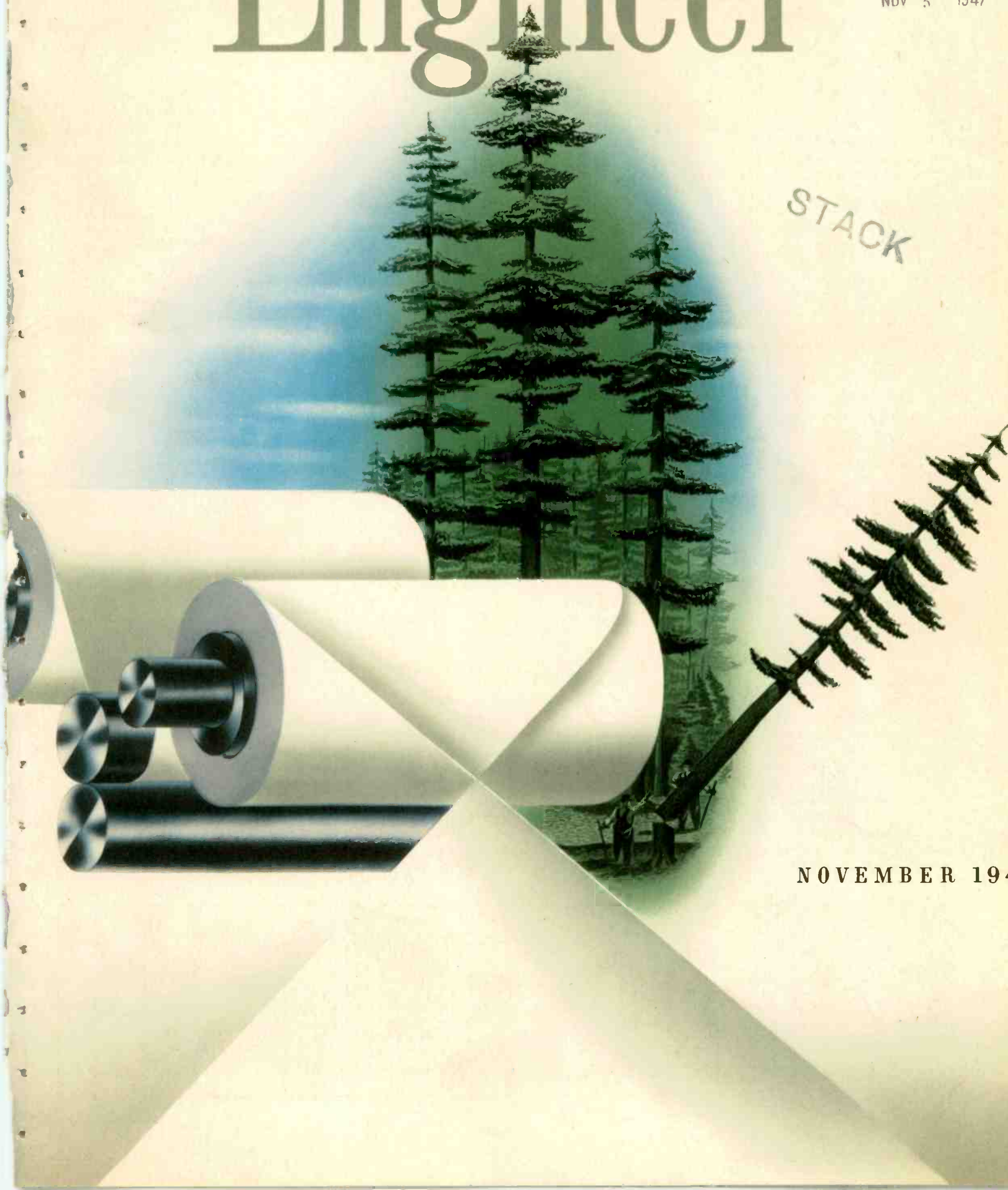
WESTINGHOUSE

Engineer



NOVEMBER 1947

Short Circuits—Custom Made

Short circuits in ordinary generating stations are most unwelcome. Great pains are taken to avoid them. But in a few generating stations about the world, they are deliberately created. In fact, short circuits are their sole product. The prime purpose of either the new one recently placed in service by the Navy (see p. 175) or the king-size high-power testing laboratory at East Pittsburgh is to produce short circuits on demand for testing many types of electrical apparatus. In the twenty-two years the East Pittsburgh laboratory has been in service, about 180 000 short-circuit tests have been conducted. Although this represents a stupendous amount of testing of circuit breakers and kindred apparatus, the station probably sets some kind of record for low load factor. The machines, in more than two decades, have supplied power to "loads" for a total of only about four hours.

The high-power laboratory, naturally, is an adjunct of switchgear-manufacturing plants almost exclusively. The high-power test station installed by the Navy is of special interest because it is one of the first, if not the first, specialized testing laboratories erected by an apparatus user. While it follows the principles of the large laboratory at East Pittsburgh, and incorporates the lessons taught by the years of experience with it, it is designed for the special job of grilling the kinds of switching apparatus that serve aboard fighting vessels and their auxiliaries.

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The East Pittsburgh laboratory is one of the oldest of the 18 or 20 other laboratories that have been built in this country and abroad, being erected in 1925. The first edition comprised two generators to provide a capacity of 390 000 kva, three phase for circuit-breaker testing up to 13.2 kv without transformers. Additions were made in 1930 and 1940 so that now it can pour 2½ million kva into a three-phase short circuit. It is considerably larger in short-circuit generating capacity than any other in the world. Next in order of capacity are two laboratories of about 2 000 000 kva in Belgium and England.

Although short-circuit capacity is the most spectacular figure relative to a switchgear test plant, it is by no means the only one of importance. A vital one is the test voltages available — both the maximum obtainable and the variety. In this respect also the East Pittsburgh laboratory is without parallel. Because of the many connections possible with its two banks each of 100 000-kva transformers maximum short-circuit kva can be obtained at virtually any desired voltage up to 345 kv, three phase and 396 kv, single phase. The top limit elsewhere is 240 kv, three phase, and 264 kv, single phase.

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The present main laboratory consists of two generators of 60 000 kva nominal rating that can be operated separately or connected electrically in parallel to provide a total of 2½ million short-circuit kva. Each has a full set of controls such as switches, timing drum, and recording devices. This duplication of equipment is of great advantage in that the test flexibility obtained more than doubles the test efficiency. For example, one test can be made and all the connections held intact pending assurance that they are no longer required while a set-up on another equipment is made and its test completed.

Including the two 20 000-kva machines installed in the original station in 1925, the laboratory is in effect three laboratories in one, although the small machines cannot readily be combined with the two big ones for a single test because of their different inertia or slowing-down characteristics. (All the energy for a test comes from the momentum of the generator rotors; the two driving motors, 6000 hp each for the big machine, and 3300 hp for the older one, simply bring the generators up to speed and supply no-load losses.)

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The laboratory is equipped to provide high currents as well as high power. Currents up to 200 000 amperes, three phase or 345 000 amperes single phase are obtainable for five seconds. Such prolonged high currents permit testing of high-power apparatus at load voltages in the 200-2800-volt range, as well as for checking mechanical and thermal ratings of breakers when carrying high current.

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An interesting adjunct to the high-power laboratory is the cold room. Here temperatures down to minus 20 degrees F can be maintained even in summer. This facility is particularly useful in checking the cold-weather performance of fuses or disconnecting switches when iced over.

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The short-circuit generators are large slow-speed machines with purposely massive rotors. Each rotor weighs about 275 tons. The moment of inertia is 8 500 000 pounds feet squared. In fact were the machines allowed to coast to a stop—which they aren't—they would roll for two and a half hours. Use of massive slow-speed rotors instead of higher speed, lighter ones, as are more common, permits withdrawal of short-circuit energy with a smaller percentage drop in speed. On a 1 000 000-kva short circuit lasting three cycles the frequency drops only from 60 cycles to 59.5 cycles.

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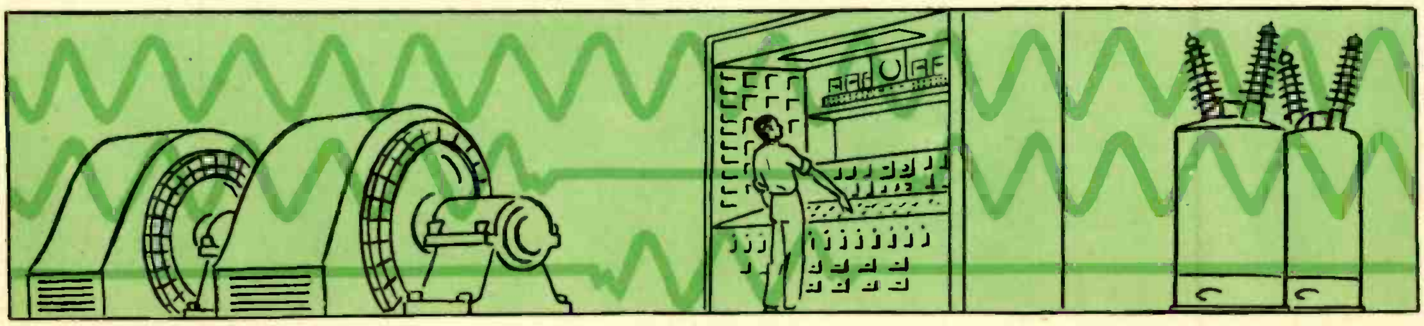
The present state of development of high-voltage systems and switching and protective devices would have been impossible without the high-power laboratory. The ability to test quickly new designs in various stages, with all variables controlled, and without disturbing a commercial power system has freed the development of switching structures of high costs and delays that would otherwise have retarded it. Although the interrupting capacities of switching equipment have more than doubled since the laboratory was modernized last, it still has testing capacity in excess of any apparatus yet required. The high-power laboratory has been of inestimable benefit to designer and builder, to power companies, and to every user of current. The Navy's new test station is another step in the development of more capable power apparatus.



WESTINGHOUSE Engineer

VOLUME SEVEN | NOVEMBER, 1947 | NUMBER SIX

On the Side

The Cover—Paper, so common and cheap as to be taken for granted, has one of the most romantic histories and most technically important futures of any common product. Its manufacture, described in this issue, is symbolized by the artist, Richard Marsh.

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A cumulative index of all material appearing in the *Westinghouse* ENGINEER will be available shortly. This cumulative index includes reference to all subject matter that has appeared in the *Westinghouse* ENGINEER from its first issue, May, 1941 through this present issue, November, 1947. Anyone wishing to have a copy will receive one without charge by addressing a request to the *Westinghouse* ENGINEER. Copies will be supplied as soon as they are available.

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We are accustomed to seeing electric stairways only in large department stores and railroad stations. They can, however, be expected to become more common because of the development of a standardized edition for use in smaller commercial establishments and public buildings. The new stairway is an example of the standardization principle at work. Because it is standardized, more will be installed, which makes them cheaper to build and permits more to be sold. The stairway is 30 percent lighter in weight partly because the length of rise is limited to 22½ feet, which is seldom exceeded by the type of buildings for which they are intended. Also, in keeping with their function in smaller buildings, the electric stairways are designed to occupy about one tenth less space. Each is capable of carrying 4000 persons per hour.

In This Issue

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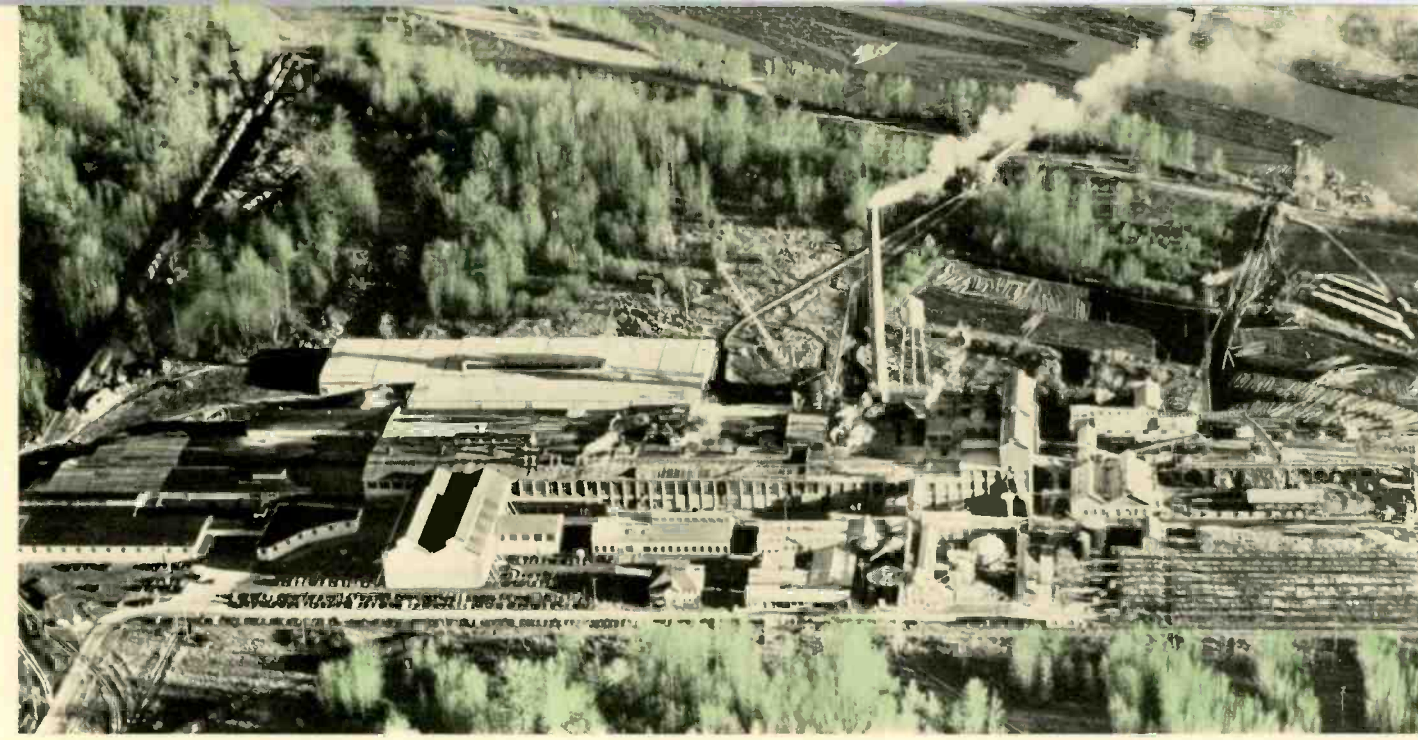


THE PAPER MEN LIVE BY

The making of paper, while it has been unchanged in principle in 1900 years, is undergoing one of the greatest industry expansions and modernizations on record. The biggest problem of the industry lies, not with its tools, for these have been marvelously perfected as to quality and volume of product, or with the demand, which seems limitless, but with insuring a perpetual supply of the raw fiber.

This has been variously called the age of steel, of power, of transportation, of atomic energy. It could also be called the age of paper. Use of paper has been expanding, at increasing rates, in two directions: variety of use and total amount. Within the past two decades paper has been made the raw material for countless products entirely new and as a cheaper or better replacement for an old material. The most phenomenal change has been its use for containers. The familiar brown kraft paper or corrugated-board carton has almost swept the wood box and crate out of existence. Paper is used for drinking cups, for milk bottles, for cleansing tissues, for building purposes, for water-proof maps and dish cloths, and many, many more. Every day new paper articles appear and are quickly accepted.

As to quantity, the United States, in 1945, consumed 17.4 million tons of paper, or nearly 250 pounds per person. The consumption has increased from 5.8 million tons in 1915 to the present figure, to a large extent because of the rising use of newsprint and kraft paper and board for containers and building papers; this has built the industry into the sixth largest in value of products.

The industry is additionally significant in many ways: its products have great effect on the daily lives of every person; unlike some of the major industries, it comprises about 700 paper-making plants and many pulp plants scattered throughout almost every region of the United States; it gives work to hundreds of thousands of people directly or indirectly; and, to the engineer it is especially noteworthy for its power consumption. The paper industry is first in kw per ton of product and third in installed generating capacity, as brought forth in the accompanying article by Mr. Baker. The indispensable role of paper in the war and the shortage that has resulted have emphasized our dependence on paper.

Also, albeit paper making is one of the oldest industries, it is currently undergoing an unprecedented modernization and absorption of many important improvements. But, to understand what the paper industry is and where it is going calls for a review of 'where it has been.'

What Paper Is

Paper is cellulose fiber formed into sheet. Cellulose is a definite chemical compound consisting of large molecules of carbon, hydrogen, and oxygen in the ratio of $C_6H_{10}O_5$ (identical to sugar in ratio, but not in molecular size or arrangement). Pure cellulose has the fortunate characteristic of being the whitest white. To make paper white nothing is added; impurities are removed. Colored paper contains natural impurities or added dyes. Cellulose in sheet form also has remarkable tensile strength, and quickly absorbs and permanently retains ink impressions. Paper is virtually inert to all common chemical reagents (witness the filter paper used in chemical laboratories). That it is inert is most fortunate as this quality is the basis of most paper-making processes.

Cellulose is almost exclusively of vegetable origin. Cotton, wood, and flax are the better paper-making materials although many others have been used with varying degrees of success, such as bamboo, hemp, straw, and even cane and cornstalks. This rules out wool and synthetic fabrics such as nylon, which are indeed a headache to the rag-paper manufacturer. Old magazines, newspapers, and other waste papers comprise an important portion (about one-fourth) of the total pulp material. The collection of waste paper is an important continuous national endeavor. It is converted into paper for mechanical and some printing uses.

Cotton fibers are nature's purest form of cellulose, being about 91.3 percent pure cellulose and 7 percent water. Prior to the middle of the last century, cotton rags served, for almost a thousand years, as the basis for most paper manufacture. As late as 1875,

Prepared by C. A. Scarlott from a variety of sources but with particular assistance from the technical staffs of the West Virginia Pulp and Paper Company, Brunswick Pulp and Paper Company, Union Bag and Paper Corporation, Rayonier, Incorporated, National Container Corporation, Container Corporation of America, Florida Pulp and Paper Company, Herty Laboratory, and the Westinghouse Electric Corporation.

rags accounted for virtually all of the paper made except building paper. Rags contribute now only about three percent of the new fiber supply. The amount of rags converted into paper has remained essentially static at slightly less than a half million tons per year since about 1910.

Throughout the ages the demand for rags has been high because of the endless rising demand for paper. Frequently the shortage has been serious and led to many expedients to relieve it. The most bizarre of these was use by New England mills, for a few years following 1855, of boatloads of Egyptian mummies for their linen wrappings. A high-quality product, candidly called mummy paper, was much in demand.

Because of the dearth of rags the search for substitutes continued throughout the eighteenth and nineteenth centuries and indeed is still in progress, as indicated by experiments begun centuries ago to utilize bamboo. Many possible sources of cellulose were tried but probably the only important success was the use of straw. A book was printed on straw paper in 1800. Paper of straw, however, is not suitable for printing. For the past 20 years the conversion of straw into paper, mostly for building purposes, has run quite consistently about a half million tons per year, or three percent of the present total.

Two hundred years ago wood was considered as a possible basis for paper manufacture. Sporadic attempts, particularly in England, were made thenceforth to use wood, but it remained for the Germans about 1840 to begin the utilization of wood as a paper-making material. Since then, its use has grown fabulously. In 1946 it comprised 90 percent of the total new fiber materials, i.e., excluding reused paper.

How Pulp Is Made

Making paper involves two distinct steps that can be performed independently or integrated in a single plant. One is the preparation of the cellulose fibers into pulp form. The second is the conversion of that pulp into paper.

Most paper, by all odds, is made from wood. This is accomplished by one mechanical process and three chemical ones. In the mechanical or groundwood method of making pulp, introduced in the United States in 1867 at Lee, Mass., by Steinway of piano fame, barked logs are held with their sides against revolving stones under a shower of water. Except for mechanical processes to eliminate slivers, coarse particles, and most of the water, no further preparation of the pulp for paper making is required. Usually some chemical pulp is mixed with mechanical pulp, in percentages up to about 20 percent, depending on the kind of paper made.

Groundwood pulp is comparatively simple to make, and obviously requires no chemicals. The paper thus made is weak mechanically because the fibers ground off by the stone are short and hence intertwine less readily. Groundwood paper is used where permanence is not required, as for newsprint. Groundwood pulp obviously includes essentially all the constituents of the original log. About half the total is lignin, the resinous substance surrounding the cellulose fibers. Lignin causes discoloration, particularly if exposed to sunlight.

Groundwood paper does, however, have the merit of low cost of production and maximum utilization of the original wood. To produce a ton of paper requires, for the groundwood process, about a cord of wood, whereas the chemical methods require from one and a half to two, mostly because they do not utilize the lignin. Of the total pulp produced in the United States, slightly more than 17 percent is groundwood.

The three chemical methods of making pulp from wood are the sulphate, sulphite, and soda processes in order of greatest use, but in reverse order chronologically. All three have the same objective: to free cellulose from its impurities, mostly lignin. In each the wood is "cooked" in chemicals that react with the lignins; the cellulose, being inert, remains untouched. The general steps and apparatus of all three are similar. To the lay visitor to the three types of mills, the only conspicuous difference is the odor.

For chemical-pulp mills of all types, wood chips, most carefully prepared as to size, are placed in huge tanks called digesters, holding from 2 to 12 tons of chips. Chemicals are added in liquor form. Steam is then applied directly or indirectly for several hours, whereupon the spent liquors are drawn off, leaving behind the pulpy mass of cellulose fibers. The pulp thereupon is washed to remove traces of spent liquors, and passed through a bewildering sequence of mechanical processes to remove undigested lumps, thickeners and various other treatments. The result is pulp, which can either be dried and shipped elsewhere to a paper mill or pumped as is to a paper-making plant integrated with the pulp mill. In the paper mill the pulp is processed mechanically in beaters, Jordans, and refiners to bring the fibers to the desired length. Finally there results a milky liquid, called stuff, consisting of about one-half percent cellulose fiber and 99½ percent water. This is ready for paper making.

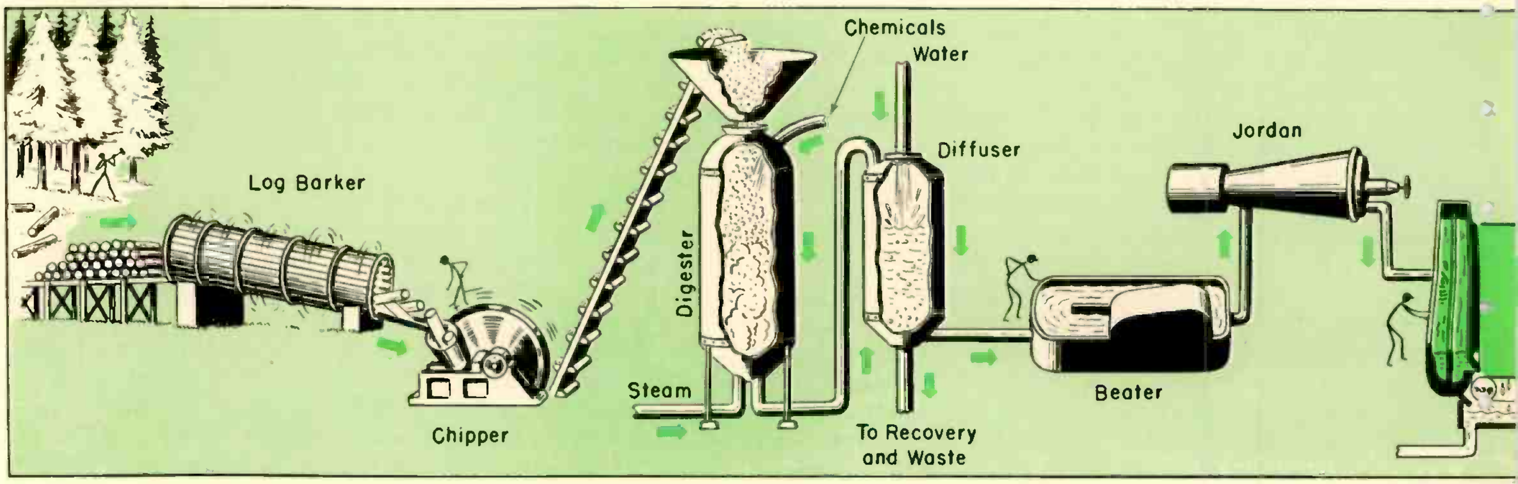
In the soda type of chemical process, patented in England in 1852, the chips are cooked for about six hours in a caustic-soda liquor. It was an outgrowth of the process for treating rags for pulp making. It still accounts for about five percent of wood-pulp production, being more suitable for the short-fibered woods such as gum, poplar, beech, chestnut, oak, and other hardwoods. The largest demand is in the production of book and fine papers where high strength is not essential.

