicting emissivity. They show that the increase in emissivity resulting from various thicknesses of organic dyed lacquers applied to aluminum is essentially the same for clear, green, yellow, blue and scarlet colors. How-

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*Aluminum paints are pigmented with high-purity aluminum, although they are sometimes referred to as "aluminum-bronze" pigments. The pigment is generally in flake form for both powder and paste and in some cases the largest cross section of the flake is 200 times the thickness.

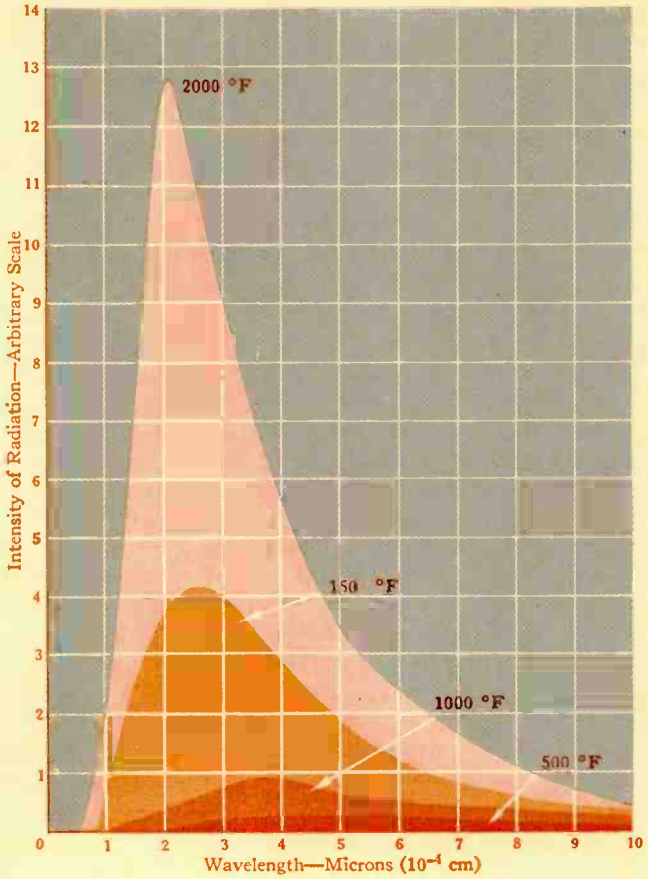


Fig. 2—Black-body radiation curves for different temperatures. Note the effect of higher temperature in increasing maximum intensity of radiation, and in decreasing the wavelength at which a maximum value occurs.

Fig. 4—Upper curve shows the effect on emissivity of different thicknesses of oxide coatings on aluminum. The lower curve illustrates the effect of various thicknesses of different colored lacquer films on the emissivity of aluminum.

(Courtesy of Aluminum Company of America.)

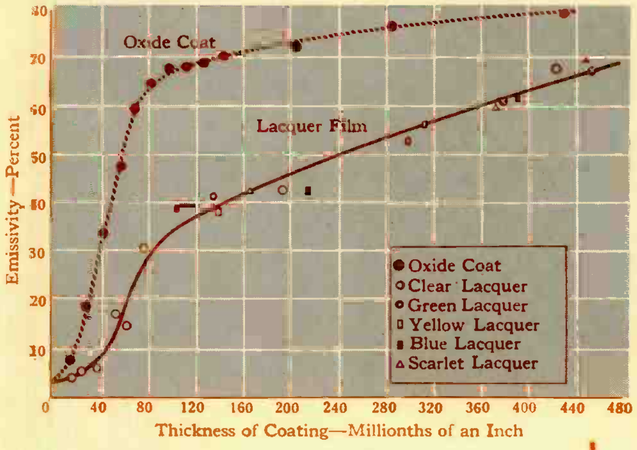


Fig. 3—Striking increases in emissivity can be obtained by proper choice of a surface finish for copper. The dotted-line curves indicate a tarnished copper with various coatings; solid lines are for a bright copper base.

(From curves by R. H. Heilman)

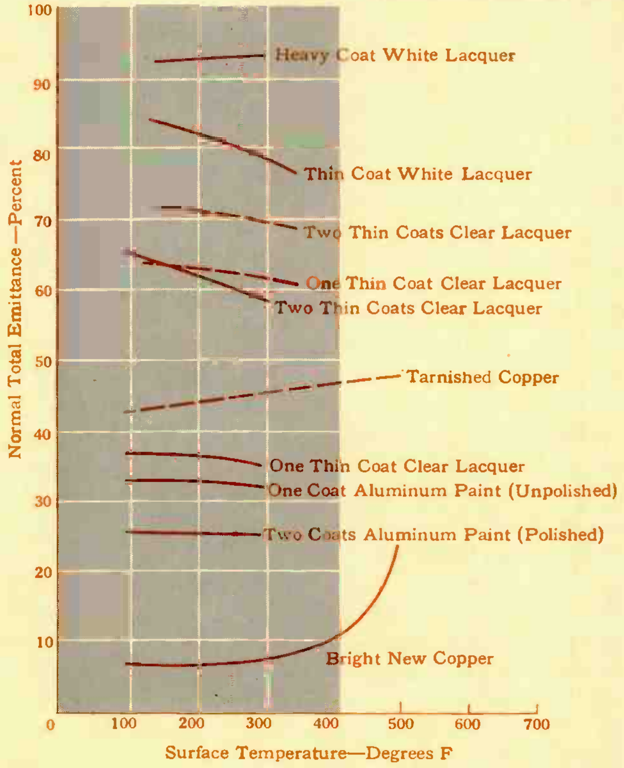
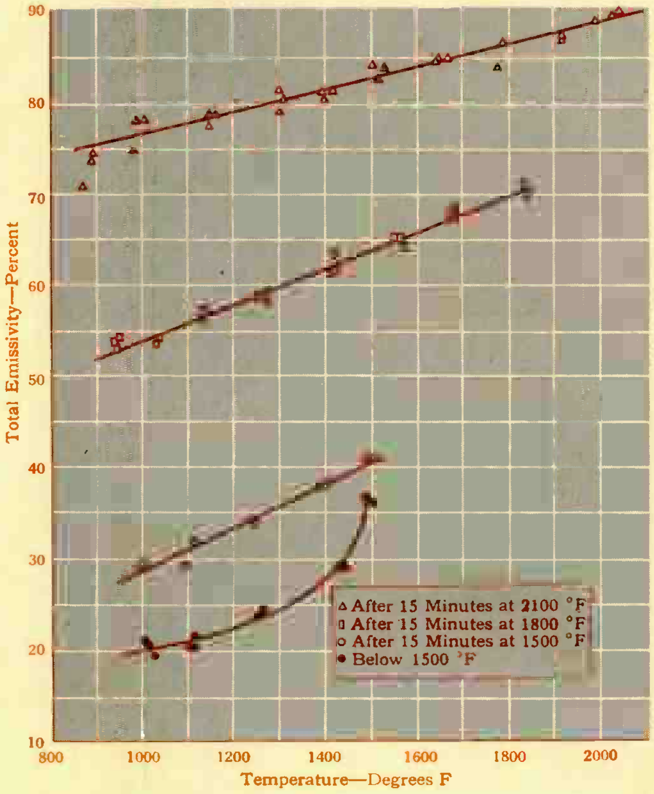


Fig. 5—Emissivity versus temperature for samples of Nichrome V.[10] These illustrate the effect of preoxidation at different temperatures. Bottom curve has no preoxidizing treatment except that incurred during the test. The significance lies in the fact that an initially nonoxidized surface may change emissivity characteristics as it operates under temperature. Conceivably this could materially alter operating characteristics of a device.



ever, lacquers pigmented with such materials as zinc oxide, lead oxide, or lamp black may show an entirely different "thickness versus emissivity" relationship.

A highly polished surface is commonly assumed to have a low emissivity and a roughened one to have an appreciably higher emissivity. For extreme methods of roughening this is true, but roughening of aluminum, to an extent that the specular reflecting characteristics are destroyed, increases the emissivity only three percent.[9]

The physical phenomenon of thermal emissivity is complicated, and the behavior of all materials cannot be explained by one simple law.[5,6] Experimentation and comparison with similar material compositions have established the radiation and absorption characteristics of many surfaces. Although many tables on emissivity[6,7,8] have been compiled, such information is understandably not available for every material nor for all temperatures. Therefore, it is often necessary in practical applications to measure the emissivity of a test panel. Methods are available for accomplishing this.[9,10]

Applications

Jet Engines—One means of lowering the combustion-wall temperature in jet engines is to maintain low emissivity of the surface facing the combustion gases and to increase the emissivity of the outer wall.[10] The low-emissivity surface minimizes the amount of radiant heat absorbed by the combustion wall; and the high-emissivity outer surface facilitates the dissipation of whatever heat is absorbed. Ceramic finishes have been developed that can raise the emissivity of combustor materials to over 90 percent at temperatures of 800 to 1100 degrees F.

Waffle Iron and Sandwich Grill—A combination sandwich grill and waffle iron for home and restaurant use employs an aluminum cooking surface, which is heated by radiant heat from resistance coils beneath the plate. The time to reach cooking temperature has been decreased by 30 percent—from 5 to 3½ minutes—merely by increasing the absorptivity of the surface facing the heating element. This also lowers the cost of operation for the consumer. The emissivity of the grid could be increased by anodizing, or applying a surface coating to the aluminum. A recent design uses a cement mixture that stands up under high temperatures and has an emissivity of approximately 90 percent. The coating is applied by spraying. The improved performance of a sandwich grill treated with this material is shown in Fig. 6.

	Old	New
Wattage	1000	850
Calibration	510 deg F	430 deg F
Waffle time	7 min	4½ min
Table temperature	180 deg F	120 deg F
Wire connection temperature	800 deg F	450 deg F

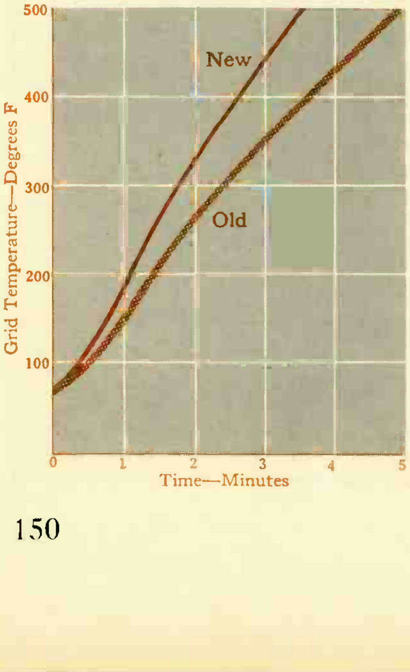


Fig. 6—The improved performance of a sandwich grill, accomplished by applying a suitable coating to the surface facing the heating element.

