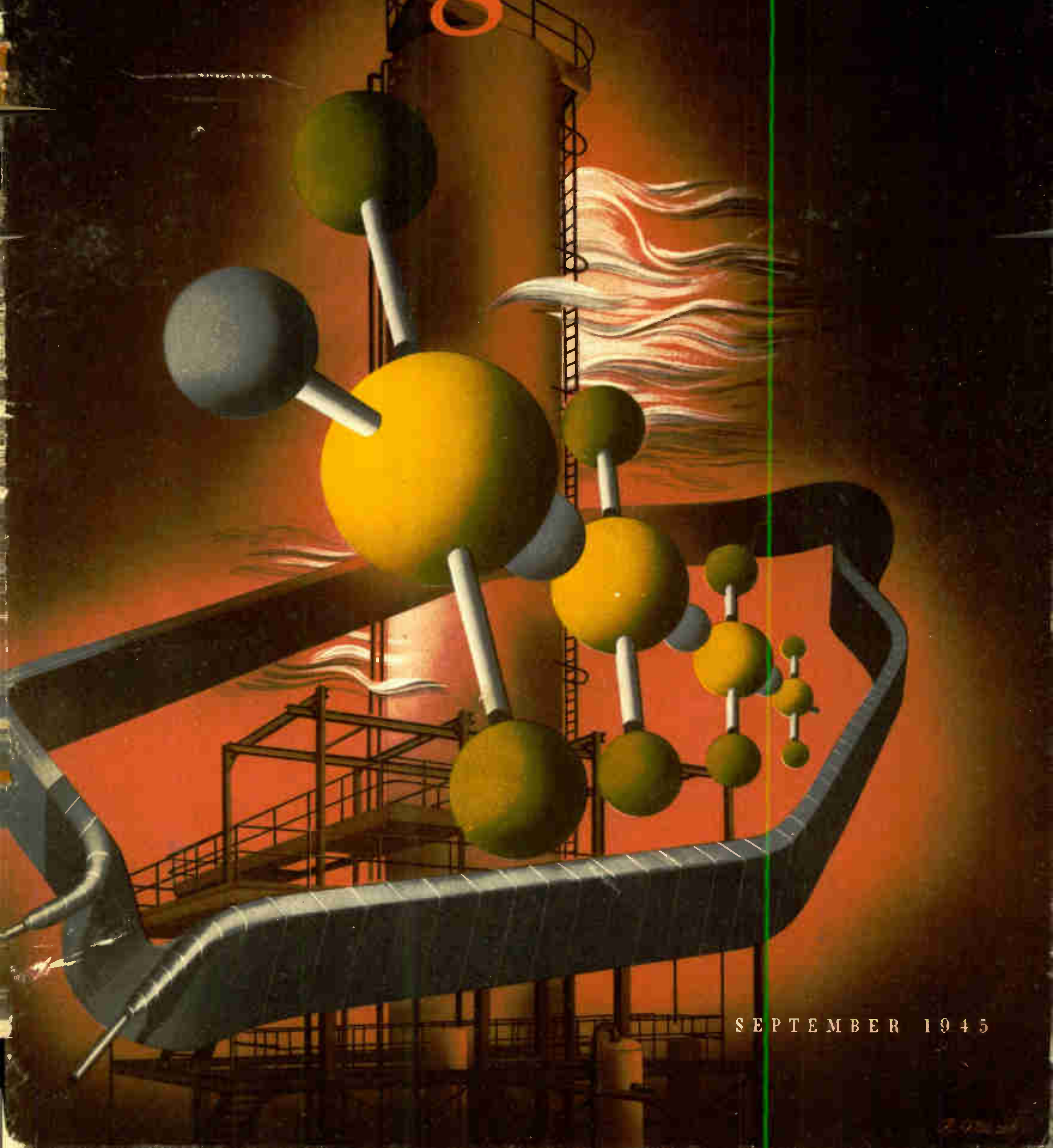
WESTINGHOUSE

Engineer



SEPTEMBER 1945

COMMUTATION—*Complex Phenomenon*

The operation of a direct-current machine is not just a matter of electricity and mechanics. It is chemistry as well. Indispensable to the satisfactory operation of a commutator, as Dr. Elsey points out in this issue, is a thin, lubricating film of cuprous oxide on the copper. Carbon riding on bare copper abrades at an intolerable rate.

This film is dynamic, ever-changing. Each time it passes under a brush the action of heat and electron flow tends to destroy it. On reappearance of the hot copper surface into air, the copper reoxidizes. At any time, the film represents a balance between many factors. If anything disturbs the continual chemical reaction on the commutator surface, causing the extremely thin film to vanish even briefly, trouble lies ahead.

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Numerous common experiences point to the chemical aspects of commutation—and at the same time indicate how sensitive the reactions may be to unsuspected conditions. During a laboratory test on brushes, the contact coefficient of friction had held constant for days. Then some cleaning was done in a far part of the room with carbon tetrachloride. Within five minutes the brush friction had more than doubled. In ten minutes evidence of excessive brush wear was conspicuous and remained for hours.

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Commutator film is extremely thin. It varies from nothing upward. The film on some commutators performing satisfactorily has been found as thin as a millionth of an inch. Films are often ten times thicker. While this minimum film seems small (the Cellophane around a pack of cigarettes is one thousand millionths of an inch thick) it is actually several thousand molecules thick.

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Rather surprising current densities occur under a brush. A carbon brush does not make physical contact with the copper over its entire surface. The carbon surface (and the copper also) is rough. At each instant only a few microscopic peaks of carbon and copper—of the order of 50 to 100 per square inch—are in contact. Research men have determined that the area of carbon actually carrying current is only about one hundredth of one percent of the total brush cross section.

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The current density is usually in the neighborhood of 35 to 50 amperes per square inch of total brush cross section. However, because the actual electron transfer area is so small the current densities of the conducting peaks are in the neighborhood of a few million amperes per square inch.

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Temperatures reached under a brush are known to be extremely high. On occasions they exceed the melting point of copper. The tiny peaks of copper in contact with the carbon get so hot, they soften or melt. When they strike the air again they cool and form glass-hard beads. This roughens the commutator so much that abrasion of the carbons is greatly accelerated.

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When excessive wear of brushes at high altitudes first thrust itself so forcibly upon engineers, it did not seem possible that high brush-face temperatures could have a part in the rapid destruction of the commutator film. How could the temperature be excessive with torrents of air 50 or 60 degrees below zero sweeping over the commutating structure? Tests demonstrated otherwise, however. Brush-face temperatures when at the subzero altitudes may be actually higher than when the machine is operating at the same loading in normal ground atmospheres. The air is so much thinner at 30 000 to 40 000 feet that, although it is colder, its effective value as a coolant is greatly reduced.

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Carbon brushes have been used exclusively for current collection from rotating copper surfaces since 1889, when someone tried an ordinary arc-light carbon in an attempt to find something that worked better than the copper-leaf brushes used up to that time. In fact, the term "brush" is a carryover from those early bundles of thin copper strips that were pressed, brush fashion, against the commutator.

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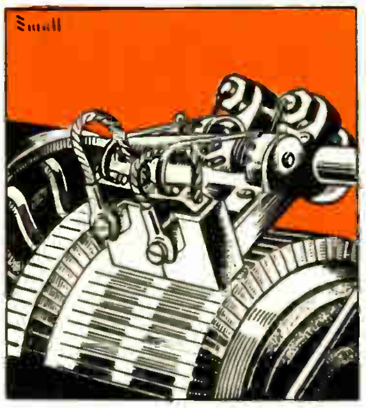
The arc-light carbons worked far better than the copper brush, but, by today's standards, not very well. They were hard, impure, high in friction, and seemingly no two were alike. It was not uncommon in those days to change brushes on a machine two or three times a day. Those old carbons were bought by the barrel at about three cents apiece. Now brush life of less than six months is cause for complaint.



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The early carbon brush was followed by one made of natural graphite which had less friction, higher current-carrying capacity, and was more uniform. However, it is a soft brush. Copper particles and dirt embed themselves readily. The natural graphite brush was superseded to a large degree by a product of the electric furnace. Under great heat, carbon is changed in mechanical structure to something resembling graphite, yet different. It is the electro-graphitic brush in predominant use today. As compared to natural graphite it is stronger, tougher, and harder, has a comparable contact drop, and better friction characteristics. For slip rings and d-c machines that require extremely low contact drop a copper-graphite brush composed of a mixture of copper powder and graphite flour in certain definite proportions is used. Most brushes, however, are of the electro-graphitic type.

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Commutator construction and brush manufacture have improved steadily and, in total, enormously. Commutation problems have mostly ceased to be a matter of commutator "fireworks" or actual machine performance. Instead it is the important but lesser problem of adequate brush wear that now occupies the spotlight.

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The number of carbon grades available by the different manufacturers probably runs into the thousands. This is indicative of the great variety of types of current-collecting machines and their needs. It also indicates that not enough is yet known about what goes on in the microscopically small space between carbon and copper. Brush selection is still often a matter of cut and try. For all the years of research in many laboratories relatively much less is known about commutation than about any of the more tangible components of the machine. The new concepts of commutation produced by Dr. Elsey comprise a long step toward making of commutation a science instead of a "black" art—but only a step.

WESTINGHOUSE

Engineer

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On the Side

The Cover—Silicones, masterpieces of molecule engineering, are discussed at length in this issue. Symbolizing them, the artist combines a 'tinker-toy' model of a portion of one silicone molecule, against a background of a chemical plant where sand, brine, coal, and petroleum are reacted to form the designed structure.

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Biggest Transformer—Under construction for the Philadelphia Electric Company is a transformer of record size. In one tank is a 105 000-kva, three-phase unit and a 30 000-kva reactor. It will be shipped complete (except bushings) in its own tank. Compact size is made possible by modified form-fit, shell-form construction.

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Happy Landings—Superduper of all landing fields planned thus far is New York City's Idlewild Airport. Covering more than 4000 acres, eventually it will have a dozen runways, some of them 12 000 feet long. Immediately, however, there will be three runways, for which most of the lighting equipment has already been purchased, which will incorporate for the first time on a commercial field many improvements produced by the war. Westinghouse, for example, will supply the floodlights, obstacle markers, smoke generators and control equipment for all three runways. For the two runways for which the marker lights have been contracted Westinghouse will supply an experimental "curtain-of-light system." The runway marker lights, or contact lights as they are called, will project beams of light vertically, in addition to the flat ground beam heretofore used. The pilot of an incoming plane will thus land his plane between two unmistakable vertical sheets of white light.

In This Issue

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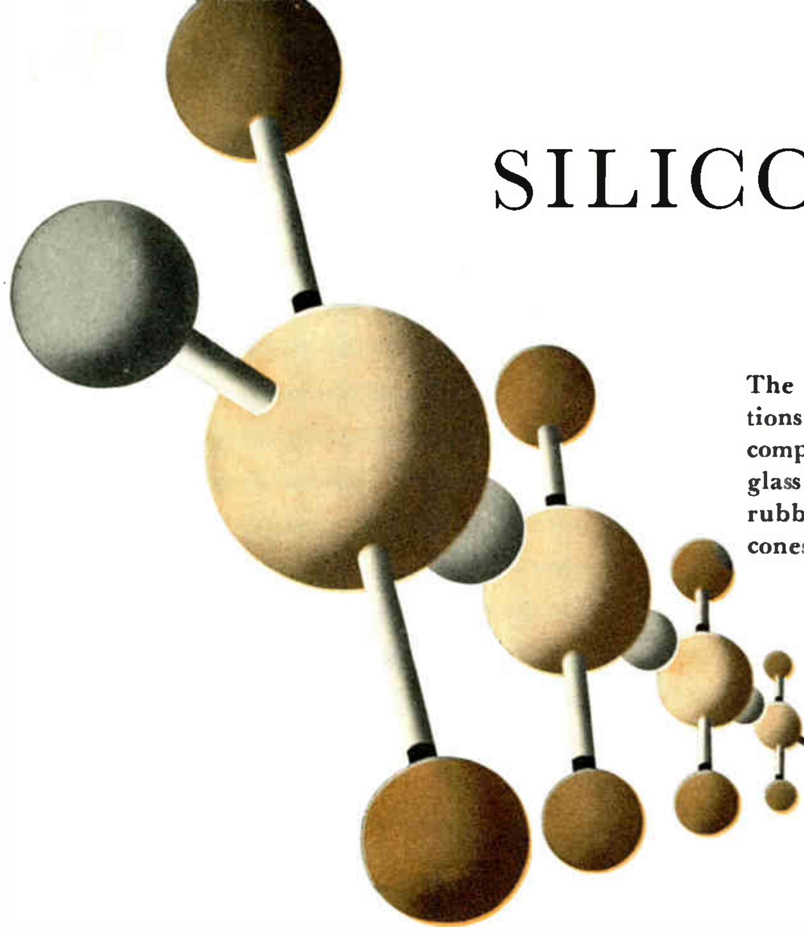

SILICONES—

Miracle of Molecule Engineering

The versatility of silicones! High-temperature electrical insulations; water-resisting surface treatments; anti-corona cable-filling compound; low-temperature lubricant; heat-resisting greases; glass polish; anti-foaming agent; diffusion-pump fluid; heat-stable rubber—these and many more are uses already proven for silicones, superb example of custom-construction of molecules.

The silicones constitute a new continent in the world of materials. The discovery of silicones and of America presents a parallel of striking similarities. Columbus, reasoning boldly from the new theory of the earth's shape, believed India could be reached by sailing westward. But he found America instead. For years explorers sought some way around this obstacle, not perceiving the worth of the new discovery in itself.

Some research work on organo-silicon compounds was done seventy years ago. But these new materials had their real genesis just after the turn of the century, at the hand of Dr. F. S. Kipping, Professor of Chemistry, University of Nottingham, England. This able scientist was intrigued by the similarities of the elements silicon and carbon. Silicon lies in the same group and next to carbon in the periodic table. Both have chemical valences of four, and share other chemical likenesses. Could he, he wondered, as had other chemists before him, make a semi-organic product in which a carbon atom would be replaced by one of silicon? Could he, in short, make silicon analogues of hydrocarbon compounds?

Kipping was indeed successful in making numerous organo-silicon compounds which in chemical language might be termed silico-ketones, but which he shortened to silicones. But, much to his annoyance, the new compounds did not generally display the same physical and chemical properties as their hydro-carbon counterparts. For four decades Kipping and his associates experimented with the organo-silicon compounds, more in the cause of pure science than with any commercial objective. In so doing, he prepared a large number of organo-silicon-oxygen compounds and laid a foundation for building the more complex silicone molecules which were developed by his successors in the field of silicone chemistry.

In this country, during the middle '30's the research scientists of the Corning Glass Works were confronted with an important problem. Glass-fiber insulation had been developed as an entirely new, inorganic, high-temperature electrical insulation. But for complete success it needed a running mate, a varnish or filling compound that was not organic. An insulation comprising an inorganic base but with an organic filler still had many of the temperature weaknesses of organic insulation. Silicone compounds appeared to be the answer because they solidify permanently under heat (i.e. they polymerize)—the very property that troubled Kipping.

Their research, with a definite practical objective in view, had prolific results. From it, not one, but scores of new useful products—all members of the silicone group—have appeared. Silicones, in short, have become the basis for a whole new branch of the chemical industry. Entirely new plants will be required for their production. The first and still the only full-scale plant is that of the Dow Corning Corporation at Midland, Michigan, which began regular production of these new compounds in 1944.

The primary raw material in silicones is sand, modified by chemicals made from brine, coal, and petroleum. The complex chemical steps are performed silently and unseen in that maze of stills, pressure tanks, cookers, and piping characteristic of synthetic chemical plants but which electrical and mechanical engineers regard as a plumbers' paradise. It resembles an oil refinery.

In constructing silicone molecules, the possible combinations of the several variables are virtually infinite (see "Silicone Chemistry in Brief," p. 134.) The total number of possible silicones is any astronomical figure you wish to write down. Several thousand silicones have already been made and studied to various degrees. Exploration of the vast field of silicone chemistry stands now at a point comparable to the charting of the north and south American continents in Balboa's or Magellan's day. Only the outlines of some sections of this new chemical continent have been delineated.

Three Broad Divisions of Silicones

In general there are three interrelated types of silicone products—resins, liquids, and rubber. Two basic properties are common to them all. One is great temperature stability. The other is water resistance.

Not only are silicones useful over a wide range in temperature but they have the very special ability to resist high temperatures. They withstand heat well above that which destroys organic compounds. The reason for the stability of silicones under heat can be set forth simply. It can, indeed, be predicted on a theoretical basis. The silicon-to-oxygen bond in the silicone chain is very strong, which means to say that a relatively large amount of energy (heat) must be applied before the bond is broken. This amount of energy is a known,

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Prepared by Charles A. Scarlott with the cooperation of the executive and technical staffs of Dow Corning Corporation, Dr. R. R. McGregor of Mellon Institute, and the engineers of Westinghouse Electric Corporation.

fixed amount. The amount of energy bonding the silicon to oxygen is 89.3 units (kilocalories per mol). The bonding energy for carbon to carbon is 58.6 units or only two thirds as much.

The second quality common in general to all silicones is water resistance. Some idea of why the silicones resist water can also be had from a consideration of the silicone molecule. It can be thought of as a silicon-oxygen-silicon chain linkage, surrounded by hydrocarbon units. In other words, a silicone presents toward water a hydrocarbon surface similar to paraffin and oil which resist water.

Silicones, as we now know them, were brought into existence by the need in the electrical industry for an impregnating resin capable of withstanding higher temperatures than organic varnishes. That the silicone resins have been outstandingly successful in this regard has been reported.*

The *silicone resins* are produced as a varnish-like liquid, but polymerize to a solid when heated for one to three hours at temperatures of between 220 and 275 degrees F followed by a cure of several hours at 450 to 500 degrees F. The heat causes the resin molecules—already long, chain-like structures—to form many side bonds to adjoining molecules, in all three dimensions. The tangle of bonds between molecules becomes so great that the substance becomes either a brittle or a flexible solid depending upon the constitution of the molecules.

Silicone resins, then, possess the properties sought for high-temperature insulation. They can be applied as a liquid to a fabric of fiber glass or asbestos, filling the interstices. Upon baking they form a permanent impregnant that repels water and resists heat far better than organic varnishes. Other silicone resins have been developed for enameling magnet wire, for bonding fiber board, for bonding mica, and for making other useful forms of electrical insulation.

*See the report on Silicone Insulation Tests on p. 135 of this issue, also the article "Insulation Temperature Limits Increased by New Silicone Resins," G. L. Moses, in the Sept., 1944 issue, p. 138, *Westinghouse ENGINEER*. Also see "Organo-Silicone Compounds for Insulating Electrical Machines," T. A. Kauppi and G. L. Moses, and "The Application of Silicone Resins to Insulation of Electrical Machinery," J. deKiep, L. R. Hill, and G. L. Moses, in *Transactions of the American Institute of Electrical Engineers*, Vol. 64, p. 90 and 94, 1945.

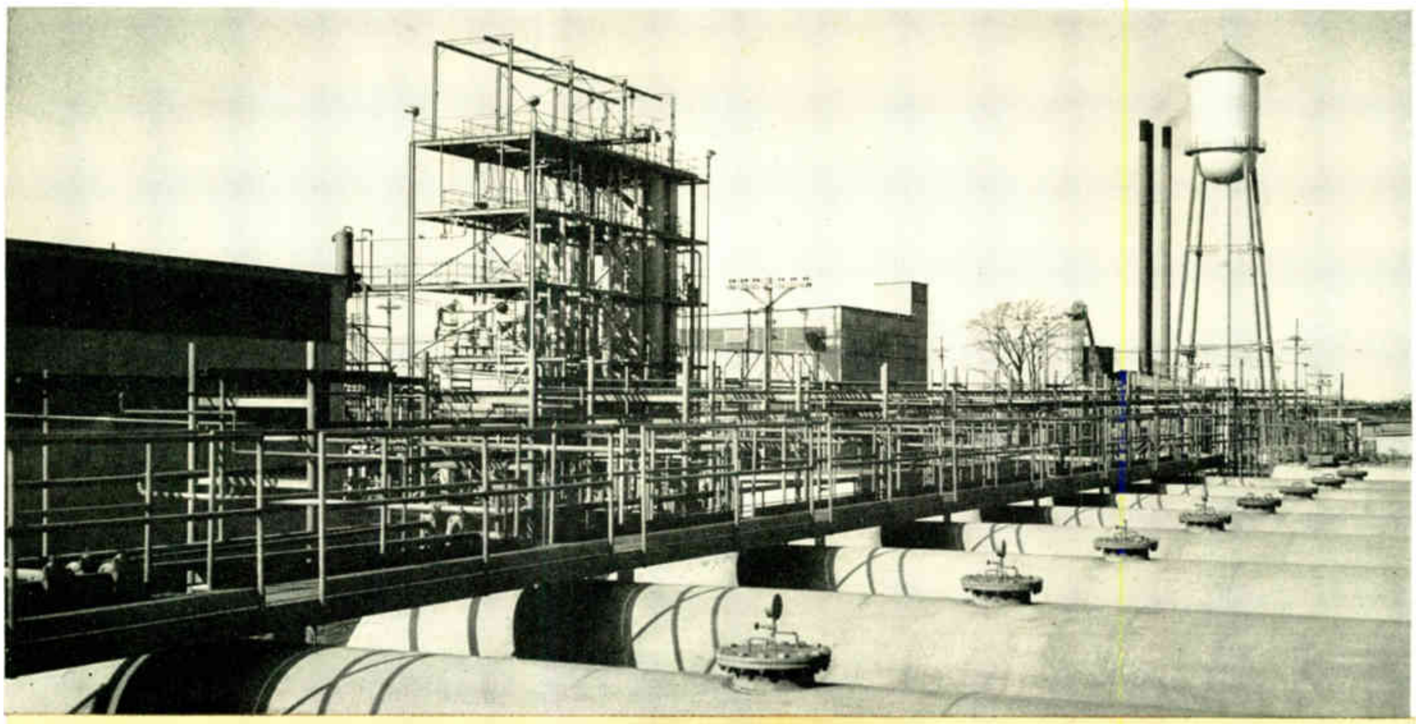
Thermosetting silicone resins have other properties of interest to the electrical engineer. The dielectric strength is good, of the order of 1500 to 2000 volts per mil on thin sections. Likewise on flashover, silicone-bonded inorganic insulation does not track or carbonize. Carbon tracking, common to most organic resins, results in greatly impaired dielectric strength. The dielectric constant of four-mil glass cloth coated with a silicone resin (DC-993) and tested at 25 degrees C and 50 percent relative humidity is 3.5 at 1000 cycles. Its power factor at 1000 cycles is 0.7 percent and its dielectric strength in volts per mil is 1500 to 2000.