The sulphite-pulp process followed the soda process by 15 years, being developed simultaneously in the United States and Sweden. Sulphite pulp, which accounts for 25 percent of the total produced from wood, is made by treating wood chips with sulphurous acid, calcium bisulphite, and free sulphur dioxide. To make a ton of sulphite pulp requires, in addition to nearly two tons of wood, 1400 pounds of coal or Btu equivalent, 230 pounds of sulphur, and 300 pounds of limestone.

For sulphite pulp, pine, spruce, hemlock, and hardwoods are used. Sulphite pulp has a wide variety of uses. It goes to make up about one third of the book and fine paper consumed, about one fourth of the wrapping paper, one fifth of the newsprint, one twelfth of the paper boards, and two fifths of the paper specialties.

Much is being heard now about the sulphate process because of the young and rapidly rising paper industry in the South, with its many large-production, ultra-modern mills. They produce sulphate pulp from the fast-growing Southern pines, which are characterized by their long fibers. Sulphate pulp is made by a modification of the soda process; chips are treated in the digesters with caustic soda and sodium sulphide. Sulphate pulp now amounts to 4 597 000 tons per year, or almost half (43 percent in 1946) of the total produced from wood in the United States. It has grown to this figure from about 75 000 tons or about 5 percent of the total 30 years ago.

Paper made from sulphate pulp is characterized by its high strength and is referred to as kraft, from the Swedish word meaning strength. The sulphate process was developed in Sweden during the 1880's and the first mill was built in North America, in Quebec, in 1907. The product is generally left unbleached and hence has the brown appearance characteristic of paper bags and corrugated cartons predominantly made from kraft pulp. The pulp can be bleached when desired; indeed, more and more bleaching is being done. Nearly a



million tons of the four and a half million tons (20 percent) of sulphate pulp produced last year were bleached. The proportion ten years ago was ten percent. Large quantities of brilliantly white cellulose fiber are produced by the sulphate process. However, bleached kraft pulp requires a large amount of high-cost bleaching chemicals. The sulphate and soda processes do, on the other hand, have the merit of permitting recovery for reuse of a large proportion of the chemicals as compared with the sulphite process.

Production of paper from rags involves a number of mechanical processes for sorting rags, freeing them from dirt, and shredding. The shredded product is finally cooked with lime or soda liquors much the same as with wood-pulp production. The pulp produced is suitable for paper making by any of the processes commonly employed with wood pulp.

One of the important aspects of pulp making is the production of valuable by-products. It is not uncommon in the sulphate mills using pine to make up to four gallons of turpentine per ton of pulp produced. In one representative progressive mill, by no means solitary, an adjoining by-product plant produces, in addition to the turpentine, 80 to 100 pounds of tall oil and 600 to 900 pounds of lignin per ton of pulp. Tall oil is the general name for a family of oils and fats useful in the production of paint oils, printing inks, soaps, and many other industrial needs.

Many attempts have been made to find uses for lignin other than fuel. Some have been successful, such as a reinforcing compound for rubber, as an ingredient for adhesives, adsorbents, binders, cements, corrosion inhibitors, fungicides, lacquers, tanning materials, and plastics.

Forming Pulp into Paper

Converting pulp into paper is essentially no different than when paper making was invented in China about 100 A.D. From the time of the early Chinese paper makers until a hundred years ago it was done by hand; now the process is done by machine. Until a few score years ago paper was made by laboriously dipping a mold with a wire-screen bottom into a vat of water and pulp, withdrawing it, and shaking the tray as the water drained away. The dried web of fibers was paper. The size of the sheet obviously was limited to the size of the mold. Now the paper is formed by a high-speed machine in a continuous, endless sheet in widths up to twenty feet.

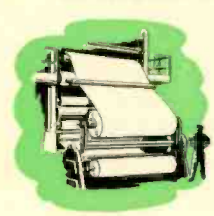
Most paper, be it newsprint, book, wrapping, or box paper, is made on a machine known as a Fourdrinier. This miraculous machine was patented by a Frenchman, Nicholas-Louis Roberts in 1798, but is called the Fourdrinier after two English stationers by that name who did much to perfect it. A Fourdrinier can be of any size and speed from the small ones for making paper a few dozen inches wide at speeds of 200 to 300 feet per minute, up to the modern, block long behemoths in kraft mills that turn out sheets 20 feet wide at speeds of 2000 feet per minute.

At the input or wet end of a paper-making machine the pulp, which is 99½ percent water and ½ percent cellulose fiber, is flowed onto an endless wire web moving at the speed at which the paper is made. As the screen with its layer of pulp moves the distance between the breast roll and couch roll at the discharge end, it is vibrated from side to side to interlace the fibers. The water, meanwhile, drains through the mesh, aided perhaps by suction at the couch end. When the screen with its web arrives at the couch roll the web is 75 percent water and 25 percent fiber, but has sufficient strength to be peeled off onto a felt that passes over press rolls to squeeze out some water. By now the paper is self-supporting so it leaves the felt and passes over a succession of steam-heated drying rolls, sometimes as many as 50, and emerges with the water content reduced to 10 percent or slightly less. It may be passed through a set of polished calender rolls to give it a hard smooth finish and wound into rolls. Thus we arrive at paper.

Another important type of paper-forming machine is the cylinder machine. In this the wire screen is wound around a cylinder that revolves partially submerged in the vat of pulp. As the drum turns, the screen accumulates a mat of fibers. The water drains or is sucked through into the interior of the cylinder so that just before the exposed portion of the cylinder dips into the vat again, the web is peeled off onto a moving felt, and carried through numerous press and drier sections as with the Fourdrinier.

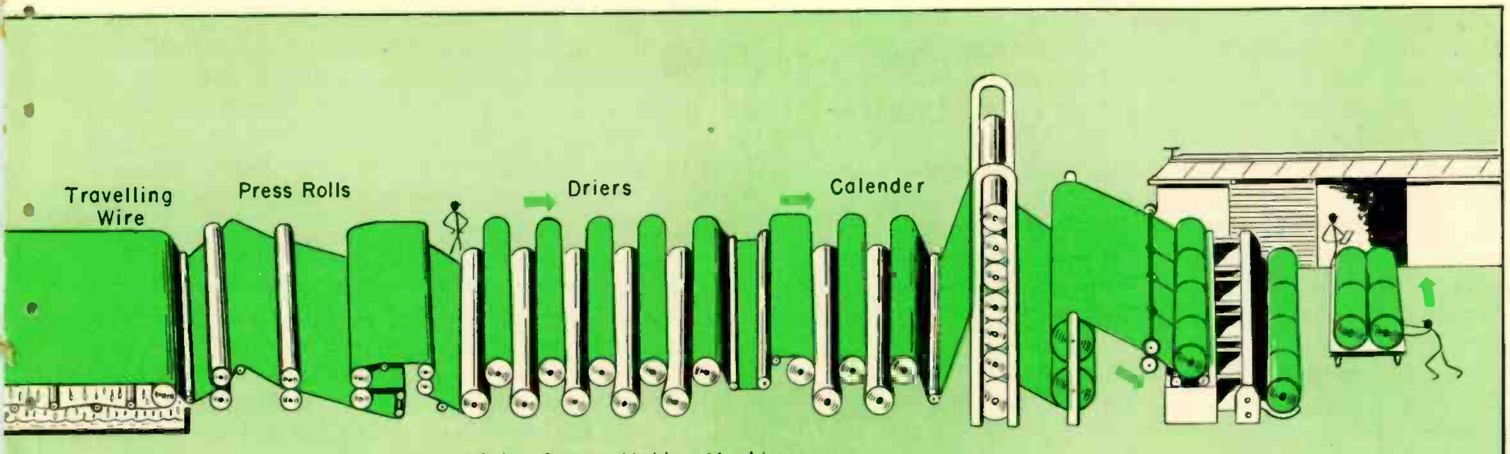
The great advantage of the cylinder machine is that the webs from two or more cylinders can be superimposed into a multilayer sheet before entering the drier section. Thus a sheet can be built up into any desired thickness from the same or different stock. The surface can be colored or of different stock than the inner plies, as desired. Cylinder machine speeds are generally slower and widths less than those of Fourdriniers but the machine provides a flexibility and type of product, particularly for speciality papers, not otherwise possible.

In addition to the Fourdrinier and the cylinder machines there are several other types. Mostly these are for forming special products such as thick wall boards.



The Raw Materials of Paper Making

An adequate supply of wood, rags, waste paper, or other source of cellulose fiber is



Fourdrinier Paper-Making Machine

obviously vital to paper manufacturing. It is, however, not the only essential raw material. Good water in river-size quantities is a requisite. One of the most conspicuous features to the visitor to a pulp and paper mill is the enormous quantities of water handled. Only by dint of diligent housekeeping can a pulp and paper mill be kept from being a wet, messy place with puddles everywhere. A pulp or paper plant is a veritable maze of piping and motor-driven pumps. Great streams of water are fed to vats; water with its load of pulp is recirculated time and time again through various screens, pulp-preparation machines, and finally falls as a veritable cloudburst from the screen on the paper-making machine. The fresh-water requirements for paper vary from about 80 tons per ton of mechanical-pulp product to 140 to 400 tons per ton of chemical-pulp paper. Furthermore, each ton of water is handled over and over again. Although the water is recycled, a paper mill requires a large amount of fresh water to make up for losses. And the water must be of high quality. Impurities have considerable effect on the quality of the paper.

Also pulp making requires large quantities of chemicals. In sulphate-pulp plants chemical-recovery divisions are sizable.

Pulp and paper making also calls for a great deal of energy, in the form of steam and electricity. Most pulp and paper companies supply all or nearly all of their own power. In the manufacture of pulp considerable fuel is available in the form of bark, wood waste, and in the case particularly of sulphate-pulp production, the lignin chemically extracted from the wood. Waste-heat boilers, supplemented by fuel-fired boilers make economic good sense.

Paper mills were first established in New England and Eastern seaboard states. Here were the requisites for paper manufacturing: good water, water power, the consuming public, and, in mid-nineteenth century when wood-pulp making was introduced, ample wood supply. The mills, by today's standards, were small, and were situated along rivers which provided both water and water power. New England in particular was dotted with small paper-making establishments. It still is. Many of the old water-wheel driven plants are still operating. Some of them have been electrified and some new mills constructed. However, the once vast forests of New England have been heavily cut. Production of pulp in New England leveled off at about one and a third million tons per year about the time of World War I and shows no disposition to change much. The percentage of the national total has, of course, dropped in this period from nearly 40 percent to less than 15 percent. The capacity in New England for converting pulp into paper has in 25 years increased, from one and a third million tons to two and a quarter million tons per year, although the percentage of the U. S. total has dropped by a half, to about 13 percent at present. Nearly one half of the pulp supply for New England mills is imported, mostly from Canada and Sweden.

New York, Pennsylvania, New Jersey, and West Virginia have, like the New England states, been important producers of both pulp and paper. The amount of pulp produced has declined some in specific amount and a great deal in percentage in the last 30 years. The paper production has, in that time, somewhat increased and still accounts for almost a fourth of the national total.

As the population centers moved westward and as pulp-material supply dwindled, pulp and paper mills were built farther and farther west, in the states hemming the Great Lakes. The story was again repeated. The forests were largely liquidated, not harvested, so that today the Lake region has numerous paper mills but the area supplies only about one fourth of its own pulp supply, the remaining three fourths being imported. These states, however, produce an important percentage—nearly one third—of the total amount of paper consumed in this country.

After the turn of the century the westward trend had reached the mountain and Pacific states. Here large, relatively modern mills were built to make paper from the enormous stands of gigantic spruce and fir that carpet thousands of square miles. The paper industry in the Pacific Northwest is young and thriving and enormous. Many of the lessons of forest conservation have been put into practice there. Timber is being cut more wisely so that there is still a chance of a continuing native pulp supply in that area.

Since 1916 the Pacific states have continued to increase their tonnages of both pulp and paper. From less than a fifth of a million tons annually, the pulp output has grown steadily to one and two thirds million tons, which is now one sixth of the total. The paper made there in this 30-year period has nearly tripled and is now just under 10 percent of the national total.

The conspicuous, almost startling, recent trend in the paper industry has been the establishment of pulp and paper mills in the Southern states to utilize the large forests of pine. About 30 years ago active research was begun to find a way to make pulp from these fast-growing, highly resinous woods. The Herty Foundation, at Savannah, backed by the State of Georgia in 1931, set about to overcome the technical difficulties of making paper from the resinous pines. This research contributed much to the development of the sulphate process to these pines. The first big sulphate mills were established in the South about 1935. Now plants producing nearly five million tons of paper yearly, or one fourth of the national aggregate, dot the Southern states—most of them of enormous size. Being new, these plants incorporate the accumulated experience in pulp and paper-making techniques and machines. Machine speeds of 500 to 1500 feet per minute are not uncommon. A few mills are undertaking 2000 fpm.

Most of the Southern mills produce kraft paper for paper bags, wrapping, and the ubiquitous corrugated-board carton. In fact the rise in the use of paper (it has doubled in ten years) for these purposes and the establishment of the kraft paper mills of the South were synchronized. Whether one was responsible for the other is not clear. Certainly they are somehow interrelated.

Pine-made pulp is not necessarily limited to kraft paper. Some of it is bleached to snow whiteness to make high-quality rayon stock. Only two newsprint mills have been built in the South although there appears to be no technical reason why newsprint cannot be made from Southern pine. In fact, the original object of the Herty Foundation was to develop newsprint from the indigenous pines and did result in a newsprint mill at Lufkin, Texas. Candidly, however, more money these days is to be made from kraft paper than from other grades; hence the new mills are predominantly of the kraft type producing sulphate pulp.

The South has much to offer the future of paper production for this country, even aside from the favorable factors of good labor supply and mild weather. The Southern pines are fast growing and easily harvested. A loblolly or slash pine tree grows to economic cutting size (about 6 to 10 inches in diameter) in 9 to 12 years. To grow a similar spruce or hemlock takes 30 to 40 years. Hence the chance of operating the Southern forest lands on a crop basis is good. For the most part the Southern paper concerns, mindful of the disaster to many Northern forests, have instituted programs of timberland utilization that will insure perpetual wood supply. Many companies own or lease sufficient acreage to provide more than a continuous supply of wood on a selective cutting and natural reseeding basis. The leading operators have instituted large programs of education for wood-lot owners to encourage and show them how to "crop" their lands. Vast programs of fire prevention and control have been instituted by private and state agencies, not only in the South, but other areas, particularly the Pacific Northwest. Fire is the great problem. If its ravages could be reduced to the minimum that seems possible almost enough wood would be saved as a result to support the present pulp manufacturing mills.

But the job of conservation of forests has not been licked, in the South or anywhere else. The loss by fire, unintelligent and indiscriminate cutting, and the pressing economic factors in an industry that historically has always found its raw material in short supply, and other demands on wood, stand ready to deplete further the forests. It is late to save the forests, on which paper—a national necessity—depends. Not too late perhaps, but late.

Thus as matters stand the mills of New England, Eastern United States and the Lake states have been pressed by the competition from more modern, fast new mills, and have been forced to live, more and more, on pulp produced elsewhere. They have increasingly concentrated on production of high-quality book, magazine, fine writing papers, and specialty products. That some of these mills of Civil War age can compete at all is surprising. But many do by virtue of management, skill, and adherence to high-grade, specialty products that can command good price.

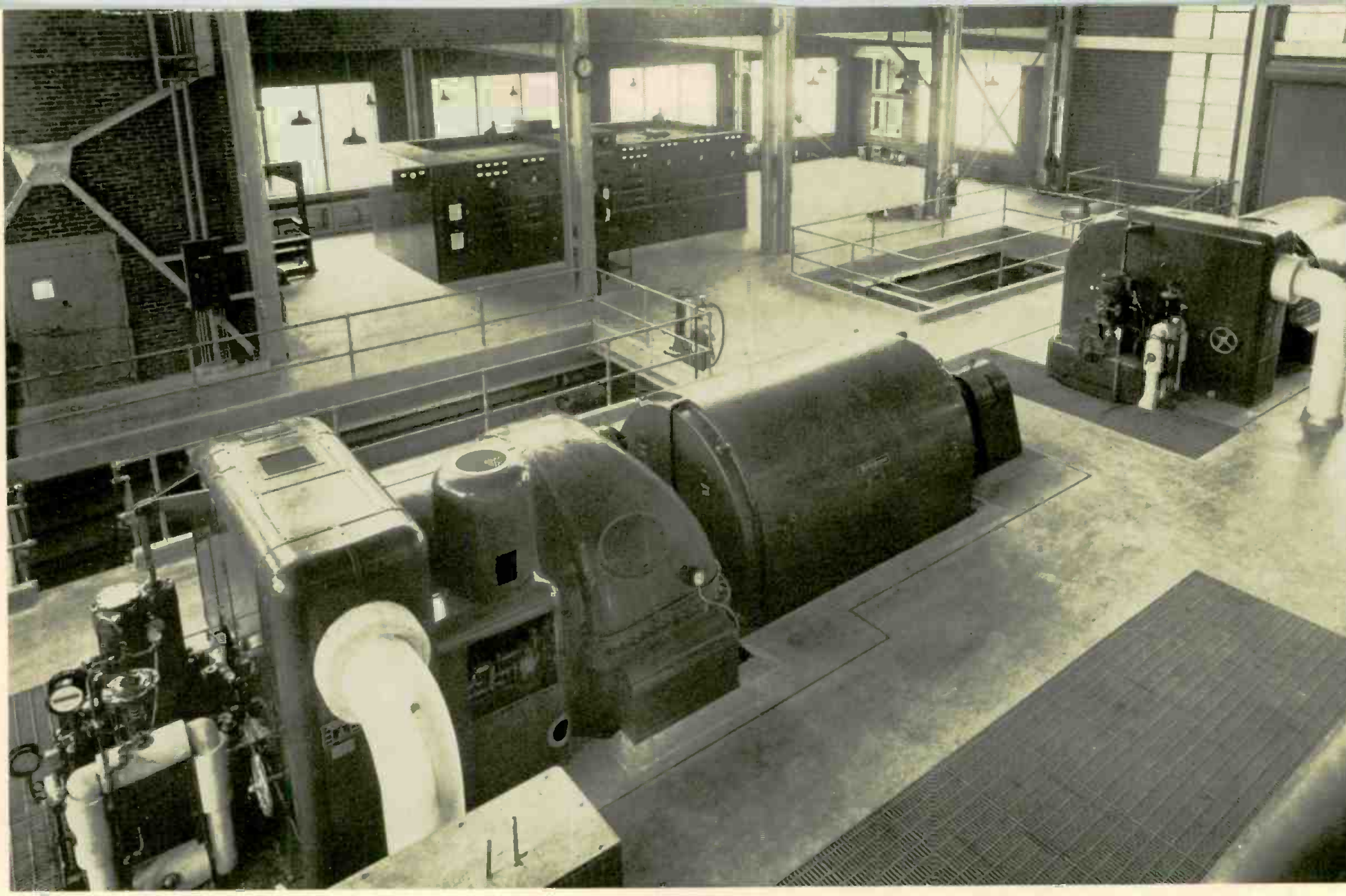
Production of newsprint in the United States remained substantially constant at about a million tons per year from 1910 until World War II. Now it is about three quarter million tons or just over one fourth of the total consumption. Canada supplies most of the deficit.

The greatest problem of the industry always has been, and still is, an adequate supply of pulp material. This was true through the centuries when substantially all paper was made of rags. Even with wood now carrying the brunt of the load, rags are scarce. And wood too is scarce. At one time the wood supply was "inexhaustible"—or so it was thought when this country was covered by seemingly limitless forests. But man's appetite for paper and the capacity of pulp mills to chew up vast acreages of timber were grossly misjudged. This has great significance to the national economy.

The search for other sources of cellulose fibers continues. Experiments are under way to develop a cotton grown at low cost especially for paper making. Many other sources of cellulose fiber are being studied; such as bamboo, marsh grasses, bagasse, soybeans, and cotton stems. None looks too promising although one or two, particularly bamboo, may prove useful as pulp "extenders."

Paper is as much a vital national resource as iron and copper and oil. The war certainly could not have been fought and won without it. Unlike mineral resources, cellulose is replaceable, although this fact and necessity have been given too little consideration.

Aerial view of the Florida Pulp and Paper Company, near Pensacola, Florida, a representative modern sulphate mill making paper from nearby pine forests.



POWER EQUIPMENT FOR THE PAPER MILL

R. R. Baker
Paper-Mill Application Engineer
Westinghouse Electric Corporation

Paper is a precision product. Yet a modern mill may produce a sheet of paper that could cover a road four hundred miles long in a single day. The machine that forms, presses, dries, and perhaps coats and calenders the paper may be as high as a three-story house and a city block long and be driven by thirty d-c motors that must be exactly synchronized in speed. Helping make the paper industry possible is a large and well-developed family of steam turbines, gears, generators, motors, electronic regulators, and controls.

To make a ton of paper requires—in addition to pulp, water, and chemicals—700 kwhr of electricity and 10 000 to 20 000 pounds of steam. The pulp and paper industry ranks first among the major manufacturing industries in power per ton of product, third in total installed kilowatt generating capacity, and fourth in annual consumption of electric energy.

Hence the generation, distribution, and use of this power is of utmost importance to the industry. Even the small mills producing 30 tons or less daily require power plants of about 1000 kw, while power plants of 30 000 kw are common for mills that make upwards of a 1000 tons of paper daily.

Electric Power and Steam Supply

In addition to power, pulp and paper mills require relatively large quantities of steam for cooking chemical pulp, for evaporating liquors in both chemical and heat recovery, for paper drying and for numerous other miscellaneous uses. These process steam requirements are met at various steam pressures from 25 to 150 psi. Because of this demand for low-pressure process steam the modern pulp and paper mill with its high-pressure boiler plant can generate a large portion of its power requirements as a by-product of the process steam. In this manner the power requirements of the plant can be generated at comparatively low cost. This method of operation has led to the development of the modern industrial extraction turbine unit. The industry has applied many such units in capacities from 1000 to 10 000 kw. These units can be either single- or double-extraction and either condensing or non-condensing, as the plant-power layout requires.

The modern pulp and paper mill with its large concentration of power utilizes 2300- and 4160-volt, 60-cycle power generation. Power is distributed on radial feeders to various load centers where it is directly applied to the larger size individual motors or where transformers serve to reduce the voltage for application to the smaller motors. Factory-built metalclad switchgear providing adequate interrupting capacity, and with provision for proper equipment inspection and maintenance, is being built for many mills now under construction. Light-duty gear provides from 25 000- to 50 000-kva interrupting capacity and heavy-duty gear from 100 000 to

500 000 kva. In connection with the power transformers for the low-voltage motors numerous mills have installed dry-type transformers, which provide dependable service for the atmospheric conditions existing in the mills. These have somewhat lower installation and maintenance costs than conventional oil-insulated transformers.

Pulp and Paper Mill Control

Centralized high- and low-voltage motor control is a feature of the modern plant design. Such control is factory-built and assembled. It provides power bus, disconnecting switches, motor control and both circuit and motor protection. Such control can be installed at minimum expense and its use permits operation with a maintenance schedule that assures the continuous service so essential to efficient plant operation.