Large-Area Cooking Grills—Uniform heat distribution on a large grill presents a problem. One means of solving this problem is to coat selectively the bottom surface of the grill with materials to increase the emissivity at desired locations, as shown in Fig. 8.

Toasters—Thermal voltage-control regulators for toasters have been made more efficient by using controlled heat-absorption surface finishes for the bimetals. These finishes increase the speed of reaction of the thermostat, as well as prevent the thermostat from losing calibration due to the possibility of an untreated bimetal becoming dirty or oxidized, during normal use, and increasing in emissivity.

One finish used for this purpose is a lacquer containing mixtures of silicone resin, mica, and carbon black. This material stands up under the flexing action of the bimetal and the surface has an emissivity greater than 90 percent at temperatures to which it is exposed. The treatment is used on the toaster bimetal shown in Fig. 7.

Another possibility is plating of finely divided metal and oxide. These electrodeposits[11] are basically metallic chromium, contain vanadium or nickel, or both, and can be applied to most metals without special equipment. These deposits have high emissivity characteristics, adhere well to the base metal, and offer good heat and chemical resistance.

Dual Benefit Applications

Electronic Tubes—In certain applications for radiant-heat controlling finishes other engineering advantages are gained simultaneously. An important common example is found in receiving tubes and industrial electronic tubes. The carbonized nickel surface used on some vacuum-tube anodes results in a high thermal emissivity coating, which dissipates heat and thereby reduces back electron emission. Also the back electron emission is still further reduced[12] by the tendency of the carbon to entrap any barium sublimed from the filament coating to the plate, and thus render it inactive as an electron emitter. This entrapment of barium or other high electron emission materials is not thoroughly understood, but it does increase tube efficiency by preventing these materials from redepositing on other elements of the tube, such as grids. Pure nickel, nickel-plated steel, and nickel-clad steel have all been examined for this application. Basically, the surface treatment involves coating the nickel surface with nickel oxide and subsequent reduction of the oxide to pure nickel, resulting in a matte finish with a thermal emissivity about half that of a black body. The thermal emissivity is further increased to approach that of a black body by carbonizing. The carbonizing treatment[12] can be carried out during the same process in which the nickel matte surface is formed, or as a completely separate operation.

Aluminum-clad steel[13,14] has been used for vacuum-tube parts in Europe for a number of years and is now being used in this country. When steel is clad with aluminum and subsequently heated to about 650 degrees C for a suitable length of time, the two metals diffuse, resulting in a conversion of the surface to compounds of iron and aluminum. The surface is rough, black in color, and has a thermal emissivity of 80 to 85 percent. In practice, tube parts such as anodes and shields are formed from the clad material, welding performed

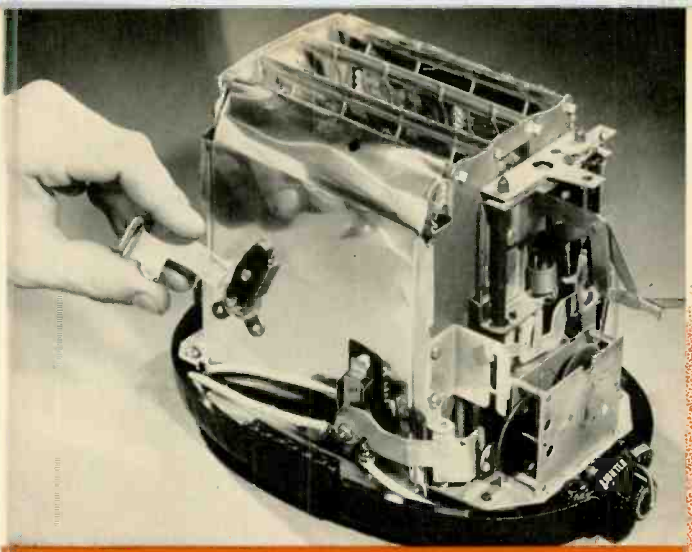


Fig. 7—This toaster bimetal element is coated with a lacquer to control heat absorption. The surface has an emissivity of over 90 percent within its range of operating temperatures.

Fig. 8—The under side of this large surface cooking grill is coated selectively to increase emissivity at desired areas.

when necessary, and then heated to form the high thermal emissivity iron-aluminum layer. Along with the property of high thermal emissivity, there are indications[14] that this metal combination can be more completely outgassed faster than some other materials, and in addition there appears to be a reduction in gas evolution during life.

This blackening effect can be produced by vacuum evaporation of aluminum on iron[13]; also other combinations of metals, such as nickel-iron and molybdenum-iron, give a similar effect.

Electromagnets for TV Tubes—The focus coils for some television sets are doughnut-shaped electromagnets enclosed in a metal case. Without a finish on the case this coil operates at a temperature of 54 degrees C. Treating the surface with a black oxide finish cuts the operating temperature down to about 36 degrees C. The electronic circuit would have been affected by the higher temperature, causing an increase in time for the focus control to become stabilized. Here again the finish resulted in multiple benefits since the treatment also offered corrosion protection.

Transformers—Another dual-purpose finish that incorporates corrosion-protection properties along with emissivity control could be helpful in dissipating heat from some types of transformers. At times convection overshadows radiation to the extent that the radiant-heat transfer is not always of major importance. For example, a wind velocity of a few miles per hour may offset the effect of solar radiation[15] impinging on an object. Therefore, for some applications, a high emissivity surface to dissipate the heat from a transformer may be more important than a highly reflecting (low emissivity) surface to ward off the solar radiation.

Capacitors—Outdoor capacitors are heavily metallized with zinc to prevent rusting of the cases over long periods of weather exposure. The freshly metallized surface does not radiate the losses as well as the previous painted finishes since the emissivity of freshly sprayed zinc is low. A finish coat of a high-emissivity lacquer is applied to reduce operating temperature and at the same time provide some added corrosion protection and better appearance. Thus a dual benefit also accrues in this type of application.

In Summation—Complete Evaluation Is Necessary

As has been outlined, advantages such as lowering the operating temperature of capacitors, increasing the speed of response of thermostats, and uniformly distributing the temperature of heating grills are obtained by selecting appropriate surface finishes. Multiple benefits, such as corrosion protection, better appearance, and controlled heat absorption can often be obtained in one finish. An important consideration is that absorption or emission characteristics of some materials (selective emitters) change as much as 80 percent according to the wavelength of the incident rays, which is in turn dependent on the temperature of the emitting body. To select finishes properly, a designer should review the principles of heat transfer and thoroughly acquaint himself with its mechanisms. With proper consideration of all aspects, surface finishes can be a useful tool in controlling radiant heat absorption or emission.

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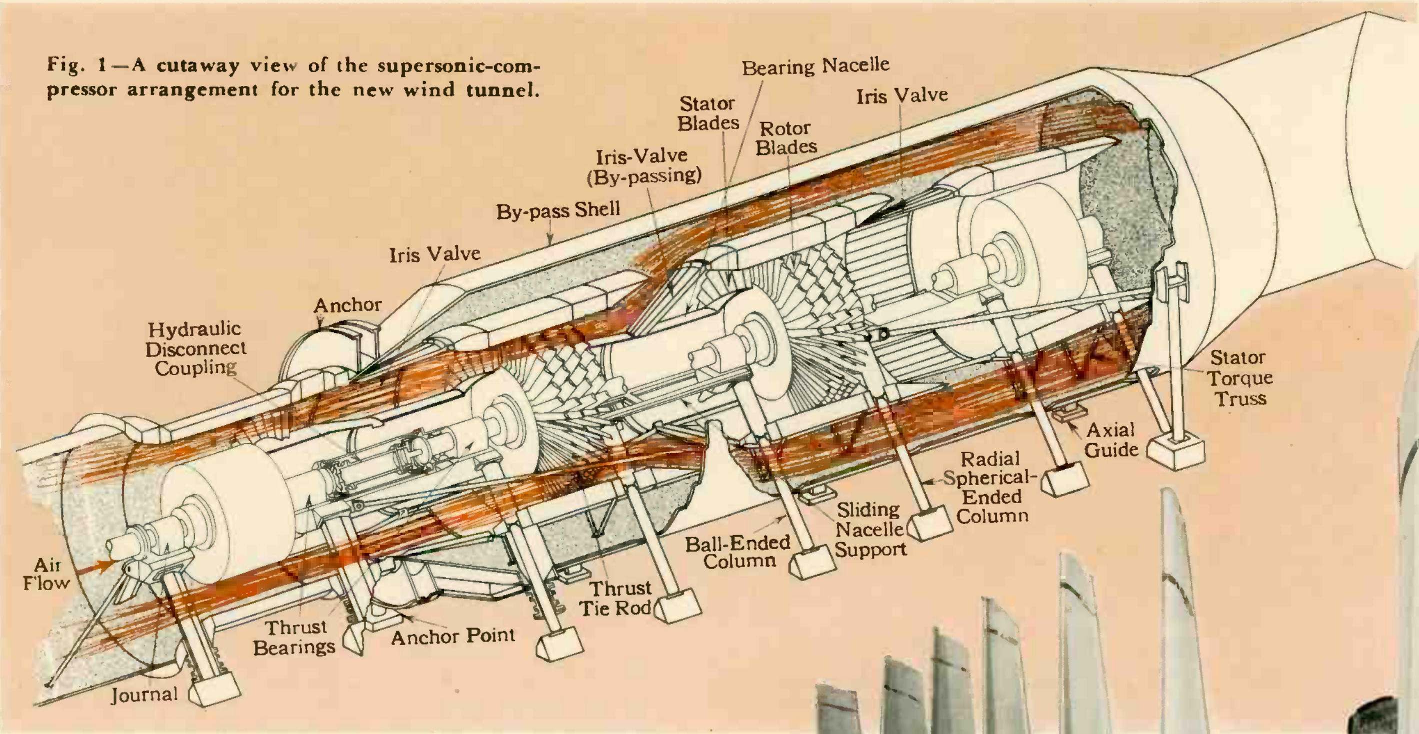
Fig. 1—A cutaway view of the supersonic-compressor arrangement for the new wind tunnel.