The full capabilities of silicone resins, electricalwise, have not been explored. Already, however, they have been used as insulating varnishes, as binders for laminated products useful as slot wedges, switchboards, coil forms, and as wire enamel.

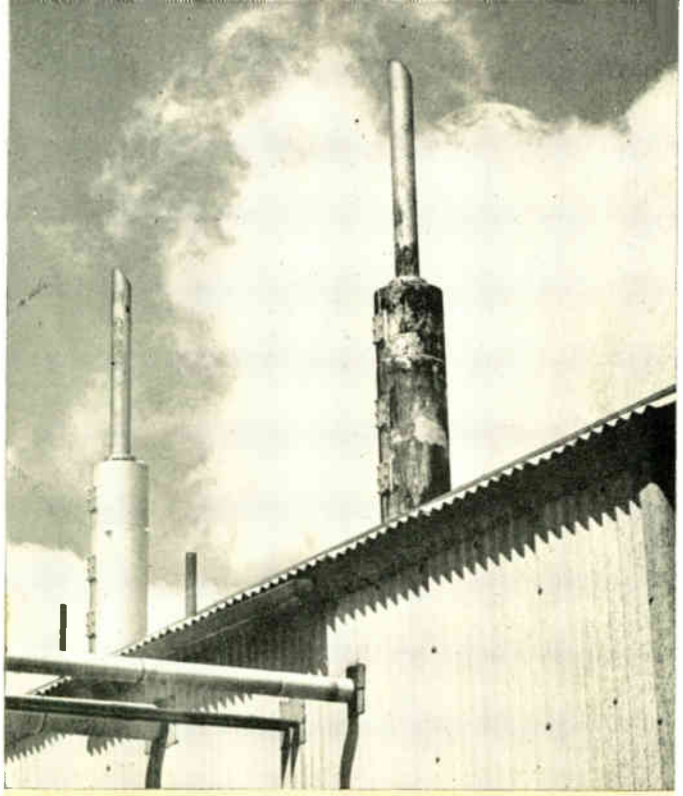
The silicone resins also have interesting non-electrical uses. Two resins have been developed as vehicles for heat-resistant paints for exhaust stacks, flues, hot-air ducts, ovens, etc. For example, the frames of the silicone-insulated test motors had been given the conventional organic-base paints. Because these motors ran at temperatures of 345 degrees F the paint soon peeled off. The frames were repainted with silicone-resin paint and, after hours of high-temperature service, alternating with periods of exposure to saturated atmosphere, show no deterioration. Thin strips of aluminum coated with silicone paint and baked for 24 hours at 480 degrees F can be bent double without cracking the paint. The full matter of silicone paints has not been explored; their future cannot yet be confidently predicted. Suitable pigments, particularly in some colors, as yet present an unsolved problem.

Certain silicone resins also make excellent adhesives for bonding glass and ceramic surfaces. They have a natural affinity for such surfaces and upon heating set to form a bond of great tenacity.

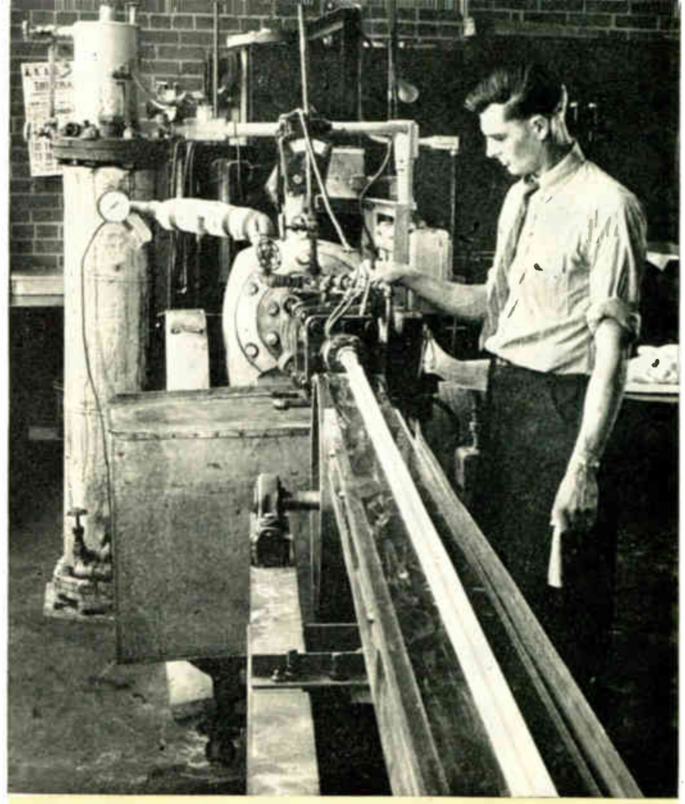
Silicone Fluids—Long-chain silicone molecules without cross-links to adjoining molecules form clear water-white



A silicone "factory" is a quiet place. No machinery moves; few people are about; nothing seems to happen. Within pipes, vats, and stills liquids meet and react. It is molecule engineering at work. Such is this plant at Midland, Mich., built solely for silicones.



These Diesel exhaust stacks tell a dramatic story of the heat stability of silicone. They were painted simultaneously, one with silicone-base paint, the other with ordinary paint.



Silicone rubber emerges from the extrusion in ribbon, tubular, channel, or any other desired form. From its appearance and feel it would easily be taken for natural rubber.

fluids having most unusual properties. Crosslinkages are controlled by the kind and number of hydrocarbon units allowed to combine with the silicon atoms. Control of the length of the molecule gives control of the viscosity over an enormous range. Silicone fluids made up of short-chain molecules are thin and extremely fluid, about like water. On the other hand, if the molecules are allowed to grow to great lengths involving several thousand silicon-oxygen-silicon units before the blocking units are applied, the product becomes so viscous that it more nearly resembles molasses in January. Almost every degree of viscosity in between these extremes is available, which is a useful possibility.

Like other basic types of silicones, the fluids are uncommonly temperature stable. The freezing and boiling points vary with the viscosity. One such fluid with a viscosity almost equal to that of water freezes at about 125 degrees F below zero at atmospheric pressure. Yet it boils at 300 degrees.

Furthermore, the logarithm of the viscosity of silicone fluids varies linearly with temperature and at a very slow rate. The viscosity of most silicone fluids changes much less over a wider temperature range than do the best grades of hydraulic oil.

These properties indicate versatility of the silicone fluids for many uses. Because fluidity is retained at low temperatures, they are of value as hydraulic fluids or lubricants that must operate in extreme cold, as in the Arctic or at high altitudes.

The qualities of silicones as lubricants are still undergoing examination but it appears that they are most suitable for fluid film lubrication where bearing loads are light, as in instruments and other light machines.

Availability of silicone liquids in a wide range of viscosities and their low rate of change of viscosity with temperature make them applicable as damping fluids for precision instruments, dashpots, gauges, and other controls. Temperature stability also makes them candidates for temperature baths and heat-transfer fluids.

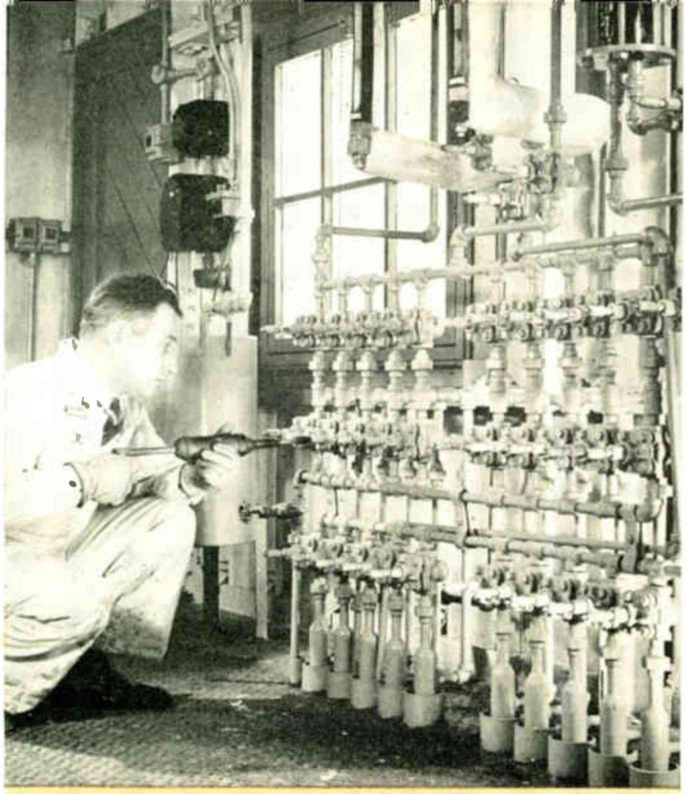
The generic trait of moisture resistance gives these silicone fluids numerous important uses. Applied to ceramic insulators and glass they provide a tenacious film that prevents wetting of the surface. Moisture stands out in droplets instead of spreading to form a film over the surface. This feature is especially valuable on electrical porcelains and glassware to maintain high surface resistivity under moisture condensing conditions. It may even have some advantages as a constituent of a polish for both general-purpose and optical glass.

Silicone fluids can also be used to provide a high degree of water repellency to other than silica-base materials. To these the silicone film may be less adherent because the natural affinity between the silicon and oxygen atoms of the silicone and the silicon and oxygen atoms of glass is not present to improve the bond. However, the film should bring to any substance a degree of protection against moisture. The obvious possibility of application to leather and textiles is intriguing but remains to be thoroughly tested before adequacy, permanency, and practicality are proved.

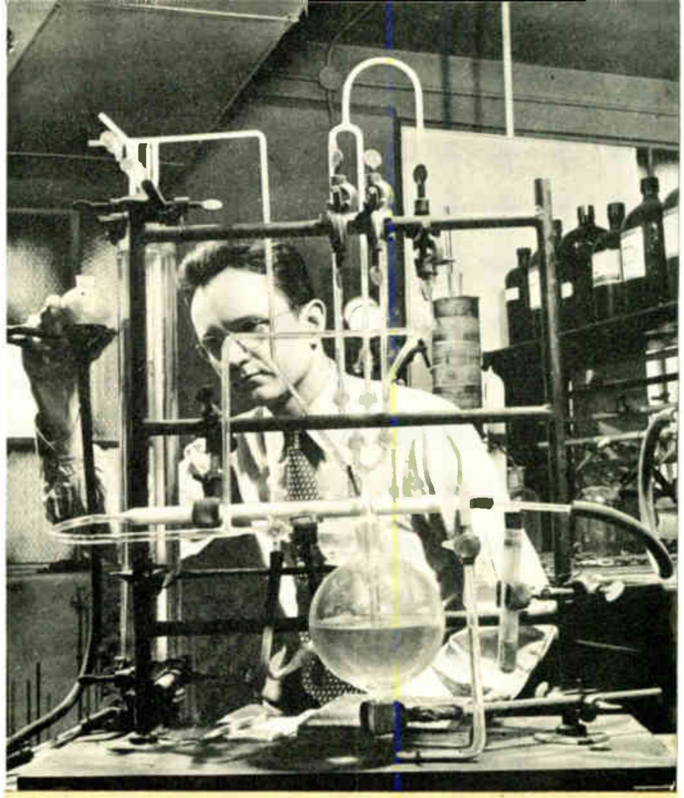
Silicone liquids have a flat or negative meniscus. This makes for accurate reading of level when such liquids are used in sight gauges. Also glass can be treated with silicones to provide a flat meniscus when water is the contained fluid.

Some fluids, particularly lubricating oil, have a tendency to foam badly, which is a great nuisance in recirculating systems, particularly those of Diesel engines. Silicone liquid in minute amount—only a few parts per million of oil—has the faculty of preventing foaming. Just why is not altogether clear. Probably it has something to do with the ability of a silicone fluid to reduce the surface tension of a liquid to which it has been added.

Another use of the fluids that demonstrates the diversity of application has to do with diffusion pumps. These pumps, used to an increasing extent to achieve the extremely low vacuums necessary in many industrial processes, require for their operation a fluid of low viscosity and low vapor pressure. Difficulty has been encountered with oils customarily used because of their tendency to gum when the pumps are opened to the atmosphere. This has necessitated frequent dismantling of the pump and thorough cleaning. Because silicone liquids



In this chemist's switchyard, silicone is a lubricant. Whether the valves control the flow of something hot, cold, or corrosive has little effect on the qualities of the grease.



Born through chemical research, silicones live by the laboratory. Every step of the involved chemical processes producing them must be rigidly checked and carefully controlled.

are chemically stable, they are superior to hydrocarbon compounds as diffusion-pump fluids.

Silicone fluids are a great aid in injection molding. Many molded products have a tendency to adhere to the mold under heat and pressure. Molds coated with a very thin silicone film release the product freely without breakage. This has greatly speeded up production, reduced damaged pieces, and even made possible the molding of some parts that previously could not be produced in presses.

An offshoot of the silicone fluid family is the group of silicone greases and pastes. By proper processing the liquid can be altered to give it the consistency of petrolatum. This grease maintains its consistency throughout the range of temperature from 40 degrees F below zero to 400 above. It is astonishing to observe a simple demonstration of this. A tube of silicone grease is removed from a low-temperature refrigerator and a soft ribbon of grease is easily squeezed into a beaker. Held over a flame the paste shows no change, no inclination to liquefy or melt as petrolatum or ordinary grease would quickly do. Silicone grease is, furthermore, resistant to oxidation, acids, and alkalies. These qualities have led to its use as a lubricant for stop cocks and pressure-lubricated valves.

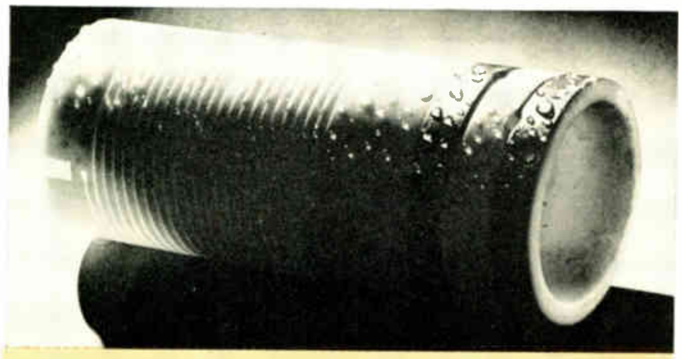
A silicone compound has solved several of the most pressing problems of military aviation. Early in this war, engine failures occurred at a distressing rate because of breakdown of the ignition systems. In the reduced air pressure of high altitudes, corona caused arc-over in the air spaces around the high-voltage ignition cables where they entered the spark-plug well. Some filling substance was urgently needed that would displace the air around these enclosed cables, and that would have high dielectric strength, and would not be decomposed by temperatures up to 400 degrees F. A silicone compound was developed especially for this purpose. More of this ignition sealing compound is used now than all other silicone compounds combined. It is a homogeneous and almost colorless grease or paste. Its consistency is such that it is easily applied to spark-plug wells and other parts of the aviation-engine ignition system.

Not only is this silicone compound moisture resistant and nonhygroscopic, but it makes surfaces of metal, ceramics, or rubber water repellent. It does not harden, crack, or flow at temperatures from —40 degrees to over 400 degrees F. Furthermore, it does not air-dry or harden on baking at elevated temperatures, or after operation in the spark plug well. Most important of all, for the required use, it is a very good dielectric, and its resistance to arcing is excellent. Mainly because of its high electrical resistivity, and because it serves as an excellent means of excluding moisture, the compound has since found other useful applications in radio and radar systems. These properties were found particularly useful in the protection of various disconnectable junctions against moisture during overwater flying.

Silicone Rubber—The third group of silicones looks and behaves like rubber. It has the softness and resiliency of natural rubber, and in addition is unaffected by the high temperatures that cause rubber to disintegrate or the low temperatures that harden rubber. Silicone rubbers retain indefinitely their elasticity and resiliency at temperatures of 300 degrees F and can be used in some places where temperatures reach 500 degrees F.

Because no suitable gasket material has been available, high-power marine searchlights have had to depend on the metal-to-metal fitting of covers. Under the severe conditions of service at sea, these fits do not keep out water, necessitating the carrying of spare dry carbons. These searchlights experience temperatures when not in operation of well below zero. When in service they are heated by the arc which, at the joints, reaches 570 degrees F. Gaskets of silicone rubber have met these rigorous conditions successfully.

Silicone rubber, applied as a coating to wire-wound resistors and glass-fiber tape, provides a heat-resistant surface not wetted by water and having good electrical properties. It makes a superior, flexible, insulating sleeving for wires and cables. Where temperatures are high or low or both it serves well as vibration mountings. Because of this temperature stability and because it does not swell in oil, gasoline,



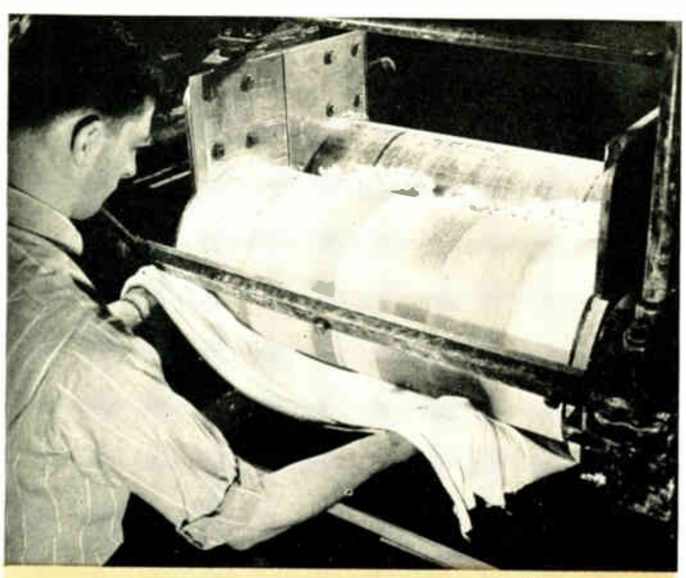
Water refuses to spread in an even covering film on a surface that has been treated with a silicone liquid.

or other hydrocarbons, silicone rubber may make printing-press inking rolls superior to the present ones. It has been used as a protective coating for glass cloth, glass and enameled objects, ceramics, iron, steel, and aluminum.

Silicone rubber is not as yet a general substitute for natural or synthetic rubber and may never be. It is deficient in tension, shear, and abrasion. However, silicone rubber does offer a happy solution to many problems in which a material is required which retains its resiliency and flexibility over a wide temperature range and which resists moisture and oil.

In almost every large human family one individual is different; is a non-conformist to family characteristics, the play boy perhaps. Silicones are not without such a member. It has come to be known as bouncing putty. This "queer" member of the silicone tribe, although long known in the laboratory as a curiosity, has recently achieved considerable public notice—as indeed so often happens in human affairs.

This odd material resists sudden change but flows slowly. It can be pulled like taffy. Laid in a pan it shortly spreads out flat. But, rolled into a ball, it has the astonishing ability of bouncing as readily as one of rubber. While no scientist in his right mind would say that "bouncing putty" will never have more than publicity value, no practical uses have been found for it. It remains a scientific curiosity.



Silicone rubber issues from the masticating rolls as a soft white sheet. Its greatest uses are where heat is a problem.

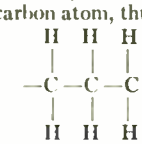
While silicones are much like a newly discovered land there is an essential difference. Any geographical discovery has definite limits. Its contours and extent can be soon charted. The boundaries of silicones, on the other hand, are virtually limitless in extent, infinite in variety. Years will be required to explore just the most useful components of the group.

And further, the development of silicones suggests that other great discoveries in the world of materials may come from the young science of molecule engineering.

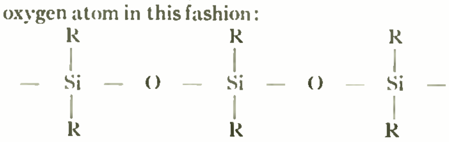
Silicone Chemistry, In Brief

The first step in the manufacture of silicones is the conversion of sand (silicon dioxide) to silicon tetrachloride ($SiCl_4$) through the use of chlorine obtained by the electrolysis of brine. From coal and petroleum are derived several hydrocarbons, such as benzene, methane, and ethane. These are converted to chlorohydrocarbons by reaction with chlorine. One or more of these chlorinated hydrocarbons are reacted with magnesium to form a Grignard reagent which is then combined with the silicon tetrachloride. The product is magnesium chloride (akin to the original brine) and a mixture of organo-silicon chlorides. These organo-silicon chlorides have some hydrocarbon bound directly to the silicon atom in place of one or more of the chlorine atoms originally attached to silicon to form silicon tetrachloride. The hydrocarbon unit may be any one of many possible ones, depending on the nature of the product sought. It may be CH_3 or C_2H_5, for example. In any case it is thought of as a unit and is termed the hydrocarbon radical, or simply *R*. When treated with water, the organo-silicon chlorides react to form hydrochloric acid and organo-silicon oxide condensation products known to chemists as polysiloxanes. These large molecules built upon a silicon-oxygen linkage are the units used in the molecular architecture of the silicones.