The Paper Machine

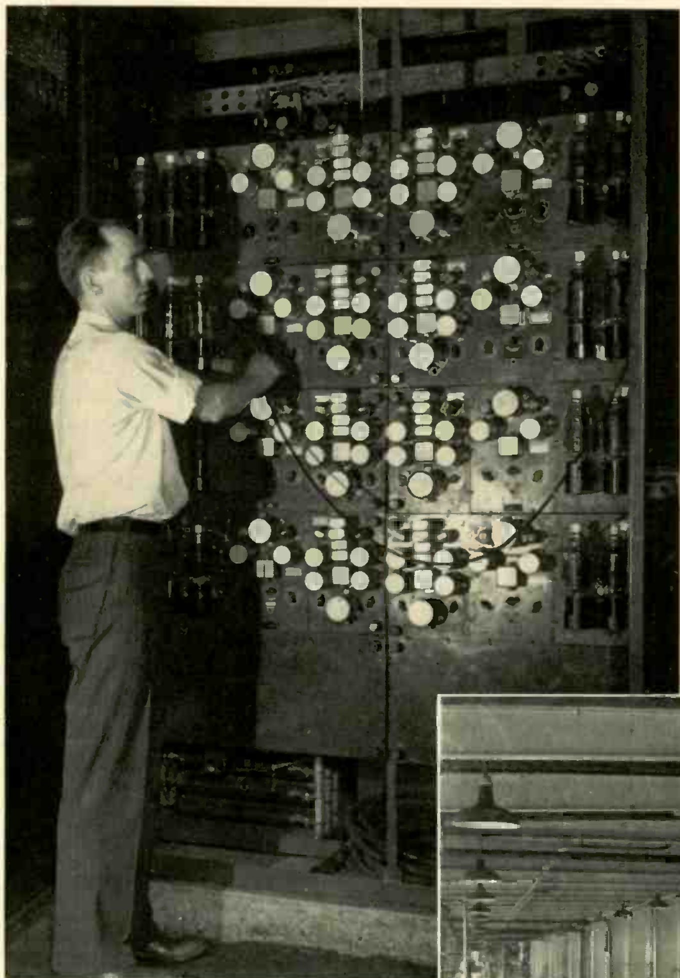
The production of both pulp and paper requires many types of special process equipment. Of this process equipment, the paper-forming machine is perhaps the most important. Its initial cost represents a very substantial investment. Its operation requires a crew of highly skilled workmen. Ordinarily the paper-forming machine is in production 24 hours a day, frequently seven days a week. The mill output, the quality of the product, and the resultant profits depend quite largely on its successful performance. This highly specialized machine serves to form a continuous web of paper from pulp introduced at the wet or forming end. The pulp enters the machine at perhaps one-half of one percent consistency and leaves the machine in the form of a firmly matted sheet approximately 94 percent bone dry. Productive speeds vary from something less than 100 fpm on board-forming machines, to perhaps 2000 fpm on machines producing lightweight tissues. The weight of the sheet formed is largely dependent on the operating speed of the machine and it is therefore necessary to maintain such speeds with a high degree of accuracy to preserve uniform quality.

Sectional Electric Paper-Machine Drive

The paper machine is becoming increasingly complex, and is being operated at higher and higher speeds with more exacting control requirements of the driving equipment. This has led to the separation of the machine into several sections from a drive viewpoint and driving each section by individual d-c motors and synchronized speed control. Sectional electric drive has kept pace with these continuously growing demands for higher speed and greater precision.

The sectional electric drive, as applied several years ago, included a d-c power supply with a single main d-c generator for supplying power to the individual section motors during normal operation and an auxiliary d-c generator for starting and accelerating the various section motors to operating speed. A motor-operated rheostat served to control automatically the excitation of the auxiliary generator during the starting period of each individual section. The section motors were held in the proper relation to the remainder of the machine by carbon-pile, differential speed regulators, which automatically controlled the excitation of the section motors requiring speed regulation.

The sectional electric drive, as built today, may include the single main d-c generator with auxiliary starting generator as with the earlier designs, or it may include individual gen-



(Above) This new electronic regulator provides precise speed control on a paper mill in Pennsylvania. (Right) This row of individual d-c motors drives the sections of a Fourdrinier machine that makes a sheet of paper 210 inches wide at the rate of 140 to 1200 fpm.

erators for each independent section of the machine, depending upon the needs of the mill. The multiple-generator system has advantages on machines requiring a wide operating speed range whereas the single generator is frequently more suitable where the speed range is narrow. With the single-generator system, Rototrol has replaced the motor-operated rheostat as control of the excitation of the starting generator. Rototrol provides the features of high break-away torque or cushion starting as required by the individual sections of the machine, as well as controlled acceleration of these sections.

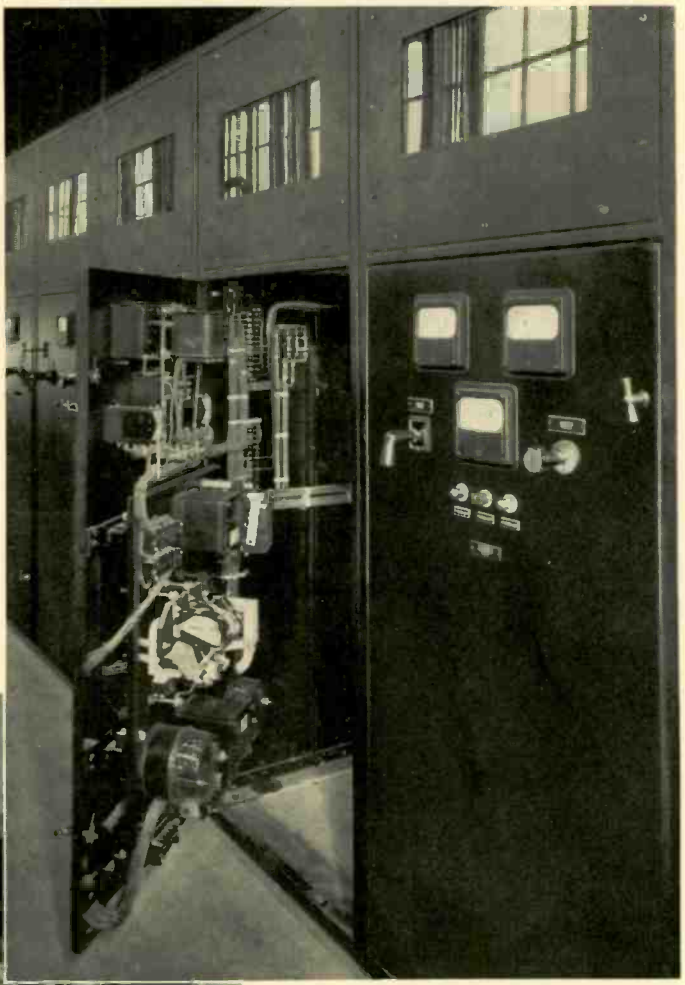
With the modern sectional electric drive the carbon-pile differential regulators are being replaced with electronic speed regulators. These electronic regulators retain all of the features of the carbon-pile regulators, including field forcing, high-speed response, anti-hunting and an infinite number of regulating points. They provide, in addition, increased sensitivity, higher speed of response and broader control range. Also they eliminate the speed changer and the other mechanical parts associated with the mechanical speed differential. With the single-generator system the electronic regulators are arranged to control the excitation of the section motors whereas with the multiple-generator system they are arranged to control the excitation of the individual generators supplying power to the various section motors.

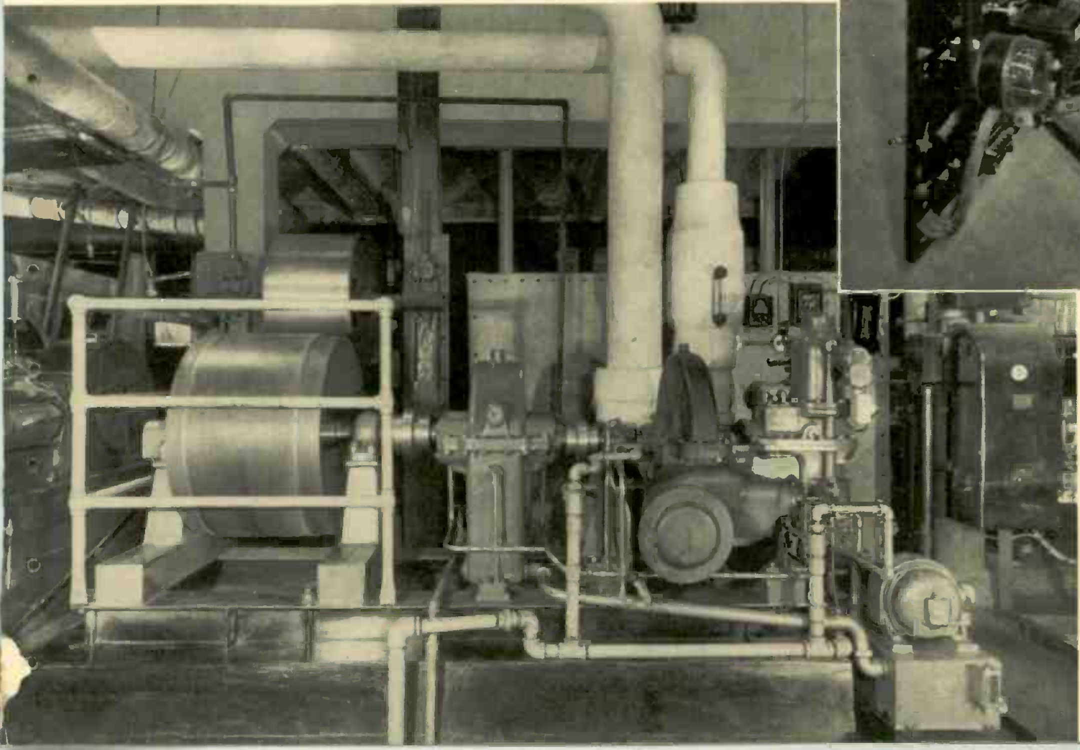
The electronic regulator consists of several basic elements. These include a master a-c reference bus, individual-section reference a-c tachometer generators, and individual-section vacuum-tube mixer circuits that compare the output of the reference tachometer of each individual section with the reference bus and provides a plus or minus error output. Also included is a two-stage vacuum-tube amplifier circuit provided with field forcing and anti-hunting characteristics matched to the particular section requirements. A grid-controlled thyratron rectifier circuit provides automatically controlled excitation for either the section motor or for the individual generator associated with the motor depending on whether a single- or a multiple-generator system is used.

Paper-Machine Developments

Paper machines themselves have experienced several improvements that have necessitated the development of suitable d-c drives. These have been synchronized with the main drive in most cases by using either Rototrol or electronic equipment. These include an arrangement of a primary couch and a second vacuum couch roll on the wire section of Fourdrinier machines. Among the other developments are a powered dandy roll, a dual press that permits operating two pressure rolls in contact with a common third roll, a single- or double-coating section by which one or both sides of the sheet are coated at formation speeds before the final machine operation, and a multi-purpose reel and unwind stand.

In connection with the multi-purpose reel and unwind stand a Rototrol permits holding uniform tension in the sheet between the calender and the reel as the roll diameter increases from an empty to a full reel. When functioning as the unwind stand for the winder operations, the same drive provides regenerative braking with the tension between the unwind stand and the winder automatically held constant as the diameter of the roll on the unwinding stand decreases from a full to an empty reel. To permit rapid manual adjustment of winder speeds an electronic inertia-compensating device has been incorporated. The electronic circuit is arranged to sense either the rate of acceleration or retardation





(Above) Typical metalclad switchgear for the control of high-voltage power in a paper mill. (Left) In some classes of mills it is economical from a heat-balance standpoint to drive the paper machine by means of a single steam turbine.

of the winder and to compensate the Rototrol regulating device so that sheet tension is not materially affected by the inertia of the roll on the unwinding stand when changing speed.

Adjustable-Speed Turbine Line Shaft Drive

In some modern mills, where plant heat balance or power layout dictates, turbine lineshaft drives are being installed for the paper machines. These lineshaft drives provide the required operating speed range, close speed regulation, and automatic control. These drives consist of a non-condensing geared turbine arranged for coupled or belted connection to the paper-machine lineshaft. The turbines are equipped with special governors that maintain close speed regulation over the required operating range. With this adjustable-speed turbine drive a direct conversion from steam to lineshaft motive power is obtained, thus eliminating electrical conversion losses. The exhaust from the turbine supplies all or a portion of the process steam demand for paper drying.

Rototrol

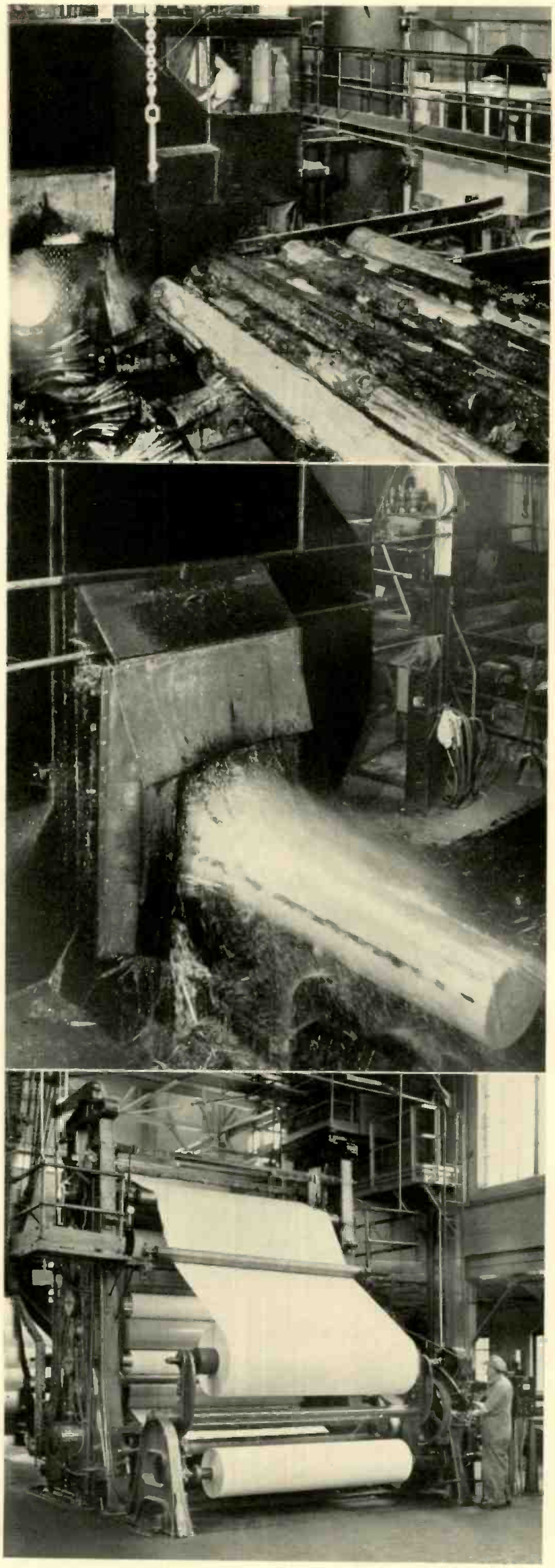
The Rototrol* has been extensively employed by the industry because of the advantages it affords in the automatic control and regulation of many functions. Among these are the operating speeds of paper-forming machines, and speed matching between sections of these machines. Also Rototrols govern the operating speeds on reels that must provide uniform sheet tension with a changing roll diameter, the driving effort where it must be a function of some other operating characteristic, the synchronization of the operation of motor-driven auxiliaries such as wet-end auxiliaries, dual press rolls, and top press rolls. Rototrol ideally meets the exacting requirements of these functions and many others. The Rototrol presents no more of a problem to the operating personnel than a standard exciter unit, yet it provides an accurate and dependable means of automatic control.

Recently the Rototrol has been applied to single-motor paper-machine drives as a speed regulator; to sectional paper machines, supercalenders, and winder drives to eliminate motor-operated rheostats and to provide the features of preset speed control and current-limit acceleration. On supercalenders the Rototrol assures uniform threading speeds and synchronizes the operation of the unwind and wind-up stands with the supercalender. On the unwinding stands of winders and supercalenders it provides constant sheet tension with varying roll diameter in connection with regenerative braking. The Rototrol is also used on primary-couch-roll drives on modern high-speed Fourdrinier paper machines to maintain a driving effort consistent with the vacuum maintained in the primary couch roll. Applied to the wet-end auxiliaries and other helper drives the Rototrol maintains uniform operating conditions over the wide range of operating speeds.

Supercalenders

To obtain a paper finish more suitable for printing and other purposes the paper is frequently supercalendered. The process of supercalendering consists of passing the sheet of paper, usually clay coated, between alternate polished steel and fibre-filled rolls. Some eight or nine of these rolls, mounted vertically one above the other, make up the so-called calender

*The principle of the Rototrol as a regulating device was set forth in the article, "Rototrol and its Applications," by E. Frisch, *Westinghouse ENGINEER,* July, 1947, p. 121.



The two top illustrations show logs ready to enter the hydraulic barker and one log emerging debarked. At the bottom is a supercalender with d-c motor drive, Rototrol-threading-speed regulator, and preset automatic control.
(Log barker photographs courtesy of *Pulp and Paper*)

stack. The stack is driven from the lower roll with sufficient pressure applied to the stack to secure the proper finish as the sheet passes through the various roll nips from the top to the bottom of the stack. The roll of paper to be supercalendered is mounted in an unwinding stand adjacent to the top roll of the stack. After passing through the stack the sheet is reeled up on a core mounted in the wind-up stand adjacent to the lower roll of the stack. The sheet is threaded from the unwinding stand, through the calender stack, and onto the wind-up stand by hand with the equipment operating at a slow or threading speed. After the sheet is properly threaded, pressure is applied to the stack and the entire equipment is accelerated to a suitable productive speed. Depending upon the type of paper being supercalendered, operating speeds from possibly 500 to 2500 feet per minute are obtained.

The modern supercalender drive provides an adjustable-speed main stack drive with both synchronized wind and unwind stands and with inertia compensation to permit rapid acceleration or deceleration in adjusting the speed of the supercalender. Such a drive includes a main d-c adjustable-speed motor with suitable gearing for direct connection to the main stack, a motor-generator set for supplying power to the d-c motor, an adjustable-speed d-c unit for connecting to both the unwind and the wind-up stands. Also involved are full automatic control with a centralized control station and the necessary auxiliary equipment to provide automatic sheet-tension control between both unwinder and wind-up and the supercalender. Rototrols provide the features of current-limit acceleration and deceleration of the main drive, automatic speed regulation over the operating speed range from threading to full productive speeds, automatic adjustment of the operating speeds of the unwind and the wind-up units to compensate for changes in roll diameter from a full to an empty core, and automatic control of sheet tension. The operations of various parts of the supercalender are synchronized so that the stack can be quickly threaded and accelerated to productive speed. The operating speed range is obtained by armature voltage control. Control of pay-out and stalled tension on the unwind stand and slack take-up, inching and stalled tension on the wind-up is possible by booster generators in the armature circuits of unwind and wind-up units.

These modern drives permit maintenance of maximum production from the high-speed supercalenders. Uniform operating speed, particularly during threading operation, reduces the hazard of personal injury, and permits more efficient operation. Automatic control of acceleration and deceleration, together with inertia compensation as applied to the unwinding and wind-up stands eliminates paper spoilage and outage time in getting the equipment up to productive speeds. Automatic sheet-tension control prevents calender cuts and sheet wrinkles and assures the production of uniformly wound high-quality supercalendered paper.

Log Barking

The removal of bark from logs with water jets has been an outstanding recent development. Bark is ripped off by jets of water at high pressure and high velocity directed tangentially at the surface of the log. To cover the entire surface of long and large-diameter logs requires movement of the jets or the log relating to each other. Provision must also be made to cover the entire outer circumference of the log. This is accomplished either by rotating the log as the pass is made, or by indexing the log at the end of each pass. Logs of large diameter require several passes for complete removal of bark. The hydraulic barkers have been developed for West Coast operations where logs up to 60 inches in diameter and 30 feet in length must be handled.

Motor drives for hydraulic barkers are fully automatic with the control for the complete operation centralized in a pulpit-type control station arranged for a single operator. The nozzle carriage and the log conveyors and manipulators are usually arranged for adjustable-speed reversing service to accommodate logs of various diameters. High production requires that the drive equipment be capable of high rates of acceleration and deceleration. The control provides many features to insure proper functioning and protection of the equipment.

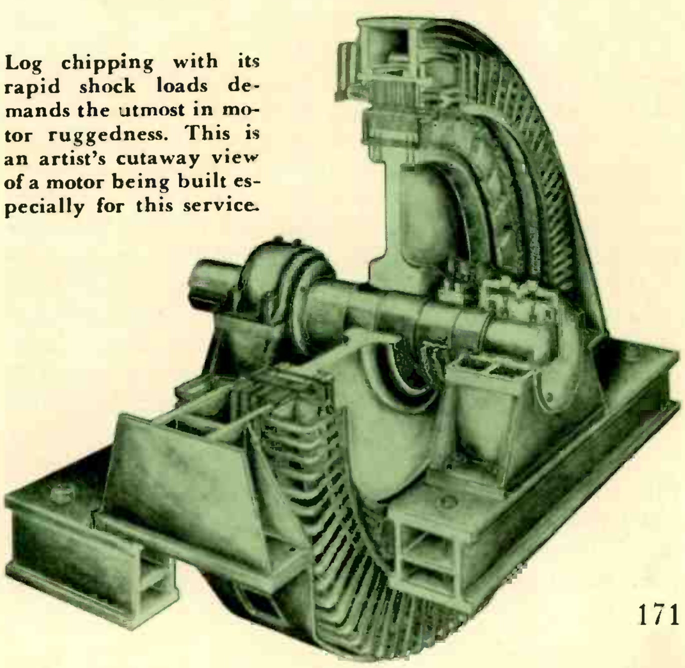
Chipper Drives

Along with the hydraulic barker the large-diameter full log chipper has been introduced. These mammoth machines are capable of chipping a 30 foot log 42 inches in diameter, and require motor ratings from 1000 to 2000 hp. They reduce such a log into chips $\frac{3}{4}$ inch long in from 20 to 30 seconds.

Synchronous-motor drives having the proper characteristics have been developed for these large chippers. Such motors must have extremely heavy mechanical construction to withstand the severe vibration resulting from the reaction of chipper knives passing through the log. The motors must also have high pullout torque to meet the peak loads and sufficient thermal capacity to meet the normal production requirements. The chipper, because of its mechanical construction has an extremely high inertia, and it is necessary to give special consideration to the design of the damper windings to provide adequate thermal capacity during acceleration.

The development of suitable electrical equipment for the specialized needs of the pulp and paper industry has not been accomplished over night. Rather, it has been the result of many years of careful study by the industry in cooperation with machinery builders and electrical manufacturers. The many different operating characteristics obtainable with the modern alternating- or direct-current motor permit of its successful application to all of the various paper-mill drives. The many types of motor mountings permit locating the drives where they best fit into the productive layout. Modern types of insulation and the various types of motor enclosures assure adequate protection against the adverse atmospheric conditions to which some of the motors are unavoidably exposed. The economic generation, distribution, and utilization of electric power has resulted in a low-cost, high-quality product meeting the demands of a rapidly expanding market.

Log chipping with its rapid shock loads demands the utmost in motor ruggedness. This is an artist's cutaway view of a motor being built especially for this service.



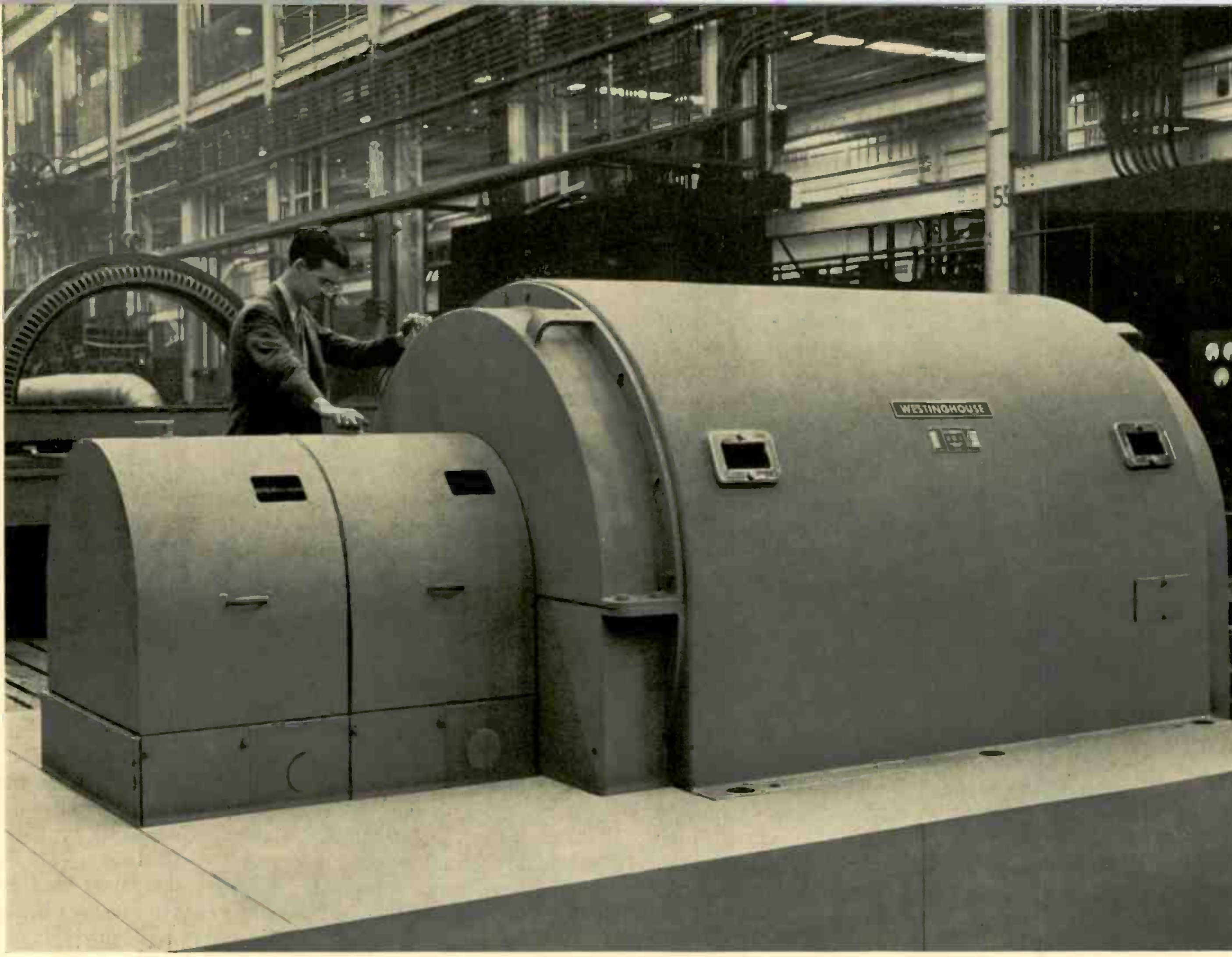


Fig. 1—Eight windows on this 5000-kw, 80-percent power-factor generator make visual inspection possible at any time.