Mechanical Aspects of the *PWT Compressor*

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Transonic rotor blades being prepared for shipment. Trailing edges have protective coverings.

When you set about to build the largest piece of apparatus of its kind, you expect to run into unusual problems. In this respect, engineers who designed and are building the PWT compressors have hardly been disappointed. Mechanical problems were not just a function of sheer size, but also involved many aerodynamic considerations.

In the transonic and supersonic wind tunnels for the U. S. Air Force's Propulsion Wind Tunnel at Tullahoma, Tenn., designers had the choice of two compressor configurations. Many small compressors could be operated in series-parallel, or a few very large compressors operated in series, each being capable of handling the required volume of air.

The design problems for individual small compressors would be comparatively simple. However, simultaneously controlling them would be complex. Such a system would involve a complicated ducting and valving arrangement to funnel air into the tunnel where and when it was needed.

With a few large compressors, fewer parts would be required, controls would be simpler, and the complicated ducting and valving needed to combine many compressors would be eliminated. Also, the large axial-flow compressors could be installed within the tunnel structure. Their disadvantage was that such huge compressors require special machine tools and facilities, and vibration, stress, and support become problems of the first magnitude. Preliminary studies, however, indicated that the large compressors were feasible and preferable for this application. Thus the decision was to build the largest axial-flow system possible, using the least number of compressors that would fulfill test-section requirements.

The compressor rotor is composed of a series of discs that carry the blading. These discs largely dictated the physical size of the system. An 18-foot-diameter disc was the largest that could be forged practically. This forging ranges from five to nine inches thick, and weighs about 30 tons. Also the shipping problem, from the forging plant in the East to the Sunnyvale, California, plant where the compressors were to be assembled, imposed about the same limitation.

With the basic size of the system determined, the configuration chosen was one transonic compressor with three stages, and four supersonic compressors (Fig. 1), three having four stages each, and the last having six stages. The transonic and supersonic compressors are located in separate tunnels with a common drive system.

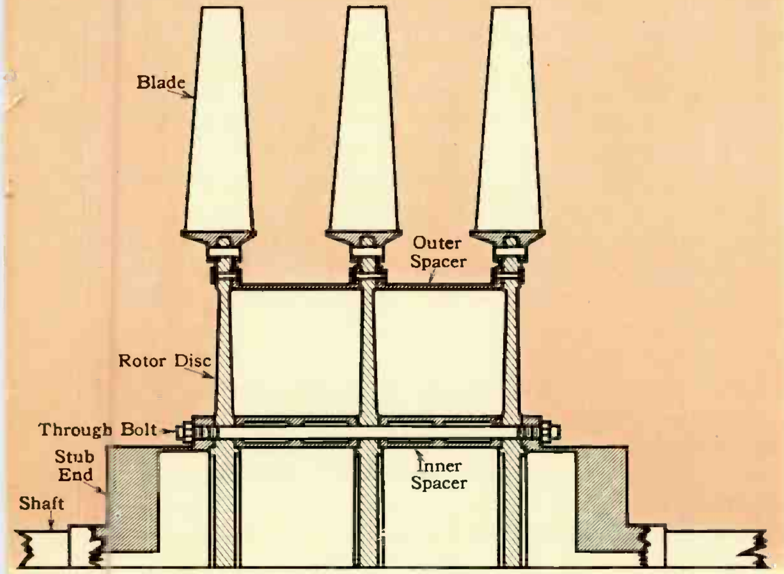
Several other basic design decisions affected the overall compressor system. The first was the necessity for using a built-up rotor rather than a one-piece construction. Also, no machine tools exist that are capable of handling a complete one-piece rotor of this size. A bolted-together, built-up rotor is the only practical solution; welded or other conceivable types would not be adequate for the high stress fields. Similar but smaller built-up rotors have proved successful.

Another basic consideration was the choice of constant-speed or adjustable-speed drive. Constant-speed drive was chosen for several reasons. Adjustable-speed motors are needed for starting, but large synchronous motors are less expensive and less complicated. Air volume can be controlled with a constant-speed machine by varying stator blade angles. Also, with a constant-speed machine and variable-pitch blades, small volumes can be obtained with high pressures. This cannot be obtained readily with adjustable speed; pressure drops off with volume as speed decreases.

The Rotors

The rotor of the three-stage transonic compressor (Fig. 2) consists essentially of: three 18-foot-diameter alloy-steel discs, on which are mounted the 6-foot-long rotating blades; two cylindrical inner spacers mounted between the discs to fix the distance between them and add rigidity to the rotor; two outer spacers between the discs near their tips, to raise the various modes of disc vibrations; two stub ends that carry the rotor in its bearings and connect to the drive shaft; and eighteen 10-foot-long through bolts, tying the stub ends and discs together through the inner spacers.

Fig. 2—A cross section of the transonic-compressor rotor, showing locations of blades, discs, spacers, bolts, and other components.



The inner spacers and stub-shaft ends must be flexible enough to follow radial expansion of the discs when the rotor is brought up to speed. At the same time, they must be strong enough to support the weight of the rotor, and rigid enough to deflect less than $\frac{1}{32}$-inch under the 350 000-pound load. The outer spacers are thin to reduce weight and thermal stresses, but give the proper stiffness to control basic disc-vibration modes. A one-piece forging would have been desirable for each outer spacer. However, a 15-foot-diameter ring with integral seven-inch flanges cannot be forged. Therefore, the side flanges consist of several alloy-steel plates welded together and finally welded to the ring forging; the complete assembly was stress-relieved.

Supersonic rotors are similar to the transonic rotor. However, additional problems are introduced by the rapid temperature rise as the air is compressed while flowing through the blading. The air can reach a maximum temperature of 700 degrees F. This temperature rise could cause an increase of a half inch in the diameter of outer spacers. However, when exposed to the hot air at the rim, the discs heat up very slowly—several days are required for the disc centers to heat. This could result in large thermal stresses in the discs and outer spacers unless they were correctly designed.

Actually, the condition in the last cylinder, where the temperature is highest, is so severe that the only practical way to solve the stress problem was to eliminate the outer spacers. Fortunately, this was possible because the vibration characteristics could be adequately controlled by the disc design alone, due to the smaller blade size in this cylinder. In the other cylinders, spacers were profiled to reduce stresses, making the ends thick and the center thin.

Rotor blades for the transonic compressor are six feet long, while those for the supersonic compressor range from 58 to 18 inches in length. Each transonic blade forging weighs 2700 pounds, while the finished blade weighs only 1200 pounds. Thus in the machining of each blade 1500 pounds of chips were created and had to be removed. Blades are made of 12-percent chromium steel, used because of its unusually high damping characteristics and its good mechanical strength and corrosion resistance. Under vibratory conditions, damping is just as important as strength. Machining of the blade forgings was done essentially by contour planing.

A special rig was built to balance the huge rotor. It consists essentially of a flat-surfaced horizontal table, nine feet in diameter, with a spherical seat about three feet in diameter. A pin through the center of the seat holds the table rigid while each disc is mounted. After the disc is placed with its axial centerline coinciding with the vertical centerline of the spherical seat, two blades (or two groups of blades) are mounted on diametrically opposite sides of the disc. The stabilizing pin is withdrawn, the spherically seated table is floated on an oil film, and any unbalance is measured by the degree of tilt of the table. Although each bladed disc weighs more than 40 tons, the rig is so sensitive that a small coin placed at the rim of the disc is sufficient to tilt the table.

In the supersonic compressor, different modes of operation may require only one, two, or three of the four compressors. Remotely operated flexible disconnect couplings are provided between compressors to disconnect those not needed. This coupling system must transmit large horsepower and provide the needed angular flexibility.

Workmen stacking transonic rotor in assembly pit. Pit is necessary to provide clearance between rotor and overhead runway.

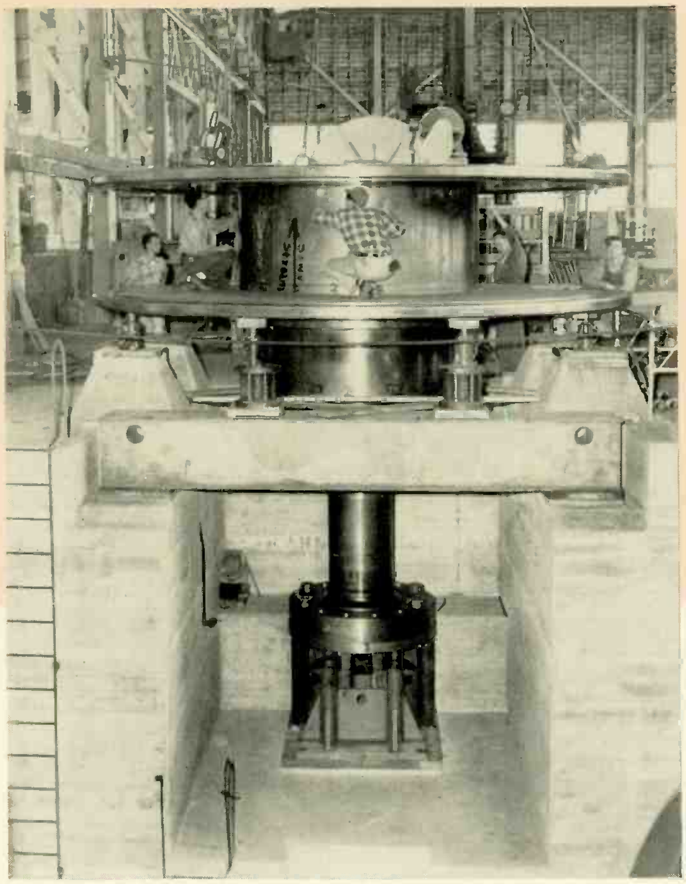
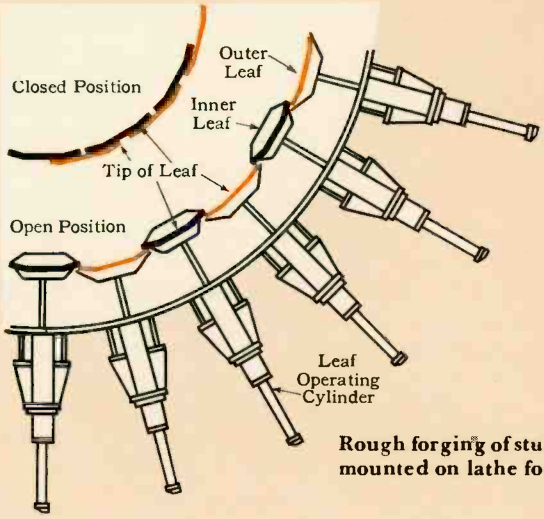


Fig. 3—Cross-section of a portion of an iris valve, showing the open and closed position of the leaves.