These large silicone molecular structures have approximate analogues among the hydrocarbons. But there is an important and essential difference. In the hydrocarbons each carbon atom is linked to an adjoining carbon atom, thus:



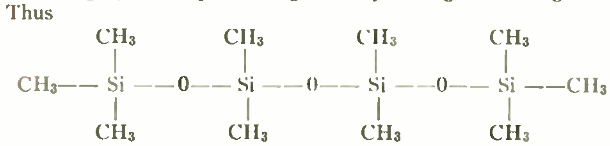
In the silicones, however, each silicon atom is linked to an adjoining oxygen atom in this fashion:



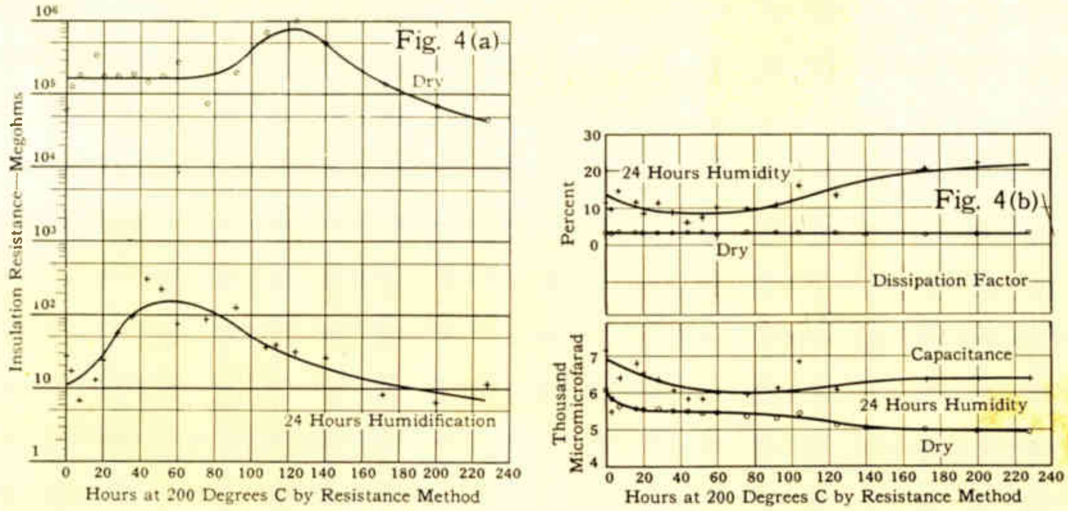
It is this silicon-to-oxygen bond that gives the silicones some of their most valuable properties, as the accompanying text depicts.

The hydrocarbon radical is the only organic component and is bonded directly to the silicon atoms. The resulting silicone is, then, clearly neither organic nor wholly inorganic. It lies midway between the two conventional fields of chemistry and may be termed a semi-inorganic compound. There are many possible hydrocarbon radicals, but CH_3 (methyl), C_2H_5 (ethyl), and C_6H_5 (phenyl) are the more common ones. Choice of a given hydrocarbon unit from among many is one of the several variables available to the silicone molecular engineer.

Another variable in the design of a silicone is the length of the chain. This chain may be only a few silicon-oxygen-silicon links long or thousands of these organo-silicon oxide units may be linked together. Eventually, each molecule must be terminated by a blocking unit, which can be an *R* unit in place of an oxygen atom. The chemist can allow the molecule to grow to almost any desired length, and stop further growth by adding a blocking unit. Thus



Thus we have a straight-chain molecule. However, one chain can be linked to the adjoining molecule by cross links to form a three-dimensional structure. This is still another variable useful to the architect of silicone molecules.



Figs. 4 (a) and (b)—Class-B insulation resistance at first increases but as the test progresses, both wet and dry insulation resistance decreases while the dissipation factor increases. This might indicate that the motor is nearing failure. Capacitance readings are shown, but on these tests are not particularly indicative of the insulation condition.

tory tests. While no serious faults were found in the HTS insulation system, there were indications which led to the manufacture of an improved silicone resin, DC-993, and to changes in some of the insulation components.

The Motor-Test Program

The principal objectives of the cooperative Westinghouse-Dow Corning test program on actual motors were:

1—To determine the relation between operating temperature and life for silicone insulation between 200 and 300 degrees C (392 to 572 degrees F). Given sufficient test points in this temperature range, reasonably accurate extrapolation both to lower and higher temperatures should be obtainable with assurance.

2—To obtain a comparison between the behavior of class-A, class-B, and silicone motors when subjected to the same type of test cycle.

3—To observe the cause of motor failure under accelerated test conditions, and to attempt to correlate the behavior of the insulation in motors with various types of laboratory tests on insulation components. If one or more laboratory tests could be found to correlate with the behavior of insulation in actual motors, then varnish and insulation development would be greatly simplified.

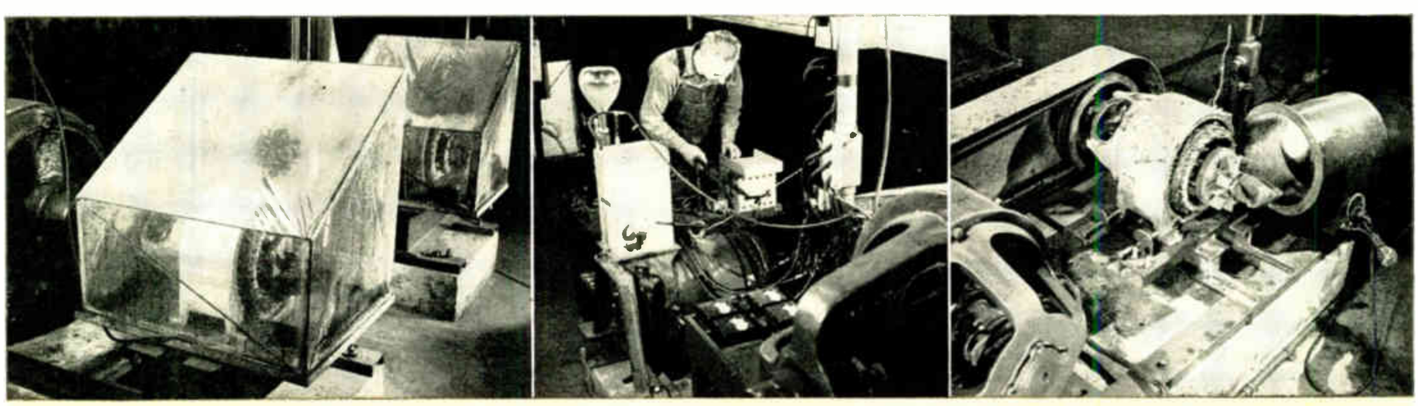
The fundamental concept followed in these motor tests is that if a motor continues to operate while thoroughly wet with water, and if the moistureproofness of the insulation (as measured by electrical properties of the wet insulation) does not change, the motor must be in good condition. It was thought that continued operation of the motors at high temperature would produce a sudden change in moistureproofness. If so, this point could be considered the "minimum life" of the insulation.*

The life of silicone insulation on motors was predicted, as shown in Fig. 1, but no attempt was made to distinguish between maximum and minimum life. The line showing the relationship of estimated life to temperature was based on a point of 5000 hours at 240 degrees C, which seemed to be a reasonable expectation from the behavior of a few of the early motors. This line represents a reduction of the expected life by one half for each 12-degrees C increase in temperature, because this is a conservative procedure when extrapolating from high-temperature tests to lower temperature operation.

Test Results to Date

The present status of the test motors is summarized in table I. It shows the number of cycles of heat and humidity completed, the actual hours at high temperature, and the calculated equivalent time at 160 degrees corresponding to the test time at the higher temperature.

*A discussion of minimum and maximum life of electrical insulation is contained in "Synthetic Insulation and the 10-degree Rule," G. L. Moses, *Westinghouse ENGINEER*, July, 1945, p. 106.



The three methods of insulation humidification are shown: First is a moistureproof tent enclosing a pan of water. In the second, air is bubbled through a bath of water and guided into the motor air intake while the air outlet is sealed. Last is a watertight end bell with a depression for a pool of water. The water is kept warmed to 5 to 10 degrees C above room ambient at all times.

The Silicone-Insulated Motors and the Test Procedure

For the aging tests of silicone insulation both alternating- and direct-current motors were chosen.

Induction Motors

The a-c motors selected for test were standard 440-volt, totally enclosed machines, modified only to place the bearings considerably farther than usual from the windings. Special provisions were used to keep the bearings cool. Bearings are, of course, an essential part of a motor, and they must be considered in any prediction of overall motor performance. However, insulation tests and bearing tests must be performed independently, so that the two types of test do not interfere.

The induction motors are rated at 10 hp, 3 phase, 60 cycles, 1140 rpm, 440 volts. The frame (number 284) is a totally enclosed type, and the brackets are the wound-rotor type of open construction. Each bracket carries an asbestos heat shield one inch thick instead of the normal air shield. The shaft carries matching, rotating heat shields of asbestos. With this and special bearing-cooling construction actual tests showed that the windings must reach a temperature above 450 degrees C to produce a bearing temperature even as much as 100 degrees.

The insulation of the stator windings is as follows:

The coils were mush wound using double glass-covered wire treated with silicone resin (DC-993). The slot cells were made from a 0.026-inch thick combination material consisting of 0.010 inch glass cloth and mica treated and bonded with DC-993 silicone. The phase insulation was cut from 0.010-inch thick combination material consisting of glass cloth and mica, treated and bonded with DC-993. The glass cloth used was silicone-treated. The center wedge was made from the same material as the slot cell. The top wedge was made from asbestos-cloth, laminated-phenolic Micarta. Untreated glass tape was applied to the end turns from iron to iron. All connections were covered with a flexible glass-and-mica tape, silicone treated, over which was applied an untreated glass tape.

The wound stators were prebaked and vacuum and pressure impregnated with DC-993 varnish at 70 percent solids. They were then given multiple dips in silicone varnish having a viscosity of 50 to 70 seconds and approximately 60 percent solids. Each dip was followed by a bake at 250 degrees C.

Railway Motor

To broaden the scope of the testing, a railway motor was included in the program because it differs from small induction motors in many respects. In addition to the purely mechanical differences between d-c and a-c motors, the insulation is applied differently. Perhaps the temperature gradients involved might produce some variations in insulation behavior.

The test railway motor is the one used on standardized P.C.C. streetcars (Westinghouse type 1432-D). The general motor design was identical to the standard production models, to which silicone insulation was applied as follows:

Armature Coil Conductors were 0.144-inch square wire, glass-covered and treated with silicone varnish (DC-990-A). Ground insulation consisted of 2½ turns of glass-backed mica wrapper 0.008-inch thick. The glass cloth was silicone varnish sized and a silicone bond was used. Binder tape was fiber-glass, sized with silicone varnish (DC-990-A). The coils were vacuum and pressure impregnated with silicone varnish at 70 percent solids (DC-990-A).

Main and Commutating Field Coils were made of strap conductors, separated by a single thickness of glass-backed mica tape 0.007-inch thick (silicone backed and sized). Ground insulation consisted of two half-lapped layers of thick glass-backed mica tape (0.007-inch thick silicone bonded and sized.) Binder tape was fiber-glass sized with DC-990-A. These coils were vacuum and pressure impregnated with DC-990-A at 70 percent solids.

Insulation details for winding the armature were made of glass-backed mica and asbestos-cloth, silicone sized and bonded. For slot wedges the best available grade of asbestos-cloth, laminated-phenolic Micarta was employed. Coils were soldered in the commutator necks with high melting solder (304 degrees C, solidus temperature for extra protection).

Both armature and stator were dipped twice in DC-990-A silicone varnish (at 50 percent solids.) Subsequently, after preliminary testing, an additional dip and bake was applied to both armature and stator.

The commutator was insulated with mica bonded with a high-temperature synthetic shellac substitute. The bars were made of silver-bearing, hard-drawn copper to avoid softening during the high-temperature bake or during operation. During all baking cycles the commutator nut was loosened to relieve the vee binding from pressure strains.

Test Procedure

The tests as carried out in this program are conducted as follows:

Preliminary

a—A low-temperature standardizing run of 48 hours at 130 to 140 degrees C is made to arrive at a dry condition. Upon cooling from this run the insulation resistance, capacitance, and dissipation factor are taken at intervals of 20 degrees C.

b—Within 12 hours of stopping run *a* the motor is placed under humidification for a period of one week. Daily readings of insulation resistance, capacitance, and dissipation factor are made and a high-potential test of rated voltage 60 cycle is applied for five minutes between windings and frame.

c—At the end of humidification the three quantities are again read within five minutes of removal from humidification. The high potential test is again applied. Within 15 minutes of the end of humidification the motor is run at full rated voltage, no load, for five minutes. Following this, insulation resistance, capacitance, and dissipation factor are measured and the standard high-potential test repeated once more.

d—The motor is then put on a drying run in which the temperature goes up to 100 degrees C in the first 1½ hours and to 130 to 140 degrees C in six hours. This temperature is maintained for eight to twelve hours.

e—If the test temperature exceeds the baking temperature of 250 degrees C a break-in run is made. This consists of taking the motor up to 250 degrees C by overloading and then setting load so that the temperature increases at the rate of 10 degrees C per hour till the test temperature is reached. This break-in time is evaluated on the basis of the twelve-degree rule. The twelve-degree rule is based on the assumption that the life of silicone insulation is halved with each successive increment of rise in temperature of 12 degrees C. This accumulated time is counted in on the time of the first heat run.

Heat Run

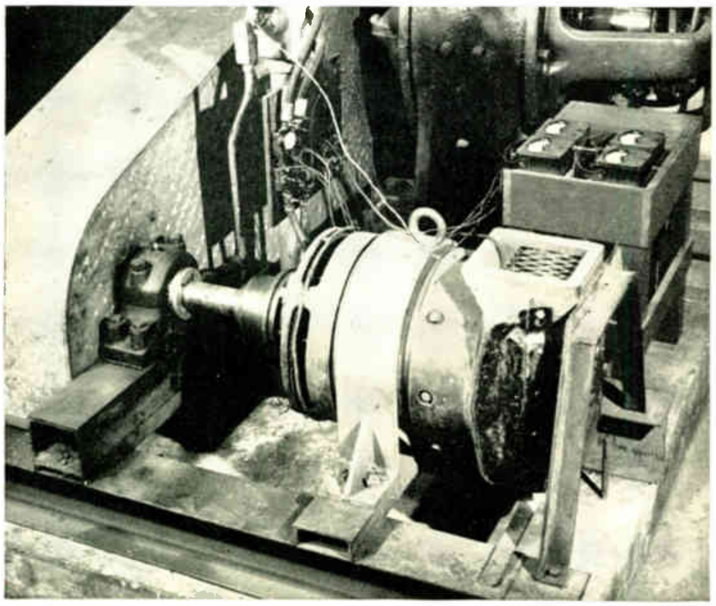
On the heat run, the test temperature is attained as quickly as possible by overloading. In the interests of testing standardization, the duration of heat runs is based on the premise that the life of silicone insulation is 5000 hours when operated at a temperature of 240 degrees C. The total length of the run at any other temperature is determined by the twelve-degree rule using 5000 hours at 240 degrees C as the base. For instance if the test temperature were to be 264 degrees C, the total estimated time would be one quarter of 5000 hours or 1250 hours.

This calculated time is divided into 25 cycles so that readings can be taken at regular intervals. The running time for each cycle in the example above would thus be 50 hours. For practical reasons, cycle times are not allowed to be less than four hours' duration. To save time the first five cycles are run according to this plan but succeeding group of five cycles is double the length of the preceding group.

The heat-run period is long in comparison to the running time that might be expected in service (at rating of 160 degrees C the motor would be stopped approximately once every 2¼ years during the estimated life of 55 years). However, it is sufficient for frequent checking of insulation condition, yet permits testing to progress at a reasonable rate.

Test Cycle

Thus a complete test cycle begins with a heat run as described. The machine is then shut down and during the cooling period, readings of insulation resistance, capacitance, and dissipation factor are taken at intervals of 20 degrees C. Finally the humidification and high-potential tests are given followed by a no-load run, and a drying run as given in *b*, *c*, and *d* under "preliminary," with the exception that the humidification test is for only 24 hours. These cycles of heat and humidity are then repeated until the motor will not run or fails to pass the high-potential test.



This traction motor equipped with silicone insulation has withstood the equivalent of over 400 years' operation at normal temperatures.

Traction Motor-Test Procedure

The traction motor, being a d-c machine, required some slight variations in the outlined general procedure. It was originally planned that the insulation resistance, capacitance, dissipation factor of the main field, commutating field, and armature should all be studied. However, it was soon found, because of the non-insulated lead ends, brush rigging, commutator, and other unavoidable bare copper, that the severe humidification caused insulation resistance, capacitance, and dissipation factor values of the commutating field and armature to reach magnitudes that could not be measured with the equipment at hand. The complexity of the circuits precluded satisfactory guarding. Hence, the data here presented is that obtained from the main field whose leads extend outside the motor, thus avoiding leakage from bare copper inside the motor.

Both the main field and commutating field are being run at 285 degrees C by resistance (estimated 300 degrees C hot spot). This is done by shunting some of the line current around the main field. This shunting amounts to 24.8 percent after 1400 hours of aging. At the start of the test it was 17.9 percent. This percentage is changed as required by the increase in the resistance at 25 degrees C of the two fields, which, in 1400 hours, has amounted to 1.75 percent in the main field and 1.85 percent in the commutating field. While the fields are at this temperature, the armature operates at 180 degrees C and the commutator at 150 degrees C.

The only other variations in procedure are in the five-minute run and high-potential test. This motor, being series wound, would overspeed if unloaded and the full 300 volts applied. Hence it is run at the maximum permissible voltage which is 125. Although this is considerably below the 300-volt rating, it is somewhat compensated by the use of 500 volts a-c for the high-potential tests. Before the high-potential test and the no-load run the excess water is blown off the commutator, vee rings, and brushholders.

Methods of Measurement

1—Temperature by resistance is calculated from the value of resistance obtained by projecting to zero time the resistance curve of the windings while cooling.

2—Insulation resistance values are one minute readings obtained with a 500-volt d-c megohm bridge. They are corrected to a temperature of 25 degrees C from temperature-insulation resistance data.

3—Capacitance values are measured between windings and frame by means of a 60-cycle low-voltage bridge. They are corrected to 25 degrees C.

4—Dissipation factor of the insulation is evaluated on the capacitance bridge and is obtained concurrently with the capacitance. Below 15 per cent, it is almost identical to insulation power factor.

None of the motors has failed. However, enough data have been obtained to warrant some conclusions as to the behavior of silicone insulation.

D-C Traction Motor

The curves of Fig. 3, showing the changes in dry and wet insulation resistance during test, are particularly significant. The dry insulation resistance is shown to increase throughout the test whereas the insulation resistance under humidification decreases. The decrease in humidified insulation resistance is relatively gradual for the first 300 hours of aging (at 285 degrees C by resistance). However, between 300 and 400 hours of aging the wet insulation resistance changes abruptly. This change is apparent after 24 hours of humidification as well as after 48 hours. After approximately 500 hours aging, insulation resistance of the humidified motor appears to have reached minimum values and no significant changes have since occurred.

The dissipation factor of the insulation after humidification correlates well with the insulation resistance. A definite knee in the curve is shown in Fig. 3 between 300 and 400 hours, which is the point at which the insulation resistance dropped sharply.

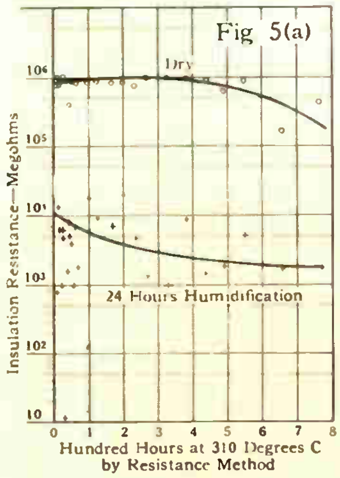
The obvious conclusion to be drawn is that the initial high order of moistureproofness was maintained for something more than 300 hours at 285 degrees C. Thereafter the insulation lost its ability to resist the passage of moisture vapor and the wet insulation resistance rapidly reached what appeared to be a minimum. In spite of this loss of the initial level of moisture resistance, the insulation is still operable. It continues to withstand the five-minute, 500-volt, 60-cycle high-potential test after each period of humidification.

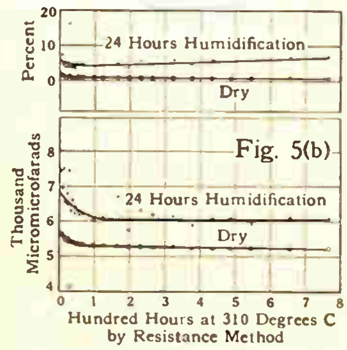
Silicone insulation (DC-990-A varnish) appears to have a minimum life on this traction motor of 350 hours at 285 degrees C. The evidence to date indicates a maximum life in excess of 1400 hours. Comparing these values with the original estimates of life shown in Fig. 1 remarkable correlation is found, as the predicted life of silicone insulation is 380 hours at 285 degrees C.

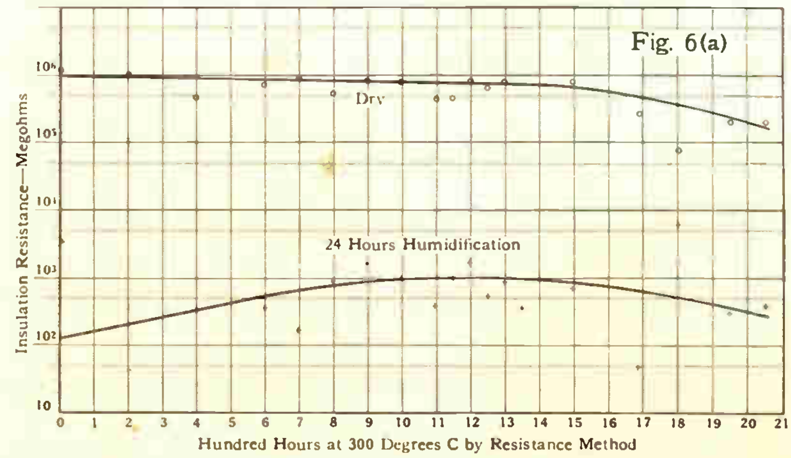
Induction Motors

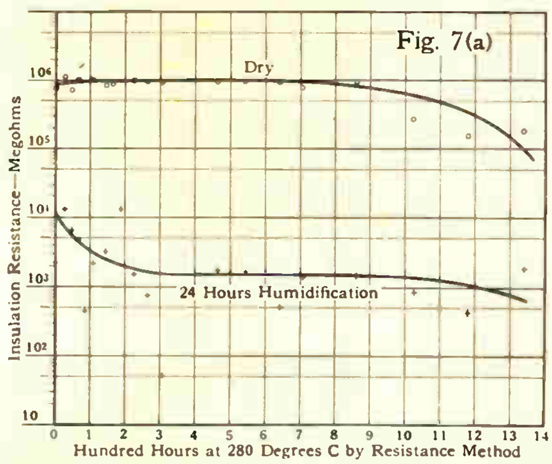
The tests on the induction motors have not shown any significant change in insulation properties although they have exceeded the original estimate of "minimum" life. Table 1 shows that motors A, B, C, and D have exceeded the life originally estimated for silicone insulated motors. Also they have exceeded the minimum life of the traction motor. In this connection it is interesting to note that the traction motor was treated with an early form of silicone resin (DC-990A) whereas the induction motors have been treated with an improved silicone resin (DC-993) on which laboratory tests had shown improved moisture resistance and thermal endurance. The accompanying curves show that the order of magnitude of the wet insulation resistance is comparable to that of the traction motor even though the induction motors employ "mush" wound coils. Tests E and F at 200 degrees C have not progressed far enough to show any changes.