Small Turbine Generators Now Standardized

Motors, even in the larger sizes, can be purchased in standard designs that differ only slightly from application to application. On the other hand, generators, and especially turbine generators, are widely different, even in the same ratings. To eliminate the multifold variations and to produce better equipment is the purpose of a standard new line of improved turbine generators for 1000 kw to 7500 kw. Other advantages of standardization accrue.

J. G. Partlow • *Generator Engineer* • *Westinghouse Electric Corporation*

The benefits of standardization have been brought to turbine generators. A recently redesigned family of high-speed, two-pole industrial turbine generators is now available in ratings ranging from 1000 to 7500 kw, inclusive, at 480 to 13 800 volts. These highly standardized units are intended to eliminate, as far as possible, the need for building each turbine-generator set as a special, "tailor made" unit and to promote "off-the-shelf" purchasing with its attendant advantages to both builder and user. About 25 percent of the generators of these ratings are used by public utilities, but the remainder is applied to a wide variety of industries, both foreign and domestic, in the manufacture of paper, lumber, sugar, textiles, petroleum, and chemicals.

Standardization is the key to producing better generators without increasing the overall cost. Each variation from the standard design, no matter how trivial, usually entails additional engineering and construction work, which can increase the cost of the unit considerably. Once the design of the generators was standardized, many improvements were made in production methods and, where applicable, simplified tabulated drawings were made for the ratings selected. Manufacturing is facilitated by the use of jigs and fixtures; for example, the component parts of the frame are premachined and accurately welded together in an assembly fixture. Thus, the advantages of adhering to standard designs are being utilized to the fullest extent.

Although two-pole turbine generators have been built in ratings below 500 kw, units smaller than 1000 kw are usually of the geared, salient-pole type because of certain economies in this range. Therefore, 1000 kw has been selected as the lower limit for the new line. The kilowatt and voltage ratings over the entire range of sizes are in strict accordance with the recommendations of the National Electrical Manufacturers' Association; table I gives the standard ratings available for machines of 80 percent power factor.

The objective of the standardized industrial turbine generators is to add several desirable features without increasing the overall cost. Accordingly, the new machines incorporate those features revealed by experience as most attractive to the majority of users. The overall appearance is modernized and uniform in all sizes; the length of the units is reduced; accessibility to the collector and commutator is improved; exciter and collector are enclosed in a streamlined housing; exciter ventilation system no longer requires ducts through the foundation. Various accessories, such as an electric indicating tachometer, an exciter air filter, and clamp-type solderless terminal lugs are included as standard features.

Uniformity of design and appearance has been achieved by redesigning the entire line simultaneously. This improves the appearance of power plants where units of different ratings are installed adjacent to one another. The exteriors of the units present a smooth, streamlined appearance. Holes in the frame, formerly used for lifting, are absent; inspection windows now serve the same purpose. Access holes for foundation bolts have been eliminated by making the bolts accessible from the outside. The new exciter is covered by a streamlined housing that encloses the collector rings as well as the exciter and fits against the outboard end of the generator.

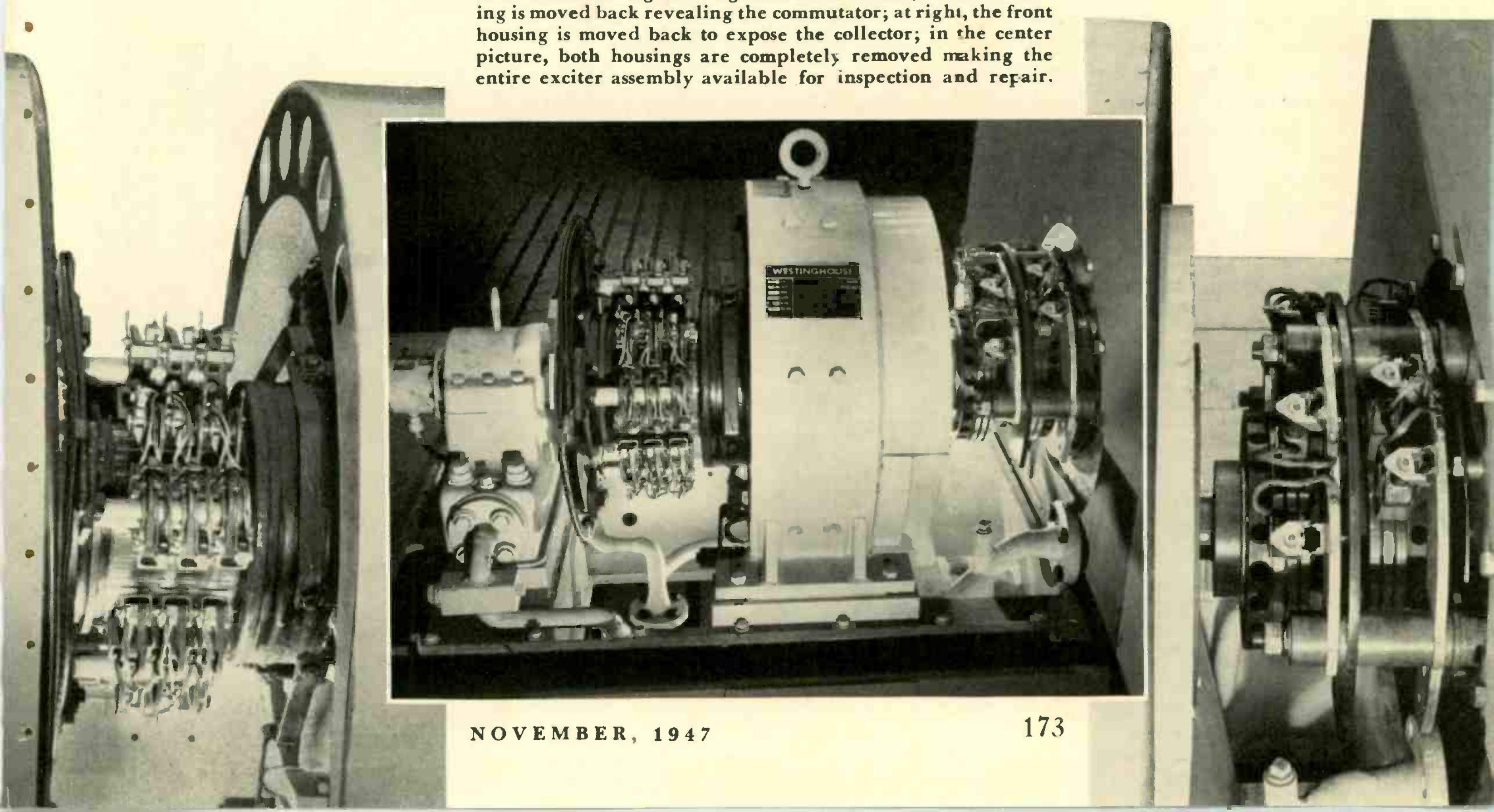
Because of the high initial cost of power-house floor space, a reduction in the amount of space occupied by a turbine generator of a given rating is advantageous. Since the establishment of the preceding family of industrial turbine generators, industry-wide standards have changed to permit a reduction of the short-circuit ratio from a nominal value of 1.0 to a guaranteed value of 0.85. This change makes possible a reduction in the axial length of the stator core. Further reduction in the length of the unit results from changes in the mechanical arrangement of the unit. These new machines use a single bracket-type bearing for the generator and a single-bearing exciter with a flanged shaft rigidly coupled to the rotor of the generator. As the previous design had used a pedestal-type bearing for the generator and a two-bearing exciter with a flexible coupling the new design reduces the length substantially. The reduction in overall length varies from five to twelve percent throughout the range of ratings.

Several special new features associated with the exciter are particularly effective in reducing installation costs and facilitating maintenance. The need for exciter ducts through the foundation has been eliminated by ventilating the unit from the generator through ducts incorporated in the exciter bedplate and generator end bell. Filters clean the air before it is returned from the exciter to the generator. The streamlined housing over the exciter is in two sections, one or both of which can be moved easily on rollers for access to the commutator or collector. The exciter bedplate contains all external oil-piping connections for the electrical machines and all electrical connections except the main leads and the leads from the temperature detectors of the stator winding.

Special brushholders allow the exciter brushes to be replaced quickly without tools while the unit is in operation. Excellent commutation is assured by the ability of the new shrink-ring type of commutator to maintain a smooth commutation surface at high speed. The commutator bars are flexibly supported and are free to expand and contract both axially and radially without distortion. Hence, the commutator remains cylindrical and concentric with the axis of rotation in spite of changes in load and temperature. Unimpaired access to the commutator is provided by the use of a pedestal rather than a bracket to support the single pressure-lubricated bearing of the exciter.

An electric-indicating tachometer becomes a standard feature. The inductor-type tachometer generator is overhung at the outboard end of the exciter and is direct connected. Separate excitation allows the tachometer generator to be dismantled and reassembled without change in calibration. The tachometer normally operates a remotely mounted speed in-

Fig. 2—The exciter housings play an important maintenance role by making it possible to inspect any part of the exciter assembly and to replace the brushes of either the commutator or collector during running conditions. At left, the rear housing is moved back revealing the commutator; at right, the front housing is moved back to expose the collector; in the center picture, both housings are completely removed making the entire exciter assembly available for inspection and repair.



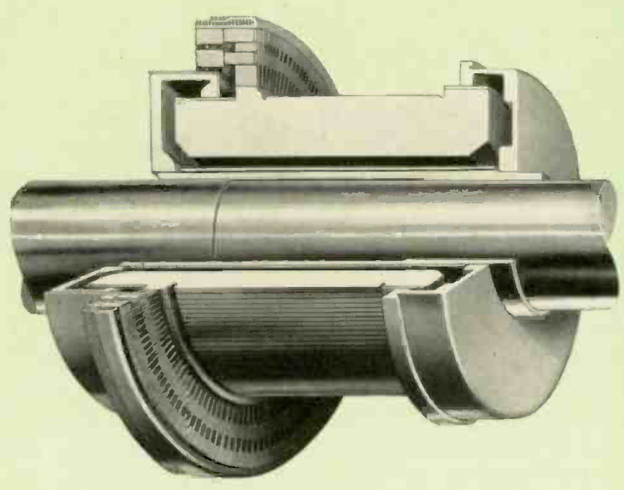


Fig. 3—The shrink-ring commutator permits axial and radial expansion of the bars and gives excellent commutation at high speed.

dicator, but a speed recorder can be used instead of the indicator if desired.

Simplified Power-Generating Unit

The standard generators are particularly adaptable for use with simplified power-generating units which consist of a steam turbine, generator, and exciter, ready-made into a compact unit which requires a minimum of time and field equipment to install. Whenever possible, the component parts are assembled and aligned and the connections are made prior to shipment. The condenser forms the base on which the turbine, generator, and exciter are mounted. Up to now, such units have been built in ratings of 5000 kw only.

Except for minor variations, the construction of the generators and exciters for power-generating units is the same as for the standard generators. Close proximity of the condenser to the bottom of the generator requires two air coolers, one located below the walkway on each side of the generator, instead of a single larger air cooler directly beneath the generator. For the same reason, a special arrangement of stator leads is required. Instead of extending straight down from the collector end of the generator, the three main leads come out to one side of the vertical centerline below the level of the generator feet, and the three neutral leads come out the opposite side. Extensions on all six leads bring one set of three leads out through the condenser structure below the exciter on each side.

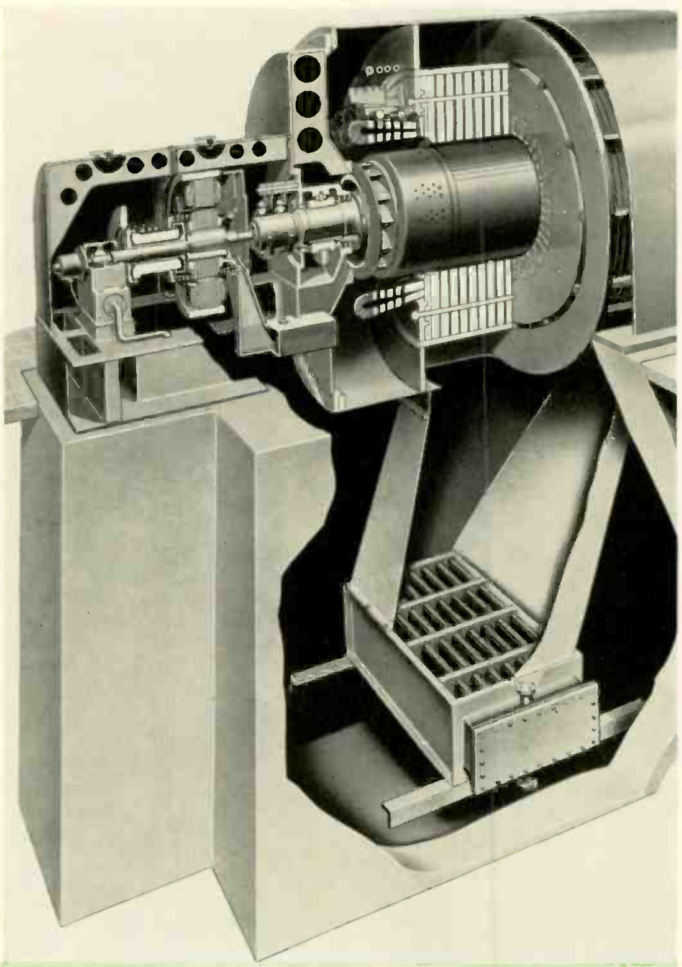
Electrical connections made in the exciter bedplate solidly connect the armature leads of the exciter through an ammeter shunt to the field leads of the a-c generator, thereby eliminating a rheostat and circuit breaker from the generator field circuit. All excitation control is obtained through variation of the field current of the exciter by its hand-operated rheostat. A discharge resistor is permanently connected across the exciter shunt field.

In addition to the resistance-coil type of temperature detectors embedded between the coil sides in the stator slots, temperature detectors are furnished in the air inlet and outlet ducts of both the generator and the exciter. The temperature of the generator and exciter bearings is indicated by dial-type thermometers. These thermometers are located on the side of the exciter bedplate so as to be visible from the station floor. Brass water piping is included in the end bells of the generator to spray the windings in case of fire.

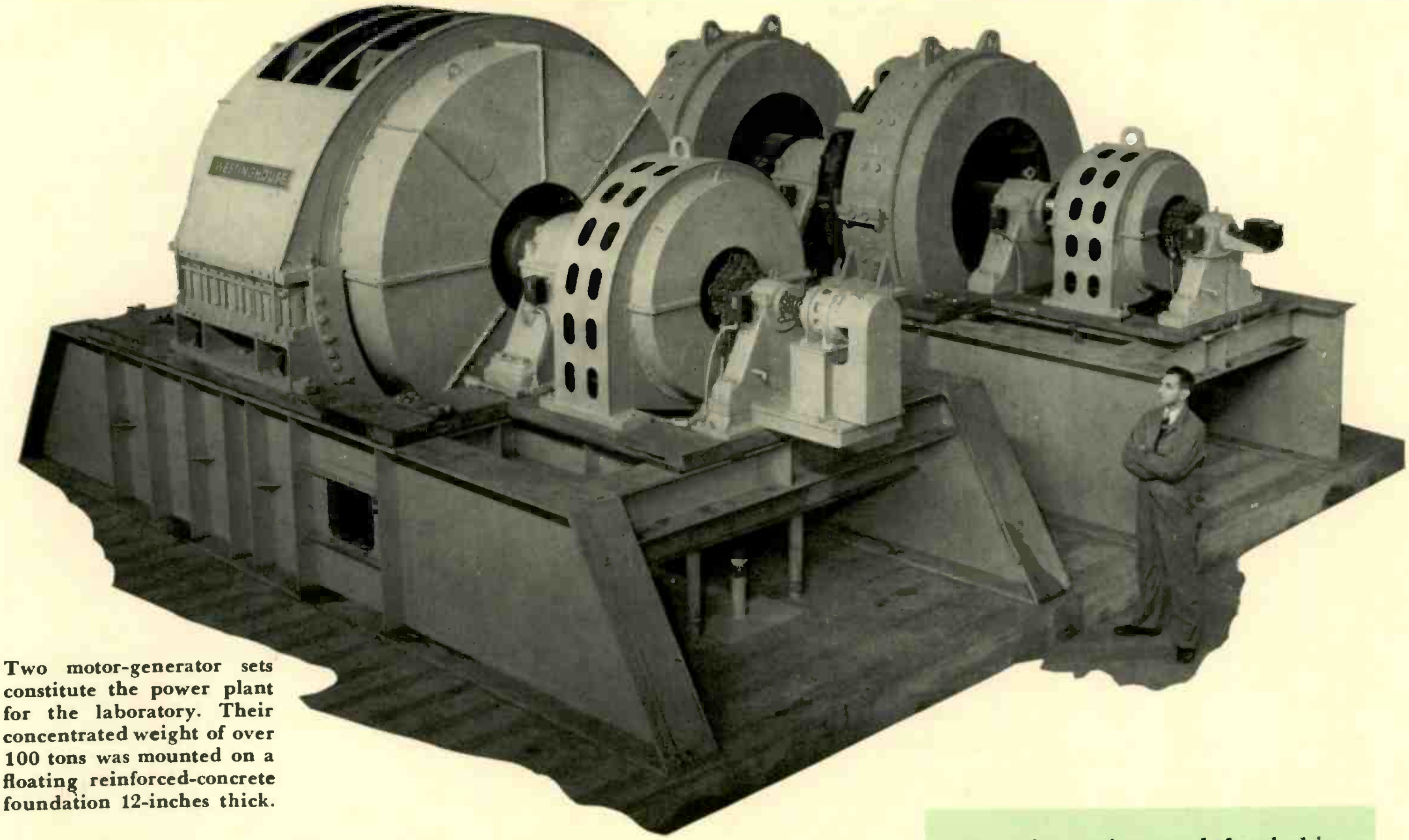
The trend in industrial turbine generators and power-generating units is toward standardization, which provides additional desirable features and permits building better machines at no additional cost. Standardization of any family of equipment has numerous advantages when considered from any point of view. It may be said of almost any product—be it a radio, automobile, airplane, or turbine generator—that its progress and potential future can be judged by the inherent characteristics that will enable it to be removed from the class of "special" and placed into that of "standard." It is anticipated that the progressive step taken on these small generators will suggest similar action on other equipment.

TABLE I—STANDARD GENERATOR RATINGS AVAILABLE,(X) AT 80 PERCENT POWER FACTOR

Capacity		Standard Voltages						
Kw	Kva	480	600	2400	4150	6900	11 500	13 800
1000	1250	X	X	X	X	X		
1500	1875	X	X	X	X	X		
2000	2500			X	X	X		
2500	3125			X	X	X		
3000	3750			X	X	X		
3500	4375			X	X	X		
4000	5000			X	X	X		
5000	6250			X	X	X	X	X
6000	7500			X	X	X	X	X
7500	9375			X	X	X	X	X



Partial cutaway of generator with one heat-exchanger arrangement.



Two motor-generator sets constitute the power plant for the laboratory. Their concentrated weight of over 100 tons was mounted on a floating reinforced-concrete foundation 12-inches thick.

The Navy's High-Current Test Laboratory

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Electrical Engineer
New York Naval Shipyard

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Switchgear Engineer

S. A. HAVERSTICK
Marine Engineer

Westinghouse Electric Corporation

Aircraft carriers and battleships now embody large concentrated blocks of electrical power for which protective devices must combine high interrupting capacity with ruggedness, compactness, light weight, and an unusual degree of reliability. To test such devices and to improve its electrical systems the Navy has built a high-power testing laboratory patterned after the world's largest such laboratory at East Pittsburgh, Penna.

WITH the completion of a high-power test laboratory in May of this year at the New York Naval Shipyard, the Navy has added another unit to its extensive facilities for testing the machinery and equipment that go into its ships.

Since the adoption of 450-volt a-c power by the Navy 16 years ago for all fighting ships except those in specialized service, the uses for electricity on board ship have so increased that the modern naval vessel has become a floating power plant in itself. This development, together with the necessity for high-speed voltage regulation within very close limits, has created problems of circuit protection which in many respects are unusual to the industry.

The low-voltage circuit breaker, being primarily a protective device, has been subjected to some very difficult service on naval vessels. The requirements of small physical size and light weight dictate the use of air-type breakers. Inasmuch as short-circuit fault currents may be 50 to 100 times the current rating of the breaker, it must have an unusually high interrupting capacity. The importance of this quality is appreciated upon consideration of the fire hazard, damage to adjacent equipment, and possible injury to personnel that would occur if the breaker failed. In addition, the breaker must not only clear the fault, but also it must be in condition for return to service without repair. These considerations are highly important on a combat vessel. More recently, main and feeder breakers have been required to function selectively, thus clearing local faults without interrupting the ship's power supply. To perform these functions the breaker is equipped with long time delay for sustained overload protection, short time delay for clearing localized faults, and instantaneous trip should the fault current exceed a predetermined maximum permissible value.

To meet these requirements of Navy service a circuit breaker must be not only rugged and highly developed but also precisely built. Problems of calibration and test thus become greatly involved when carried on under simulated service conditions. Heretofore, much of this work has been carried on by utilizing manufacturers' test facilities. The new test station will enable the Navy to proceed with its own test program as an independent agency. Although the high-current laboratory is primarily intended for testing circuit breakers, its facilities will also be used to test fuses, contactors, switches, transformers and related devices.

The principal pieces of rotating equipment in the laboratory are the two large motor-generator sets, one for alternating current and the other for direct current. Each generator is brought up to speed unloaded by a small a-c wound-rotor motor after which the high inertia of the generator rotor maintains the speed for the fraction of a second the generator actually delivers short-circuit power.

Considering the amount of power they develop these generators are very small. The direct-current set, for example, delivers 50 000 amperes at 250 volts—or 12 500 kw peak power —yet its physical size is only that of a 3000-kw machine. The reason, of course, is the short length of time the power is delivered. The short-circuit current is required for less than half a second, usually for only a few cycles.

The direct-current set is made up of two armatures that can be operated either in parallel or in series to produce 50 000 amperes at 250 volts or 25 000 amperes at 500 volts. The two d-c armatures are mounted in tandem on a single shaft and are driven by a 200-hp, 720-rpm motor. The a-c set, rated at 100 000 amperes, 500 volts, is built as a single unit and is driven by a 500-hp, 720-rpm motor.

The selection of switchgear for the laboratory presented many special problems not usually encountered in the industrial field. All of the circuit-switching apparatus must withstand severe service of a highly repetitive nature and yet require a minimum amount of maintenance. Because it is essential that this laboratory reproduce tests over and over again, it is highly important that the time of operation of the main circuit breakers, field switches, and closing switches be exactly duplicated for each test. In addition, the test circuits must be calibrated within close limits so that variations caused by resistance or reactance do not distort the results. This required very careful selection of the proper size and capacity of switching devices as well as the best possible design and construction of these items.