Rough forging of stub shaft being mounted on lathe for machining. ▶

A long hollow-shaft forging carries external teeth on each end. One end of this hollow shaft is a cylinder, within which operates a double-acting piston attached to the downstream compressor rotor. When the compressor is shut down, shifting is performed by a remote control. This is accomplished by a separate hydraulic system, which pressurizes either side of the piston, depending on whether the coupling is driving or disconnected.

The Stators

While the rotors are big, their stators are bigger. The machining of these stators requires some of the largest machine tools used in industry. The inside bores of the stators vary from 30 feet for the transonic compressor to 22 feet for the last supersonic machine. Since the stator section for the transonic compressor is approximately 34 feet long and that of each supersonic compressor about the same length, the stators were assembled from several sections, each approximately eight feet long. Each section contains either two or three rows of stator blades, and is fabricated in quadrants. Each stator consists of an outside shell, controllable stator blades and their operating mechanisms, and shroud rings attached to the blade ends. These inner rings or shroud rings help stiffen the stator blade sections and prevent spillage of air as it progresses in an axial direction through the compressor.

As mentioned earlier, a constant-speed compressor system was chosen. Hence, compressors have controllable stator blades to meet the wide variations in flow requirements of the tunnel. These flows range from 7 to 13 million cubic feet per minute at compressor inlets, and result in a Mach number ranging from 1.4 to 3.5 at the supersonic test section.

All stator blades are equipped with trunnions extending through the stator casing. Each blade turns in specially designed bearings mounted in the outside shell and in the shroud rings. The blade-shifting mechanism is designed to change blade orientation by plus or minus 15 degrees while compressors are in operation. A 2-hp gearmotor drives each row of stator blades through a continuous 360-degree shafting system. At each blade a small gear box provides a reduction from the shafting system and drives a screw system attached to the lever arm of each blade. A tremendous mechanical advantage is gained and remarkable accuracy between angle variations from blade to blade results due to a 52 111 to 1 motor-to-blade speed reduction.

The stator blades for the compressors are of cast steel, since they have no centrifugal forces acting on them and the vibratory loading is not as severe as that on the rotor blades.

The Iris Valves

Since the pressure ratios and flow requirements in the supersonic system require the operation of either one compressor alone, or two or more compressors in tandem, the discharge from the last operating machine must be bypassed around the others. A 45-foot inside-diameter bypass duct extends over the last three supersonic compressors. The inlet to this duct connects to the outlet of the first supersonic unit and the outlet discharges into the tunnel circuit. Bypassing of compressors is accomplished by iris valves (Figs. 1 and 3).

Each iris valve consists of 24 overlapping leaves, which are hinged at the upstream end of one compressor and seat at the downstream end of the previous compressor. When the valve is open, the leaves form an approximately cylindrical duct leading from one compressor into the next. When closed, accomplished by folding the leaves over one another, the air passing through the outlet of the last operating compressor is directed into the cylindrical bypass shell, and on into the wind tunnel proper.

The leaves themselves are fabricated box-like structures 17 feet long, 4 feet wide, and 10 inches deep, each weighing

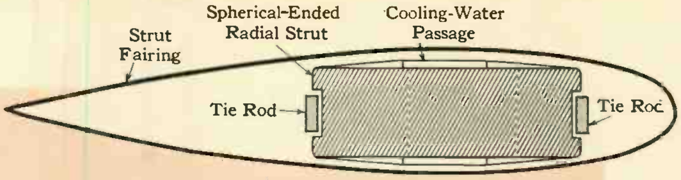
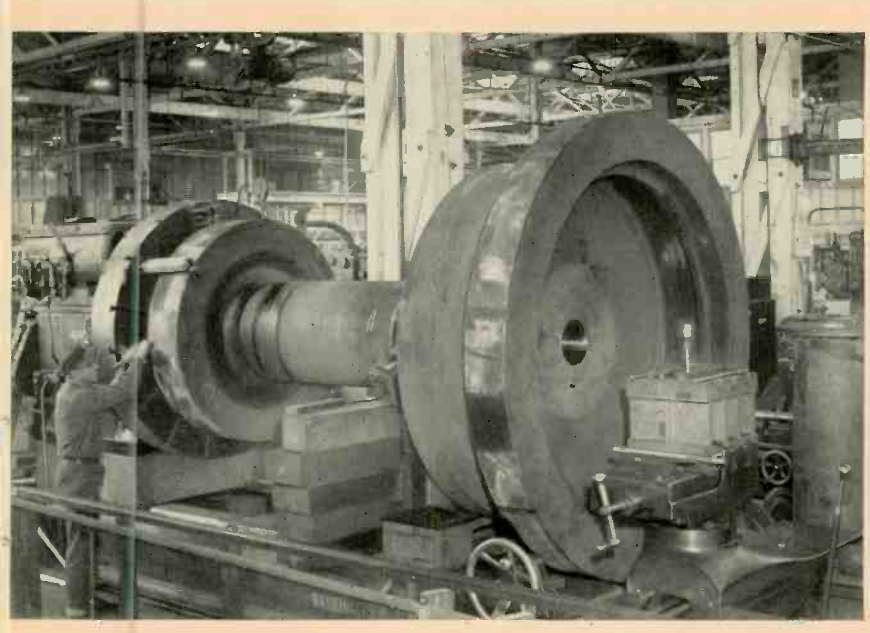
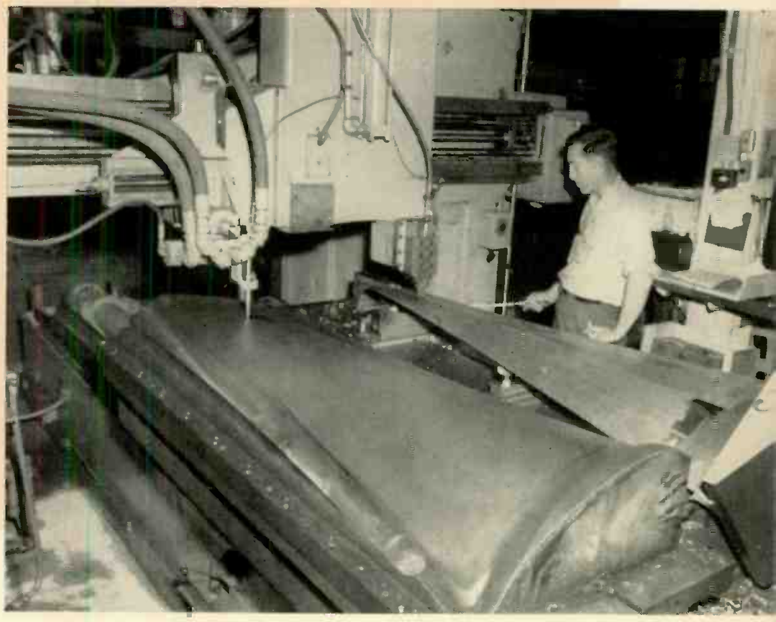


Fig. 5—The spherical-ended struts and tie rods are streamlined by the addition of a fairing.





Profile planing the warped surface of a six-foot-long transonic rotor blade.

approximately 5000 pounds. These valves are operated remotely by individual hydraulic cylinders arranged radially around the outside of the bypass shell.

Aerodynamic considerations demand that leaves be of minimum thickness and surfaces be smooth and streamlined. The strength requirement, however, dictated the thickness. To keep weight to a minimum and provide the necessary strength, a fabricated design was used.

The Supporting Structure

The rotor of most turbo-type machines is supported on its own stator. For steam turbines, the bearing pedestals are located outside the turbine cylinder and rest on extensions of the cylinder. Similarly the bearing pedestals of most axial-flow compressors are supported on struts that, in turn, are supported within the stator and attached solidly to it. This makes the rotor and the stator a common mechanical system.

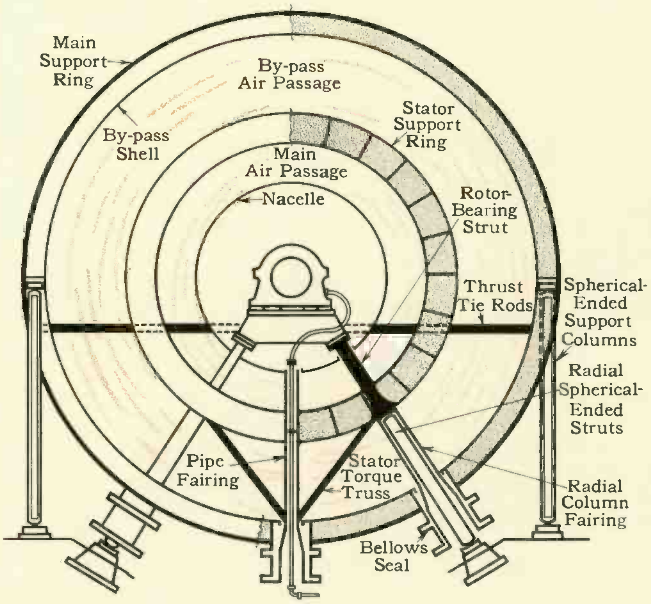


Fig. 4—Parts of the supporting structure are shown in this cross section of the supersonic compressor.

The extremely large size of the Propulsion Wind Tunnel, however, necessitated supporting the rotors entirely independent of the tunnel or bypass shell. This excludes the possibility of harmful tunnel loads and distortions disturbing the rotor alignment, and the possibility of rotor vibratory forces being transmitted to the tunnel. Only two major structural connections are permitted between the rotors and the tunnel, in the form of thrust-tie rods and stator torque-truss rods. Their design is such that they are not capable of transmitting vibrational forces of a significant character or sizable magnitude.