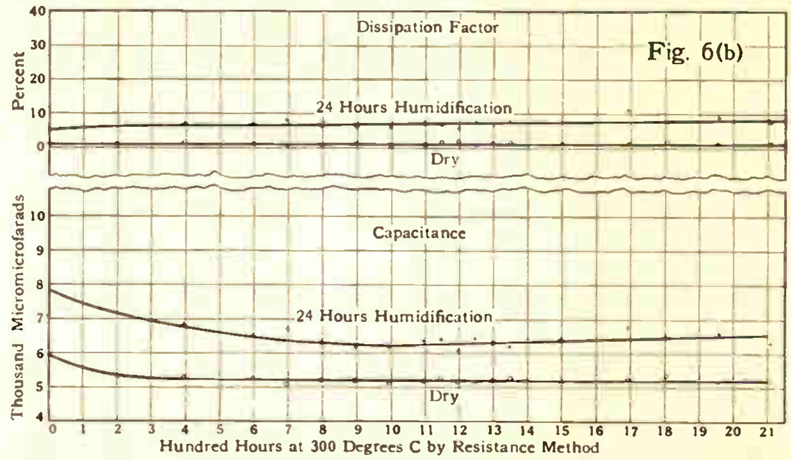
Humidification of motor test D is somewhat different from the other induction motor tests in that humidification is being done by the end-bell enclosure. Although results are similar, in that minimum life has not been reached, the wet insulation resistance is of the order of 3 megohms as compared to 2000 megohms for the other silicone-insulated machines. The severity of this type of humidification is quite apparent. The stator actually appears soaked.

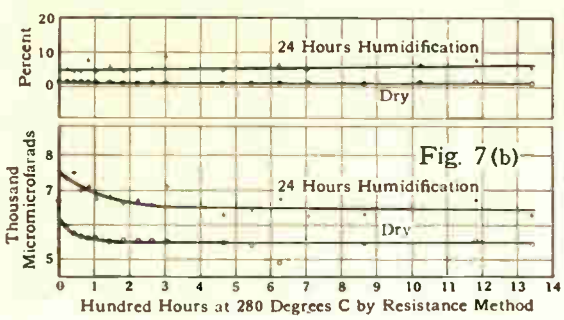


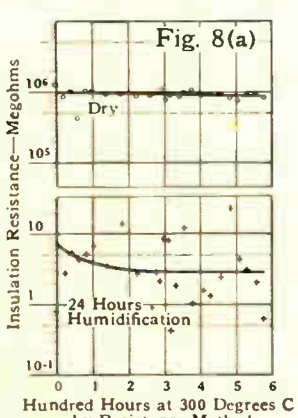


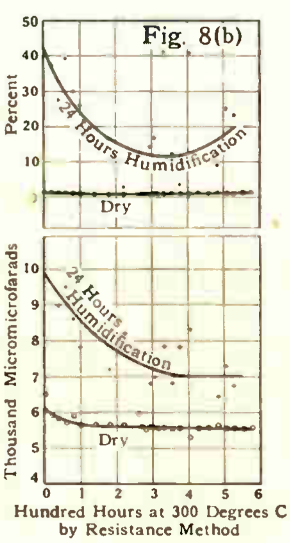












Figs. 5 (a) and (b), 6 (a) and (b), 7 (a) and (b), and 8 (a) and (b)—All these figures are for silicone insulated induction motors. The dry insulation resistance shows a slight tendency to drop in each case. The wet insulation resistance is decreasing somewhat in all motors although the knee indicating minimum life has nowhere been reached. Dissipation factors show remarkable correlation in every test. Capacitance measurements however seem to give no particular indication of the insulation condition. Fig. 8 is of a motor where the end-bell method of humidification is used and shows clearly the severity of this procedure. Water stands over all parts of the machine in large droplets.

The tests on the class-B machines do not reveal any significant information to date. In general, the wet insulation resistance is of lower magnitude than that of silicone insulation. Their minimum life has not been reached, although the moistureproofness is apparently decreasing rapidly. The insulation appears to be somewhat more brittle than does the silicone insulation on which tests are more advanced.

From the induction motor test data available to date, it is safe to conclude that motors treated with DC-993 will give longer minimum life than those treated with DC-990-A and much longer life than that of class-B insulation motors. In other words, the curve in Fig. 1 can be raised to some higher position which will be determined at the conclusion of these tests.

Conclusions

Tests have demonstrated that silicone insulation has thermal endurance at least as great as was first predicted on the basis of rather meager tests on a few machines. This is far beyond the order of magnitude of life normally accepted as typical of the best class-B insulation.

Silicone-insulated machines have been demonstrated to have outstanding moisture resistance, which is maintained under severe accelerated thermal aging tests.

What's New!

A Handful of Power

Thinking of a two and one-half kilowatt electronic tube for use in broadcasting or industrial applications calls to mind a vision of a huge "bottle," probably water cooled. The newly developed tube (Westinghouse WL-473), an air-cooled pliotron with a plate dissipation of 2500 watts, weighs but three and one-quarter pounds and is easily held in the palm of the hand.

Shades of yesterday! A two-kw oscillator with auxiliaries was a bulky apparatus.

This tube is a forced-air cooled triode with a thoriated tungsten filament. The forced air flow required is 100 cubic feet per minute for maximum anode dissipation. The amplification factor is 22. Because of low inter-electrode capacitances and its short filament and grid-lead lengths, these tubes can be used as class-C radio-frequency power amplifiers and oscillators at 60 megacycles with 100 percent input. For this application the maximum ratings are: d-c plate volts, 3000; d-c plate amperes, 1.4 average; plate-input watts, 4200 maximum. The power output for typical operation in this class is 3250 watts.

In other classes of service the WL-473 pliotron can be used:

1—As an audio-frequency amplifier and modulator class B. Maximum signal power output in watts, 4350 (from 2 tubes).

2—Radio-frequency power amplifier class B. 800 watts power output.

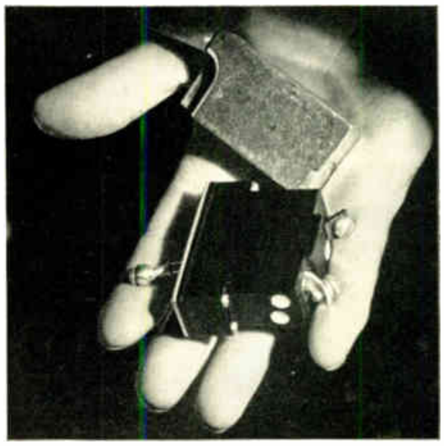
3—Plate modulated radio-frequency power amplifier class C. Output watts, approximately 2700.

This triode is at present being extensively used in the oscillators that provide the radio-frequency power for induction-heating and dielectric-heating equipments. The tube, because of its compactness for such a high rating, offers many design advantages when used in either amplitude-modulation or frequency-modulation broadcast transmitters as an a-f or r-f amplifier or as an oscillator.

Multum in Parvo

Much in little exactly describes the new Westinghouse ANC 77-A circuit breaker. For aircraft equipment it is not enough that it be good, it has to be small. Here a switch-type circuit breaker with thermal-trip element capable of interrupting (at sea level) 3500 amperes at 28 volts direct current is compressed into a unit no larger than a cigarette lighter, and weighing but 2.5 ounces.

On modern military planes, many auxiliary operations are performed by electrical devices and controlled by manually operated switches. Some of the more important devices so controlled are turrets, radio, landing gear, flaps, lights, various motors, and solenoids. The switches must be small panel-mounting types in various ratings from 5 to 50 amperes. The construction must be such as to minimize fire hazard, resist salt spray and have good vibration and shock characteristics.



Comparable in size to a cigarette lighter, this breaker has high interrupting capacity, is flameproof, and shock resistant.

The ANC 77-A breaker is of a cam-toggle design that has excellent vibration characteristics and withstands high shock tests. Seven ratings (5 to 50 amperes) are

Rings of Light

Fluorescent lighting is especially applicable to seeing tasks where glare is an annoying factor. The fluorescent lamp has been highly successful because it is an extended, low-brightness light source. For the home, its use has been restricted in some degree by the long tubular shape. A new, circular Westinghouse fluorescent lamp, called the Circline, has been developed for postwar distribution that permits its use in floor and table lamps, bringing to home-seeing tasks the same degree of eye ease existing in modern offices.

The new 32-watt circular tube lamp is 12 inches in diameter. Three sizes of these lamps will be produced when wartime-manufacturing conditions permit. The hoop-like ring of light can be used by itself or in conjunction with diffused light from an incandescent lamp. In this lamp are elements of new ideas in decoration, using its cool efficient light to strike different notes in the home.

The familiar, efficient fluorescent lamp now appears in circular form, which makes it suitable for service in the home both for utility and for decorative effects.

encompassed in the one size of switch. Enclosed in a plastic case, it is flameproof and fool-proof. The breaker successfully passes the cotton-lint test that consists of surrounding the breaker loosely with cotton lint and interrupting current equal to its maximum rating. The housing must prevent flames from escaping when operated at rated current at altitudes up to 50 000 feet (1500 amperes at 40 000 feet). This is evidenced by the non-ignition of the lint encompassing the breaker housing.

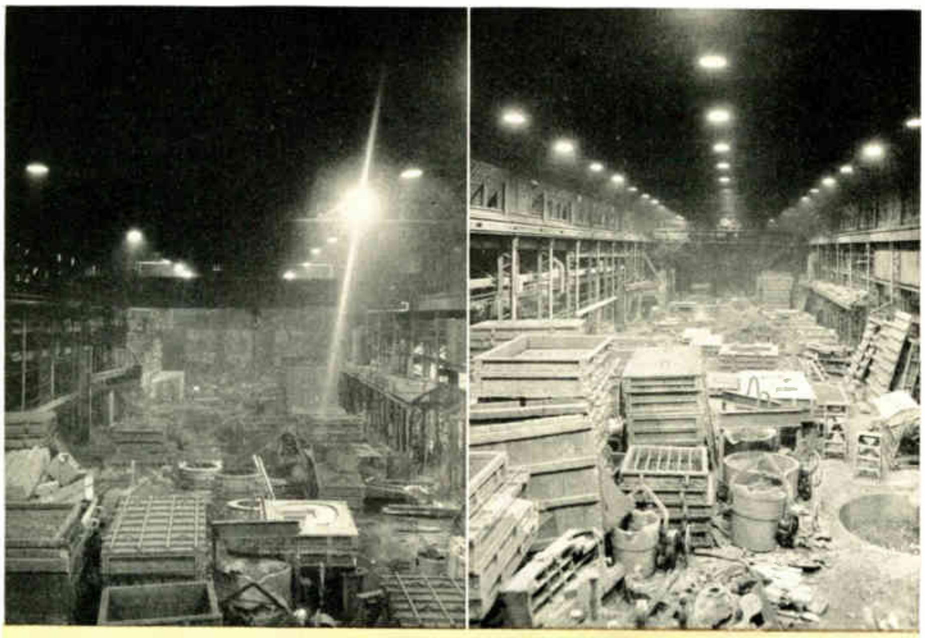
The thermal-trip feature of this breaker switch provides a protection for the cable in case of short circuit. It is further invaluable in that it thus prevents overheating of the cable and eliminates this fire hazard. By isolating short circuits through thermal-trip action, the breaker preserves continued service on the remainder of the system.

Light for Heavy Industry

The smoke, fumes, and dirt associated with heavy industries such as steel mills, foundries, plating works and cement plants add greatly to the problem of providing adequate light in these necessarily large factories. Ordinary open-type reflectors quickly become covered with an accumulation of dirt, and illumination may drop 30 to 40 percent in a short time. The Westinghouse dust-tight and vapor-tight Millite luminaire under similar conditions loses but a few percent in light output and the pattern of distribution is unchanged.

The Millite luminaire is ruggedly constructed for heavy duty. The housing is a heavy sheet steel with a special acid-resisting baked-on enamel. The fixture has a drip cap at the top and a water-drip skirt at the bottom. These with a heavy, treated-asbestos gasket make it weather-tight and vapor-tight. The cover glass is held in a strong cast-aluminum ring permanently hinged to the housing. The cover glass is flat heat-tempered plate glass one fourth inch thick. It resists heat and impact to an unusual degree. The reflector, which is entirely protected from exposure, is spun from heavy-gauge aluminum sheet and is treated by the Alzak process to assure permanent high efficiency and ease of cleaning.

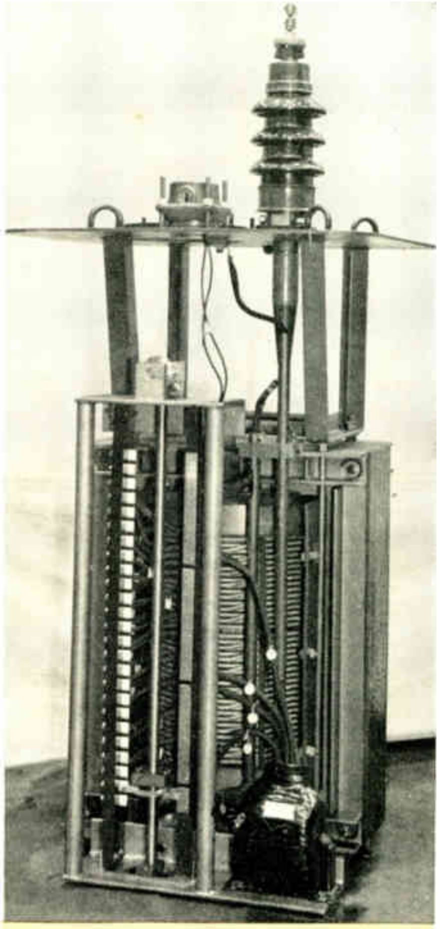
The cost of lighting in the heavy service industries normally includes inordinately high maintenance costs. To produce a given amount of light continuously with open-type reflectors, maintenance must be regular and frequent or else many more lights must be operated at reduced efficiency. Millite, being a totally enclosed luminaire completely protected from dirt, reduces maintenance cost by providing higher maintained average illumination. The Millite luminaire is available with concentrating, medium, or wide distribution reflectors, making practical applications for mounting heights from 15 to 80 feet. The incandescent lamps used range from 300 to 1000 watts. The Millite fixture is also available for use with the 400-watt mercury lamp.



The difference in illumination in large areas between an ordinary lighting system and a properly engineered Millite installation is shown by before and after views.

A Space-Saving Ground-Fault Neutralizer

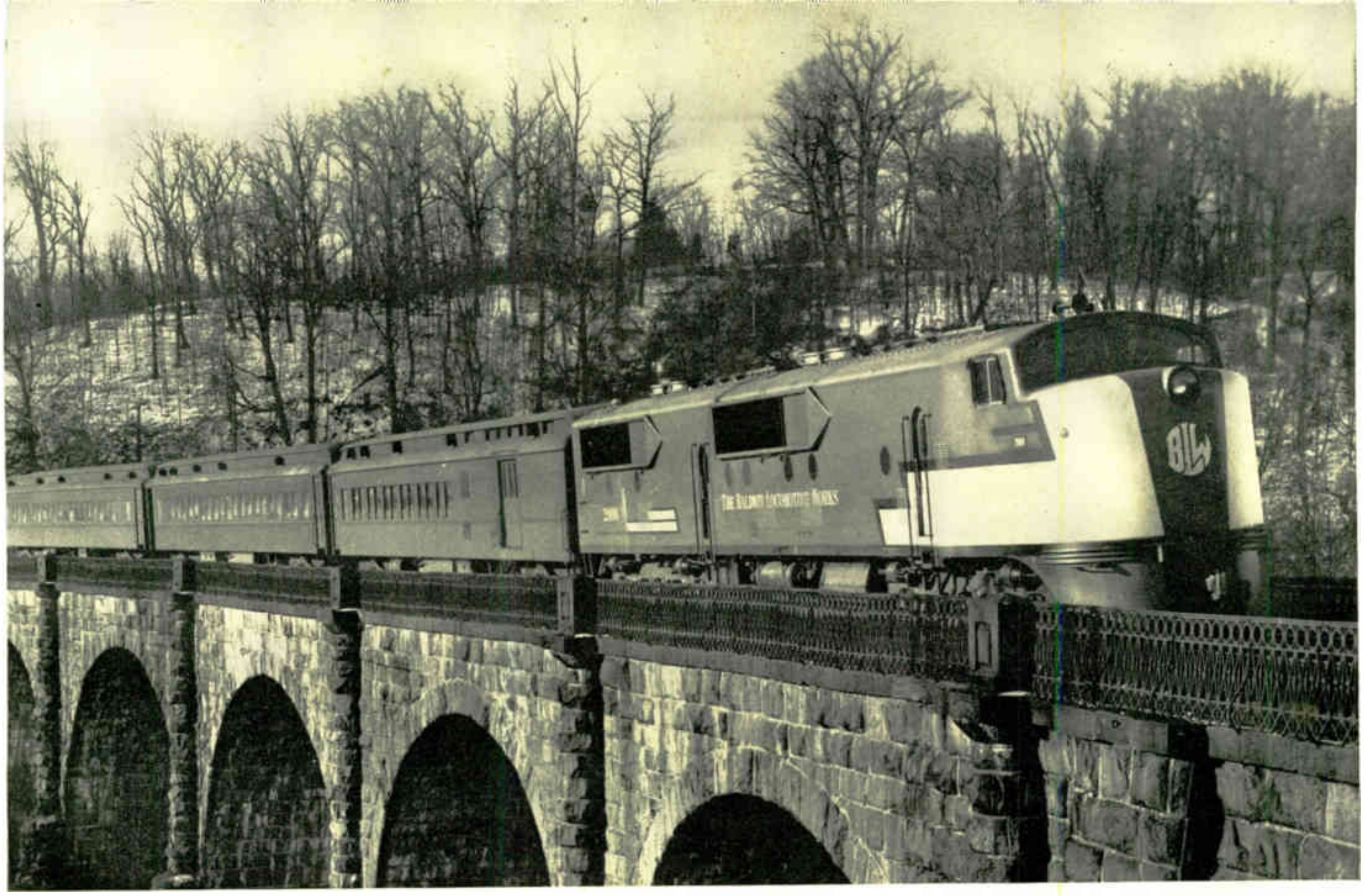
For high-voltage transmission lines, the general practice followed in the United States calls for a neutral solidly grounded or grounded through an impedance. In some lines a tunable reactor is used. Reactor grounding can be used on systems of any voltage but use of reactors on systems of 69 kv or less is standard. A newly designed ground-fault neutralizer occupies little more than half of the space usually required for similar equipment.



This ground-fault neutralizer uses a tunable reactor. The motor-driven tap-changing mechanism is evident.

Often the economics of the system determines the use of such a reactor. It neutralizes the line-to-ground charging current of the unfaulted phases in the event of a single-phase-to-ground fault, thus minimizing the fault current. The reduced current generally keeps the arc from restriking following a current zero. Thus the system is largely self-clearing for lightning-caused flashovers and similar faults. This is of importance in secondary systems where spare lines and high-speed relaying are not feasible.

The ground-fault neutralizer is a single-phase, oil-immersed reactor. The tank is the Sealed-Air type construction having air impounded above the oil, minimizing oxidation and providing adequate room for expansion of the coolant. The reactor is tunable and has a motor-operated tap changer. The reactors for use on lines of 23, 34.5, 46 and 69 kv are standard equipment. Other ratings are special. They are rated up to 160 amperes in either the four-to-one or two-to-one ratios.



One of the two new 2000-hp Diesel-electric locomotives in trial passenger service crossing the famous stone bridge of the Baltimore & Ohio Railroad near Baltimore, Md.

The Diesel-electric locomotives are powered with two 1000-hp engines, one of which is visible in this view down the corridor away from the cab. The two direct-current generators are just visible in the background.

Modern Diesel Electrics

Specialization of road locomotives, i.e., for freight or for passenger service, is declining. The newest Diesel-electric locomotive is a step in this direction. Larger motors lower the speed at which it can operate continuously at full load.

Two high-speed Diesel-electric locomotives of 2000-hp each—as powerful as any yet built—and embodying the summation of numerous improvements in engines and electrical equipments, have recently entered demonstration service. These new Baldwin-Westinghouse units are intended for high-speed operation of both passenger and freight trains up to 90 mph. Each 80-foot cab contains as its power plant two standard 1000-hp Diesel engines driving two d-c generators, supplying power to four geared-traction motors, each one third larger than any heretofore used with 2000-hp Diesel-electric locomotives.

Each cab is mounted on two swiveling trucks, which has the merit of simplicity, yet is satisfactory for locomotives of moderate tractive effort.

The weight on drivers of freight locomotives should be as large as possible because high starting tractive forces are necessary, yet since these locomotives will be used in high-speed passenger service, the weight per axle must be limited so as to minimize damage to track. To accommodate these two conflicting requirements the load per axle was fixed at about 60 000 pounds which necessitated six-wheel trucks. Under good rail conditions, the starting tractive force per driving axle is 18 000 pounds or a total of 72 000 pounds for each cab.