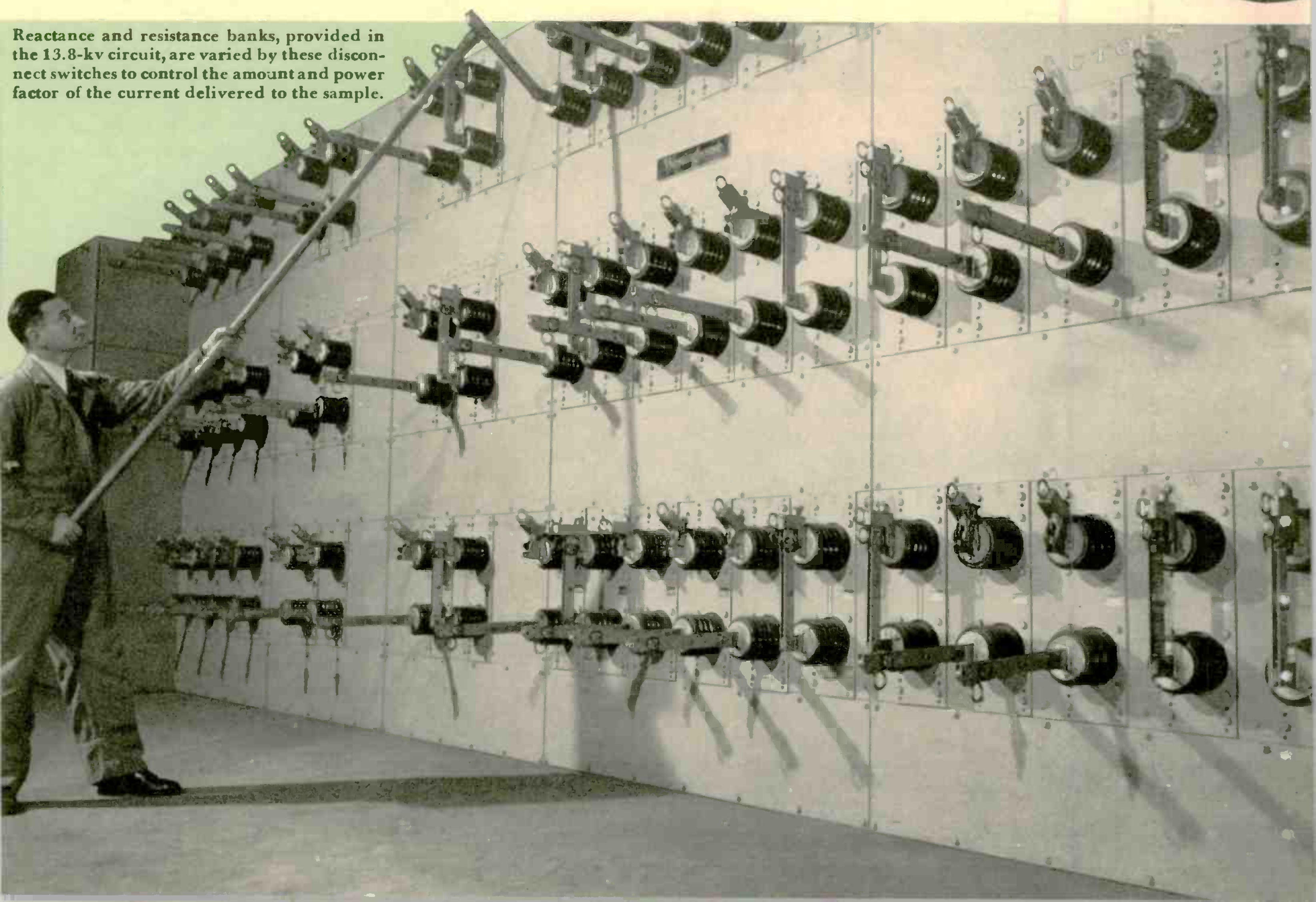
The power supplied to the high-current laboratory is brought into the building at 2300 volts, 3 phase, 60 cycles. These 2300-volt circuits are all controlled by De-ion air circuit breakers of horizontal draw-out design, in a metalclad switchgear structure. The air circuit breakers are closed by means of Rectox-solenoid operated mechanisms that derive energy from a small auxiliary transformer connected to the incoming line, ahead of the main supply breaker. The tripping coils are energized by a 48-volt station battery supply.

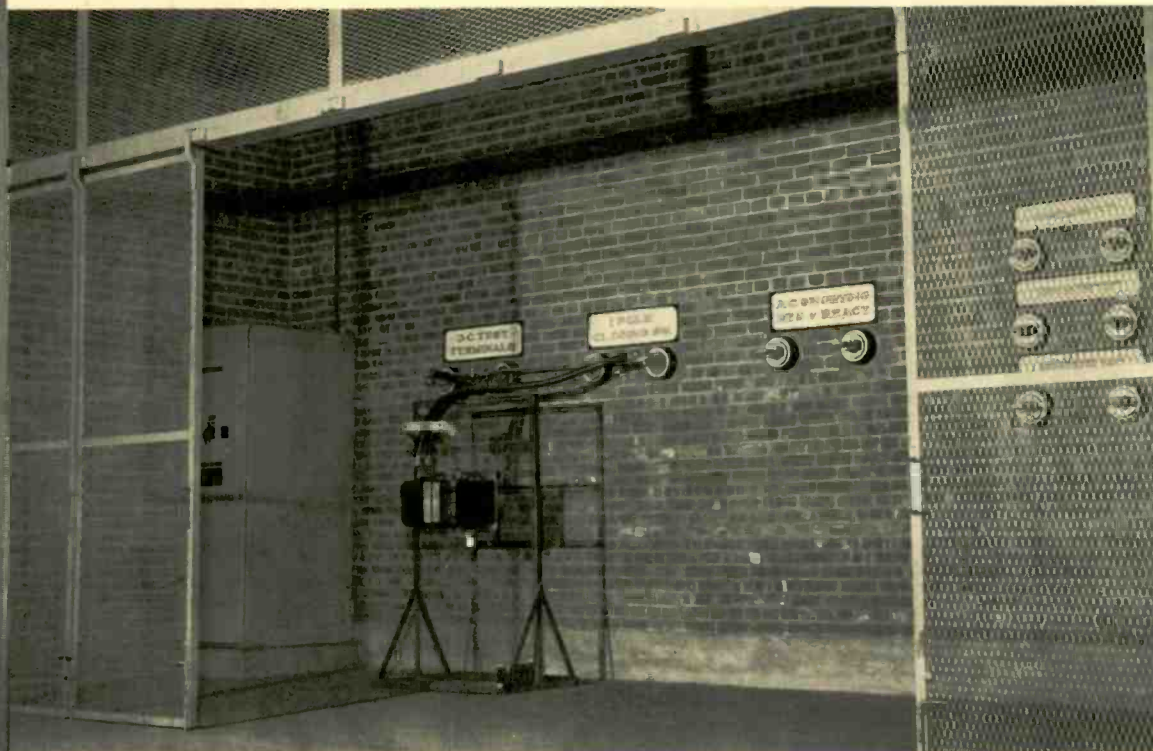
A 200-kva auxiliary transformer reduces the 2300-volt power to 460 volts for the motor-generator excitation sets and other miscellaneous auxiliaries. The auxiliary power transformer and its low-voltage switchgear form a close-coupled power center. The 460-volt circuits are all controlled by electrically operated, draw-out type De-ion air circuit breakers.

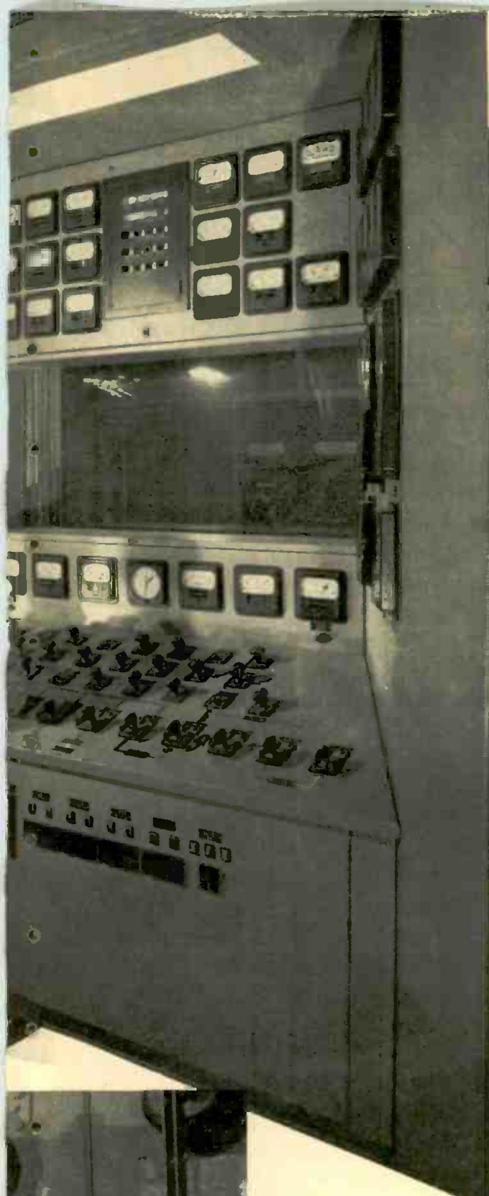
Alternating-Current Test Circuit

From the main a-c generator, the 13.8-kv circuit extends to the back-up breaker, which is a draw-out Deion air unit specially

Reactance and resistance banks, provided in the 13.8-kv circuit, are varied by these disconnect switches to control the amount and power factor of the current delivered to the sample.







The control-room desk is arranged so that the operator can easily watch the various instruments, relays, and control switches, and view through the window the entire test area.

designed for this type of service. This breaker interrupts the main test circuit either through the sequence control system if the sample successfully withstands the test, or through protective relays should the sample fail or a fault develop in the circuit. Reactance and resistance banks are provided in the circuit to permit control of the amount and power factor of the current delivered to the test sample.

The last link to be closed in the test circuit is a closing switch of very rugged construction. It is opened by a Rectox-solenoid mechanism and held by a latch released by a high-speed shunt trip coil. When the shunt coil is energized, the switch is closed through a heavy accelerating spring to impose the test. Its time of operation must be consistent, since this switch together with a synchronous timing mechanism permits the operator to impose the short circuit at any preselected point on the a-c wave.

A metal-enclosed bus conveys the test power from the closing switch to the transformer bank which reduces the circuit voltage from 13.8 kv to 500 volts. These transformers are designed and arranged to provide a minimum circuit reactance. For the same reason the distance between the generator, transformer, and test cell was held to the minimum and the bus arrangement and spacing carefully chosen for least reactance.

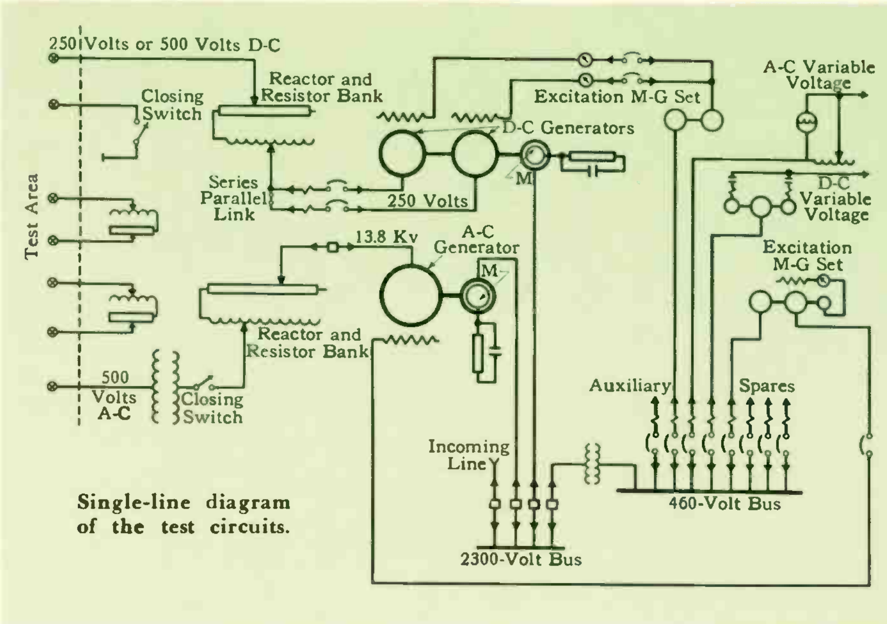
The a-c test rating of 100 000 amperes, 500 volts, is more accurately defined as 100 000 rms (root mean square) amperes asymmetrical (averaged for three phases) at the test cell on the 500-volt side of the test transformer. To obtain this rating the reactance of the test transformer, including the 500-volt bus to the test cell, could not exceed 5.77 percent. It was assumed that the transformer and test bus would comprise 40 percent of the total reactance of the test circuit, with the generator sub-transient reactance constituting the remaining 60 percent. Accordingly, the generator was designed to have a transient reactance not exceeding 15.1 percent and a sub-transient reactance not exceeding 8.68 percent. The actual values obtained were slightly less.

Direct-Current Test Circuit

The direct-current test circuit is controlled by low-voltage, metal-enclosed switchgear containing draw-out air circuit breakers electrically operated with Rectox-solenoid closing mechanisms and 48-volt, d-c shunt trip coils. The circuit extends through a reactor and resistor bank equipped with disconnect switches, similar to those for the a-c test circuits. The resistance and reactance of this circuit govern the value and rate of rise of the short-circuit current. A single-pole closing switch, also similar to that described for the three-phase a-c test circuit, is used for either the d-c test circuit or for single-phase testing on the a-c circuit.

Provision is made for selective tripping tests by a bank of single-phase reactors having terminals brought out to the test area for a set-up of three single-pole breakers in series. The breakers can be connected in series, or cascade, and a shunt load connected to each. These loads can be adjusted to various values and carried by the breakers for 60 seconds, after which a short-circuit current of predetermined magnitude is applied. This test duplicates the circuit conditions found in many actual power-distribution systems.

The laboratory also includes secondary power units to pro-



Single-line diagram of the test circuits.

vide a-c closing and tripping control power for the electrically operated apparatus. A variable-voltage transformer and induction regulator provides alternating current over a range of 80 to 490 volts, and a three-unit motor-generator set supplies direct-current control power at any voltage required between 28 and 280 volts.

Control Room

The brain center of the laboratory contains the main control desk, oscillograph table, sequence-switch table, and a dark room for developing oscillograph records and photographs. The desk provides for the complete control of the laboratory equipment from closing the incoming power supply breaker to initiate the test to opening the back-up breaker after the test is completed.

The sequence-switch equipment consists of a motor-driven, cam-type drum having sufficient segments to control automatically all of the individual test operations. The connections to the various points on the sequence switch are made by individual plugs and receptacles on a board similar to an oversize telephone switchboard. This board provides combinations for all the various test set-ups.

An important adjunct to the sequence-testing equipment is a synchronous timing device. It consists of a pilot generator attached to the main a-c set shaft, a phase shifter or "peaking" transformer and an electronic circuit in which the principal element is a thyratron. By means of a dial on the phase shifter, any point on the voltage wave can be selected for the imposition of the short circuit.

All power and control circuits required for tests lead into a well protected area where samples to be tested are mounted. Seven sets of main power terminals are provided for the a-c and d-c circuits. The test cells are enclosed by removable steel screens to protect personnel without limiting their visibility. A cabinet at each side of the area provides for the secondary and control terminals that enter the area from the a-c and d-c variable-voltage control power circuits, the oscillograph connection, the sequence equipment, and the main control desk.

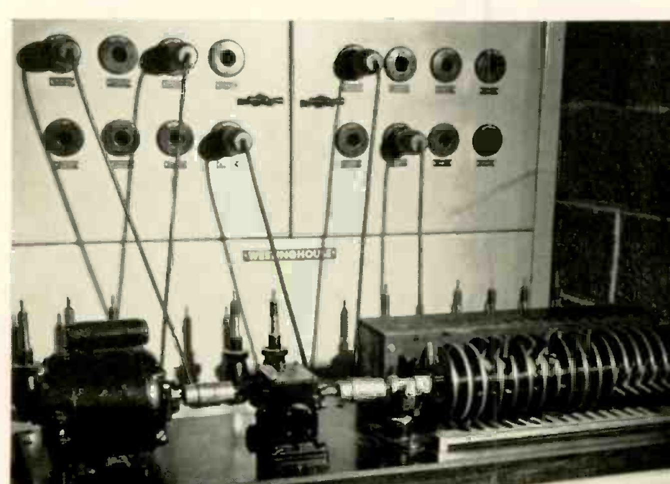
For the safety of operating personnel, an intricate visual and audible alarm system is installed to warn that a test is about to take place. Flashing red lamps located in the machine room, the test area, and the control room are energized when the field breaker of any of the test generators is closed.

A typical test on a breaker would proceed in the following manner: After the sample to be tested has been connected to the power terminals in the test cell and the secondary control circuits have been completed, the reactor and resistor banks are adjusted by the operator through the disconnecting switches. The operator may then leave the machine room and test area, as all of the remaining functions are performed from the control room. Oscillograph connections are made, the sequence equipment is adjusted, and warning signals, both visual and audible, are energized. The control-desk operator then starts and adjusts the generator that will deliver the test current. The back-up breaker is closed next, and the remainder of the test procedure is transferred to the oscillograph operator. When the oscillograph equipment is in readiness, the operator closes a switch to start the sequence testing equipment. The sequence switch then energizes in turn the oscillograph elements and motors, the test closing switch, and finally, at the conclusion of the test, opens the generator field breaker and main breaker.

The new test station will play an important part in the Navy's research and development program. Some phases of this program are: (1) the development of fuse protective devices of high interrupting capacity, (2) the investigation of bus structures and switchboard designs with a view toward reducing weight and space requirements consistent with safety, (3) the development of improved contacts and contact materials, and (4) the development of improved insulating materials having arc-resisting qualities. Many phases of these problems are peculiar to the Navy, which by having the necessary test facilities available can carry on the research work using personnel who are in direct contact with the problem.

As indicated at the dedication of the laboratory on April 3, 1947, by Vice Admiral Earl W. Mills, Chief of the Navy's important Bureau of Ships, the laboratory will be of assistance in maintaining for the Navy the reputation of having the finest equipped fighting force afloat.

The "sequence" switch actually runs the test after the appropriate set-up has been made by the operator.



Progress with Mercury Lamps

The mercury-vapor lamp is one of the most versatile of light sources, supplementing the incandescent and in some cases edging it out of time-honored uses. An electrical discharge through mercury vapor is an efficient producer not only of visible light but also of some very important invisible radiations such as the spectacular black light and those employed in bactericidal work.

E. W. Beggs • *Illumination Engineer* • *Westinghouse Electric Corporation*

The outstanding recent development in mercury-vapor lamps is the extension to larger sizes of the quartz arc-tube design with its high efficiencies, small, brilliant light sources, freedom from restrictions as to burning position, and high output in the ultraviolet. Of particular interest are the 400-watt E-H1* lamps now being introduced for street lighting and the 1000-watt A-H12 lamps for lighting and floodlighting large areas. Their companion lamps, the improved 400-watt D-H1 and the new 1000-watt B-H12, will bring high-output lamps with the advantages of the quartz arc tube to the black-light and photochemical fields.

Photochemistry and photocopying applications have needed a high-powered lamp of the single-wall, arc-tube type like the familiar 3-kw A-H9. A new lamp, known as the 3-kw B-H9, designed especially for this service, with an arc tube of high transmission glass, brings new economy to these fields for mercury-vapor lamps.

The wide expansion of old applications for mercury lamps that took place during the war is continuing today, and new uses are being created. The long and recently much increased lamp life at high efficiencies, the tremendous light output now available from a single light source, the special color and brightness characteristics of the arc stream, and the high output in the ultraviolet region, are the principal features of mercury-vapor lamps. These are helping to solve old problems and are opening new fields for the use of radiant energy.

Quartz Arc-Tube Developments

New, larger and improved double-bulb lamps, with quartz arc tubes instead of glass, have been in the development laboratories since before the war, continuing a trend that began in 1936 with the introduction of the 85-watt type A-H3. That lamp was superseded in 1937 by the 100-watt A-H4, and then supplemented by the 250-watt A-H5 and the 400-watt D-H1, developed in 1938 largely for use at the World's Fair. The 250-watt C-H5 came in 1942, and now the improved 400-watt D-H1 and E-H1, and the new 1000-watt A-H12 and B-H12 lamps are achievements since the war's end.

Enclosure of the arc in quartz instead of glass permits operation at higher vapor temperatures and, consequently, at higher pressures, which has several points of merit. Higher pressures in the discharge tend to shift the radiation toward the longer wavelengths so that relatively more energy is generated in the visible spectrum. This means an increase in lumens-per-watt efficiency. Also, as vapor pressures increase, the gaps between the spectral lines tend to be filled in and the lines themselves are widened, spreading chiefly toward the longer wavelength side. This is evident from Fig. 1. Thus the color of the light is improved. The higher pressure is also responsible for a higher intrinsic brilliance of the arc.

The 2537-Angstrom line is the principal resonance line of the mercury-vapor discharge. It represents about 85 percent of the total radiant energy in the low-pressure discharge of Fig. 1. This line is produced with high efficiency, about 85 percent, and is the principal energy used in all bactericidal

*American lamp manufacturers generally identify mercury-vapor lamps by type numbers in which the "H" stands for mercury (Hg). The number following the letter "H" designates the size or wattage and the type of transformer required, i.e., all H1 lamps will operate on an H1 transformer. In the sunlamp series, the S4 lamp will operate on the H4 transformer, but the RS sunlamp requires none so no suffix number is used. The preceding letters, A, B, C, D, etc., signify variations such as burning position, type of outer bulb, electrode design, etc. The suffix numbers and prefix letters were assigned as the lamps were and are standard throughout the lighting industry.

This article is a revision of a paper presented at the annual convention of the Illuminating Engineering Society, Quebec, Sept. 18–20, 1946.

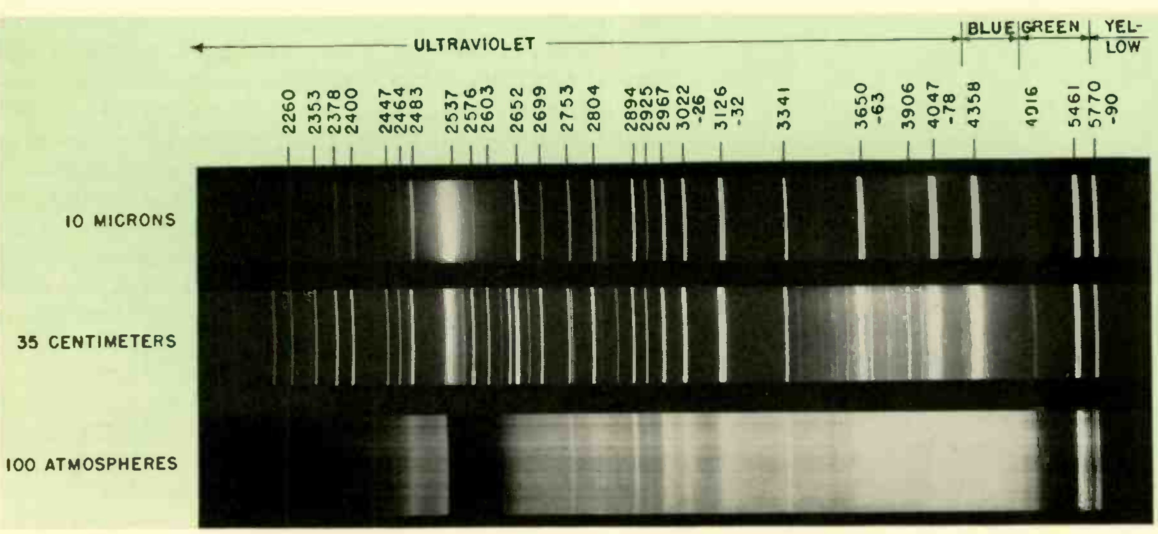


Fig. 1—Photospectrographs of mercury discharges in quartz. The top strip shows the radiation of a bactericidal lamp; the middle strip is for medium-pressure lamps such as the sunlamp; and the bottom one is of the A-H6. The film and exposure time were chosen to depict the ultraviolet ranges; hence, the red end is not shown in its full relative strength.