The bearing pedestals of the transonic compressor, as well as those of the first supersonic compressor, are supported on struts that extend through the stator support rings to a rigid connection with the foundation. The stator cylinders for these two units form integral continuations of their respective tunnel shells. This is not the case with the remaining three compressor units of the supersonic machine.

A fixed anchor point was established for the entire supersonic tunnel, from which point all expansions and contractions of the tunnel take place. This point is located just downstream from the stator cylinder of the first unit so that close control of the position of the first stator is maintained with respect to its rotor. Thermal movements of the compressors and bypass shell, from the fixed point, are limited to the axial direction by lateral guides along the bottom centerline of the bypass shell. This axial movement may be as much as five inches at the supports for the last compressor, where temperatures go as high as 700 degrees F. The compressors—floating independently inside the bypass shell and weighing about one and a half million pounds—must be freely supported to allow for this movement, and yet must be maintained in accurate axial alignment with bearing supports rigid enough to maintain high critical speeds. Small wonder the compressors posed some unique structural problems!

The stators of the three final units are supported at each end by a stator support ring, which rests upon two radial, spherical-ended columns passing to the foundation through sealed openings in the bypass shell (Fig. 4). These columns operate like large single ball bearings, and allow the stators to roll freely over the ground during thermal expansion. The rotor bearings are rigidly supported from each stator support ring by two radial rotor bearing struts, integral with the ring and in line with the radial spherical-ended columns.

The radial columns are of solid steel designed for sufficient cross-sectional area to obtain the necessary bearing-support rigidity. Stress was not a factor. The ends of the columns rest in cylindrical seats designed to provide a large area of contact. The axis of the cylindrical seat runs approximately parallel to the tunnel axis, since the greatest thermal motion is in this direction. Radial thermal expansion of the stator causes the columns to roll slightly across the seat.

The columns are grooved to receive long flexible tie rods that are prestressed to insure positive contact pressures on the column seats under all operating conditions (Fig. 5). A cooling-water jacket is also provided along the columns to help control expansion, which would be detrimental to shaft alignment.

Surrounding the columns are streamlined fairings in the form of sheathlike housings. These are open to the atmosphere at the bottom and sealed at the top, where they are rigidly attached to the stator support ring. A flexible bellows seal is employed between the fairing and the bypass shell to allow for thermal expansion in the axial and radial directions and to isolate vibrations.

The rotor bearing struts are solid steel of air-foil cross section. They are located under the bearing journal centers with adequate clearance provided from the stator blades. These struts carry the stator thrust loads to the thrust-bearing support bridges. To avoid high-temperature bending stresses, the struts are not cooled.

The thrust bearings are arranged in groups of two on thrust-bearing support bridges (Fig. 6). These bridges rigidly connect compressors one and two and compressors three and four, forming two independent thrust systems, with no rigid mechanical connection between them. The bridge structures are designed to collect the rotor and stator thrust loads of each system for the thrust tie rods, and to minimize the flexibility of the thrust-bearing supports caused by the eccentricity of the bearings over their struts. The bridges are bolted to the top flanges of the rotor bearing struts. The combined thrust loads in each system are carried directly to the bypass shell by a pair of pin-ended thrust-tie rods.

The thrust-tie rods dictate the axial location of compressors. They extend from the thrust bearing bridges to the bypass shell, sweeping back at an angle of about 25 degrees to the compressor centerline. The ties pass through the upstream stator support rings of compressors two and four where each rod is separated into two sections (Fig. 7).

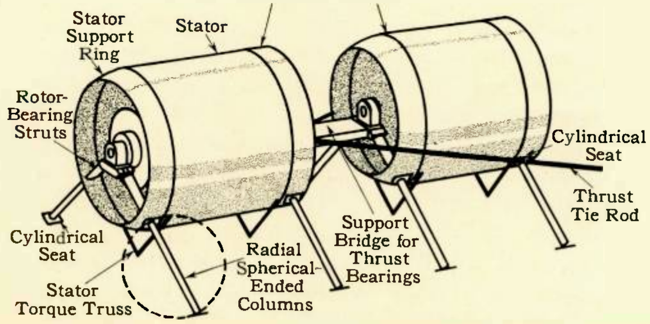
The tie rods are solid steel, forged in a streamlined shape, with a cross-sectional area of 75 square inches. The longest section is a single forging 31 feet long, weighing approximately four tons. The tremendous size of the rods is necessitated by thrust loadings of about 1 350 000 pounds and by the required axial stiffness of the compressor support.

The compressors, resting on radial spherical-ended columns, would be entirely unstable without the stator torque trusses (Fig. 8). Two of these simple pinned trusses carry the torque reaction from each stator to the bypass shell. The lateral guide along the bottom of the shell then carries it to the foundation. Links between the trusses and the bypass shell provide for any thermal expansion as well as isolating radial vibrations.

The bypass shell is banded by four main structural rings. The first ring carries the tunnel fixed anchor point, while the remaining three rings are spaced between compressor units and at the end of the bypass shell. Each ring is supported at its horizontal centerline by a pair of vertical spherical-ended columns. Aside from supporting the bypass shell, the main rings stiffen the shell and provide solid connections for the thrust tie rods and the iris-valve operating cylinders. Between rings, the bypass shell is broken at the top by huge hatches, which allow removal of compressor stator sections and the completely assembled rotors.

This sampling of design and manufacturing problems illustrates the magnitude of the task of constructing the PWT compressors. Individual components are huge, which in itself creates machining and handling difficulties. The fact that these parts must be precisely made, and then accurately fitted and assembled into a much larger structure further complicates the matter. The completed compressor will obviously embody a large amount of engineering and manufacturing effort.

Fig. 6—The thrust and support system for a pair of compressors.



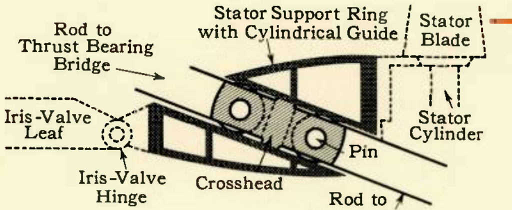
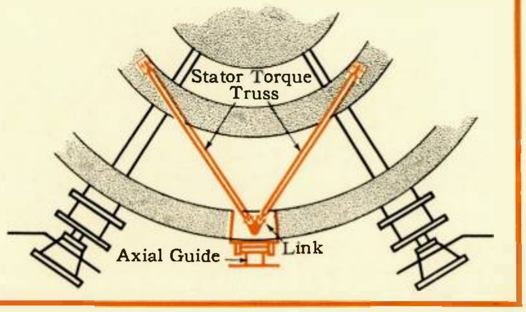
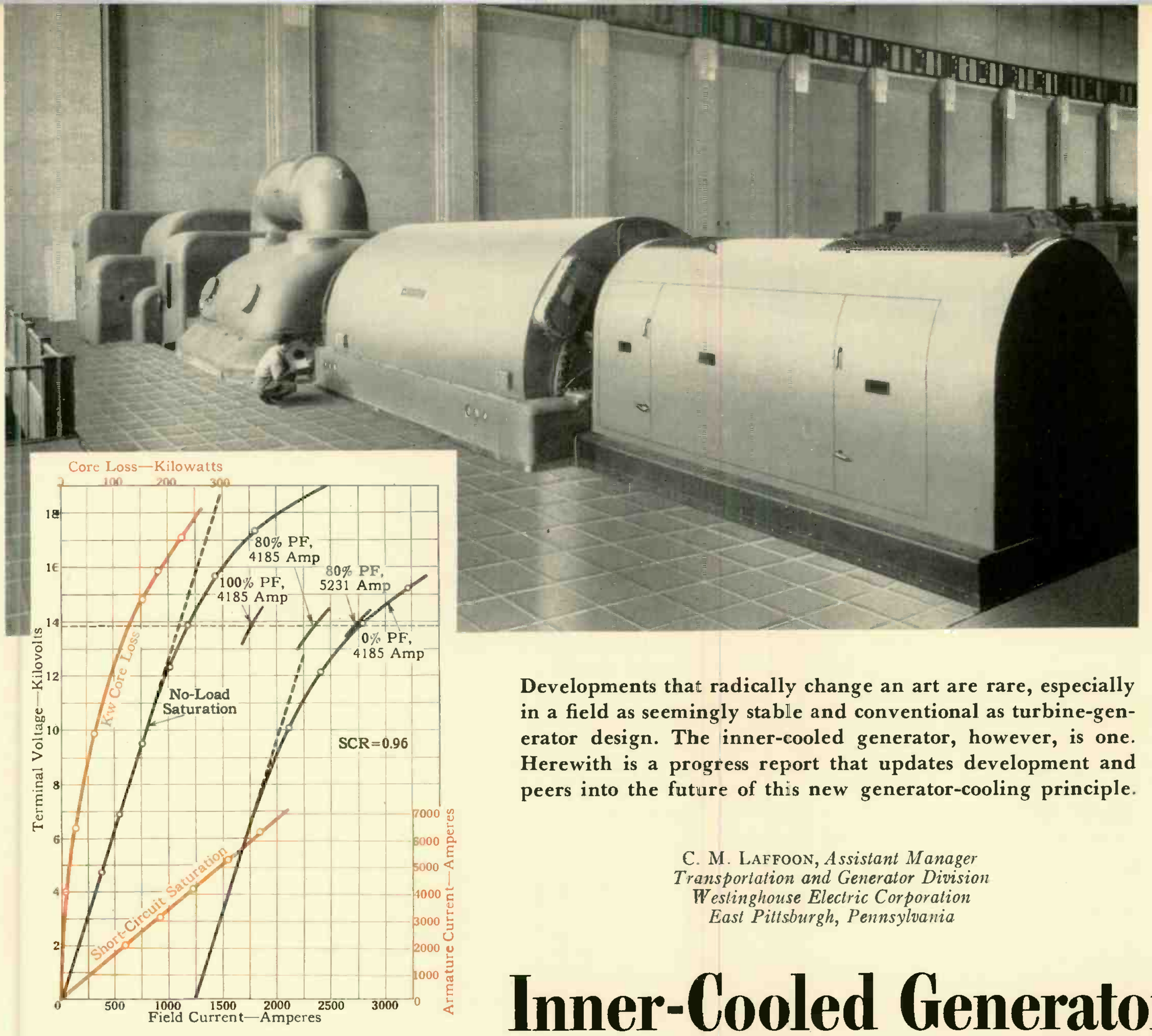


Fig. 7—The thrust-tie rod arrangement is shown in this cross section of a portion of the stator support ring.