Motors and generators large enough to start a train are far larger than needed at operating speeds. Previously the lower limit of continuous operation at full tractive effort of Diesel locomotives of this size and speed has been about 30 mph. The use of large traction motors on these new locomotives reduces the safe minimum speed under full load to 21.5 mph, which makes them much more suitable for both freight and passenger trains.

Iodide-Treated Brushes Maintain the Essential Co

Disappearing into thin air is no joke when it is the carbon brushes on the generators of high-flying airplanes that are doing the disappearing. The perilously short life of brushes at high altitudes focussed attention on the importance of the commutator film. The resulting extensive research program provided a successful answer—the treatment of brushes with metallic halides—an answer of concern not only to those who fly, but also to operators of any direct-current machine. The new brush treatment has already solved several stubborn commutation problems on railroads, locomotives and in steel mills. Other uses are in prospect.

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Westinghouse Electric Corporation

The obvious basic features of a direct-current motor or generator are copper, iron, and insulation. But, one thing more, far more intangible and complex, so small and inconspicuous as often to escape notice, is an absolutely essential component—a thin film on the commutator. That a film between copper and the brush faces is essential to adequate brush life and to good commutation has long been accepted. Many a skilled operator judges the performance of his machines by the color and condition of the commutator surface.

The operation of military airplanes at high altitudes made it imperative that the matter of preserving the films on the commutator of heavily loaded aircraft generators be intensively studied. In the thin air experienced on these flights the films would sometimes disappear, allowing the carbons to ride on bare copper. Under this condition complete erosion of brushes may occur in less than a single flight—clearly an intolerable condition.

The nature of the film has never been analyzed exactly but it is known to be complex. The factors affecting it are many and their interrelationships obscure. The ideal commutator film is thought to be composed substantially of cuprous oxide, (the oxide of monovalent copper). All other substances present in actual films are probably either non-essential or are definitely harmful.

Clean metallic copper cannot be exposed to air without acquiring a tarnish film. At room temperature this film gradually increases in thickness although the rate of growth is so slow that the film remains transparent and practically colorless for a long time. During the turning of a commutator to size as one of the final steps in its manufacture, the copper is heated by the work done upon it. As copper is oxidized more rapidly at higher temperatures, each spot of the metal, as it emerges from under the turning tool, acquires a thicker film than it would get if it had been exposed at room temperature. In addition this initial film is further thickened during the seating of the brushes. The coefficient of friction between unseated brushes and a copper commutator is normally high. As the brushes are worn to a seat under light electrical loads, their faces become polished. At the same time the film upon the commutator increases in thickness as its surface is burnished by the mechanically loaded brushes under which it moves. If the brushes have been properly chosen, if the machine is well designed and if the running-in conditions are correct, the film gradually increases in color, thickness, and polish. The friction between carbon brushes and commutator surface gradually decreases.

Commutator Film Continually Made and Unmade

However, the formation of a commutator film by electrically loaded brushes is a relatively complex dynamic process. It is not nearly as simple as the preceding paragraph indicates. The heat appearing at the brush-commutator interface is generated not only by friction but also by the electric energy dissipated at this interface. The coefficient of friction between a high-grade, well-seated electrographitic brush and the burnished copper-oxide commutator film is often two-tenths or higher. The double contact drop for this same type of brush lies between one and a half to three volts.

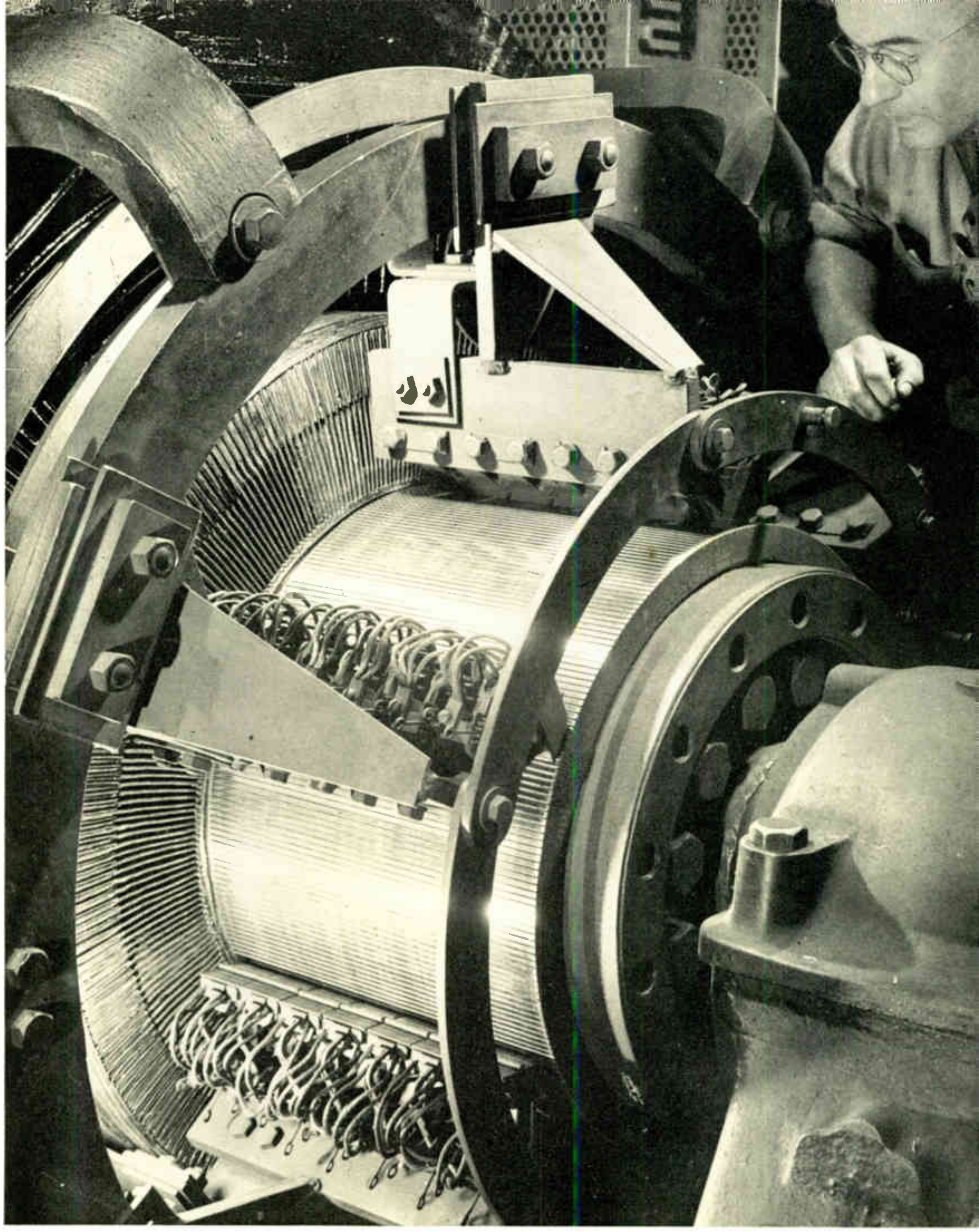
At any given instant the electron transfer between the commutator and a brush takes place at only a few highly localized areas on the brush face. When the electrical load is added to the already present mechanical load these spots become hot. These overheated, active areas of the brush being in close contact with the commutator react chemically with the copper-oxide film to form metallic copper and carbon monoxide. Thus the electron transfer areas on a brush face become chemically reducing agents, de-filming rather than filming agents.

When one of the minute areas of freshly reduced metallic copper emerges from under the brush and contacts the air, it immediately is reoxidized. However, this same area soon passes under another brush, perhaps to be reduced again before the oxide film has been re-established to normal thickness. However, normally, at any given moment the active electron-transfer area is small. Hence a freshly oxidized spot may pass under several brushes without again being reduced, thus allowing the film to be built up to equilibrium thickness during the repeated periods of air exposure. With continued operation, an area on a commutator is frequently reduced and again reoxidized. Therefore the oxide film should be regarded as dynamic rather than static.

The performance of many types of direct-current machines stands to be improved by the research on commutation made so necessary by stratosphere operation of aircraft.

This article is based in large part on AIEE Technical Paper 25-108 "Treatment of High-Altitude Brushes by Application of Metallic Halides," by H. M. Elsey.

·mmutator Film



Whether in the air or on the ground, preservation of an oxide film on commutators is essential.

The character of the cuprous-oxide film on a commutator depends on many variables. The properties of the brushes, the shape of their faces, the angle at which they contact the commutator, the spring loading placed upon them, the area of the commutator covered by them, their operating temperature, the temperature of the commutator, and the purity of the ventilating air all play essential roles in controlling the thickness and quality of the film. The film, as explained above, is a dynamic, alterable structure. A slight change in operating conditions may drastically alter it in a few hours.

Commutator Film Is Affected by Many Factors

A seemingly insignificant change in the surroundings may affect it. For example, a shift in the wind direction may bring a trace of hydrogen sulfide into the room. A leaking gas tunnel has also been responsible for the malperformance of a group of machines in a steel mill. The edges of the commutator in such contaminated atmospheres became covered with a continuous gray film of copper sulfide and the brush tracks were blotched with irregular patches of this compound scattered in between the normal cuprous-oxide areas. Copper sulfide may completely replace cuprous oxide as a commutator film, if the hydrogen sulfide in the air reaches the concentrations sometimes found in a kraft paper mill. Brush wear is always excessive under such conditions. In general anything that alters the ability of the air to oxidize copper and thus maintain a continuous, well-polished cuprous oxide film on its commutator impairs the performance of a machine and affects brush wear.

Copper that initially has a high polish is roughened by repeated oxidation and reduction. However, continued operation of a commutator under ideal operating conditions increases, rather than diminishes, the finish of the surface. A properly chosen brush polishes the oxide film as it is formed and prevents the roughening that would otherwise follow repeated oxidation and reduction. Thus the ideal brush is an excellent burnishing tool; it "flows" rather than abrades the commutator film. Actual brushes, however, to a greater or less degree, fail to maintain a burnished, continuous layer of cuprous oxide that is substantially free of other materials. Frequently the film becomes rough and so non-uniform in its composition and properties that cleaner brushes are added to remove this undesirable film. Or, as a last resort, the commutator may be "re-turned" and the development of a new film attempted, probably with the aid of a different grade of brush.

Oxygen and Moisture Are Important

The foregoing indicates why the heavy-duty airplane generators present such a difficult problem to the designer. These generators must weigh as little as possible, and hence the commutators and brushes must be loaded to the limit. Heavily loaded commutators retain an oxide film only with difficulty even in ground service or in low-altitude flying. If the bombers are flown to an altitude of thirty-three thousand feet, where the oxygen is approximately one-fourth of that at sea level, the commutator film naturally is lost.

Lack of the active oxidizing agent is, however, not the only cause for the loss of the essential cuprous-oxide film in high-altitude flying. The water content of the rarefied air is only one-thousandth that normally at earth's surface. The extreme dryness of the ventilating air is a major cause of the disappearance of the film. The beneficial effects of water vapor are

Commutator film is not a static thing. It is continually being unmade and remade. The film on a given area may be all or partially destroyed when it passes under a loaded brush, and is reformed on emergence. The film represents a delicate balance between these two active and complex conditions.

usually ascribed to lubrication of the brush-commutator interface by water vapor adsorbed in the film or brush.

Possibly the true role of the water is not that of a lubricant but of a catalytic agent promoting the oxidation of copper. As soon as the film on the commutator disappears the brushes and copper grind one another away in a short time.

Epidemics of rapid brush wear occur frequently on earth-operated machines also. Such epidemics often, if not always, are associated with an unusually low water concentration in the air. The trouble often is avoided by feeding steam into the air of a generator room during extremely cold weather.

The Development of a Brush Treatment

Clearly the aircraft-brush problem required the development of a brush or a treatment for a brush that would maintain the commutator film under the adverse conditions of atmosphere and commutation of airplanes in high altitudes. To this end it was believed that a solid film having lubricating properties would be helpful. Many substances were added to the brushes, some of them giving encouraging improvement. Lead iodide, however, proved to give far superior results.

From previous experience it was expected that lead iodide—a soft, yellow solid—would behave like molybdenum sulfide by coating the copper with an adhering lubricating film. Surprisingly this does not happen. Instead the lead-iodide treated brushes develop a characteristic dark satiny film that seems identical with the normal cuprous-oxide film. This film becomes burnished as it passes successively under the brushes and stays even in air low in oxygen and water vapor.

Lead-iodide treated brushes maintain a perfect film even in the most adverse conditions. The mechanism by which lead iodide accomplishes this is not known with finality. Probably it is through formation of an intermediate compound, cuprous iodide. This, being extremely unstable, is readily oxidized to cuprous oxide even in an atmosphere where the normal oxidation of copper would not occur. In other words, lead iodide does not itself form the desired film but forms first an unstable one whose prompt destruction does result in the necessary film of an oxide of copper. In any event, the introduction of lead iodide into a brush offers a means by which the rate of copper oxidation can be greatly increased, even in an atmosphere of very low oxygen content and with almost no water-vapor content.

The iodide impregnation in the brush does not itself form the desired copper oxide. It first forms another film, quite unstable, that breaks down to the oxide.

Further convincing evidence of the effectiveness of iodine compounds is given by a laboratory demonstration. If a commutator is allowed to run under conditions that cause the brush to wear rapidly, introduction of only a whiff of iodine vapor into the air surrounding the commutator stops the dusting. Under simulated high-altitude conditions, untreated brushes, which dusted in the absence of iodine, showed low wear and developed an oxide film on a copper ring when iodine vapor was introduced. Bromine vapor proved similarly effective.

Because bromine vapor also prevents brush dusting, studies were extended to cover the metallic compounds (i.e., halides) of iodine, bromine, chlorine, fluorine, in short, all members of the chemical family known as halogens. All were effective. Each decomposes at the brush-commutator face by heat to form the corresponding metal and free halogen. The halogen is very reactive and may recombine either with its original metallic partner, or with the carbon of the brush, or with a bare copper spot on the commutator.

The copper halides differ greatly in their thermal stability, the iodide being the least stable and the fluoride the most stable compound. The comparatively high stability of copper fluoride should retard the rate at which it is oxidized. Under operating conditions this might lead to the existence of a film that contains substantial amounts of both the oxide and the fluoride of copper. It is therefore preferable to choose a treatment that, under the given operating conditions, develops a film substantially free of any compound other than the desired cuprous oxide.

All of the metallic halides tested as brush treatments are capable of limiting brush dusting under simulated high-altitude conditions. However, from the standpoint of their practical application, some are more suitable than others. For example, certain halides, which are water soluble, but not deliquescent, and which contain no water of crystallization, can be added to the completed brushes from a water solution. However, these water-soluble halides could accidentally be leeched out of the brushes when the ventilating air-duct connected to the generator happens to direct water onto the commutator and brushes. For this reason the more easily soluble halides are less desirable as treating agents.

Difficulties also arise in the case of halides that are so unstable thermally that dissociation of the compound takes place not only at the brush-commutator interface, but throughout the brush itself. The ideal halide should be thermally stable to temperatures up to those attained in the face of the brush. Another major objection to certain halides is the fact that they absorb water and dissolve in it. Or, one or more of the thermal decomposition products may deliquesce in air or react so as to leave an undesirable residue in the brush or on the commutator.

The lead formed by the thermal decomposition of lead iodide may remain in the brush either as lead or as lead oxide. Some of it may be mechanically transferred and enter as an impurity into the copper-oxide film on the commutator. In any case, the physical and chemical properties of the solid residue are such that it is not detrimental to commutation. Certain other metallic halides tested give non-uniform films and high contact drops, although they prevent actual brush dusting.

Application of the Halides

War needs necessitated the early adoption of a treated brush. Lead iodide was chosen in preference to others as the most promising halide treatment for the first large-scale application. Many thousand airplane generators now in service have been so equipped. In fact, all heavy-duty generators placed on high-altitude bombers are fitted with brushes containing one of the metal halides as an anti-dusting agent. Tests with other halides are being continued, however, with the thought of perfecting treatments suitable for different commutation problems.

The temperatures at which some electrographitic brushes are fired are so high that the iodide must be placed in the carbon plate, from which the brushes are sawed, after manufacture. This can be done, either by immersing the brushes in the fused iodide, or by carrying out metathetic reactions in the plate by successive immersion in the proper chemical solutions. The latter operation must be done with great care as trace amounts of excess reagents or products of reaction often disastrously affect brush performance and the leeching out of small concentrations of such compounds is laborious.

Certain halides can be incorporated into metal-graphite brush grades at the time of molding. While lead iodide can be successfully molded into metal-graphite brushes care must be taken in the curing of the brushes; otherwise undesirable reactions take place between the copper and the iodide.

Other Uses of Treated Brushes

Brush treatments capable of maintaining an oxide film on a heavily loaded commutator operating under the adverse conditions encountered in the upper air certainly warrant a trial in difficult brush applications at more normal levels. Manpower and material limitations have severely handicapped the execution of such tests. However, in such severe service as is imposed on the brushes of high-speed electric locomotives, halide treatments have definitely improved commutator conditions and have increased brush life. Recently a group of test brushes were removed from a locomotive after eighty-five thousand miles of high-speed service. The brushes are in excellent condition and the wear has averaged only ten mils per thousand miles of service.

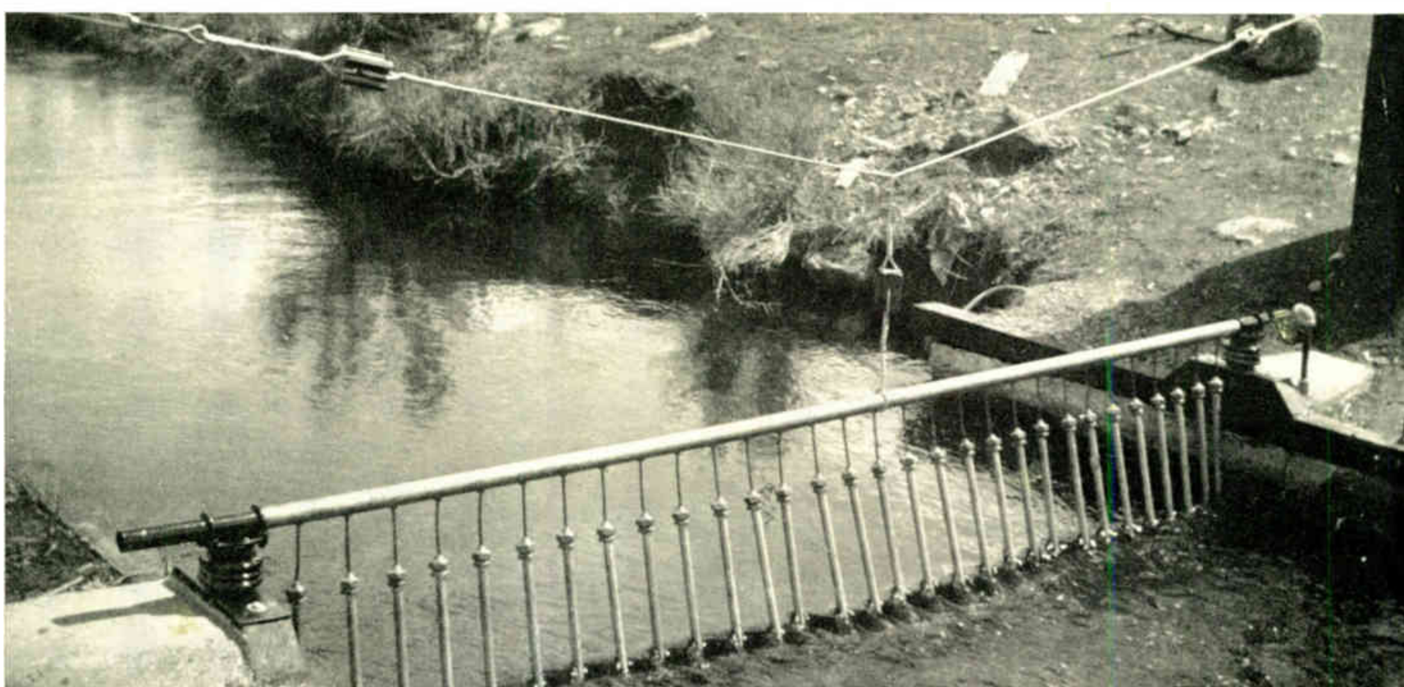
Exploratory applications have been made in other fields where commutating conditions are unusually difficult. Each application presents a new problem. In all cases the brush grade, the type and the amount of treatment must be properly matched to the machine and to the operating conditions. Though progress has necessarily been slow enough, experience has now been accumulated to prove that this new, purely chemical approach to the old problem of formingand maintaining a satisfactory copper-oxide film on commutators and slip-rings will prove as effective in many ground applications as it was in its initial one, namely the solution of the high-altitude brush problem. There are many possible variations in the halide treatments. Wherever preservation of commutator film is a problem one of these treatments may be of value.

An Electronic Fence for Fish

Even fish are now feeling the effects of electronics—and literally. An electronic fish screen keeps fish from going where they are not wanted or where they might be injured. Such places are at the entrances to irrigation ditches, in hatcheries or at the openings to the water-wheels of hydro-electric installations.

Wire screens have been used, but for small fish, particularly in hatcheries, the mesh must be so small that it quickly clogs up with debris. The electrical system provides an invisible barrier across which fish will not pass but which does not impede water flow.

In this system, devised by the Electric Fish Screen Company, a series of vertical bars are spaced several inches apart and suspended in the stream so they can swing freely to pass floating objects. The bars are insulated from ground. An electronic impulse generator delivers sharp electrical impulses through the water between the bars and a ground. These provide an effective barrier to the fish without injuring them.



An electronic fish screen stands guard at the entrance to the Fairchild Irrigation Canal at Merceo, California.