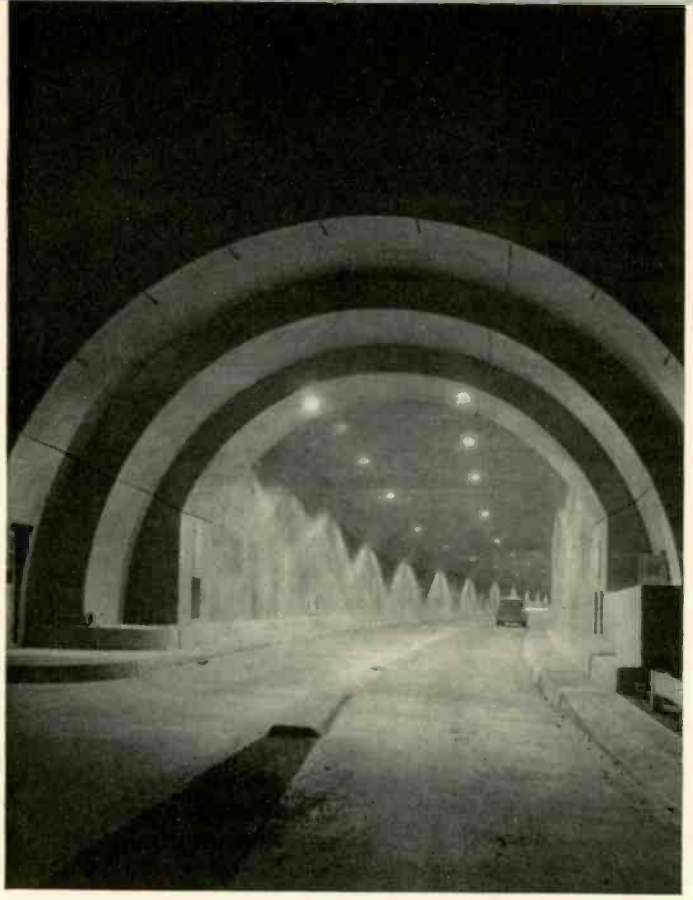


Fig. 2—Six years of service with quartz mercury lamps in the Pennsylvania Turnpike Tunnels reveal a high degree of economy and dependability. The spacing of the lamps achieves good illumination of the roadway with the smallest number of units.

lamps. While the efficiency of generation is high, the pressure is low, the wattage loading is very low, and so the total output of a given arc tube is small, only about one-third watt per inch.

The 2804, 2894, 2925, 2967, 3024, and 3132 lines are in the erythema and vitamin-D producing band. They are sometimes classified as antirachitic radiations because they are the ones used in the treatment and prevention of rickets. These are the lines that give the quartz mercury sunlamp its potency.

At vapor pressures such as used in sunlamps the spectrum

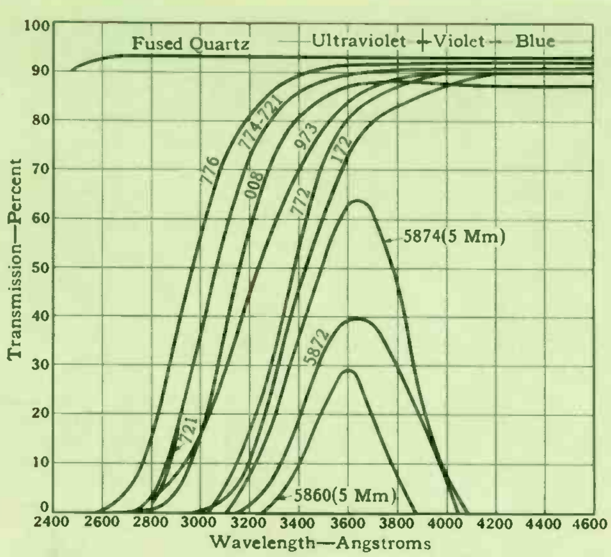


Fig. 3—Transmission curves for various types of glass in the ultraviolet and visible spectrum. The values given are for a thickness of one mm except as indicated for the two "black light" filter glasses shown.

is like that shown of the medium-pressure lamp of Fig. 1. The erythemic rays represent approximately seven percent of the radiation originating from the quartz arc tube. The relative amount of 2537-A energy generated by the arc tube is reduced at these higher pressures, and drops from 85 percent at 10 microns to about 3 percent at 1.1 atmosphere.

The 2967-A line is the peak line for the production of vitamin D. The principal objective of a quartz mercury sunlamp is to produce particularly large amounts of 2967 A and the lines adjacent to it. Therefore pressures in the middle range are generally used.

The line 2804 lies at the approximate lower limit of the natural sunlight spectrum at sea level. Lamps designed to simulate the radiation of the sun should produce no wavelengths below this. In ordinary practice the lower wavelengths are filtered out by the outer bulb of the lamp. To meet the requirements of the American Medical Association for a lamp for general distribution designated as a sunlamp, the total of all radiations of 2800 A and below must not exceed one percent of those between 2804 and 3132 A.

The two lines, 3342 and 3650 A, are the "black-light" lines used for creating fluorescence in dyes and pigments. Most substances that fluoresce under these rays also fluoresce more or less under the excitation of adjacent lines, particularly 3132 A and 4047 A.

The output at 3650 is high in all medium- and high-pressure mercury discharges. In the medium-pressure arc, the 3650 line represents more than 10 percent of the total radiation. The relative power of 3342 A is approximately 1½ percent, so that about 90 percent of the power in this region is at 3650 A.

The percentage of power radiated as 3650-A energy is a maximum at somewhat over one atmosphere vapor pressure, which is approximately that used in the black-light lamps, types D-H1 and B-H12, listed in table I. The higher pressures of these lamps are of advantage because they result in greater overall power in the arc. This power in watts loading per inch of arc stream of the lamps in table I extends over the range from 58 in the B-H9 to 180 in the A-H12.

The strong lines in the visible spectrum are: 4047 A, violet; 4358 A, blue; 5461 A, yellow-green; and 5770-90 A, orange-yellow. These lines give the light of a mercury lamp its characteristic color, which is perhaps best described as bluish-white with a greenish tinge. The spectrum of the mercury discharge is noticeably deficient in red.

At extreme pressures of 100 atmospheres, Fig. 1, the spectral lines appear against a background of energy radiated almost continuously throughout the entire spectrum. A distinct void exists at the resonance line 2537, where practically all radiation is absorbed by the vapor itself. An appreciable amount of visible energy is radiated by medium- and high-pressure arcs between the principal lines from 4916 to 6900 Angstroms, not shown in Fig. 1. Arc wattage at the high pressure shown runs to almost 1000 watts per inch of length.

In photochemistry all lines and ranges of the spectrum are occasionally useful, although most applications require the violet and near ultraviolet regions including principally the four lines shown in the strips at 3132, 3342, 3650, and 4047.

The two fundamental requirements for a photochemical reaction are, first, that radiant energy be absorbed by the reagent involved and, second, that the absorbed energy be of the specific frequency or wavelength required to cause electronic excitation in the substances that absorb it. Chlorine has an especially high absorption from 3100 to 3400 A and is readily activated by these rays. Hence chlorination processes are often most successful with this type of radiation.

The type and thickness of glass used for the inner and outer envelopes of the lamps and for intervening surfaces such as tubes and plates determine the net amount of useful radiation received by the chemicals irradiated. This is shown by the curves of Fig. 3.

Improved Performance of Quartz Lamps

Cathodes of thorium, introduced by Gustin and Freeman in 1941, avoid the rapid destruction of the quartz arc tube caused by the corrosive effect of barium, which limited the life of early quartz lamps of the hot-electrode type. These electrodes also sputter less and blacken the arc tube to a lesser extent, resulting in good maintenance of light output throughout life. A more recent improvement is the use of an evacuated outer bulb together with larger diameter, which reduces the evolution of moisture and hydrogen gas from the glass. This prolongs the useful life of the quartz arc tube, particularly when operated horizontally, because the hydrogen released directly or generated from the moisture baked out of the glass would gradually destroy the quartz.

Service tests with the 250-watt A-H5 lamp having a No. 774 glass outer envelope, originally used in the Pennsylvania Turnpike Tunnels, showed that if this outer bulb becomes overheated the lamp life is seriously shortened. Use of No. 172 outer glass eliminates this difficulty. The C-H5 lamp is made with this more resistant outer envelope, and has been performing well in the horizontal position in this installation since 1941. The same type of glass is also used in the new E-H1 and A-H12 lamps recently developed for general and street-lighting service. It cannot be used for black light, however, because of its low transmission in the ultraviolet. The new large-diameter bulbs now used on the D-H1 and B-H12 lamps increase the safety factor and make it easier to design equipment that will not overheat the outer bulb glass.

The Three-Kw B-H9 Black Light and Photochemical Lamps

The three-kw A-H9 mercury-vapor lamp for general lighting service was introduced during the war. Its most spectacular application was in the Budd Airplane Plant at Bustleton, Pennsylvania, where its use reduced lighting maintenance to a minimum, which was particularly important at that time. These lamps were also used somewhat in other industrial applications such as steel mills and in airplane and blimp hangars, where access to the fixtures was particularly difficult and the lighting had to be done with a minimum number of units with long-life lamps.

Experiments with the 3-kw A-H9 in blueprinting and photochemistry indicated the desirability of a lamp of this type made with glass of a higher transmission in the near ultraviolet. The new 3-kw B-H9 is made with No. 973 glass. It has an arc two inches longer to improve the uniformity of prints made with wide paper in large automatic blueprint machines and to prevent accidental interchange with the A-H9.

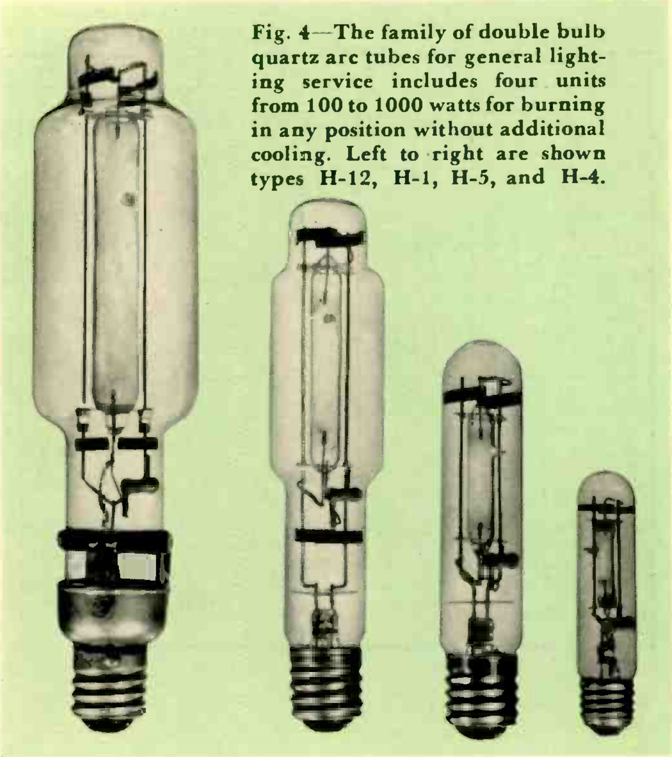


Fig. 4—The family of double bulb quartz arc tubes for general lighting service includes four units from 100 to 1000 watts for burning in any position without additional cooling. Left to right are shown types H-12, H-1, H-5, and H-4.

Lamp Performance

Lamp Life and Lumen Maintenance

The useful life of the quartz lamps, listed in table I is generally limited by the gradual decline in output during burning. It is also affected by the number of times the lamp is started. Each time the arc is struck some of the electrode material is sputtered away and deposited on the inside of the arc tube at each end. The useful life of the average quartz mercury-vapor lamp, therefore, is the number of burning hours required to reduce its lumen output to a point where the lamp should be replaced. This time is shorter with the smaller, higher loaded quartz arc tube than with the conventional glass type because the latter has a larger inner arc chamber.

The life of the familiar glass-type mercury-vapor lamps is determined chiefly by the service life of the oxide cathode used. These lamps generally fail to light when the oxide-emission mixture embedded in the cathode is sputtered away. The life varies somewhat with the number of times the lamps are started, and so too does the darkening of the arc tube. The drop in output of all mercury lamps is more rapid during the first 100 hours of burning and is gradual thereafter.

Fig. 5—Three-kw A-H9 general lighting and B-H9 black light and photochemical lamps. The B-H9 is made of glass having a higher transmission in the near ultraviolet and has a two-inch longer arc stream.

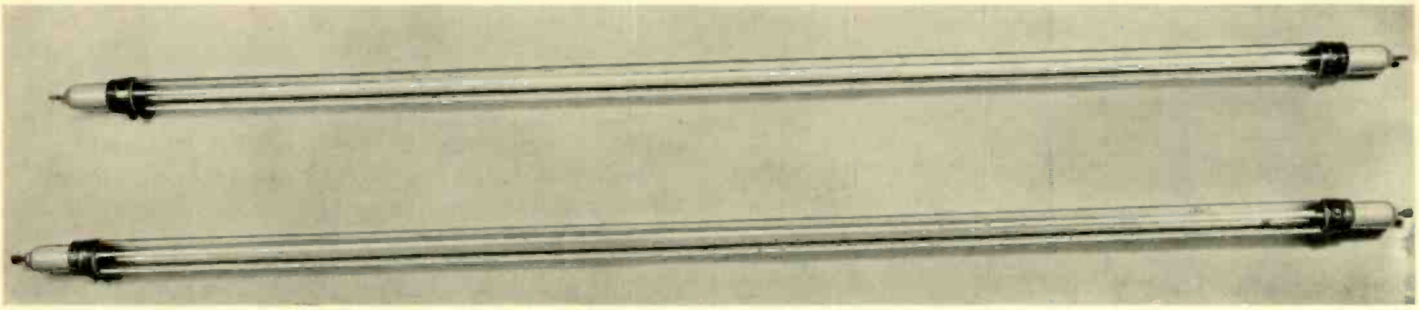


TABLE I—COMPARISON OF MERCURY-VAPOR LAMPS

[1]Watts (Lamps only)	100				250		275	400				1000			3000	
Type	A-H4	B-H4	C-H4 (Spot) E-H4 (Flood)	S-4 (Sun-lamp)	A-H5	C-H5	RS (Sun-lamp)	A-H1 B-H1	D-H1	E-H1	F-H1	[2]A-H6	A-H12	B-H12	A-H9	B-H9
Initial Lumens	3000	—	—	3000	10 000	10 000	—	16 000	20 000	20 000	16 000	65 000	60 000	60 000	120 000	120 000
Rated Average Life 5 hours per start	1000	1000	1000	[3]1000	1000	2000	[3]1000	4000	[4]1000	2000	4000	75	2000	2000	4000	3000
10 hours per start	—	—	—	—	—	3000	—	6000	[4]—	3000	6000	—	—	—	6000	4500
Maximum Overall Length (Inches)	5⅝	5½	5 7/16	5¼	8	8	6⅞	13	11	11	13	3¼	14	14	54⅞	56⅞
Light Center Length (Inches)	3 7/16	3 7/16	—	3 7/16	5	5	—	7¾	7	7	7¾	—	9	9	—	—
Burning Position	Any	Any	Any	Any	Any	Any	Any	[5]—	Any	Any	[5]—	Horiz.	Any	Any	Any	Any
Electrode Type	Thorium	Thorium	Thorium	Thorium	Thorium	Thorium	Thorium	Oxide	Thorium	Thorium	Oxide	Mercury	Thorium	Thorium	Oxide	Thorium
Vapor Pressure (Atmosphere)	8	8	8	8	4.5	4.5	1.1	1.2	2.5	2.5	1.2	110	1.5	1.5	0.4	0.4
Striking Voltage (Volts)	250	250	250	250	250	[6]250	—	220	[6]220	[6]220	220	1200	[6]220	[6]220	850	850
Operating Voltage (Volts)	130	130	130	130	135	135	[7]110–125	135	135	135	135	840	135	135	535	535
Starting Current (Amperes)	1.3	1.3	1.3	1.3	2.9	2.9	3.2	4.7	4.7	4.7	4.7	2.6	12	12	9.3	9.3
Operating Current (Amperes)	0.9	0.9	0.9	0.9	2.1	2.1	2.4	3.2	3.2	3.2	3.2	1.4	8.2	8.2	6.1	6.1
Starting Time (Minutes)	3	3	3	3	4	4	2	7	4	4	7	2 Sec.	4	4	7	7
Restriking Time (Minutes)	3	3	4	3	4	4	3	7	4	4	7	2 Sec.	6	6	8	8

[1]For total wattage add transformer watts which ranges from 8 percent to 25 percent of lamp watts.
[2]The A-H6 is water cooled and requires an outer jacket generally of quartz or No. 774 heat resisting glass. A similar lamp for air jet cooling is the B-H6 rated at 900 watts.
[3]Life of the S-4 and RS sun lamps is rated at 1000 applications in normal sun lamp use in the home, or 1000 hours at 5 hours per start.
[4]Rated average life at 5 hours per start for D-H1 in any position is 1000 hours. At 10 hours per start the rated average life is 3000 hours in the vertical position only.
[5]The A-H1 and F-H1 are designed for base up burning, the B-H1 for base down burning. These types must be operated within 10 degrees of vertical.
[6]For normal indoor use. Higher striking voltages are desirable for dependable starting at lower temperatures.
[7]For 50–60 cycle a-c operation only. Operates directly from regular lighting circuit.

Color

As shown in Fig. 1, the mercury spectrum is not continuous, and therefore the colors of objects lighted by mercury lamps are not true. Before the war, European engineers developed a mercury lamp with color correction by means of fluorescent phosphors coated thinly on the inside surface of the outer bulb, and with cadmium in addition to the mercury in the arc tube. These lamps are again being offered in Europe for use where the uncorrected mercury-vapor light will not satisfy the requirements.

In the United States, this system has not been found of much interest because the correction is only partial and the efficiency of the lamp is reduced. Lamps with quartz arc tubes are slightly better in color quality and considerably superior in efficiency. This type of lamp therefore is being increasingly used for general lighting. Ordinarily, however, where straight mercury light is not suitable, a mixture of mercury and incandescent tungsten-filament lamps is used. The incandescent lamps provide an excellent color correction, and insure continuity of operation should the mercury lamps be momentarily extinguished.

Use of fluorescence to correct color and even to increase efficiency of light production is quite logical because mercury lamps generate large amounts of ultraviolet energy that could be converted by phosphors into visible light. The 3650-A line, for example, is one of the most powerful of the entire spectrum. At 2½ atmospheres pressure, as in the D-H1 lamp, the 3650-A line represents over 10 percent of the total radiated energy, which is about equal to that of either the important 5461 or 5780-A lines, which now provide most of the visible-light efficiency of the lamp. If phosphors were available to convert this energy into visible light, they might therefore contribute greatly. They might be coated on the inner surface of the outer bulb as in European lamps, or they might be coated on the reflector or the ceiling and walls of the room. To be effective, however, these fluorescent pigments must be practically snow-white under ordinary visible light as are the phosphors used in fluorescent lamps, or they will lose by absorption more than they add by fluorescence. This is still the limitation in the European lamps and in pigments available for reflector and ceiling paint.

TABLE II—ACCEPTABLE LABORATORY TEST TEMPERATURES FOR MERCURY LAMP PARTS (MEASURED AT 25 DEGREES C AMBIENT)

Lamp		Outer Bulb Degrees C	*Base Degrees C
100 Watt	A-H4	400	170
	B-H4	400	170
	C-H4, E-H4	400	170
250 Watt	A-H5	400	170
	C-H5	475	170
275 Watt	RS	250	170
400 Watt	A-H1, B-H1	400	170
	D-H1	400	170
	E-H1	475	170
	F-H1	425	200
1000 Watt	A-H6, B-H6	Special Cooling Required	
	A-H12	475	200
	B-H12	400	200
3000 Watt	A-H9	375 degrees C minimum to 550 degrees C maximum throughout length of arc tube.	
	B-H9	375 degrees C minimum to 550 degrees C maximum throughout length of arc tube.	

*A 10 degrees C higher test temperature is considered acceptable in street-lighting and outdoor floodlighting fixtures because the ambient temperatures during operation are generally lower than in other types of service.

TABLE III—BRIGHTNESS OF MERCURY ARCS

Lamp	Lumens	Arc Length (Inches)	Effective Arc Diameter (Inches)	*Average Candles per square inch
A-H4	3 000	1	3/32	3 200
C-H5	10 000	1⅝	5/32	3 800
A-H1	16 000	6	7/16	600
F-H1	16 000	6	7/16	600
E-H1	20 000	2⅜	7/32	3 800
A-H12	60 000	5	7/16	2 700
A-H6	65 000	1	3/64	135 000
A-H9	120 000	48	7/16	500

*At 90 degrees from axis of arc stream.

Ambient Temperature

The light output of the double-bulb mercury lamp is little affected by ambient temperature. During the past ten years, the A-H1 lamp has been used both indoors and outdoors under widely varying temperature conditions with no ill effect on performance, and this lamp is now considered satisfactory for temperatures down to −20 degrees F. The single-bulb lamp such as the A-H9 and the B-H9 is, on the other hand, somewhat critically affected by ambient temperature, particularly if the surrounding air is moving. The arc tube is exposed directly to the cooling air, and under extreme conditions, such as a high wind in winter, the arc might even be extinguished. These lamps are, therefore, suitable for use only above 32 degrees F unless special precautions are taken.

Ambient temperature affects the striking voltage (table I) of all discharge lamps. Higher voltages are recommended for street lighting where quartz lamps are used in cold climates.

Fixture-Temperature Limitations

The maximum safe laboratory test temperatures for the various parts of the lamp are given in table II. These limits are for use chiefly by fixture designers and application engineers. They represent the operating temperatures reached during laboratory test runs on a fixture, beyond which the lamp may fail or lamp performance may be affected in service.

The values shown have been found safe through years of use. Where operating temperatures fall below the limits given in table II good lamp performance in service may be expected. The outer bulb will neither soften nor damage the arc tube by exuding moisture, the basing cement retains its strength, and where the mechanical base is used the solder remains hard and the base and socket metal and the lead wires resist corrosion in ordinary atmospheres. Above these limits, however, difficulty may be encountered.

Special Cooling

The natural movement of the surrounding air is ordinarily sufficient to prevent overheating for all lamps except the A-H6 and the B-H6, which require special cooling. The A-H6 is designed to operate immersed in a flow of cooling water, while the B-H6 is designed to be cooled with two high-pressure air jets impinging on the lamp bulb just opposite each electrode.

If the B-H9 must be forced-air cooled, the system must provide a fairly uniform temperature throughout the length of the lamp or mercury condenses at the cool spots and performance is unsatisfactory. Ordinarily, a flow of only a few cubic feet of air per minute is needed, and it should be distributed over the length of the lamp to avoid unevenness of operating temperature.

Alternating-Current Frequency

When a mercury-vapor discharge lamp is operated on alternating current the arc actually goes out each time the current reverses and must restrike as the voltage rises on the next half cycle. Most lamps are designed to operate on 60 cycles and, in general, are operable at frequencies as low as 25 cycles. At lower frequencies, however, the gas between the electrodes has time to deionize and the electrodes have time to cool, so the arc may not restrike. Higher frequencies are, ordinarily, satisfactory for all mercury-vapor lamps. Suitable auxiliaries must be used for the particular frequency involved. The RS sunlamp, however, is limited to 50- to 60-cycle systems.

Starting and Restarting

Most mercury-vapor lamps have two main electrodes and one starting electrode. When such lamps are started, a glow is created between the starting electrode and the main electrode located near it. This ionizes the argon starting gas, and shortly thereafter the arc strikes between the two main electrodes mounted at opposite ends of the arc tube.

At this point in the starting cycle, the mercury-vapor pressure is low, the operating current is high, and the voltage across the lamp is low. As the mercury in the arc tube vaporizes its pressure increases, which causes the voltage to rise. The mercury finally becomes entirely vaporized, and then somewhat superheated, at which point equilibrium is reached. The equilibrium point is determined chiefly by the characteristics of the lamp and the transformer, which is designed to limit the ampere flow so that the lamp operates at its proper wattage. The starting times given in table I show the time required to bring an average lamp up to approximately full output when operated in open air under ordinary indoor conditions on a lag circuit.