Fig. 8—The stator torque truss and axial guide of the supersonic compressor.





An installation view of the inner-cooled generator at the Huntley Station of the Niagara Mohawk Power Corporation and characteristic curves of this machine.

Inner-Cooled Generators

A Progress Report

Developments that radically change an art are rare, especially in a field as seemingly stable and conventional as turbine-generator design. The inner-cooled generator, however, is one. Herewith is a progress report that updates development and peers into the future of this new generator-cooling principle.

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AT THE TIME inner cooling of generators was announced in 1951,* a prediction was made that its use would usher in a new era in the design, application, and operation of such machines, without encroaching on thermal and mechanical limitations for ratings much larger than those then in use or contemplated. That prediction is now fact. The first turbine generator using inner cooling for both rotor and stator coils is now in operation at the Huntley Station of the Niagara Mohawk Power Corporation. The turbine of this unit has a maximum rating of 100 mw, and at 30-psig hydrogen pressure and 0.8 pf, the generator rating is 100 mva (see Table I).

This unit was designed on the basis that the maximum temperatures of the rotor and stator copper, stator core, and structural parts would not exceed the limits specified in the proposed revisions of AIEE Standard No. 1 and ASA C-50 Standards for rotating electrical machinery. These temperature limitations are: (a) 130 degrees C maximum total temperature for class B insulation of the stator and rotor windings; (b) 95 degrees C total temperature for the stator-core laminations; (c) 110 degrees C total temperature for structural parts at the ends of the core for high power factor and at underexcited local conditions.

Conventional resistance temperature detectors (RTD) were permanently located between the top and bottom coil sides at different axial positions of the stator core, and thermocouples and other temperature-measuring devices were temporarily installed on other accessible parts of the generator for use during testing. (Temperature detector locations are indicated in Tables II, III, and IV.)

Test Results

Factory tests were made on this unit to obtain generator characteristic curves, segregated losses, load-temperature runs, and reactance and time-constant coefficients from short-circuit oscillographic records. A reactor absorbed the reactive-kva loading. The generator was tested at hydrogen pressures up to 90 psig. However, the test operation with higher pressures was for experimental reasons, so data

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*"Generator Coils Cooled Internally—Rating Increased by One Half," by C. M. Laffoon, *Westinghouse* ENGINEER, November, 1951, p. 170-2.

These tables give a résumé of performance and test data obtained from factory tests on the 100-mw inner-cooled generator built for the Niagara Mohawk Power Corporation. These results are for 30- and 45- psig hydrogen pressure; tests were conducted for experimental purposes at higher pressures, up to 90 psig. Estimated performance was met.

TABLE I—GENERATOR CAPABILITY AND RATING FOR DIFFERENT GAS DENSITIES

Characteristics	Capability (30 Psig, 80 Mw*)	Rating (45 Psig, 100 Mw*)	Capability (60 Psig, (110 Mw*)
Power factor—Percent	80	80	80
Megavolt amperes	100	125	137.5
Short-circuit ratio	0.90	0.72	0.66
Terminal voltage—Kv	13.8	13.8	13.8
Stator current—Amperes	4185	5231	5754
Rotor current—Amperes	2360	2750	2915

*Rating ratios for different gas pressures are special for this unit.

included here is limited to operation at 30 and 45 psig.

Characteristic curves (p. 157) are quite similar to those of conventional units of the same rating; the significant departure occurs in the magnitude of the rotor current, which is approximately twice that of a generator of conventional design. Total temperatures, segregated losses expressed in percent of calculated total loss, and reactance coefficients of the generator are included in Tables II to VII. All are based on a 100-mva rating at 30-psig hydrogen pressure.

In connection with the test data, certain conclusions should be noted: (1) Expected performance was met with ample margin for short-circuit ratio (SCR), reactance coefficients, time constants, and total temperatures of the stator and rotor windings, stator core, and all mechanical parts for the ratings at 30- and 45- psig hydrogen pressures. Segregated losses were slightly in excess of calculated values due to underestimation of losses in the metallic supports for the Micarta air-gap baffle located on the collector end of the unit.

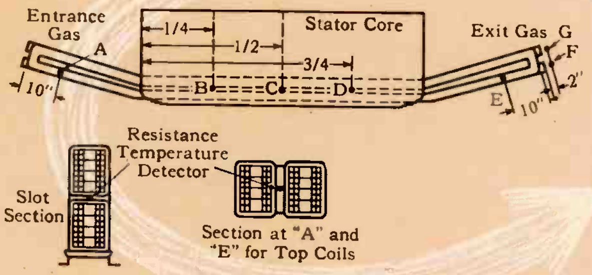

TABLE II—TOTAL TEMPERATURE OF STATOR WINDING BY CONVENTIONAL RESISTANCE TEMPERATURE DETECTORS

	Locations of Resistance Temperature Detectors	Total Temperature—Degrees C (30-Degree Cooling Water)		Observed Temperature Rise (+40 Degrees C Ambient)
		100 Mva, 0.8 PF 30 Psig	125 Mva, 0.8 PF 45 Psig	
1	Between adjacent top coil sides at *A*	55.7	56.9	No Standard
2	Between adjacent top coil sides at *E*	70.6	79.5	No Standard
3	Between top and bottom coil sides at *B*	61.2	67.6	100°C ASA C50
4	Between top and bottom coil sides at *C*	66.0	71.6	100°C ASA C50
5	Between top and bottom coil sides at *D*	71.4	76.7	100°C ASA C50
6	At discharge gas from top coil at *F*	87.5	93.3	No Standard
7	At discharge gas from bottom coil at *G*	78.0	84.5	No Standard

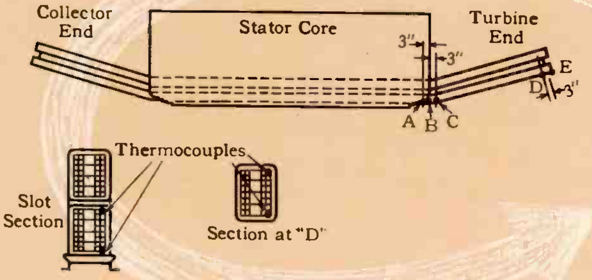

TABLE III—TOTAL TEMPERATURE OF STATOR COPPER, COOLING DUCTS

	Locations of Thermocouples on Bare Copper and Cooling Duct	Total Temperature—Degrees C (30-Degree Water Temperature)		Maximum Allowable Temperature—Degrees C
		100 Mva, 0.8 PF 30 Psig	125 Mva, 0.8 PF 45 Psig	
1	On top strand of top coil at *A*	89.3	102.3	130 (AIEE No. 1)
2	On top strand of top coil at *B*	89.3	102.5	130 (AIEE No. 1)
3	On top strand of top coil at *C*	91.0	104.1	130 (AIEE No. 1)
4	On top strand of top coil at *D*	101.0	116.5	130 (AIEE No. 1)
5	On top duct of top coil at *E*	92.4	99.7	130 (AIEE No. 1)
6	On bottom strand of top coil at *A*	82.2	90.5	130 (AIEE No. 1)
7	On bottom strand of top coil at *B*	82.2	90.5	130 (AIEE No. 1)
8	On bottom strand of top coil at *C*	83.0	93.1	130 (AIEE No. 1)
9	On bottom strand of top coil at *D*	96.5	110.5	130 (AIEE No. 1)

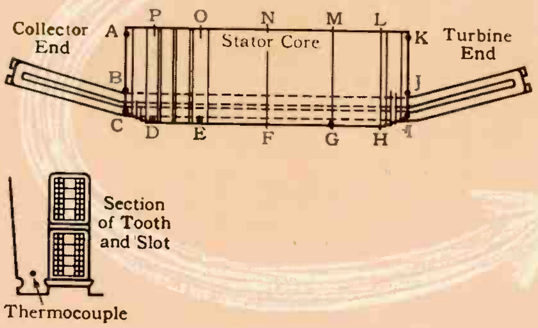

TABLE IV—TOTAL TEMPERATURE OF STATOR CORE AND STRUCTURAL MEMBERS

	Thermocouple Location	Total Temperature—Degrees C (30-Degree Cooling Water)		Maximum Allowable Surface Temperature—Degrees C
		100 Mva, 0.8 PF 30 Psig	125 Mva, 0.8 PF 45 Psig	
1	Embedded in finger plate at *A*	48.0	48.5	110 (ASA C50)
2	Embedded in finger plate at *B*	48.0	48.5	110 (ASA C50)
3	Embedded in finger plate at *C*	50.0	51.5	110 (ASA C50)
4	Embedded in finger plate at *I*	56.0	56.5	110 (ASA C50)
5	Embedded in finger plate at *J*	56.0	56.5	110 (ASA C50)
6	Embedded in finger plate at *K*	68.0	75.5	110 (ASA C50)
7	Embedded between laminations at *D*	51.6	56.7	95 (ASA C50)
8	Embedded between laminations at *E*	62.9	67.4	95 (ASA C50)
9	Embedded between laminations at *F*	62.2	65.7	95 (ASA C50)
10	Embedded between laminations at *G*	72.5	73.4	95 (ASA C50)
11	Embedded between laminations at *H*	79.3	83.5	95 (ASA C50)
12	Embedded between laminations at *L*	51.4	53.7	95 (ASA C50)
13	Embedded between laminations at *M*	59.2	61.4	95 (ASA C50)
14	Embedded between laminations at *N*	56.5	57.7	95 (ASA C50)
15	Embedded between laminations at *O*	66.0	66.8	95 (ASA C50)
16	Embedded between laminations at *P*	68.5	70.8	95 (ASA C50)

Information obtained from the test makes possible changes on future units to bring the losses within calculated values. (2) Temperatures of all active structural parts were unusually low and demonstrated that higher current loadings could be handled satisfactorily over a wide range of gas pressures. (3) The generator could not be loaded to full capability ratings at gas pressures of 60 to 90 psig due to limitations in the reactor capacity. However, extrapolation of the test results for actual loads at these higher gas pressures indicated that the expected capability ratings could be carried without exceeding the temperature-limitation standards. (4) The overall test results were gratifying, and have furnished the basic data needed to design, build, and rate inner-cooled units now on order as well as those in the future.