A-C Systems for Aircraft

A discussion of alternating-current systems for aircraft presents an unusual opportunity to electric power engineers. It gives them, as it were, a time telescope by which they can see all at once in retrospect the whole development of the alternating-current power system. A-c systems for the big planes of tomorrow embody a complete power-generation and distribution system comparable in every way with a public-utility system with all the attendant problems of synchronization, protection coordination, distribution and switching—and on which is superimposed the additional problem of need for stringent economy of fuel and weight.

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THE big flying liner and the super-bomber of tomorrow may use 120 kilowatts of electrical energy. At 28 volts this would be 4000 amperes—far too much current to distribute through the areas of a huge plane. Designers of these huge aircraft find before them the same problem that faced the public-utility engineer just before the turn of the century of how to overcome the bottleneck of distribution of increasing amounts of direct-current power over appreciable areas. The answer probably is alternating current.

Integrated a-c systems for aircraft are new, but the use of alternating current on aircraft is not at all new. As long ago as 1918 high-frequency wind-driven alternators were used to supply power to the rotary-spark-gap radio transmitters built during World War I. During the early 1930's, radio transmitters on Navy seaplanes were operated from wind-driven alternators, and later, from alternators driven by gears from the main engines.

The need for battery standby power for emergency radio operation shifted attention from a-c equipments to the development of d-c radio apparatus. As soon as batteries became standard equipment, low-voltage direct current was available for other purposes and electric operation of accessories became inevitable.

The use of two or more generators in parallel to meet increased power demands became common and the simplicity of parallel operation with d-c generators became a powerful argument for the use of direct current. The advent of World War II and new combat needs stimulated the development of still more equipment. By 1939 it was necessary to increase system ratings by doubling the system voltage and adopting 24-volt systems for all large airplanes. (The so-called "24-volt" system actually supplies about 27 volts to the distribution network.)

Status of D-C Systems

Because of steadily increasing military loads, pressure grew for still higher voltages. However, the convenience of battery standby power discouraged most attempts to promote the use of direct current at voltages higher than would be practicable for aircraft batteries. It was also feared that any substantial increase in direct-current voltage would lead to troubles of arc interruption at high altitudes. Some few farsighted advocates of a-c systems as a means of going to higher voltages had even more objections to overcome. Not only would battery standby power be impossible, but also the simplicity of parallel operation of d-c generators would be replaced by the complications of synchronizing and paralleling alternators.

During the past few years, remarkable improvements have been made in the 28.5- and 30-volt generators used in d-c

The fabulous plane of Tomorrow will shortly become the plane of Today. Already ordered is a fleet of these 204-passenger Consolidated Vultee Aircraft Corporation airplanes for world-wide travel. Carrying 15 300 pounds of baggage, mail and express together with its full complement of passengers and crew, this huge, two-deck aircraft will make the run from New York to London in nine hours. Weighing 320 000 pounds when loaded, the plane cruises at a speed of 340 mph. Its six 5000-hp pusher-type engines provide a maximum speed of 370 mph and can carry the ship to a 30 000-foot ceiling. The maximum cruising range is 4200 miles. The wing span (230 feet) is equivalent to the height of a 21-story building. The tail itself is five stories high.

systems. Outputs of 100, 200, 300, and finally 400 amperes were obtained from a single engine-mounted generator. The higher ratings were made possible by the 4000/10 000-rpm generator take-off provided on new-model engines. All of these generators are used with load-responsive voltage regulators, which permit parallel operation of any number of generators and batteries in any combination of ratings, regardless of individual variations in generator speed.

With airplanes growing larger and with distribution systems becoming longer and more intricate, 27-volt systems must carry thousands of amperes in place of hundreds. Power must be delivered to load points with a voltage regulation of three percent or less for continuous-duty devices, and a regulation of six or seven percent for intermittent-duty devices. With the nominal voltage of 27 volts used for continuous-rated devices, continuous-duty wiring must have sufficient cross section of copper (or aluminum) to limit voltage drop to a little over 0.75 volt.

Higher Voltages—The importance of using the highest possible voltage lies in the fact that as voltage is increased, the current that can be transmitted by a given conductor for a given percentage regulation increases proportionately and the power that can be transmitted increases as the square of the voltage ratio. The limitation occurs when the voltage is too high to control safely. However, at some value of voltage, heat dissipation from the conductor rather than voltage regulation becomes the limiting factor and no further increase in current is permissible. Beyond this value power still increases directly with voltage. For low-power circuits, mechanical limitations that prevent reduction in conductor size may preclude approaching either of the above limits.

In any consideration of high d-c voltages at altitudes greater than 20 000 feet, the problems of circuit interruption and motor commutation become extremely important. Because of these problems it does not now appear practicable to use d-c equipment, even at the comparatively low value of 120 volts, on modern military aircraft that operate at altitudes of 40 000 to 50 000 feet. At these altitudes, destructive arcs will be maintained at fairly low voltages. As air density decreases the voltage at which these arcs persist also decreases. At 40 000 feet, arcs of considerable length are maintained by potentials as low as 50 volts.

The use of even moderately high d-c voltage is impossible at contemplated flight altitudes unless pressurized or large, multigap switching devices are developed. Such devices, however, cannot prevent arcs to circuits resulting from battle damage. These might cause a fire although altitude tests of 120-volt, direct-current systems indicate that most such faults burn clear and extinguish themselves.

Even if higher voltage d-c switching problems are solved, successful commutation on small d-c motors at high altitudes requires a large increase in the number of commutator bars between brushes compared to the number used on 30-volt motors. This usually necessitates a reduction in the number of poles and an increase in the weight of the motor in spite of the smaller current carried by the brushes.

The Case for Alternating Current

The weight savings possible through the use of high-voltage distribution are too great to overlook. Apparently the only way to utilize a substantially higher voltage is to design the system for alternating current. Such a system is outlined in Fig. 1. Altitude tests show that the use of alternating current at 200 volts does not involve any major circuit-interruption problems even at 50 000 feet. Thus the characteristics of high-voltage alternating current at once overcome the two major objections to the use of high-voltage direct current at ceiling altitudes; a-c arcs are much easier to extinguish than d-c arcs at corresponding voltages and currents, and a-c machines have no current-collection problems.

The saving in weight of distribution copper by using 200 volts in place of 30 volts amounts to hundreds of pounds on the airplanes for which alternating current will be required. Admittedly, the use of alternating current brings many new problems that must be evaluated and solved. However, alternating-current systems can be demonstrated as both desirable and practicable.

Load Considerations—Radio was probably the first electrical load. It is still one of the most vital. Radio power-supply problems have undergone many changes. Early transmitting tubes required high voltages and many early aircraft radio transmitters used alternating current because potentials as high as 2000 volts were available with excellent reliability through the use of transformers and rectifiers.

Advances in radio and tube design have greatly reduced power requirements for communication equipment. Radio operation from present d-c systems is fully practicable. Most aircraft radio equipments are supplied from dynamotors as their battery operation when the main engines are not running. The Navy, however, favors a-c power for high-power

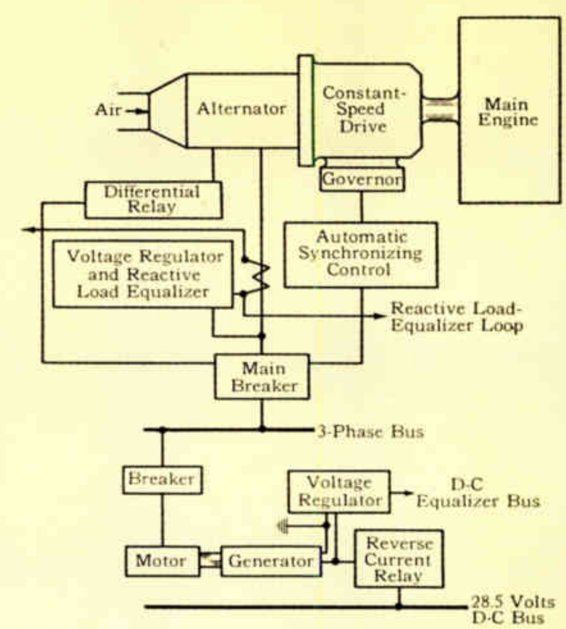

Fig. 1—Shown here diagrammatically are the components of an a-c electrical system designed for use on large airplanes.

airplane radio equipment and uses double-output generators that supply high-frequency a-c power for radio and 30-volt d-c power for the distribution systems. Alternating-current power of several thousand volts is an absolute essential for some new electronic devices. Such voltages cannot be obtained from d-c machines suitable for aircraft. Radio requirements can be supplied from an a-c system with no particular difficulty. Moreover, a-c power that now has to be provided by special generators, or by separate d-c to a-c inverters for some of the special high-powered a-c operated equipment could be supplied by the central system. Requirements for emergency radio operation can be met by small auxiliary sets used only when the airplane is on the ground, and which will be needed for ground operation of lights and other accessories.

While the power demands of radio have lessened, other demands on the aircraft electrical system have increased. As airplanes grow larger, many functions must be converted from manual operation to power operation. Brakes, flaps, bomb-bay doors, pumps, landing-gear mechanisms, and many other devices must be actuated by either hydraulic or electric power. The controversy between the proponents of hydraulic or electric operation will probably overshadow any consideration of the relative merits of a-c versus d-c electric operation. One important consideration for military airplanes is the fact that electric wiring is less vulnerable to combat damage than hydraulic piping carrying inflammable fluid at a pressure of 1200 to 3000 pounds per square inch.

In general, electric apparatus appears to be more easily controlled by precision instruments, particularly of positioning apparatus, while hydraulic apparatus, especially at low operating speeds, provides smoother operation and more direct application of heavy forces. Electric operation has definite advantages for remote control or for power transmission over any considerable distance. Any intermediate scheme makes use of electric transmission to a hydraulic pump and servo-system located at the point of operation. In one case calculations indicated a saving of more than three pounds per horsepower as compared to the weight of a hydraulic transmission.

The long-range high-performance passenger planes to come are envisioned as requiring some 150 motors ranging in size from one-fiftieth hp to 20 hp. Most of them will be fractional-horsepower motors for actuator purposes. Refrigerators, water coolers and other luxury items will require still others. In addition to motors, the connected equipment of the dream plane of the not-so-distant future will include radio and radar instrumentation (perhaps even television), lighting, heating and cooking, bar facilities and even such homey things as razors and curling irons. Planes now under contemplation commonly are considered in terms of generating capacity of the order of 80 kw. One plane under design is to be provided with 125 kva of generating capacity. The theoretical super-plane to come may use upwards of 150 kva. Such equipment and load clearly calls for alternating current.

With d-c systems, series-wound motors are generally used for electrically operated heavy-duty actuators, because they deliver their rated torque regardless of voltage, as long as the voltage is high enough to supply the required current. Induction motors, necessary with a-c systems, on the other hand, lose torque rapidly as the voltage decreases—the maximum torque available varying as the square of the applied voltage. Even at maximum voltage, no a-c motor is as efficient as a d-c motor in producing a given required starting torque on the basis of inch-pounds per pound per kilowatt. However, this consideration should not be over-emphasized because, for the same starting torque, the a-c motor is usually lighter than a low-voltage d-c motor with its heavy commutator and brush rigging even though the a-c motor requires more kilowatts. A seven-horsepower a-c motor is shown in Fig. 2.

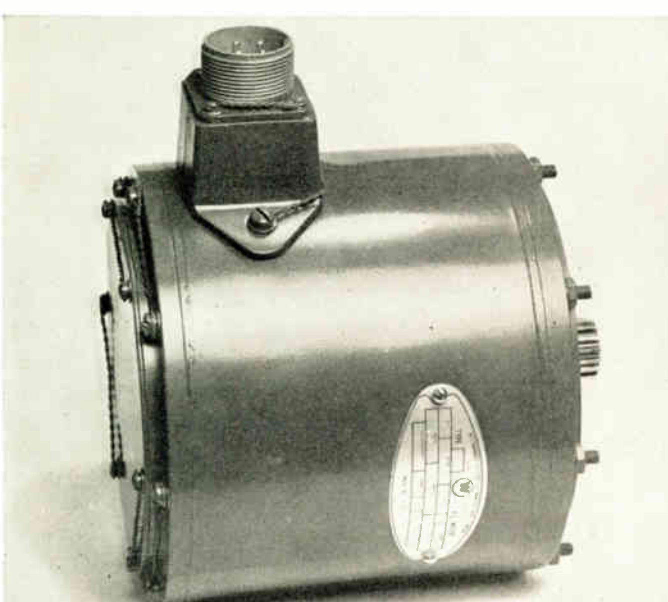

Fig. 2—Encompassed in a space approximately six inches cubed is this seven-hp (intermittent duty), 195-volt, three-phase motor that operates at 7400 rpm on a 400-cycle system.

For other than torque applications, a-c motors have several advantages. They are simple and reliable, the bearings being the only wearing parts. One of the heaviest loads on large military airplanes is the power required by power-driven turrets. Two variable-voltage motor-generator sets operate each turret. When driven by a 400-cycle motor, one large turret-drive motor-generator, shown in Fig. 3, is 10 pounds lighter than the 27-volt equipment, a weight saving of about 13 percent. Alternating-current motor drive is especially suitable for pumps of all sorts. Gyroscopes (Fig. 4) are often driven by a-c motors to avoid undesirable effects sometimes found in d-c motor drives. Alternating-current gyroscopes have so many advantages over d-c gyroscopes that they are frequently used on d-c equipped airplanes although they entail the extra complication of special inverters.

Whatever voltage is selected for the central system, undoubtedly other voltages will be required. With an a-c system any number of voltages can be obtained by means of static transformers. Voltage transformations with d-c power, however, require rotating machines. These are usually dynamotors (or motor-generator sets if voltage control is necessary).

Modern military planes require large amounts of both a-c and d-c power. If the basic system provides direct current, then inverters or motor-generator sets must be used to provide a-c power for instruments, gyroscopic devices, electronic devices, and other combat equipment. If the basic supply provides a-c power, then rectifiers or motor-generator sets are required to provide d-c power for d-c operated devices and for control and relaying circuits.

Requirements for a Modern A-C System

The a-c system brings with it one enormous problem—frequency! An a-c system for airplanes must provide reasonably constant frequency and voltage. Variable-frequency alternating current has been seriously proposed and could be used for constant-torque induction motors by maintaining the system voltage proportional to frequency. Radio or lamp loads could not be operated on such a system and motor speeds would vary with the frequency. Constant-voltage, variable-frequency power on the other hand, though proper for radio or lamp loads, is not at all suitable for motor loads. Thus both voltage and frequency must be reasonably constant if all types of a-c loads are to be supplied.

The requirement that the main alternators must be driven from the main engines and not from speed-regulated auxiliary engines vastly increases the difficulties of providing a constant-frequency a-c system, because the power take-off driving the alternator operates over a wide speed range: from 2100 to 8100 rpm for one representative airplane. A variable-ratio, speed-governed drive is required that maintains the alternator at 6000 rpm while the engine varies over a speed range of approximately four to one.

Frequencies of 200, 240, 360, 400, and 800 cycles for the a-c system have been considered. Each has strong advocates. When divergent transformer and motor requirements are considered the most favorable compromise is 400 cycles. This frequency permits maximum motor speeds of 24 000 rpm, speeds required for some gyroscope applications. Four hundred cycles has been definitely established as the preferred frequency, which is now not likely to be changed.

There is no longer any controversy over the number of phases to be used. In 1937 an 800-cycle, single-phase system using auxiliary-engine-driven inductor alternators was tested in an experimental airplane, the XB-15. The performance of 800-cycle capacitor motors proved disappointing, and system stability difficulties developed. In 1941, a 3-phase, 400-cycle system with parallel operation of two 14-pole, 12.5-kva auxiliary-engine-driven alternators was tested in the gigantic Army airplane, the XB-19. On the whole, the XB-19 power installation was successful and its operation vindicated the judgment of the engineers who had insisted that polyphase power is essential for stable parallel operation of alternators and for the satisfactory operation of high-speed a-c motors. Of two- or three-phase power, three phase gives the lightest overall weight and somewhat better motor performance and has been adopted. A grounded neutral is desirable to assure some starting torque on motors even with one line interrupted. Typical speed-torque curves with one and two lines missing in a three-phase aircraft system are shown in Fig. 5. The grounded neutral provides line-to-neutral value in the event of accidental grounding of one of the lines, reducing the danger to the crew from electric shock.

The line-to-line voltage is 208 volts at the generator. Extensive altitude tests established that this voltage would provide "burn-clear" characteristics in the case of usual cable faults. The resultant line-to-neutral voltage of 120 volts provides standard voltage for such single-phase equipment as may be required.

Several alternators of moderate rating are preferable to one or two alternators capable of supplying the entire demand. Continued operation under conditions of severe damage from hostile fire requires maximum flexibility in making the output of each generator available to each vital load, either by means of parallel operation or by means of bus-transfer switches. Multiple circuits for all vital feeders are required for the same reason.

Variable-Ratio Drives—The problem of driving an alternator at a constant speed of 6000 rpm, while the power-take-off shaft speed varies from 2100 to 8100 rpm, is occupying the attention of many mechanical engineers. At present, hydraulic transmissions appear nearer final development than do mechanical devices or electro-mechanical transmissions and have proved successful on test.

All variable-ratio hydraulic drives change ratio with load because of two factors. First, there is some actual slippage, and second, the stresses are high and elastic deformation cuts down the stroke slightly as the torque increases. This tendency to shirk load is an important advantage when alternators are operated in parallel. It helps distribute sudden changes in load while the governors are adjusting the drive controls for new conditions. A further safeguard, provided by an over-running clutch incorporated in the drive, prevents any possibility of reverse loading during parallel operation. Such reverse loading, if permitted to occur, would expend power in a futile attempt to raise the speed of the main propulsion engines through the drive.

Constant-speed operation of generators provides one definite advantage apart from constant-frequency considerations. It permits a tremendous reduction in the weight of the generator or alternator. The weight of an electrical machine of given output varies almost inversely with the speed at which it is operated. A machine operating at 6000 rpm is much lighter than one that develops the same output at 2100 rpm. Although step-up gears could increase the speed from 2100 to

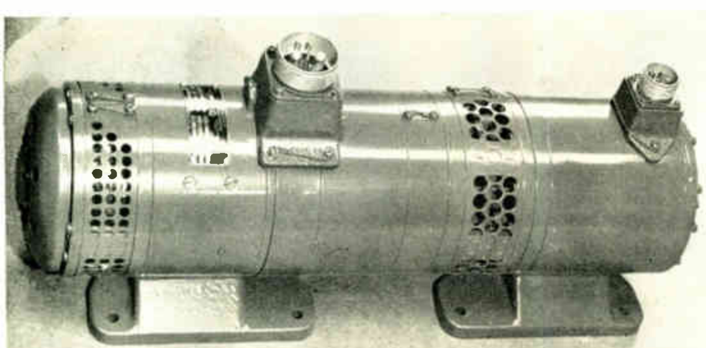

Fig. 3—Developed for powering gun turrets, this three-kw variable-voltage generator is driven by a five-hp, three-phase, 400-cycle motor. The full-load field excitation is only one watt.

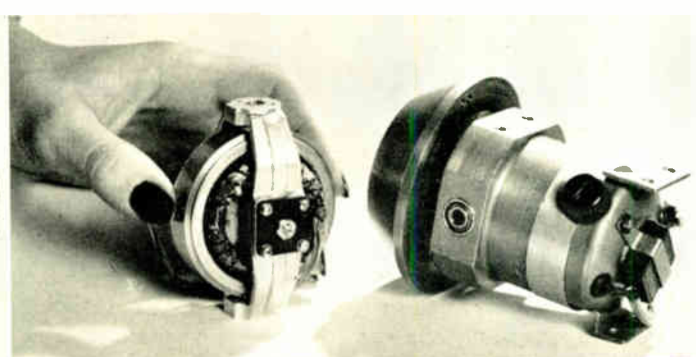

Fig. 4—An example of the weight and space savings possible with alternating current is given in the relative sizes of these gyroscopes. The a-c drive (left) is lighter, smaller, and simpler.

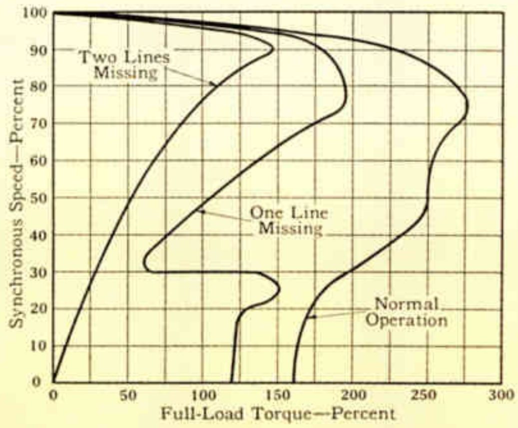

Fig. 5—The desirability of a grounded neutral is shown by these speed-torque curves indicating starting torque available with one or two lines interrupted.

6000 rpm, the same gears would drive the alternator at 23 000 rpm at the high end of the speed range, an obviously impracticable speed for a machine of appreciable size. Much of the weight of the variable-ratio drive can therefore be charged to the reduction made possible in alternator weight at constant-speed operation. Similar considerations also apply to d-c generators, especially for sizes appreciably larger than those now in use.

Speed Governor—A speed governor must be provided that will maintain the alternator speed at 6000 rpm (within permissible variations) and also control torque for parallel operation of alternators. That is, it is necessary to establish a definite relation between speed and torque so that the governor can simultaneously maintain system frequency and alternator load division. Because alternators operating in parallel must all have the same speed, individual loads must be exactly proportional to the applied torque. The speed setting of the alternator speed governor should be responsive to load, and errors in speed calibration will appear as an incorrect division of torques.

Obviously all governors should produce the same incremental droop in speed as alternator load increases. The stipulated speed droop from no load to 150-percent load is eight percent. With a system frequency of 400 cycles at 75-percent load, the no-load frequency is about 417 cycles and the frequency at 150-percent load is 384 cycles. One-percent error in speed calibration will produce nearly 20-percent error in torque or load division.

The governor should operate rapidly enough to keep the alternator load division within permissible limits even at maximum rates of engine acceleration. The over-run clutch, however, prevents major system disturbances during such acceleration periods, and there is little danger of damage even if the load shifts rapidly between alternators.