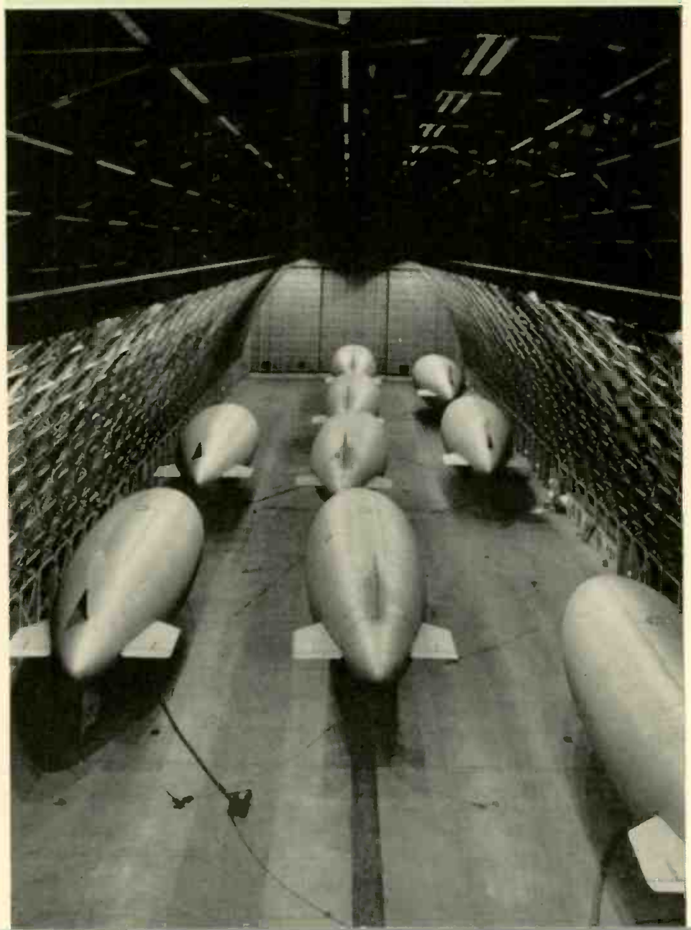
If the current should be interrupted or the line voltage should drop more than 15 percent for a moment, the lamp will go out. In this event, the arc tube must cool so that the mercury-vapor pressure drops low enough for the arc to restrike at the starting voltage available. The time required for this cooling depends upon the type of lamp involved and upon the ambient conditions. The effect of ambient temperature is, naturally, greater with single than with double-bulb types.

Restriking time, which is the cooling time to restrike the arc, is also given in table I. It is not necessary for the entire lamp to reach room temperature for the arc to restrike and, therefore, as the arc starts again the lamp heats more quickly than when started from normal room temperature.

Brightness

All medium- and high-pressure mercury arcs are brilliant, the A-H6 being the brightest. Its central core is one-fifth the brightness of the sun—that is, approximately 190 000 candles per square inch. The values given in table III show average candles per square inch of projected arc area in several representative lamps. The effective width of the arc stream used in the computations includes practically all of the luminous energy radiated. The values are approximate only but they show the relative merits of the various lamps particularly for applications where light control is important.

Fig. 6—Enormous Navy blimp hangar lighted by 42 three-kw A-H9 mercury lamps. These direct lighting fixtures are suspended beneath the catwalk 133 feet above the floor.



Eight-to-One Range Adjustable-Speed D-C Motor

For fifty years the accepted speed range for a direct-current motor by field control has been four to one. Now it has been doubled for four-pole motors with only slight modification of the field connections and additional field control. Such a motor bridges the gap in speed range between that obtainable with the standard motor and the more expensive motor with armature voltage control.

R. W. Moore, *Motor Design Engineer**
Westinghouse Electric Corporation

A speed range of eight-to-one by field control is possible with a d-c motor embodying two separate magnetic circuits and a two-circuit armature winding. The construction of such a motor, shown in simple form in Fig. 1, differs only slightly from a conventional d-c motor.

The eight-to-one speed-range motor has special shunt fields connected as shown in a typical schematic diagram, Fig. 2. Shunt field 1 is assembled on poles marked *A* and *B* and identified as the main field. Shunt field 2 is assembled on poles *C* and *D* and called the variable field. The main field is designed for full excitation voltage; the variable field is designed for one half excitation voltage.

To obtain an eight-to-one speed range, both the main field and the variable field are changed simultaneously, as shown in Fig. 3. For the slowest or base speed the main-field current is a maximum and the variable-field current is also a maximum in cumulative direction. To increase speed the strengths of both the main field and the variable field are simultaneously varied until at maximum speed—eight times base speed—the main-field strength is but 60 percent of full field and the variable-field strength is 35 percent of full field in the opposing direction. This is accomplished by a rheostat in series with the main field, and a potentiometer rheostat for the variable field, their handles being mechanically connected.

*Since preparing this article, Mr. Moore has transferred from the Motor Department to Steel Mill Application Engineering.

The speed of such a motor changes with variations of field current for the same reason that any d-c motor changes speed with changes in flux. That is, for any amount of flux the speed must be such that the generated armature voltage equals the applied voltage minus the resistance drop in the armature circuit. The conductors under the main-field poles have a voltage generated in them proportional to the flux in the magnetic circuit. The same is true of the conductors under the variable-field poles. However, these voltages have directions dependent on the relative polarities of the fields. The conductors under the main-field poles are in series with the conductors under the variable field because a two-circuit armature winding is used. Therefore, the generated voltage appearing at the brushes is the sum of the voltages generated in these conductors in series and a high speed can be obtained by reversing the direction of flux in the variable field.

A review of the factors that limit the range of a standard adjustable-speed motor helps clarify how an eight-to-one speed range is obtained by the field arrangement described. The factors are: changes in residual magnetism, armature distortion, demagnetization of the main field by the armature and increases in reactance voltage. These factors cause instability or poor commutation when the field of a motor is weakened beyond that required to obtain four times base speed; therefore, the operation of a standard adjustable-speed motor under these conditions is generally unsatisfactory. The fact that the main field is reduced to a low magnetic intensity results in a greater effectiveness of these factors.

Thus, the flux at eight times base speed is 12½ percent of normal. Referring to Fig. 4, which is a typical hysteresis loop for a d-c machine, the field strength to obtain 12½ percent flux may be as low as 3 percent or as high as 13 percent of normal, depending on the magnetic condition of the machine. Clearly any change that affects the residual magnetism of the machine changes the flux appreciably at these low field strengths, causing thereby a relatively large change in speed. Because the armature ampere-turns acting at the pole tips are many times the main field, negative flux appears under one pole tip and positive flux under the other. This flux spreads into the interpolar zone, increasing the reactance voltage. The center of commutation may change, possibly because of a

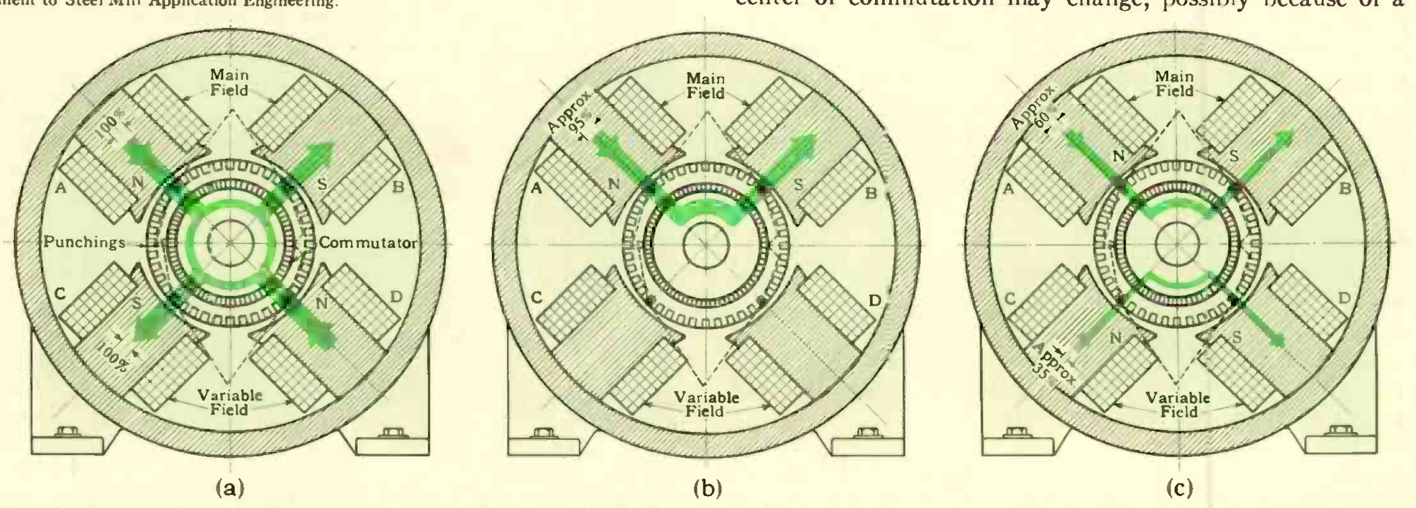


Fig. 1—Cross-section of a four-pole motor with a two-circuit field winding to obtain an eight-to-one speed variation; interpoles are omitted for simplicity. This arrangement gives stable operation and satisfactory commutation over the entire range. The colored lines show the direction and magnitude of the field flux for: (a) base speed, with full main field and full cumulative variable field; (b) about 215% base speed, with zero variable field; and (c) maximum speed, with minimum main and maximum bucking variable fields.

slight shift of the brush in the holder or because of the effective compensation changes resulting from variations of residual magnetism of the commutating-pole magnetic circuit. This results in a direct demagnetizing action on the main field. As small as this effect is, at very weak main-field strength a large change in flux, and therefore speed, occurs.

The reactance voltage of a d-c machine is directly proportional to speed as is also the compensating commutating voltage. However, even with interpoles, there are limitations in the reactance voltage that can be successfully commutated. These limitations exist for the eight-to-one speed-range motor. By maintaining a strong main field, increases in reactance voltage resulting from factors other than speed, such as armature distortion, are minimized. The essential fact is that if the fields are kept strong the elements that limit the range of an adjustable-speed motor have little effect.

The limiting factor in this type of motor is commutation at the top speed. A mechanical limit fixes the top speed at which the motor can be operated, and, therefore, determines over what speeds the eight-to-one range can be obtained.

Regulation curves of an eight-to-one speed motor are shown in Fig. 5. As the safe mechanical limit of the motor tested was 3600 rpm, only the full-load point at this speed was taken and, therefore, no regulation curve could be drawn. Over the range plotted, good regulation is obtained. This is accomplished by reducing the fields as shown in Fig. 3. The reduction in main-field strength also keeps down the iron losses in the armature portions that are at high flux density at high speed. Stable operation and satisfactory commutation were obtained over the eight-to-one range.

This wide-speed-range motor appears to have its greatest application in the machine-tool industry. Its use may eliminate the expense and space requirements of a motor-generator set needed with the conventional d-c motor to obtain the necessary speed range. Lathes, boring mills, milling machines, and similar devices require constant horsepower over wide speed ranges. Although it is for such machines that this motor is more adaptable, it can be used on any application where d-c power is available and where the speed ranges up to eight to one are desired.

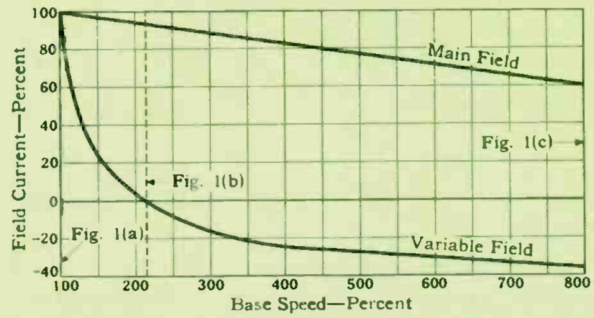


Fig. 3—From base speed to maximum speed the currents in the two fields are continuously varied in this manner. The typical field strength values illustrated in Fig. 1(a), (b), and (c) can be picked from these curves, as indicated above.

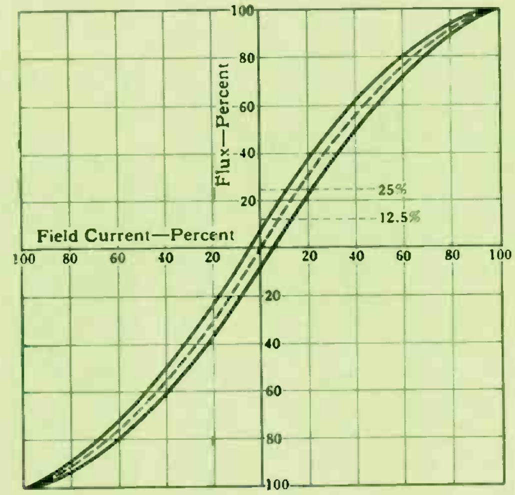


Fig. 4—Conventional hysteresis loop for a d-c machine.

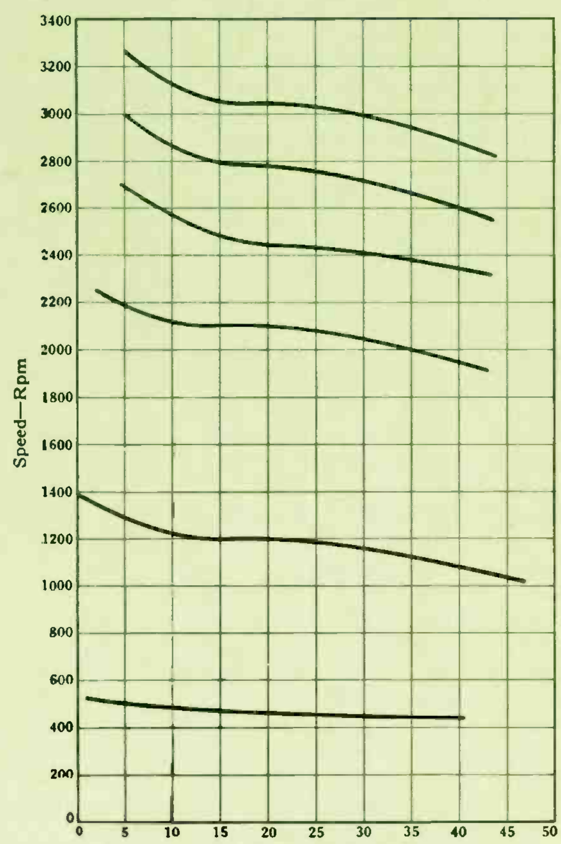


Fig. 5—The speed regulation with load of a 5/7.5-hp, 450- to 3600-rpm motor at different speed levels is excellent.

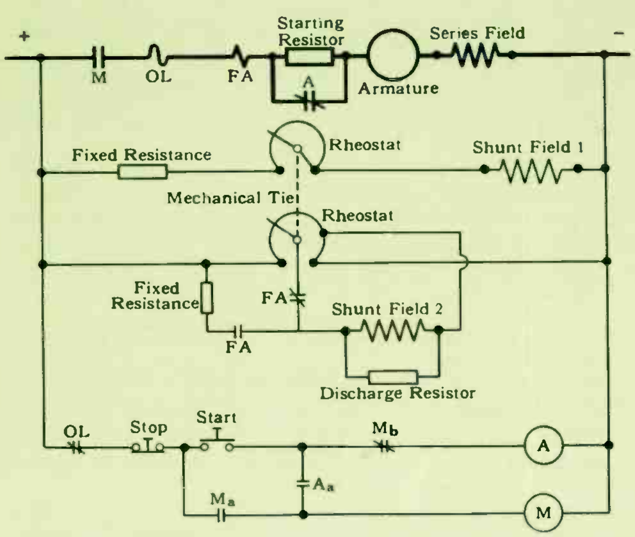


Fig. 2—Schematic diagram for control of the 8:1 speed-range motor. Sequence: Push *Start* button; coil *A* energized, opening *A* and closing A_a. *M* coil energized, closing *M* and starting motor; M_a closes and M_b opens, deenergizing coil *A*; after time delay, *A* closes, shorting the *Starting Resistor*. The *FA* relay provides full field during starting.

STORIES OF RESEARCH

Smooth Riding Ahead

Getting rid of unwanted motion has been a big problem ever since man started traveling on wheeled vehicles. Shock absorbers and springs have been improved greatly over the years, but the first major advance in a long time had its debut, strangely enough, on the battlefields of North Africa. There a gyroscopically controlled hydraulic stabilizer kept Allied tank guns trained on the enemy even while the tanks were bouncing along over rough and mountainous terrain.

Now Dr. Clinton R. Hanna, inventor of the tank-gun stabilizer, and his associates, S. J. Mikina and L. B. Lynn, at the Westinghouse Research Laboratories have applied the same idea to take the bounce and sway from railroad cars, busses, and automobiles. Combined with a tilt regulator that banks the vehicle at the proper angle regardless of speed, the new unit promises to give travelers the smoothest ride in transportation history.

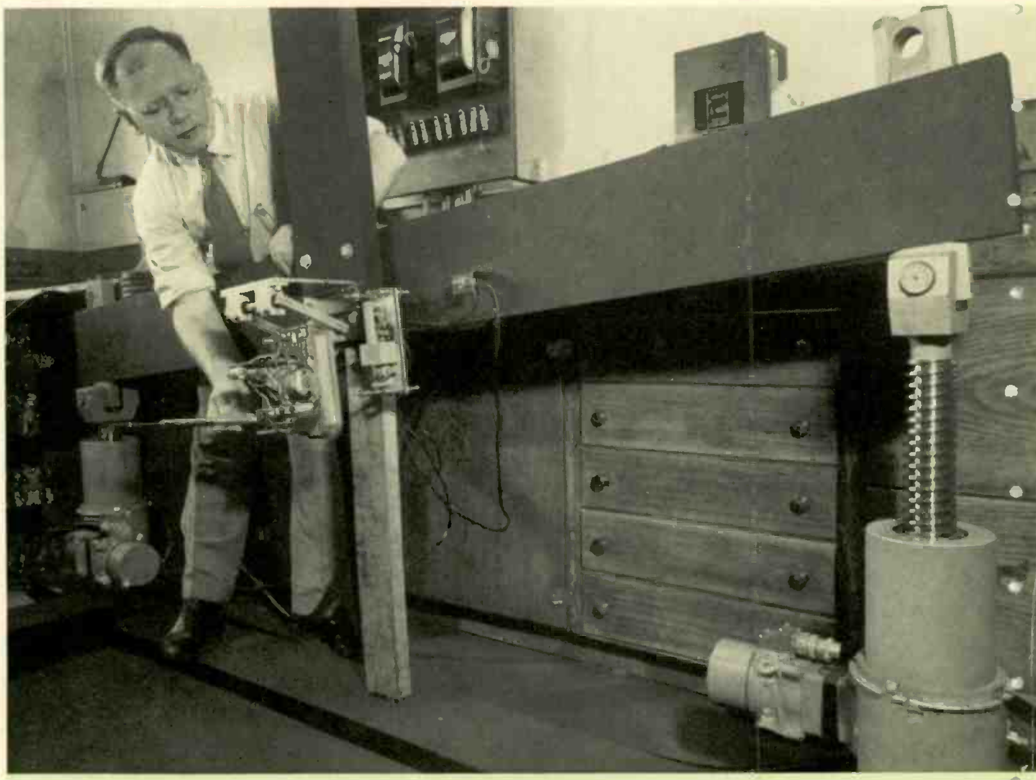
Six power-driven hydraulic shock absorbers—four to handle vertical bumps and two for sidesway—perform the trick of stabilization. A set of sensitive valves with floating weights attached instantly detect the slightest motion of the car body and signal the absorbers to provide just the right force to oppose the motion. In effect, the stabilizer pushes the wheels down into the valleys and raises them over the peaks, while the car body remains relatively motionless. This is a special advantage of the stabilizer because all of the hydraulic power goes to movement of the wheels, helping them up and down and thereby improving traction.

The car tilter consists of a pair of electrically driven screw jacks, mounted between trucks and car body at diagonal ends of the vehicle, and controlled by a small pendulum and gyroscope. When the car rounds a curve that is not correctly banked for the particular speed at which the car is traveling, the pendulum feels gravity and centrifugal force and moves inward or outward to close electrical contacts. This sends a signal to a motor-generator set that provides the power for a variable voltage system, and the jacks are actuated to tilt the car body to the correct bank angle.

This angle is such that the passengers tend to fall inward, because of gravity, with a force that just opposes the outward centrifugal force, enabling them to walk along the car aisle just as easily as if the car were on smooth straight track. A maximum bank of six degrees is provided by the tilter, which can be added to or subtracted from the customary track bank, depending upon the condition to be corrected. Even under the worst conditions—40 percent overspeed, for example—the tilter can bring the car to within less than one degree of perfect equilibrium.

With development of the stabilizer, Westinghouse research men have cut a large swath in the major problem of shock-absorber design: how to control the resonant frequencies of car bodies in motion. At such frequencies, a one-inch irregularity will cause a bounce of several inches in the car body; and if there were no damping, the amplitude of the oscillation would build up until the car would shake itself to pieces. The best shock absorbers are capable of reducing this bounce to about three or four times the road bumps. The new stabilizer brings it down to less than one, an improvement in rideability by a factor of four to one. Thus, the bumps in railroad or bus travel are lessened some 75 percent.

Passenger comfort is the chief objective of the car stabilizer and tilter. But there is also an important economic advantage for railroad and bus lines. Higher speeds will be permissible, with safety and with comfort greatly exceeding present standards. The resulting improved schedules will permit greater traffic over present roads. What's more, the cost of stabilizers is insignificant compared to the cost of re-laying track to make present curves easier for the needed higher speeds.



In a test set-up at the Westinghouse Research Laboratories, S. J. Mikina illustrates the principle of the car tilter. By pressing against a pendulum in the center, Mr. Mikina simulates the centrifugal force that throws a railroad car or bus outward when it rounds a curve. The tilter is teamed up with a stabilizer unit designed to take most of the bounce and sway from vehicles.

Oxidation—Friend or Foe?

If you take a handful of microscopically divided iron particles and expose them to air, they will instantly burst into flame. But if the same iron particles are compressed into a solid block, oxidation of the metal will be slowed down to a minute fraction of its former rate.

Therein lies the heart of a problem that chemists would like very much to solve. Nearly all elements are unstable and are ceaselessly combining with oxygen in the air, with the release of unrecoverable energy. The reason that this union is not sudden and explosive is bound up in the protective action of an oxide film—only a few molecules thick—which slows down further oxidation enormously.

The nature and behavior of that film is of great importance, not only to the fundamental research man but also to the engineer concerned with the development of high-temperature alloys. A piece of metal exposed to air at room temperature will oxidize rapidly in the first few minutes, but as the film is formed, the rate will level off to a negligible rise. At high temperatures, however, the rate of reaction is stepped up greatly; with tungsten it goes ten times faster with every 100-degree C increase in temperature. At such temperatures, corrosion becomes a critical problem.

Doctors E. A. Gulbransen and J. W. Hickman of the Westinghouse Research Laboratories are looking for the answers in the atomic structure and behavior of the oxide film itself. With an electron microscope they are able to get a picture of the physical structure of the film. An electron diffraction camera provides an insight into the film's chemical nature, while a highly sensitive microbalance enables the scientists to measure the rate at which particular metals oxidize. A considerable amount of data has resulted on the structure and behavior of oxide films over a wide range of temperature, which one day may yield secrets of great importance to the metallurgist and to designers of high-temperature equipment.

Recently the two men tackled the problem of oxide films on molybdenum. With a melting point of 4748 degrees F (iron, 2800; copper, 1976) and great wear resistance at high temperatures, molybdenum is rapidly becoming important as a structural material, especially since methods have been found to produce it in large and complex shapes.

But, although the melting point of molybdenum is very high, its normal oxide (MoO_3) melts at the relatively low temperature of 1460 degrees F. By comparison, the oxide of aluminum doesn't melt until the temperature reaches around 3720. As a result, the protective film on molybdenum disappears around 1460 degrees F, and the metal becomes an easy prey for corrosion.

An interesting and significant phenomenon was noted by the two men in their studies. A sample of molybdenum was placed in the microbalance in a vacuum with the temperature around 1800 F. Then a tiny quantity of oxygen was added. Immediately the oxide MoO_3 was formed, which, being very volatile, began to vaporize rapidly. Next the oxygen was reduced to virtually zero. A new oxide, MoO_2, was formed which gave a very protective film. If a way could be found to make this highly protective oxide stable in the presence of air (it now breaks down rapidly in normal air to form MoO_3), a major step in the development of oxidation-resistant molybdenum would be taken.

In their all-out attack on the basic causes of rust and corrosion, the two men have taken some 15 000 diffraction patterns, several thousand electron microphotographs, and about 1500 rate measurements. With such exhaustive data, the likelihood of finding the right combination of facts becomes increasingly greater.

Photoelastic Resins Grow Up

The study of "frozen stresses" is a valuable tool in the kit of the mechanical research engineer. Take a plastic model of a crane hook, heat it to about the boiling point of water, apply a load, and then cool gradually to room temperature. When viewed through polarized light, the plastic replica will show vividly the location, direction, and magnitude of the stresses—vital information to the designer of industrial equipment.