Present Situation

Sixteen turbine generators using inner cooling for both stator and rotor windings, and involving a total capacity in excess of three million kw, now are under construction. Individual units range in ratings from 100 to 320 mva. As a result of extensive application of engineering manpower, money, and new equipment on this development program over the past few years, single-unit, 3600-rpm inner-cooled turbine generators for a rating range of 60 to 300 mw now can be built. But much of the credit for success belongs to those utility companies that have cooperated in carrying out this program. And wider participation by more purchasers is accelerating the manufacture of a greater number of units, spreading the development costs, facilitating the solution of manufacturing processes and procedures to reduce manufacturing costs, and shortening the time required to reach the goal of sharing manufacturing economies.

TABLE V—TOTAL TEMPERATURES OF ROTOR WINDINGS

Temperatures by Rotor Winding Resistance	Degrees Centigrade		
	100 Mva, 0.8 PF 30 Psig	125 Mva, 0.8 PF 45 Psig	Maximum Allowable Temperature
Average temperature	81.0	85.5	120 (ASA C50)*
Calculated maximum temperature	106.0	113.5	130 (AIEE No. 1)

*Average temperature rise by resistance measurements +40 degrees C.

TABLE VI—TOTAL TEMPERATURE OF WATER AND HYDROGEN GAS IN COOLER

Temperature by Thermometer	Degrees Centigrade	
	100 Mva, 0.8 PF 30 Psig	125 Mva, 0.8 PF 45 Psig
Water entering cooler	32	32
Water leaving cooler	40	43
H_2 gas leaving cooler	45	45
H_2 gas entering cooler	77	81

TABLE VII—SEGREGATED LOSSES IN PERCENT OF CALCULATED TOTAL LOSS AT 30 PSIG

	Calculated	Based on Test Results	
Hydrogen Pressure—Psig Output—Kilowatts	30 80 000	30 80 000	45 100 000
Loss	Percent		
Windage	16.5	16.5	22.0
Core loss	7.5	9.7	9.7
Stator—I^2R	14.7	14.5	22.7
Rotor—I^2R	41.4	42.9	58.0
Load loss	6.0	9.9	15.5
Bearing loss	7.5	5.0	5.0
Seal loss	1.9	1.5	1.5
Exciter losses (calculated)	4.5	4.5	5.5
Total losses—Kilowatts	100	104.5	139.9

TABLE VIII—PER UNIT VALUES OF REACTANCE AND TIME CONSTANTS FOR 100 MVA RATING

Reactance and Time Constants		Comparison of Values	
		Calculated	Test
Synchronous reactance	X_d	1.16 P.U.	1.13 P.U.
Transient reactance (unsaturated)	X'_{du}	0.257 P.U.	0.230 P.U.
Transient reactance (saturated)	X'_d	0.226 P.U.	0.218 P.U.
Sub-transient reactance	X''_d	0.196 P.U.	0.190 P.U.
Negative-sequence reactance	X_2	0.196 P.U.	0.200 P.U.
Zero-sequence reactance	X_0	0.070 P.U.	—
Transient (short circuit) time constant	T'_d	0.573 Sec.	0.667 Sec.
Open-circuit transient time constant	T'_{do}	2.30 Sec.	2.30* Sec.
Sub-transient (short circuit) time constant	T''_d	0.035 Sec.	0.027 Sec.
Armature (or direct current) time constant	T_a	0.27 Sec.	0.33 Sec.

*Calculated value

Evaluation

Inner cooling makes possible the construction of 3600-rpm, single-unit generators for ratings of 350 mw and higher, which may be needed by the industry during the next ten years. For moderate hydrogen pressures of 30 to 45 psig, and ratings of 100 mw and above, inner cooling permits a 50-percent reduction in the weight of the rotor and stator copper, magnetic material of the stator core, and the rotor forgings, without any sacrifice in performance. Reduction in physical size of generating units for a given rating is of great importance because of the appreciable savings in copper, steel, nickel, and other critical alloying metals. Reduction in rotor diameter of 15 percent, and weight of 50 percent, simplifies the forging problem and results in improved mechanical performance and reliability. Rotor forgings of more uniform quality and improved reliability can be produced by the forging manufacturer because: (1) Smaller ingots are less contaminated with dirt, sand, nonmetallic materials and gases, the presence of which result in inclusions, nonuniformity, and lower ductile properties of the material. (2) Forging and heat-treating operations can be more penetrating and effective with resultant improvement in forging quality.

In ratings of 150 mw and up, inner cooling is essentially mandatory. In ratings below 150 mw and down to 60 mw, it makes possible a major improvement in the use of materials. At present, cost savings resulting from the decreased amount of materials are more than offset by large development costs for tools, new manufacturing equipment, and engineering. However, at present price levels, the purchaser of inner-cooled turbine generators obtains several power-generation cost savings and advantages: (1) Reduction in physical size and weight results in lower cost of generator foundations, smaller and lower cost cranes for erection and maintenance operations, shorter rotor-withdrawal dimensions, and smaller stations. (2) Reduced weights and more efficient cooling make possible a small increase in generator efficiency at full load and an appreciable efficiency increase at fractional loads for gas pressures of 30 to 45 psig. (3) The generators are designed with mechanical parts adequate for appreciable overloads at higher gas pressures without exceeding total temperature limitations required by present specification standards, or that may be required by future standards. (4) The 75- to 90-percent increase in reactance coefficients results in lower short-circuit currents, which reduce the duty on circuit breakers and the mechanical stresses imposed on stator windings. Yet it is believed the magnitudes of the unsaturated transient reactances are not approaching values that will introduce too difficult generator-stability problems under transient load changes. (5) Elimination of the thermal gradient through the insulation-to-ground of the stator winding permits the insulation to act primarily as a dielectric barrier, so thermal considerations have appreciably less effect on physical size of the generator for higher stator voltages. (Stator voltages of 20 to 24 kv are now being used on the 200- to 250-mw inner-cooled turbine-generator units.) Still higher voltages will be available for single-unit turbine generators for ratings of 300 mw and above. (6) The average difference in temperature between the stator core and the stator copper is appreciably less than for a unit of conventional design, so the shearing forces on the insulation due to differential expansion of copper and core material are reduced.

A Look Ahead

For the immediate look ahead—on the basis of development, design, manufacturing experience on inner-cooled turbine generators, the test results on the Niagara Mohawk generator and auxiliary equipment, and its limited operating experience at 45-psig hydrogen pressure—the generator rating to match the maximum turbine rating should be based on 45 psig with a capability rating at 60-psig gas pressure. In this 45- to 60-psig hydrogen-pressure range, generators for given ratings can be built with still smaller and lighter active parts, and with no sacrifice in efficiency and reliability. This move could result in immediate cost savings.

The time is approaching when attention must be given to preparation of standards for inner-cooled generators. The temperature performance of such machines should be based on maximum total temperature of the parts under consideration and, further, the chosen temperature limits should be realistic and should be used to determine compliance with contract specifications and the performance limits under actual operating conditions. The maximum total temperature of any stationary part of the generator at "ground" potential can be obtained by an embedded thermocouple having detector leads brought out to permanent terminal boxes. Such detectors cannot be installed on the bare copper of the rotor or stator winding and provide adequate safety during normal operation. In the case of the stator winding, thermocouples can be installed on the bare copper on neutral coils and used for test purposes under specially controlled isolated-system conditions. Thus an incremental correction value can be obtained to add to the total observed temperatures measured by thermocouples in contact with the external surface of the coil insulation, in conformity with prescribed locations and methods of installation.

The average total temperature of the rotor winding can be obtained by a comparison of its resistances under cold and hot conditions. The incremental correction value—to be added to the observed value procured by resistance measurements—can be obtained with reasonable accuracy by calculation, in conjunction with actual temperature read on different accessible rotor parts by means of temperature-sensitive paints or surface-applied devices.

In the case of Westinghouse inner-cooled turbine generators, the locations of the sections where maximum value of actual copper temperature exists are definitely known because cooling gas enters the stator conductors at the collector end of the generator and discharges at the turbine end. Maximum temperatures of the copper and the cooling gas occur at the outermost portion of the conductor at the turbine end, and total temperature of the gas discharging from the stator conductors can be obtained by temperature detectors permanently installed in the gas stream adjacent to this section. From temporary thermocouples installed on the bare copper of the neutral conductors at this section, the maximum total copper temperature can be obtained under controlled test conditions. Since the magnitude of the maximum copper temperature is relatively close to the maximum discharge-gas temperature, the incremental factor to be added to the normally measured maximum gas temperature will be relatively small, and can be determined by measurement with reasonably close accuracy.

Since cooling gas definitely enters the rotor winding at both ends of the rotor, and discharges at the mid-section of the rotor body, maximum temperature of rotor copper is found at the rotor mid-section. At the ends of the rotor coils, the copper temperature is essentially the same as that of incoming gas, and the average for the entire winding is known from resistance measurements. On the basis of linear temperature variation, the maximum value at the rotor midpoint can be readily calculated. With this temperature distribution and the known value of excitation current, a more nearly correct temperature distribution can be calculated, and the maximum temperature of the winding at the mid-section of the rotor closely approximated.

During the past several years, a relatively large number of hydrogen-cooled turbine generators have been built for outdoor operation over a wide range of climatic conditions. Some of these units have several years of service, and all are satisfactory as to operation and maintenance. Savings in investment costs of outdoor power-generating stations should justify extended development of this idea and widen its use. Appreciable additional savings could be obtained by combining or integrating the design of the generator and the main step-up transformers so that the leads between them could be reduced to a minimum, the lead construction greatly simplified, and its cost essentially eliminated. The high-voltage leads from the transformers could go to the high-tension switchyard and, if needed, low-voltage cables for the station motor-driven auxiliaries could be carried through simple ducts to the points of utilization.

Further savings, simplicity, and reliability of operation could result from using direct-coupled house generators of sufficient capacity as the main power supply for all auxiliaries and excitation units. It is presumed that a complete or partial alternate back-up supply would be available from the main power system.