A "soft" drive (one that has considerable droop with load, either because of slippage or because of a torque-limiting device) greatly reduces the difficulties of governor control and materially reduces the speed of response necessary to prevent over-frequency and excessive torque when an engine is accelerated rapidly. The droop in the drive is momentarily added to that in the governor so that the momentary torques are reduced and the governor is allowed ample time to reach the proper setting.

Droop in the governor is produced by a kilowatt-responsive element in the governor calibration system. To avoid problems involved in complicated interconnections, each governor responds to the load on its own alternator only. Load division may be adjusted in flight by biasing the governor calibration by electrical remote control. This adjustment raises or lowers the entire speed-torque curve but does not introduce a change in its slope.

Voltage Regulator—Voltage regulators on an a-c system with paralleled alternators must accomplish two results; they must control the system voltage and they must divide the reactive circulating power loads to prevent overheating of individual alternators or serious reductions in synchronizing torques. System voltage is a function of the total excitation, including any negative excitation or demagnetizing effects produced by low-power-factor loads. The proportion of total excitation applied to the field of any one machine determines the power factor instead of the voltage of that machine. That is, a slight change in the excitation of a single alternator paralleled to a high-power bus will have much less effect on the bus voltage than it will have on the distribution of circulating reactive power. Voltage regulators for use with paralleled alternators are provided with an automatic reactive-load compensating circuit that prevents appreciable unbalance of power factor between alternators. The compensating circuit is responsive only to the circulating zero power-factor component of the alternator outputs so that it can operate to redistribute the excitations without changing the system voltage.

The Alternator—Main-engine-driven alternators now available are eight-pole, 400-cycle, 6000-rpm machines. Mechanically, they are required to withstand 9000 rpm without failure, because in the event of governor failure some types of drive will go into direct ratio with a possible maximum alternator speed of 8100 rpm. The machines are of salient-pole, rotating-field construction. Damper bars are used in the pole faces to provide anti-hunting characteristics. Such an alternator is shown in Fig. 6.

Excitation is provided by means of an exciter either built integral with the alternator or coupled to it at the end opposite the mounting flange. The exciter is designed for a high "ceiling" output because the short-time overload capacity of an alternator varies directly with the amount of excitation power that can be supplied. Heavy overload capacity insures system stability and provides the short-circuit current nec-

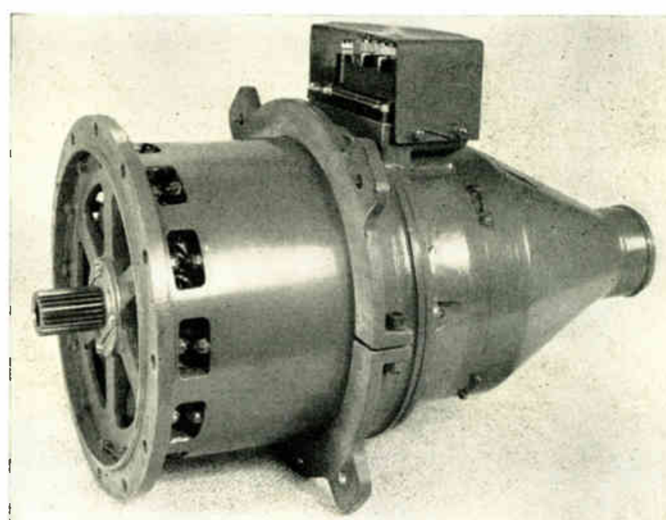

Fig. 6—Rated at 40 kva, this main-engine-driven alternator is an eight-pole, 400-cycle machine operating at 6000 rpm.

essary to clear faults rapidly enough to avoid loss of synchronism or loss of motor load.

Parallel Operation—Parallel operation of several small alternators provides maximum reliability, especially for systems exposed to the hazards of combat service. The full output of the system is instantly available wherever needed. The requirements for successful parallel operation add complications to the speed-control and voltage-control problems; solutions to these problems are but little more complicated than similar problems satisfactorily solved on the XB-19.

The system layout must be such that operation can be obtained with isolated alternators and sectionalized distribution lines so that failure of, or damage to, paralleling equipment will not render the system inoperative. Transfer breakers must be provided so that any feeder can be connected to each of two or more alternators and so that loads can be shifted as required to avoid overloads or to compensate for combat damage.

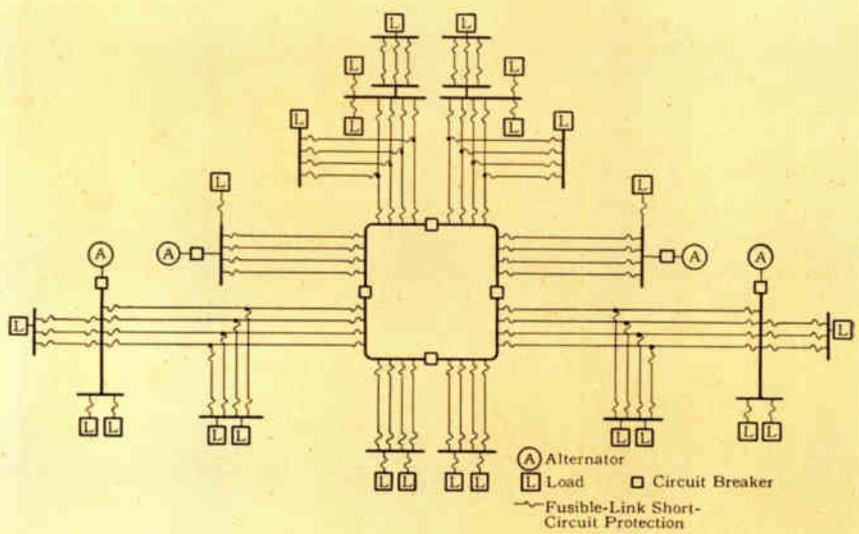

Fig. 7—Typical central-bus distribution system with fusible-link protection.

Equipment is now being developed for synchronizing. It is similar to equipment already tested on the XB-19. A "dead-bus" relay allows the first alternator that comes up to speed to do so independently of the synchronizing controls and to be connected to the system. As soon as voltage is available on the system, the automatic synchronizing equipment comes into play. Before the other alternators are connected to the bus they are brought up to the proper voltage and frequency, and then automatically connected when in the proper phase relationship with the system voltage to avoid disturbance to the system.

The Distribution System—Aircraft distribution problems approach those encountered on naval vessels. Every consideration must be given to continued operation even after severe damage by hostile fire. Attempts have been made to provide two separately routed feeders for each vital load, but in most cases this involves a penalty of too much weight. Instead, each major feeder consists of nine or twelve spaced conductors; that is, three or four per phase. Subdivision of the feeders permits a reduction in total copper since the spaced leads dissipate heat much better than a single large conductor. A typical central-bus distribution system with fusible-link short-circuit protection is shown schematically in Fig. 7.

The subdivision of the main lines into parallel conductors makes possible the use of fusible links for clearing of faults on lines or at loads. At least three conductors per phase are required. Four are used for all vital circuits so that at least two faults in any given section can be cleared without failure of the section. Use of a fuse of incorrect rating can destroy the protection for a large portion of the entire system by causing circuits to open in incorrect sequence with resultant loss of vital sections.

Fuses cannot protect the system against faults occurring on the buses where the subdivided feeders are tied together. For this reason, it is proposed on military aircraft to provide armor for vital buses. In most cases such armor will consist of a structural member.

Likewise fuses cannot protect the system from faults occurring within alternators. Differential current relaying is used for protection against damage to the system or to the airplane from alternator faults. Relays operate when the incoming and outgoing current in any phase does not balance because of phase-to-ground or phase-to-phase faults within the alternator. Operation of any one of the differential relays opens the main breaker for the particular alternator and simultaneously kills the alternator excitation. Shutting the machine down minimizes danger of fire or further damage to the alternating-current generator.

Additional alternator protection is provided by a thermal relay responsive to exciter voltage. This relay opens the exciter field in the event of sustained operation at exciter ceiling voltage, because such operation indicates either faults or excessive overloads beyond the capacity of the alternator.

Frequency must remain within certain limits for proper operation. A relay is provided to take the alternator off the bus if the frequency falls below a minimum value. An over-speed release in the drive prevents over-frequency.

Main breakers and transfer breakers are of the "latched-in" type so that momentary voltage dips cannot cause drop out. They are controlled from a 30-volt auxiliary d-c control circuit. Operation of d-c control magnets is necessary to close or to open breakers. System stability demands extremely fast operation (0.01 to 0.015 second) of the differential relay and main breaker in the event of an alternator fault to provide coordination with fuses in the distribution system.

Applications of electricity on military airplanes have developed far more rapidly than d-c power-system capacity has increased. Now that, by aircraft standards, virtually unlimited power is being made available, it is reasonable to suppose that our inventors will respond with an avalanche of new devices made possible by the new power system.

The a-c system as outlined should not be compared with the last word in d-c systems. For proper perspective, it should be compared with early 12-volt systems. The system described may well develop into electric installations as far ahead of present ideas as a present d-c super-bomber system is ahead of a power system using a single 15-volt, 15-ampere generator. With the exception of the actual size of the power equipment, most of the apparatus for a-c installations will be required whether the system is designed for 150 kva or for 500 kva, so that the relative advantages of alternating current will increase with increased capacity.

Naval Research, Insurance for Peace*

A nation is attacked only when it seems ill prepared to defend itself. A continuing, vigorous, coordinated program of military research is a powerful but inexpensive instrument in the cause of peace. It is anti-war insurance.

Captain Leonard B. Loeb, U.S.N.R.
Naval Ordnance Laboratory

A maritime nation depending on its navy for the protection of its interests must be prepared to engage in extensive naval research and development in peace as well as war. This development must be apart and beyond the general industrial research development of the nation as a whole, first, because of its specialized character, and second, in the interests of security. Thus a maritime nation must at all times maintain active research programs in laboratories under the direction of its material bureaus.

Certain peoples have been ascribed as having superior skill in research and development, especially along technical and scientific lines. Nothing could be more erroneous. The score, cast up at the end of this war, will probably show that in some directions the enemy has made some very notable progress. In others, however, frequently in fields in which his opponents have been successful, he has met complete failure. Also in this war, as in the last, the enemy in general not only made few *great* advances *during* the conflict, but also for the time available in the prewar and wartime research periods the contributions of the allies separately, and much more so collectively, greatly outdid the enemy.

It must be realized that the enemy spent from six to eight years in the most intensive and extensive research programs along certain lines of war munitions, (e.g. rockets, torpedoes, mines, submarines, etc.). Thus it is not surprising that by 1940 he had accumulated stocks of new devices in production which were released to the world as new weapons at various supposedly propitious periods during the ensuing years. Aside from a few developments the greatest advances came from those units that were fostered during the prewar years.

Thus the nation technically best equipped to fight a war, offensive or for self-preservation, must in time of peace, by foresighted and costly research and developments prepare for war. For in any case, years are required to develop and place in production a new device. Even if given time, it is clear that under the immediacy of war conditions, despite increased financial assistance and manpower, the devices so produced cannot in some respects be as good as if developed on a more leisurely basis. This is particularly true in fields where much preliminary basic research must be done before good weapons can be developed.

It is impossible for the human imagination to transcend certain limits in foreseeing the future needs. Hence in peacetime the research developments of value in the next war must derive their inspiration from relatively few sources, such as:

1—Exploitation or development of new postwar fundamental scientific discoveries to future wartime applications with the attendant basic research essential to a high degree of effective utilization.

2—The improvement and further development of existing devices in the light of new advances or as the result of special basic research.

3—The solution of questions or difficulties arising from battle problems, war games, and maneuvers.

4—The development of new tactical procedures arising from strategical studies related to possible conflicts in specific war theatres with certain special requirements. This unquestionably is the most difficult field for deriving new methods, because it calls for advance strategic planning involving great but realistically disciplined imagination. It is one exploited in Germany under the spur of the strategy fostered by the principles of Geopolitik.

The great mass of technical military development results from the focusing of many minds on the problems arising during actual warfare. In peacetime one is not able to experiment in a completely realistic manner on death-dealing and destructive instruments. It took a battle of Jutland to teach the value of armor-piercing shells and the proper compartmentation of ships and damage control. A Pearl Harbor and the sinking of the Prince of Wales and the Repulse were required to teach us the lesson of adequate anti-aircraft fire power concentration on modern battleships.

There are problems for which our imaginations and experiments are incapable of giving us a true solution in times of peace. Not only this, but under stress of war it becomes possible to enlist the best brains and to have the necessary funds in order to develop the material to its utmost. Further, the constant interplay of measure and counter-measure involved in any military operation stimulates development as it never can be stimulated in peace.

Thus, while the initial peacetime development in the larger scale logistics and production sphere, as well as in the development of weapons and tactics, is of great value—and gives one an important head start in war—too much cannot be expected solely from peacetime development. Nor should too great a reliance be placed on the peacetime devices in the event of war.

One fact must not, however, be forgotten and that is that in times of peace much *basic* research can be done as a preliminary to later wartime development that cannot be undertaken under urgent war conditions. It was primarily here that the German enemy had his greatest advantage.

While a strong program of peacetime research is vital, an enormously augmented research and development program in time of war is equally as important. In the plan a proper balance must be struck between the two. It is urgent that in peacetime the organization of both these programs should be such as to enhance progress with the outbreak of a war.

Aside from the urgent considerations of research as a necessary insurance measure, it is actually an inexpensive form of insurance. It pays great dividends in an emergency. If $10 000 000 is annually spent in its support for twenty-five years the total investment is still less than the cost of two

*This article is an abstract of a talk given at a dinner in honor of Dr. C. E. Skinner, at Pittsburgh, Pa., May 29, 1945.

modern battleships. Perhaps a single device developed thereby would save an undetermined but large number of war vessels, including battleships. The destruction wrought by the robot bombs in London alone (which caused total damage greater than the blitz) was significantly —very significantly—reduced by devices whose cost of development probably did not exceed $10 000 000. Not only in peacetime is naval research a necessary form of insurance as it is a powerful deterrent to war, but one that in war pays dividends.

Unquestionably naval research must be properly guarded. Fortunately the problem of security is simplified somewhat by the fact that if one enjoys the advantage of two years, or even one year, in the employment of a new weapon over an enemy, one has perhaps gotten all that could normally be expected of that advantage. It is this temporary advantage that fundamentally must be striven for in all military research and development. Little more can be hoped for.

Several Kinds of Research

Research is of different sorts, with different objectives. These might be conveniently classed as fundamental, basic, and industrial. Fundamental research reveals new effects, phenomena, forces, or radiations, and delineates their more purely scientific characteristics and theoretical implications. Basic research is a vital initial step in an industrial research program and should be antecedent to all such programs. The engineer or industrial scientist does not, from the results of fundamental research, have the necessary data on which properly to base his applications to the design and development of a useful device. Much basic research must be done whose objective is the investigation of phenomena with an eye to practical application.

Industrial research and development has for its end the adaptation to industrial, technical, or scientific use, on a widespread scale, of the fruits of fundamental research for the benefit of society. It might perhaps be called engineering research. Actually, industrial research is a combination of fundamental research and of engineering. Such investigation aside from the industrial objective is in certain essential points different from fundamental research.

Consideration of naval research during peace, especially with our inability clearly to foresee future applications to the strategy of a possible future war, indicates that basic research following on the heels of gains from new fundamental research constitutes the most important item of such studies in prewar years. For in basic research necessary to the development of future weapons and countermeasures lies the most profitable naval insurance against future aggression, since, with this knowledge, these devices can readily be designed to meet any emergency.

It was the realization of this fact that enabled the Nazi-controlled German government to proceed during the six or more prewar years on an intensive program that yielded the jet-propelled weapons and planes, the influence mines, the homing torpedoes, the many improvements in submarine design, the tanks and the other devices that gave them such powerful initial advantages in the war. It was, however, their inability to foresee in detail their strategical and tactical use in the actual conflict that gave the allies opportunity for appropriate countermeasures. For example, the Germans could not have foreseen that the "battle of Britain" would be lost despite their material superiority in numbers of aircraft by the employment of the unexpectedly effective fighting and fire power of Spitfire and Hurricane fighters combined with the invaluable British radar.

It may not, however, be our good fortune to have adequate time in the next war. For example, when we were faced with the influence mine beginning late in 1939, it was necessary to carry on basic research of the influence fields of ships, to devise the most elaborate installations on all ships, to develop complete servicing stations and to establish the necessary techniques for the preservation of our ships. When it is considered that this required studies of aspects of physical phenomena completely unknown, the development of rugged and rapid recording instruments perhaps 100 times as sensitive as those previously used, as well as major alterations in existing ships, the short time of three years required seems fantastic. But, three years is not a short time.

The Conduct of Naval Research

The principal means of naval research open at present are:

1—Utilization of various naval research establishments.

2—Utilization of the research possibilities directed by the National Academy or its committee to be established on the basis of Wilson Committee report as will later be indicated.

3—Utilization of our educational laboratories.

4—Utilization of non-military government research agencies of which their are several.

5—Utilization of research facilities made available by industrial organizations.

Certain aspects of research, especially those involving the development of weapons and countermeasures, must be carried out directly in the naval establishments. In addition, amelioration or extension of existing devices must also be done by the Navy in its own establishments. Primarily this is because such projects must be worked out closely in relation to the naval command and with the fleet. They thus require closer liaison with the service than is possible in industrial establishments. Again, work of a top secret nature should be kept well within the naval establishment. Certainly no fundamental research can properly be carried out under these auspices. Most aspects of either industrial or naval research are inimical to good fundamental research. Fundamental research is and always will be the special function of educational and pure research institutions. On the other hand, this function of the educational institutions must be recognized and they in turn should not be lured into the industrial or naval research by the offer of financial subsidy. Diversion of these agencies might stop scientific progress, production of fundamental research, and in fact all research at the source. For preeminence in fundamental research in a nation is a requisite to preeminence in applied research. Nevertheless it is the peacetime duty of naval establishments to engage in much basic research. In fact this is one of their prime missions.

How far they will be able to do this cannot now be answered. Under war pressure elaborate plans were initiated to build up outstanding naval research establishments for the future.

Great and superlative research achievement in war as in peace is not an attribute monopolized by one nation. It depends solely on attracting or developing the best scientific talent, giving it the necessary incentive, enlightened direction, adequate material facilities, and sufficient time to achieve results. In the measure that this is done, a country obtains for itself invaluable scientific wartime insurance.

Indeed, Congress has been most generous in trying to further this plan. But the question is not what will be done now, but what will be done in the future. The important item in all such research lies in the quality and quantity of its scientific personnel. This is the most vital, difficult, recurrent and costly item. It implies radical changes in our civil-service regulations to enable proper recruiting and employment of personnel as well as adequate remuneration and promotion together with adequate funds.

Whether such funds are likely to be available in the future with an economy-minded nation is a matter of deep concern at present. Congress, although research-minded, has in the past approved items in the naval budgets for research without earmarking them exclusively for research. On the other hand they have sharply curtailed naval expenditures on other items. Irrespective of the value placed by the high naval command on research this economy has resulted in the sharp curtailment of research, in the interests of maintaining an operating Navy. While this sad record of the past may be definitely behind us, it is not impossible that the old mistake will not be repeated. With this in mind it will be necessary to depend on other sources for some at least of our vitally needed basic research. Perhaps the most important source will be our large industrial research agencies.

With victory the valuable functions of the National Defense Research Council and the Office of Scientific Research and Development will be terminated. These agencies mobilized the scientific research resources of the country to work on problems and weapons vital to the war effort that could not be undertaken by the armed forces. The total cost of the O.S.R.D. program alone to date is some four hundred and seventy two million dollars. In its place there will be a Research Board of National Security. This Board, approved by the President, will consist of some forty members of which about half may come from the armed services, or on their nomination, and the rest will be representative civilian scientists nominated by the National Academy of Sciences. Both the May bill of the House and the Byrd bill of the Senate wisely allot this Board the necessary funds for conducting research for national security as an independent appropriation. In this fashion freedom from complete domination of important basic security research programs by the non-scientifically expert members of the armed forces is precluded. Precluded also is any chance that research funds will be diverted to other uses.

The May and Byrd bills differ only in that the May bill allots the funds directly to the National Academy, making them responsible for the work without precisely indicating how they shall act. The Byrd bill designates the constitution of the Board, its duties and privileges and assigns funds directly to the Board. In essence, as outlined by the Byrd bill, the Board will function much in the fashion as did the O.S.R.D. during the war. It shall contract to use existing research facilities but shall not organize laboratories of its own.

The solutions of nature's riddles cannot logically be planned in advance through a system of research devised by one master mind. It requires many scientists, working independently from many different approaches, using different means and proceeding with no assurance that any one worker or group will succeed at any given time.

This creation of a Research Board for national security does not absolve the armed services from themselves carrying out their own basic research. It is intended rather to support more extensive basic research projects less likely to be taken up by the armed services and to coordinate and supplement their research activities.

Aside from the question of maintenance of security it is a serious question as to how much one should curtail the fundamental research of our educational and government research institutions in the interests of naval research. In normal times it is possible, but more difficult than in war time, to isolate portions of such institutions for military research. While such research allotted to a University brings funds in its support, these funds do not benefit the institution in its main function if properly spent for the purpose intended. Naval research problems are not proper thesis problems and they divert the interest from fundamental research. The air of secrecy shrouding such work is unhealthy for an institution of learning or one devoted to pure research. On the other hand, valuable fundamental research techniques can be imparted to representatives of the military laboratory staffs by our scientific laboratories and there should be exchange of personnel between both types of institutions. Portions of military projects, which by their nature do not demand some secrecy classification, could be properly farmed out to such institutions. Other than that we should not in peacetime carry on much such work in these institutions.