One stumbling block to researchers in this field, however, has been the limitation on the size of plastic models. The resin ordinarily used cannot be produced in pieces thicker than 1⅛ inches, and this is a definite handicap to three-dimensional stress studies where thin sections must be removed for examination.

Westinghouse research engineers, H. F. Minter and M. M. Leven, have the answer to this problem with perfection of a photoelastic resin piece six inches in diameter and three feet long. With a newly developed technique, they believe they can produce sizes and shapes suitable for any kind of three-dimensional study. The resin is a member of the Fosterite family—the moisture-proofing plastic widely used during the war for protecting radar components. Not only is the resin suitable for casting in large sizes, but it is also 35 percent more optically sensitive for "frozen stress" measurements than the standard material. This means that more stress lines are presented for examination, and the analysis is correspondingly more accurate. In addition, the Fosterite replica doesn't fade in usefulness with time. The standard material must be used from two to three hours after machining; otherwise stresses develop along the edges of the sample that seriously hamper precision studies. Fosterite pieces, on the other hand, show no stresses even after a month following machining.

A still further advantage of the new photoelastic resin is the shortness of the curing period. From two to three years are required to cure the standard material, whereas Minter and Leven were able to produce the large cylindrical piece in about a month.

Although a simple process, the newly developed technique required months of painstaking research. The Fosterite is poured into an evacuated glass mold, which is then made vapor-tight and placed in a water bath at sub-ambient temperatures that vary with the size of the piece. The temperature is raised gradually to about 100 degrees F, after which it is removed from the bath and baked in an oven. Reason for the water bath is that Fosterite resins, in the transition from liquid to solid, give off tremendous quantities of heat, which if released suddenly would create stresses and cracks in the solid piece and destroy its usefulness as a test material. The bath slows down this heat release to a point where the cured piece is essentially free of stresses.

The new resin and its associated technique of production should provide researchers in the photoelastic field with a much more useful material for "frozen stress" determinations, one that lends itself to more precise studies, and that can be turned out faster and in larger quantities.

A new "king-size" photoelastic resin piece, six inches thick and three feet long, is demonstrated by M. M. Leven of the Westinghouse Research Laboratories. Many times larger than the standard resin sample shown beside it—the latter is limited to thicknesses of 1⅛ inches—the new resin permits photoelasticians greater freedom and accuracy in their study of three-dimensional stress patterns.

Mention in these pages recently of two high-temperature lubricants evidently touched a widespread need. Although the discussion frankly stated these two materials were definitely in the experimental stages, the interest manifested by letters was astonishing. While much is yet to be learned about the new lubricants, the magnitude of interest suggests the desirability of setting forth the essence of what is known—both favorable and unfavorable—about them. Both materials have merit, but they cannot be considered panaceas for all high-temperature lubrication problems.

Two Heat-Resisting Lubricants

G. L. Sumner • *Materials Engineering Department* • *Westinghouse Electric Corporation*

Two materials are having interesting applications as high-temperature lubricants. One is molybdenum sulphide; the other is boron nitride. They are as different chemically as they are in appearance—one is black; the other, white—but both have achieved the same success alone and in combination with other materials in offering solutions to specific, stubborn problems of lubrication of moving parts subjected to elevated temperatures.

Molybdenum Sulphide

Molybdenum sulphide, frequently referred to as "moly sulphide," is a mined product refined by oil flotation and marketed as a finely divided black powder. In this state it contains inherent abrasive materials, mostly silicious, which must be removed by a special treatment. It also contains other impurities such as poly-sulphides, oxides, acid-soluble salts, free sulphur, and varying amounts of the flotation oils, which require special and careful processing for removal.

This dry, refined powder exhibits remarkable properties in reducing the friction of moving steel parts, particularly at high temperature where ordinary lubricants such as oils and greases rapidly oxidize and fail to provide lubrication, and where heavy pressure is brought to bear on small areas such as in the lubrication of center stocks in machining operations. It has also been effective as an experimental dry lubricant of ball bearings. Favorable results have been obtained in tests under both normal and high-temperature conditions by impregnating, or, perhaps better, coating the surface by rolling the balls and retainers in the dry powder. Naturally, the bearings lubricated in this manner are noisy, in view of the absence of a cushion of oil or grease to deaden the sound. Considerable reduction in noise is obtainable through the use of Micarta retainers.

Molybdenum sulphide can also be used effectively in combination with other materials such as mineral oils, various kinds and types of grease, and with synthetic lubricants such as those of silicone base. In such combinations the material with which it is mixed can either be used to coat the metallic surfaces with "moly" or the vehicle may contribute to lubrication by its inherent oiliness.

The mechanics of how "moly" functions as a lubricant cannot as yet be fully explained. One theory is that of layer lubrication. Lubricating-oil films that prevent metal-to-metal contact between moving parts, to be effective must have the property of adherence, wetting ability or "oiliness." Also the uneven surfaces of the metals are thought to provide small pits or walls that aid in the retention of the oil, thereby furnishing minute oil cups for feeding oil to the high points or rubbing surfaces of the metal. This is particularly true on freshly machined surfaces. When these high points are worn off to smoothness, reflected in low profilemeter readings in microinches, the capacity to retain pools of oil in these oil cups decreases, but by this time the need for a high degree of oil retention has also decreased. Also, probably the pores of the metal have absorbed oil, which aids in supplying a film when the small oil cup reservoirs are depleted. This is particularly true with cast iron or sintered products.

The particles of the rectified and refined molybdenum-sulphide powder are so small that they offer large surface area for contact with the surfaces of other materials. When the powder is rubbed on a freshly cleaned steel surface and the excess shaken off, it can be seen even with the naked eye that the area where the "moly" has contacted the steel has darkened in color and that the steel has apparently retained something from this union that is not readily removed by rubbing with a clean cloth.

Further experiments indicate that this layer of molybdenum sulphide provides a cushion when applied on steel to steel, which aids in reducing the friction on moving parts, much in the same manner as an oil film but apparently not to the same degree. However, it has an advantage over the oil film in that it does not thin out with heat, and it is largely for this reason, and because it does not appear to become readily oxidized at even relatively high temperatures, that it offers possibilities for improvement in stability for high-temperature applications. In certain applications, when oils or other lubricants won't stay put, and where high temperatures obtain (even up to several hundred degrees F), it appears that molybdenum-sulphide powder will fill a long felt need.

Additional experiments have indicated the usefulness of molybdenum-sulphide powder in combination with lubricating oils covering ranges in viscosities from 50 seconds at 100 degrees F in the light oils to heavy-bodied oils having viscosities up to 200 seconds at 210 degrees F or higher. With light oils particularly, the powder tends to settle so that agitation just prior to use is desirable—like the medicine label which reads "shake well before using."

Molybdenum sulphide has sometimes been used suspended in a solvent, such as mineral spirits, whereby the solvent evaporates and leaves the "moly" deposited on the bearing surfaces. This means of application is not normally recommended because of the tendency for oil and powder to separate and also because the solvent offers a fire hazard.

Molybdenum-sulphide powder has also been found effective in the lubrication of chains on conveyors operating in ovens and elsewhere at temperatures up to several hundred degrees F when applied by means of a "puff can" or spray gun. However, this dusting-on method is wasteful unless the excess or non-adhering portion is caught for reuse. In this application, the higher cost of molybdenum sulphide as compared with other lubricants may be justified because of its resistance to oxidation at these high temperatures. Also its non-carbonizing properties and its ability to reduce labor costs materially due to a substantial decrease in lubrication schedules are in its economic favor. Another advantage is that it does not appear to build up a non-lubricating film or coating under these high temperatures that requires removal before adequate lubrication may be obtained. Apparently, addition of more powder is all that is necessary for uninterrupted service.

Molybdenum sulphide can be suspended in water by emulsifying gums and chemicals and applied by brushing or spraying. In this form, where moisture is present, there has been some evidence of tendency for corrosion, which even the use of protective chemicals has failed to eliminate completely. However, the temperatures in hot-chain applications should readily evaporate moisture so that danger from corrosion is greatly reduced if not completely eliminated. This method of application should be economical unless the materials being carried on the chain conveyor are subject to contamination with, or are affected by the vapors.

Boron Nitride

In contrast to "moly," boron-nitride lubricant is a light, fluffy white powder, which was first produced as a by-product in the manufacture of ignitors for ignitron rectifiers. It was often referred to as white graphite, because it felt slippery to the touch. It is now produced synthetically, primarily for use in the manufacture of ignitors, but in only relatively small amounts because manufacture is very slow, laborious, and requires very high temperatures (1900–2000 degrees C).

Its use as a powder without a vehicle or binder is almost prohibitive because of cost. However, in combination with other lubricants in the amount of 5 to 25 percent or even higher, its cost can be justified in certain applications. However, the use of boron nitride as a high-temperature lubricant (it is very doubtful if its use could be justified in low- or medium-temperature work) is still definitely in the experimental stage of development.

Color does not distinguish a high-temperature lubricant. Molybdenum sulphide is silvery black; boron nitride is white as chalk. Both have promising futures as high-temperature lubricants.

Boron nitride, because it is the product of the arc furnace, obviously should be able to remain unchanged for an almost indefinite period in high temperatures. However, this white powder does not appear to have the property of forming a layer of film on metal similar to molybdenum sulphide and experiments confirm the thought that it can best be used in combination with some other lubricating material.

The most logical combination would be with a material which had at least some inherent lubricating properties as well as stability at high temperatures. This led to the trial with silicone bases which thus far seem to be best suited for incorporation with boron-nitride powder.

Combinations of molybdenum sulphide, boron nitride, and silicone bases are also possible, though the relative merits of lubricants in varying percentages have not yet been properly evaluated. It is doubtful whether improvement in lubricating properties over straight silicone-boron nitride combinations can be effected, although some cost reduction in favor of molybdenum-sulphide methods is possible.

One of the main reasons why boron nitride has not been extensively used as a high-temperature lubricant is its high cost. As manufactured at present it costs nearly $100 a pound —an exorbitant figure for a lubricant. This cost might be greatly reduced if the demand were sufficient to warrant its manufacture on a production basis. No such demand has yet appeared. Boron nitride will probably not be produced in large quantities in the near future. However, there is always the possibility that the laboratory product of today may be in fairly low-cost production tomorrow.

Availability of Molybdenum Sulphide and Boron Nitride

Several Westinghouse lubricants containing molybdenum sulphide have been in use for the past two or three years. These, together with the material numbers under which they are stocked and the approximate price at which they are available at the present time, are:

1—M8565-3 is a purified molybdenum-sulphide powder useful as a dry lubricant for iron and steel over a fairly wide temperature range. It does not work as satisfactorily in contact with copper and bronze surfaces. The cost at present is about $6.00 per pound.

2—M8577-1 is a grease in which molybdenum sulphide has been incorporated. Experience indicates it is a good lubricant for steel bearings and for the lubrication of machine-tool center stocks. The cost per pound is $2.30.

3—M8532-1 is a high-temperature lubricant containing silicone grease and molybdenum-sulphide powder. It has excellent heat stability at high temperatures. The cost is approximately $12.00 per pound.

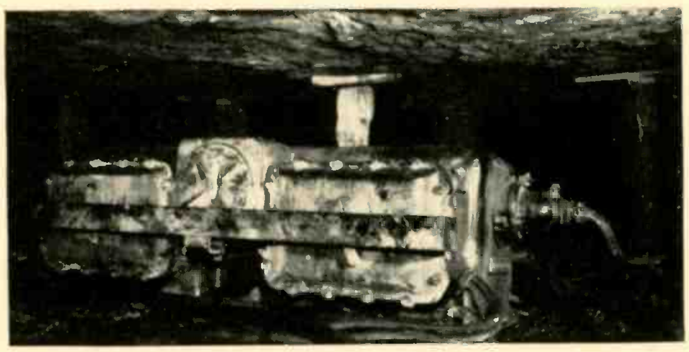
4—M8577-2 is a compound containing molybdenum sulphide in water suspension and is used for mechanisms operating at high temperatures. In this application the water content is evaporated and the molybdenite deposited on the metallic surfaces. However, in contact with water the molybdenum-sulphide powder has shown corrosive tendencies. Efforts to combat this through the addition of protective chemicals have not yet been entirely successful.

5—Boron nitride either as a powder or in combination with other lubricants is not stocked at present.

high at night as during the daytime. As an aid in the fight to reduce night-driving accidents, a new street-lighting luminaire has been designed to direct more light on the road surface and at the same time protect the motorist from glare.

The luminaire is specifically designed for use with a horizontally mounted, 400-watt, mercury-vapor lamp of 20 000-lumen output; it is also being adapted for use with 10 000-lumen mercury lamps and for incandescent lamps. The oval shape is used because of the length of the lamp and makes it possible to utilize approximately 50 percent of the light output as compared to the 27 to 30 percent for present units; this represents an effective increase of 60 percent. Better control of the light plus the use of special glassware makes the refractor appear uniformly luminous when viewed from any angle and results in a source of high candlepower but with a minimum of surface brightness and glare. A minimum amount of heat and light is reflected through the light source itself, resulting in a lower operating temperature of the lamp and a higher maintained efficiency for the luminaire.

The optical system of the new luminaire consists of an aluminum reflector and a glass refractor. The oval shape produces a wide spread of light on the pavement and permits the output from each luminaire to merge with that of adjacent units. This continuous path of pavement brightness ahead of the driver is expected to be an important contribution to driving safety, especially in wet weather. The unit is particularly useful for heavy traffic arteries where high levels of illumination are required.



Cables can be changed easily by a plug-and-receptacle type connector to permit running the shortest length to an installation.

A-C Power Centers Tailored for Mining Service

UNDERGROUND operation imposes a tough set of conditions on electrical apparatus. It must be built so that it can be moved frequently by whatever means available and it must not be readily damaged by falling objects or dripping water, nor create a hazard in explosive atmospheres or wet areas. Its dimensions, particularly the height, are limited.

The growing use of alternating current in mining operations for such machines as cutters, loaders, drills, and conveyors has presented an urgent need for portable a-c power centers designed to meet such conditions. Answering this requirement is a new power center which incorporates a dry-type, three-phase transformer and either two or four explosion-proof, low-voltage circuit breakers. Three transformer ratings, 75, 100, and 150 kva, are available for standard voltages up to 7200 volts primary and 600 volts secondary.

The power centers are compact, standing only 25½ inches high, and are skid mounted to simplify moving them about. They are comparatively light, the dry-type transformer weighing only half as much as a liquid-filled unit of the same rating. The assembly includes a high-voltage plug and receptacle and two or four low-voltage plugs and receptacles, which are interlocked to prevent insertion or withdrawal of the plug when the breaker is closed. A dust-tight and water-tight tap changer permits five-percent adjustment of the secondary voltage.

The high-voltage and low-voltage transformer windings are hermetically sealed in a nitrogen-filled boiler-plate compartment to protect them from moisture, coal dust, or mechanical injury. The nitrogen atmosphere eliminates the possibility of fire and the necessity of inspection, filtration, or reconditioning of liquids. Insulating materials are mainly of inorganic type, such as mica, asbestos, porcelain, glass, silicone, etc. These features and others of the design result in a transformer offering the maximum safety in the severe service attendant to mining operations.

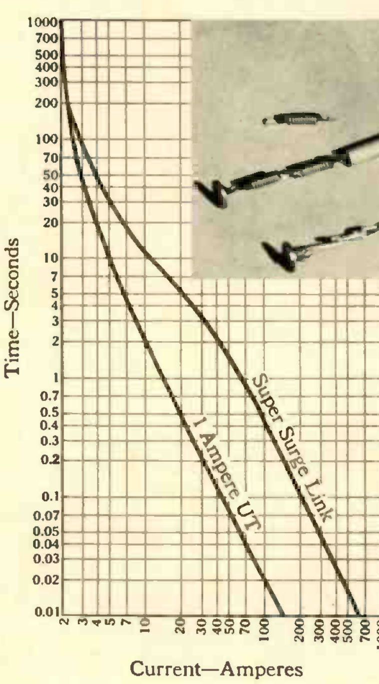
Surge Resisting Fuses

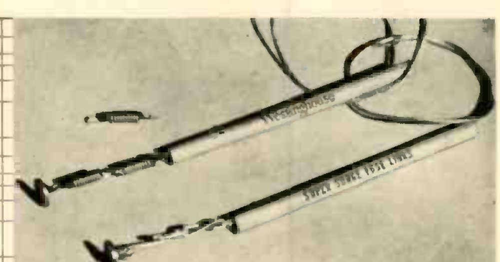
FUSES are simple things. At least in appearance they are. Yet a fuse designed to perform accurately under a variety of conditions may call for a variety of skills in electrical, mechanical, and heat engineering. A new distribution-transformer fuse with the special ability to ignore short lighting-induced surges, or extremely brief high-peak loadings, called in its design for the most careful consideration of heat conductivity and radiation, convection effects, heat-storage ability and other thermal factors in addition to the usual ones of mechanical and electrical adequacy. The result is a fuse link, with blowing characteristics different from the conventional as indicated by the curves. These Super Surge fuses, as they are called, keep transformers in operation during surges or short-time peak-load conditions. If overloads continue beyond the safe thermal capacity of the transformer, the fuses stand ready to operate before trouble develops.

Formerly, fusing practice for small transformers had to be a compromise. If fuses were made large enough to carry harmless lightning surges, they were too large to blow on heavy overloads allowing the transformers to become dangerously overheated. When fuses were installed small enough to protect the transformer against these sustained overloads, lightning surges would blow the fuses and plunge the area into darkness, or safe capacity would be sacrificed during temporary peak loads.

The new Super Surge fuse links have time-current curves matching the American Standards Association's safe thermal loading curves for small distribution transformers. This makes available all the thermal overload characteristics of the modern transformer while a better protective ratio for transformer fusing is obtained. Fuse sizes can be specified closer to the actual full-load current with the assurance that the transformer will continue to function through temporary, harmless peak loads.

The new fuse links are of the universal type for any indicating or non-indicating NEMA standard distribution porcelain or open-type cutout box up to 15-kv rating, and are available in ½-, 1-, 2-, 3-, and 5-ampere sizes in the standard 20-inch lengths.





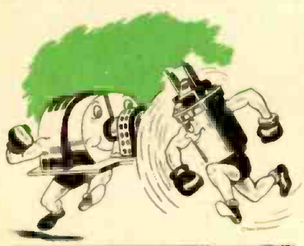
When the solder which holds the assembly together is softened by the current, the springs cause the circuit to break. Equal overload protection is provided up to 200 percent of rating. Increased operating time at higher currents passes the instantaneous surges.

PERSONALITY PROFILES

The career of *H. L. Flatt* as a test engineer dates back to his early experiments with perpetual motion as applied to the family barrel churn on his father's farm in northwest Iowa. Following graduation from Iowa State College in 1926 he entered the test department of the Delco-Light Division of General Motors Corporation, later transferring to the Westinghouse test course in East Pittsburgh where he gained experience in testing control equipment being manufactured for the Navy. Selecting a civil service career as electrical engineer in the Navy Department in 1928, he was placed in charge of the electrical power section of the Material Laboratory, New York Naval Shipyard in 1930. Under his supervision many new and novel testing facilities have been developed for the Navy, the latest addition to the power section of the Material Laboratory being the new high-power test station.

Both *S. A. Haverstick* and *J. D. Gard* had much to do at the Westinghouse end of planning the Navy's high-power test station. Haverstick has been concentrating on application of electrical equipment to marine service almost since the time he joined Westinghouse after graduating from Lehigh with a B.S. in electrical engineering in 1937. Most of his attention has been directed to Diesel-electric vessels such as net tenders, tugs, rescue vessels, and Coast Guard cutters. He followed the accounts of the recent Antarctic expedition with great interest and experienced a fatherly feeling of pride every time some exploit of the ice breaker, *North Wind*, made the papers.

Gard has been busying himself with applications of the many types of switchgear to all manner of industries since about 1930. Before that, and soon after he came with Westinghouse upon graduating from Alabama Polytechnic Institute in 1927 (B.S. in E.E.) he had the interesting experience of helping develop the early talking movies. It made a home-movie addict out of him, too.



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R. W. Moore has, in the eight years since he graduated from the University of Wisconsin, obtained a rather concentrated body of experience with electric motors. He entered the d-c design section of the Motor Division of Westinghouse upon completing the graduate-student course in 1940, at a time when the demand for motors was unprecedented. During the war he assisted in the design of motors for naval vessels, for the electric torpedo, and for mines. Early this year he moved from design to application in the Steel Mill Section, and he has been using his knowledge of motors to good advantage. Of late he has been helping plan the electrification of steel mills to be built in France and South Africa. Moore rounded out his formal engineering training with an M.S. in E.E. from the University of Pittsburgh in 1945.

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Ask *E. W. Beggs* what he has been doing these past several years and he quickly states, "I've had the most interesting career in Westinghouse"—which his record does not refute. His work as a lighting application engineer has brought him in contact with some of the most glamorous of activities. Treasure hunting, for example. Ever since underwater lighting first received publicity in the sinking of the Navy submarine S-51 in 1925, and the United States Navy engineers sent an appeal to Westinghouse for a special lamp, Mr. Beggs has been in intimate touch with every phase of deep-sea activity such as salvaging and treasure-hunting expeditions. He has assisted such explorers as Sir Hubert Wilkins on the occasion of his submarine trip to arctic waters and Simon Lake in his efforts to salvage valuables from the *S. S. Lusitania*.

Having served in the Naval Reserve from June, 1917 to November, 1918 including the Aeronautics Division of the United States Navy, Mr. Beggs was particularly fitted to help solve underwater lighting problems of the Navy.

Other noteworthy lighting activities of Mr. Beggs are: underwater lighting of swimming pools, new railway signal lamps, aviation lamps, and lamps for picture-projection machines. He was active in the development of the new Bi-plane projection lamp, which enables projectors to produce better screen illumination.

Beggs has helped launch many interesting lighting applications. He assisted in lighting the airports for the first experimental flying of airmail at night. He helped develop the first landing lights for airplanes. Beggs was among those who worked with the young movie industry when indoor studios were being introduced. Work on special lamps for underwater lighting of swimming pools brought him in contact with Gertrude Ederle and other famous swimming stars. Lighting at the Chicago and New York World Fairs had much to do with their success; Mr. Beggs helped develop the special mercury-vapor lamps first tried commercially at the New York Fair. Quite a record for a chemical engineer (Cornell, B.Ch., 1919)!

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Chemistry has a big place in production and operation of power equipment, as indicated by the life story of *G. L. Sumner, Sr.* Sumner was graduated from Pennsylvania State College with a B.S. in chemistry in 1914, and the following three years worked as a chemist for the Illinois Steel Company, and later for the National Tube Company. In 1917 he joined Westinghouse as a research chemist. In the years since, his work has largely been concentrated on the development of lubricating oils, the solution of lubrication problems, and the application of cutting oils. He has done a great deal in connection with corrosion, particularly in relation to lubricants. He has been and is active on several national committees for establishing standards in connection with lubricant cutting fluids, etc.

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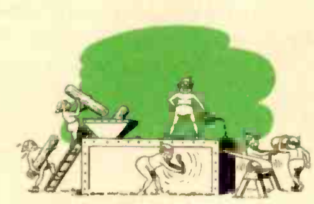
With a veritable flood of demands from pulp and paper mills for turbines, motors, and control for one of the greatest expansion and modernization programs on record for any industry, *R. R. Baker* has wished many times he could pull the needed new equipment out of his hat as readily as he can rabbits. Baker is an amateur magician of no mean skill and has, on occasion, given demonstrations of magic and legerdemain before assembled organizations. A second and quite dissimilar avocation is music. He plays the violin—and well, as those who have heard the KDKA Little Symphony Orchestra can attest. Baker graduated from college—University of Michigan—during World War I in time to work for a while at Westinghouse in the production of rifle grenades and later in



the Army as a Lieutenant in the Ordnance Division. The war over, Baker returned to Westinghouse and worked for a time with generators, starter motors, and cutouts for automobiles. Then in 1921 he began the activity for which he is nationally known—the application of power and electrical apparatus to pulp and paper mills. This work has taken him to most of the mills throughout the United States and even a few in Canada and Mexico.

Stars of Mercury

This picture, in one sense, is a fake. Because true photographic reproductions of lighting installations are all but impossible, the photographer has here achieved a striking effect by taking the picture through a fine screen held close to the camera lens. The scene is in an East Pittsburgh aisle, of the still-experimental 1000-watt mercury lamp. The canopy of the 1-kw lamps, which are 20 percent more efficient than the 400-watt lamp, brings the illumination at working levels to 45 footcandles.