If the function of the main generator is to supply power to the transmission and distribution system, magnitude of the generated voltage is of no operating concern. Generator and transformer designers can then select a generator voltage that makes possible the lowest cost generator-transformer combination with an improved overall efficiency. The lowest cost generator results when optimum voltage is used. With close coupling between generator and transformer, optimum generator voltage could be lowered by using two or three times the usual number of phases per pair of poles, and the maximum number of parallel circuits per phase. By properly connecting the generator winding circuits to windings on the transformer cores, the multiphase power produced by the generator can be converted to three-phase power for transmission and utilization. This requires a larger transformer, but the increased transformer cost would be more than offset by the reduced generator cost. The overall cost of the combined unit would be less.

With inner cooling used in conjunction with other promising items and improved materials, still greater progress can be made to increase the generator output per unit of material and to provide economies of appreciable magnitude for the benefit of both manufacturer and user.

Personality Profiles

The fundamental concepts of electrical insulation were outlined in the May issue in an article by a well-qualified team of research men, Drs. Dakin and Swiss. This issue features a follow-up on insulation for rotating machines, by an equally well-qualified team of development engineers—*G. P. Gibson* and *Graham L. Moses*.

The name of Moses has cropped up on these pages with fair regularity for several years. As manager of the Insulation Development Section of Transportation and Generator Engineering, he has had intimate contact with recent developments in insulation for large machines.

Gibson, on the other hand, is a newcomer to these pages, although an old hand at insulation problems. His particular field is small integral-horsepower motors. A graduate of the University of Nebraska in 1930, he spent his first several years with Westinghouse on the motor test floor. In 1939 he transferred to the insulation and coil design section of motor engineering. Then, in 1946, he became a member of the A-C Development Section, where he worked on the first Life-Line motor design. Since then he has worked on various phases of motor design as well as insulation. In 1952 Gibson was assigned to the section responsible for a-c motor development where he worked on the Life-Line A motor, and in 1953 became a member of the advanced development group.

Any profile of Gibson would be incomplete without mention of his birthplace —Wahoo, Nebraska. Gibson is quick to explain that the town is unique in more respects than its name, being the birthplace of such talented people as Darryl Zanuck, movie executive, Dr. Howard Hanson, composer, and "Wahoo Sam" Crawford, baseball player of the Ty Cobb era. And we might add, it has turned out at least one very capable engineer.

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George H. Heiser works in what he calls a "mechanical engineer's paradise." His enthusiasm is understandable. Heiser is manager of mechanical engineering in the Sunnyvale, California, plant, where many diverse mechanical products are made—the PWT compressors, hollow-jet valves, turbines, gears, dam gates, and butterfly valves, to name a few. The problems involved in designing and constructing this huge equipment are enough to make any mechanical engineer's mouth water.

Quite naturally, Heiser is a mechanical engineer himself, a graduate of the University of Nebraska in 1936. He joined Westinghouse via the Graduate Student Course, and was assigned to the Steam Division, where he spent the next ten years, except for one year at the Research Laboratories as an exchange engineer.

In 1946 Heiser went West to join the Joshua Hendy Iron Works at Sunnyvale. When Westinghouse acquired the plant a year later, he rejoined the Company.

Heiser went to Mexico City in 1950 to help negotiate an order for two 102-inch hollow-jet valves—the largest ever built. His interest in this job may well have provided the impetus for writing about the valves, which he did last year in the ENGINEER. The article in this issue was a natural, since Heiser figured prominently in the design and manufacture of the huge PWT compressors; in fact, he found time to take a personal hand in the design, inventing the hydraulic disconnect coupling used in the system.

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Five times in the past *C. M. Laffoon* has written for the *Westinghouse* ENGINEER; five times on basic electrical engineering subjects that were "hot" at the moment. In this issue he continues this habit with his progress report on inner cooling, a generator development freely acclaimed as one of the more radical advances in the last three decades. Since his last appearance (November, 1952) Laffoon has been appointed assistant manager of the Transportation and Generator Division, thus taking on new responsibilities. His interest in generator development continues however; in fact, inner cooling still demands a major portion of his energies.

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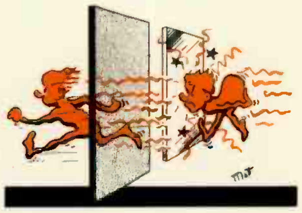
As a liaison engineer, *Robert M. Leedy* has a dual responsibility. First to help division engineers find the answers to specific engineering or manufacturing problems, and second, to see that the knowledge gained by one group is made known to others who could use it. One method of approach involves seeking out all sources of information on a subject, and absorbing, correlating, and evaluating it. This is precisely what Leedy has done in the article on surfaces to control radiant heat.

Leedy's background originally was in metallurgy; he is a graduate metallurgical engineer from Carnegie Institute of Technology (1947). He was for a time a metallurgical engineer in the Materials Engineering Department, where he worked on both ferrous and nonferrous applications. Since joining the Liaison Engineering Department in 1950, his scope of activities has broadened to include most engineering materials, and to a lesser extent all engineering and manufacturing problems.



As Leedy points out, his job doesn't make him an expert in any one field—unless it is the extremely broad one of materials in general. But to anyone who believes in the old saying about variety, his work is extremely well seasoned.

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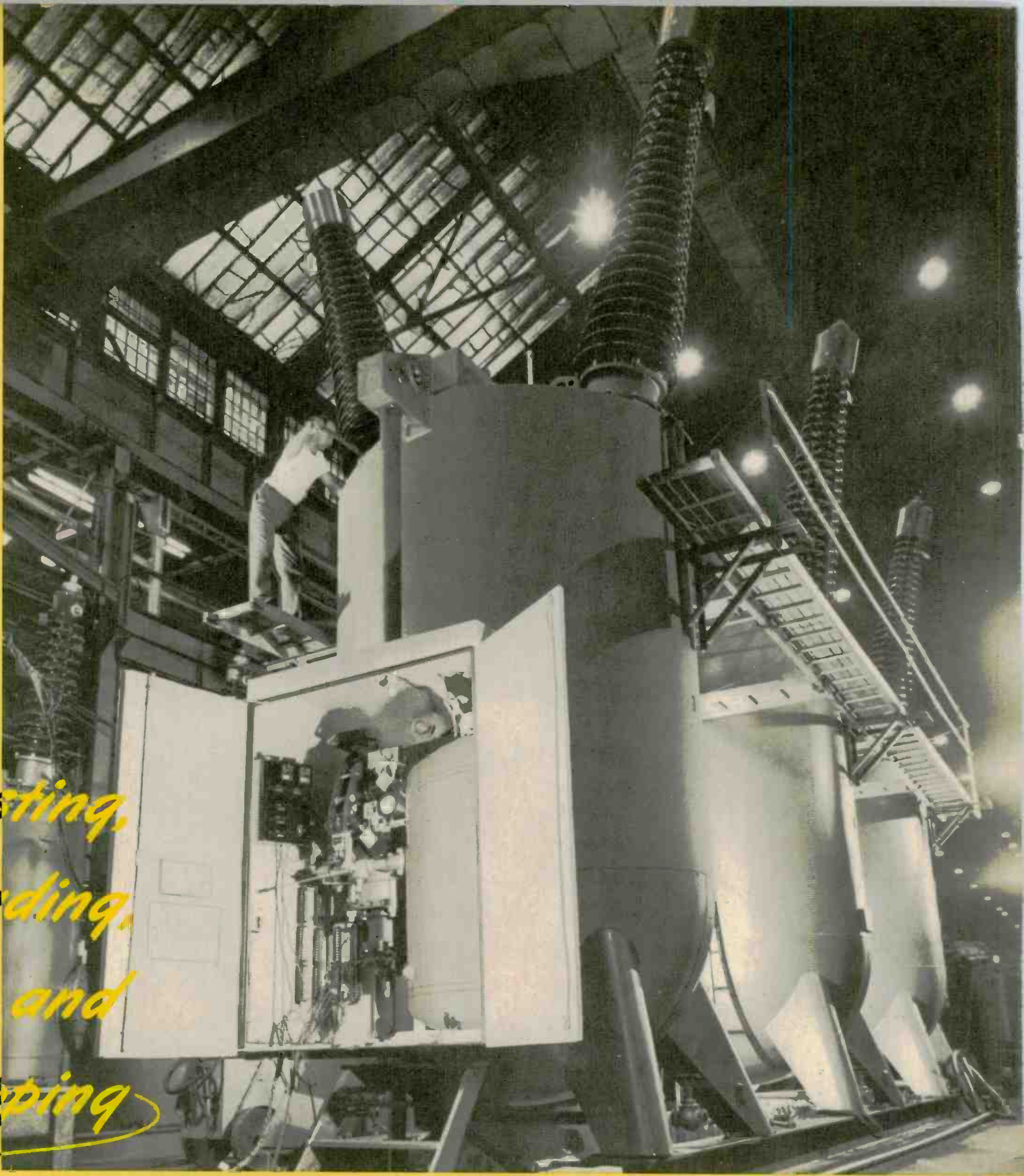
When *B. E. Rector* went to the University of Kentucky, he and a few others who had lived in the mountainous parts of Tennessee were looked upon as hillbillies. Rector and his pals encouraged this notion, even to the extent of going barefooted in the snow. "Darned near killed us," Ed says, "but anything for effect." Now his joking takes milder form—mostly as a fantastic collection of racy stories.

After Rector graduated, in 1943, as an electrical engineer, he went straightaway to Westinghouse. The war was at its height, so that after only two months on the Student Course he was snatched away for an assignment in electronic-equipment application. In 1946, he transferred to the mining section of Industry Engineering, where he has since been working on equipment problems for metal mines, potash mines, and—lately—quite intensively for taconite processing. On the side, he has been an instructor in electronics in the Westinghouse-University of Pittsburgh graduate-study program and had an important hand in the preparation of the well-known "Industrial Electronics Reference Book."

Right now Rector is engaged in a reclamation project of his own. He has ten acres east of Pittsburgh, which he is trying to win back from brush that has overrun it.

Testing, loading, and shipping



The first of 35 huge 25-million-kva circuit breakers to be built by Westinghouse for Ohio's new 330-kv system.