Industrial concerns have industrial research laboratories engaged in essentially the same type of work as naval laboratories. In time of war they become the big partners of the Navy in the research and development for national defense. While many fields of interest in industrial research laboratories in peacetime may have no immediate relation to naval problems, enough of them do have to require close liaison and cooperation. Again the results of peacetime industrial research projects in many fields, which the Navy could never itself undertake, serve the Navy excellently in time of emergency. Thus the basic research carried out on special magnetic alloys by various industrial concerns proved to be a godsend to the Navy in the present emergency. The question of security so important to the Navy introduces no great problem in industrial laboratories as their work is already highly classified. Whether it be by direct contact with the Navy or with the new Defense Research Council of the National Academy a certain number of the Navy's problems will undoubtedly be farmed out to industrial research laboratories. Finally, if serious curtailment of funds for naval research should occur, the Navy establishment will have to lean heavily on the industrial researches in certain fields of common interest where they cannot maintain adequate staffs to carry on the basic work.

We must hope that the future will find us much better prepared for war than we have been in the past—if not, then with the weapons of the future, God help us.

[*The wastefulness of scientific effort is reduced and its net gains are enhanced by the free and effective exchange of ideas among various workers even in fields that are not apparently related.*]

Wide Speed Ranges with Servo-mechanisms

Servo-mechanisms, brought to a high point of perfection by war needs, have many ordinary uses. They can be applied to machine tools to provide a positive drive of component parts of tools that must operate in perfect unison. Wide speed ratios are available which, preset, remain constant. Gears or mechanical linkages are not required.

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Mgr., General-Mill Engineering
Westinghouse Electric Corporation

Enormous ranges in speed—as much as 1500 to one—as needed for some machine-tool drives can be obtained without gearing with the aid of servo-mechanisms. Speed ranges of 100 to one are well within the range of direct-current motor schemes and are generally ample. However, some turning lathes and boring mills require a much larger range, quite often more than 1000 to one. This is because the feed or advance of the cutting tool is specified as a certain amount per revolution of the work, which also varies over a wide speed range. The total range is the product of the two.

Such wide limits in speed have always been considered excessive for electrical drive. In such cases, the feed mechanism has been driven from a shaft geared to the table, so that its speed is proportional to the table speed. A set of change gears is interposed between this shaft and the screw driving the tool-feeding mechanism to give the necessary range in feed and the desired number of feed speeds to cover the range satisfactorily. On the larger boring mills and turning lathes, this mechanism becomes elaborate and expensive, especially when a large number of feed speeds are desired.

The war hastened the development of various types of servo-mechanisms because of their usefulness in gun fire control schemes. With adaptations of these mechanisms, electrical drives on machine tools can cover wide speed ranges without any mechanical linkage between the table and the feed screw.

Servo-mechanisms for use on machine tools can be defined as closed, electrical regulating systems for control of a mechanical operation, usually some distance removed, that require some amplification of the control forces. In other words, operation of a control device with slight effort at one point compels a motor to make a proportional movement with considerable force at a remote point.

A servo-mechanism can be applied to the feed drive of a boring mill as shown schematically in Fig. 1. A servo-unit, consisting of a small single-phase induction motor with three-phase secondary, is connected to the table and turns at a rate proportional to the table speed. Another servo-unit is connected to the feed screw. Its speed is proportional to the feed speed. Suitable electrical connections are made between the two units and an electronic servo-regulator.

Starting with the machine at rest, if the table only is rotated a small amount, the voltage phase relation of the servo-units changes and an error voltage is applied to the regulator, the amplitude being proportional to the error. The regulator responds to the voltage and causes a current to flow in the field of the d-c generator, which is used to supply power to the feed motor. A voltage is developed by the generator that causes the feed motor to rotate in a direction to move the machine tool in the proper relation to the table movement. Hence the feed servo-unit moves in the same direction as the table servo-unit until error voltage is no longer applied to the regulator, the voltage on the generator feed motor falls to zero, and the feed motor stops. If the table continues to move, a continuous error voltage is applied to the regulator. This, in turn, constantly excites the generator the necessary amount to cause the feed motor to run at the correct speed to keep the two servo-units in the proper voltage phase relation.

This system compels the feed motor to rotate at a speed exactly proportional to the table speed. Basically, it is a position regulator of the synchronous type. That is, there is no slip in the system and the feed motor must turn exactly the same number of revolutions as the table motor, or in some exact ratio depending upon the gearing arrangement.

The arrangement described gives only one fixed speed per revolution of the table. To vary the feed per revolution of the table a speed-changing mechanism must be between the table and its servo-unit. However, this device is much simpler and less expensive than the speed-changing mechanism usually built into the gear box on the rail of a conventional boring mill, because the torque load is small.

This arrangement entails no mechanical connection between the table and the feed screw. All speed-changing devices with accompanying clutches, etc., can be eliminated from the rail. Reversal of the direction of the feed for a given direction of the table can be accomplished easily by reversing two leads of either servo-unit.

A differential synchro-tie unit and a mechanical regulator can replace the electronic regulator, but is not as sensitive. The electronic regulator provides high sensitivity more effectively and includes anti-hunting features, thus making the motor operate more smoothly, especially at low speeds.

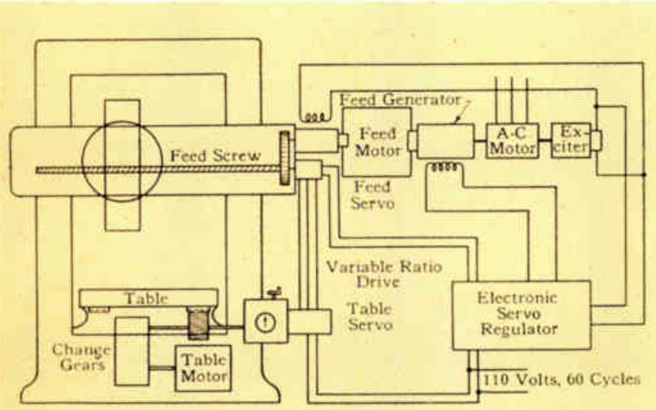


Fig. 1—Simplified diagram of servo-motors as applied to obtain an extremely wide range of speed on a machine tool.

STORIES OF RESEARCH

Pure Water

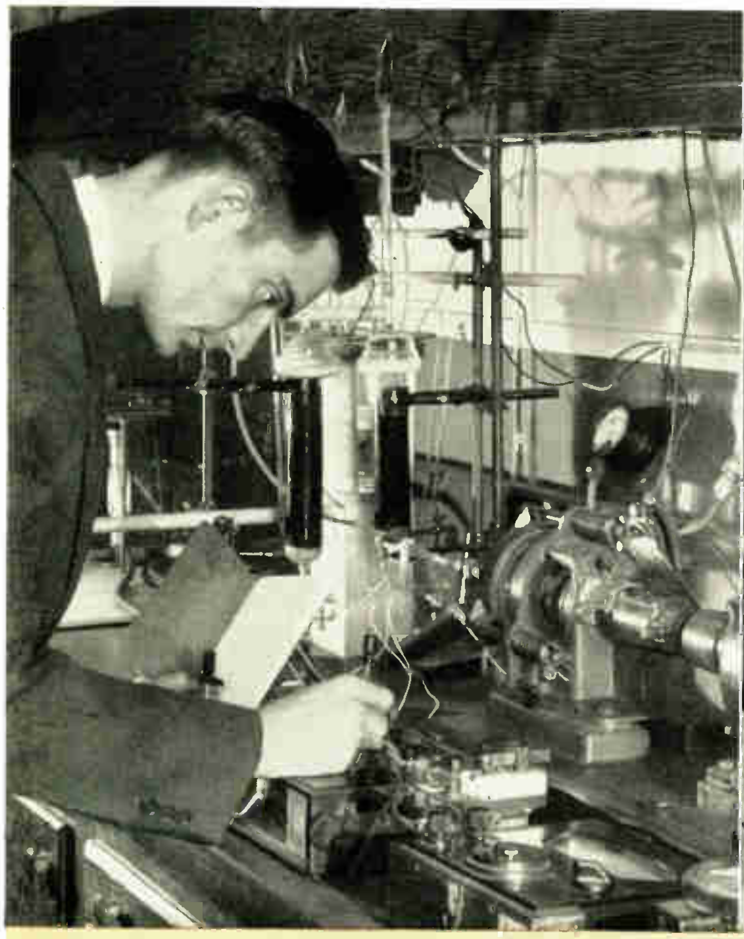
WATER used for cooling large electronic tubes is scrutinized for contamination even more thoroughly than is the water we drink. Certain ions, which enter the water from impurities picked up in the circulating system, must be removed or the water ceases to be a good insulator.

For many applications, distilled water is used for cooling high-potential vacuum tubes. Fresh distilled water has a resistivity of 300 000 to 500 000 ohms per cm cube. With the addition of impurities, this resistance is lowered by an amount depending on the nature of the impurities. In this connection, some surprising facts were recently brought to light. Water that had become murky and discolored because of immersed pieces of rusty iron and steel, registered relatively unchanged resistivity, whereas clear water, which had circulated in a system of copper pipes, contained sufficient metallic ions to lower the resistivity materially.

Electrolytic water-purifying equipment has been set up in the Westinghouse Research Laboratories by G. W. Hewitt and W. H. Davenport, Jr. that operates while the water is circulating through a cooling system. Because distilled water, particularly when hot, picks up impurities from the metallic portions of the circulating system, the test system is constructed entirely of plastic tubing, glass and tin-covered copper where metal is essential. Tin causes much less contamination than copper. Even the rotary pump for circulating the water is made of glass to minimize contamination.

The water passes through a chamber in which are two electrodes of opposite polarity. Each electrode is enclosed in a porous ceramic cup. The metallic ions are attracted to the negative electrode and are trapped within the porous cup. The acid-forming ions go to the positive electrode. The metallic ions at the negative electrode form a hydroxyl with the release of small amounts of hydrogen. The acid-forming ions enter into solution at the positive electrode with the release of small amounts of oxygen. In a large system, in the space about the electrode within the porous cup, the concentration of the metallic or acid-forming ions can be as high as 1000 parts per million.

The solutions within the porous cups are therefore drawn off and passed through two resin filters. The characteristics of these filters are such that the metallic hydroxyls in the solution from the negative electrode have the metallic atoms replaced by hydrogen, with the formation of water. The acid solutions from the positive electrode porous cup are reduced by the acid-absorbing resin in the second filter, water again being a product of the action. The water from both resin filters



The electrical measurements taken by W. H. Davenport show that this filtering system so thoroughly removes from water the impurities that lower its resistivity that the treated cooling water has a resistivity greater even than the best exhibited by distilled water.

Starting with a water-thin, amber-colored liquid such as is being "brewed" by Mr. Foster, upon polymerization Fosterite becomes a nonporous solid impervious to moisture and resistant to fungus, both vital for tropical insulation.

is fed back into the main circulating system. The filters, of course, eventually need to be reactivated.

With this apparatus the purity of cooling water for electronic equipment can be maintained. In fact, contaminated distilled water has been purified beyond the level of freshly distilled water with this system. Instead of resistivities up to 600 000 ohms, contaminated water has been raised to a resistivity of 5 000 000 ohms, about ten times that of distilled water.

Fosterite

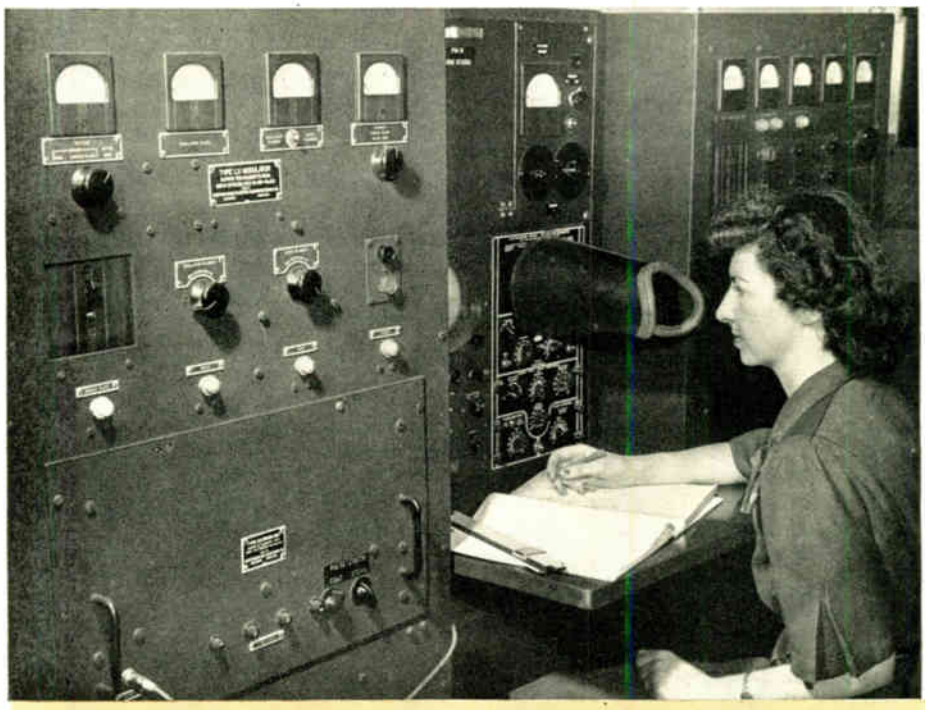
EARLY operation of electronic equipment in the South Pacific was hectic because, sometimes in a matter of hours, the ever-present moisture had ruined transformers and other apparatus. Aided and abetted by sudden changes in ambient temperature, particularly in airborne equipment, moisture found its way into the interstices of the windings treated with ordinary impregnants. One of the best solutions to the problem of providing moisture-proof coatings and impregnants for electrical apparatus is Fosterite, a polymerized resin developed by Mr. Newton C. Foster of the Westinghouse Research Laboratories.

To overcome conditions of excessive humidity and wide variations of ambient temperature, many schemes were tried such as that of putting the transformers in cans and filling the cans with oil or gum. High ambient temperatures often cause the cans to swell and leak. Also, the necessary bushings through the metal container sometimes develop leakage. In general, this method is successful, but it imposes a serious increase in weight, 50 to 100 percent in some equipments—a vital matter in airborne equipment. Another method involves impregnating the transformers with varnish and coating the outer surface with extra coats, but this method at its best is not adequate to meet the desired specifications. Moisture is then readily absorbed by the impregnating varnish because the best varnishes known contain only from 25 to 50 percent solids. When the volatile solvents leave the varnish in drying, the resulting capillaries provide channels for entrance of undesirable moisture.

Fosterite contains no solvents and, before polymerization, has a very low viscosity—in fact, it is almost as fluid as water. Because of this fluidity, it fills completely all the interstices in the coil, even spaces in the fibrous material. Because it contains no solvents, no capillaries that provide channels for moisture entrance are formed when polymerized by heat treatment.

All Fosterite-treated transformers are given an immersion test of two hours in a 65-degree water solution, followed by two hours in a cold water solution at about 25 degrees C. If the insulation resistance to ground or between windings falls below 2000 megohms, the transformer is considered to have failed. In some actual tests, the insulation resistance of Fosterite measured 1 000 000 megohms before the test and lost but little in resistance during the test. This resin has proved to be from 100 to 10 000 times better than other moisture-proofing treatments. In one laboratory test, a small Fosterite-treated transformer was submerged in tap water for 18 months and the insulation resistance was still sufficiently high for satisfactory service.

Aside from its imperviousness to moisture, Fosterite is invaluable as an impregnating compound because of its 100 percent filling of the spaces in the coils. This increases the actual dielectric strength of the unit as a whole because the open spaces within the coil where corona might occur are eliminated. As a result of this improved treatment, transformers can be made smaller and ratings increased.



This equipment provides the detailed data from which Miss Helen Storm produces the operating profiles of the Hipersil cores used in high-frequency equipments.

Facets of Wartime Research

WAR-NEEDED materials, both new and old, are a major concern of research. Often, after such materials are developed or improved, it is necessary for the research engineer to delve deeply in many fields of science to produce adequate testing equipment to appraise the characteristics peculiar to the material under scrutiny. Such has been the case in the magnetics section of the Westinghouse Research Laboratories where, under the guidance of Dr. Sidney Siegel, transformer cores of special steel are checked.

New demands placed upon transformers of limited size in high-frequency equipment made it imperative that eddy-current losses be minimized. Grain-oriented Hipersil wound-type cores made of steel strip only two mils thick made possible some of the required characteristics. The transformers, variations of which will play important parts in television, must transmit with high fidelity short unidirectional modulated pulses of voltage of high amplitude. The power involved is large though the time is small—as short as a microsecond. The overall efficiency must be 90 percent or better.

The unitized test apparatus uses standard coils into which the wound cores are clamped. The equipment to the left of the operator in the illustration generates and modulates the voltage pulsations whose amplitude and duration can be controlled closely. The voltage pulse applied to the transformer is shown on the left-hand oscillograph.

The portion of the apparatus to the right of the operator contains the power supply and also the capacitor and resistance components of a circuit whereby the B-H characteristics of the core are explored. The performance of the transformer is observed on the cathode-ray oscilloscope to the right in the form of the familiar hysteresis loop. As in the other oscilloscope, the output is readily calibrated by reference to the coordinates superimposed on the cathode-ray tube end.

Low-Loss Ceramics for High-Frequency Applications

EARLY in the history of radio development it was evident that electrical insulation with excellent characteristics for power-frequency use was inadequate for high-frequency applications. This demand for insulation with lower energy losses became more and more acute as the frontier of the useful frequency range was pushed higher. The demands for radio and ultra-high-frequency equipment incident to World War II resulted in an unprecedented need for more and better ceramic high-frequency insulation. To meet this need, a new type insulation, low-loss Zircon porcelain, was developed at the Westinghouse Research Laboratories under the direction of Dr. Ralston Russell, Jr.

The burden of high-frequency ceramic insulation imposed by tremendous war demands has been in large part shouldered by the porcelains known under the generic name of Steatite. Steatite, until recently, has been internationally utilized without serious competition from other ceramics in the radio field, and is today the standard to which all other ceramic high-frequency insulation is compared.

Zircon porcelain has been known for several years to be an excellent ceramic material for spark-plug insulation because of its resistance to heat shock and its low current leakage at elevated temperatures. Zircon porcelain received little consideration for high-frequency use until 1942 when new-type Zircon porcelains were developed. Tests show these new porcelains, predominantly the mineral Zircon ($ZrO_2{\cdot}SiO_2$) plus some clay and fluxes, to be materials having electrical and physical qualities equivalent to the better grades of Steatite and, in some important respects, substantially superior.

The greater uniformity of quality of Zircon ceramics, as compared to Steatite, stems partly from the nature of their raw materials and partly from the differences in the requirements of their fabricating and firing processes. Mineral talc as mined varies in its composition and nature with the several deposits and also within any one deposit. The manufacturing process thus requires very close control of the raw materials. The sources of usable talc are somewhat limited, which, together with fairly rigid manufacturing requirements, limit the available volume of high-quality Steatite ceramics. Zircon is found in the sands of beaches throughout the world, including Florida, India, Brazil and Australia, and the material is replenished by the sea. Zircon is also a constituent of many igneous rocks. As derived from beach-sand deposits, it is uniform in constituency and poses no unusual raw-material processing difficulties. Comparable Zircon ceramics are thus produced from raw materials of whatever source, provided purity and particle size are adequately controlled.

While Steatite is largely confined to the dry press process, Zircon can be readily processed by any of the methods used for forming in steel dies (dry or semi-wet), by plastic forming using standard equipment, and by slip casting. Much success has been achieved with the "Prestite" method, a pressing process in which a uniform density is developed in an evacuated steel die. Some Zircon compositions have total shrinkages identical with high-tension porcelains so that dies are interchangeable for the two materials.

Through manufacturers' publications and by direct tests, the relative physical and electrical characteristics of Zircon and Steatite porcelains, and transparent fused quartz were established. Zircon porcelain is somewhat heavier than Steatite, with clear fused quartz the lightest. Fused quartz and Zircon porcelain have no water absorption against 0.0 to 0.6 percent in some Steatites. In some cases, there is penetration when Steatite is immersed in a dye solution under pressure but none for Zircon porcelain. The linear coefficient of expansion in clear fused quartz is by far the lowest of the three materials. That of Zircon porcelain is about half that of the comparable grade of Steatite. The American War Standards specify certain requirements for this class of insulation for heat-shock resistance, tensile, compressive and transverse strengths, and impact resistance. The standard Zircon porcelain is indicated to be superior to commercial Steatite in all these respects.

A comparison of the required electrical characteristics of the two ceramic materials shows the consistent superiority of a standard Zircon porcelain over most commercial Steatites. Loss-factor tests have been made from 60 cycles to 200 megacycles. For frequencies above 100 megacycles, samples were tested in a reentrant resonant cavity (such as described on p. 174, November, 1944 issue). In addition, tests of dissipation factor, resistivity, and dielectric constant were conducted at temperatures from 25 to 600 degrees C. In all of these electrical tests, the high-frequency electrical properties of Zircon porcelain are superior to those of the average grade of Steatite commercially available and, in most respects, are comparable to Ultra-Steatite. Zircon is one-third heavier than either Steatite or high-tension porcelain. However, even for airborne equipment, this does not pose any particular problem because the percentage of porcelain used in a given amount of equipment is minute compared to the total weight of the equipment. In many applications, the superior tensile, compressive, and transverse strengths permit the design of porcelain components substantially smaller with Zircon than with other porcelains, electrical creepage requirements permitting.

Some of the applications for which Zircon has proved itself peculiarly valuable are radio and radar components, where mechanical strength and superior electrical characteristics are essential. It is used in coaxial-cable terminals, bushings for transformer and capacitor cases, and is expected to provide a material of great strength for use in bus supports. It is also used for electrical insulation where elevated temperatures are encountered. Because Zircon porcelain is readily extruded in shapes which permit forming into large bushings as easily as ordinary high-voltage porcelain bodies, it has been possible to meet special requirements for bushings in development activities where large voltages at high frequencies must be controlled. New applications for Zircon porcelain are continually developing, and this relatively new material is already insured an important future.

Dr. Russell uses a modified Charpy impact-testing machine for comparing the relative impact strengths of standard high-voltage and Zircon porcelains. The two test pieces in the foreground have equal strengths although the Zircon specimen is smaller.

PERSONALITY PROFILES

The Kauppi-Grant, Moses-Horrell combine make a pair of tug-of-war teams—with motors in the middle. Moses and Horrell provide the best-insulated motors possible. Kauppi and Grant team up to do their best to make them fail. *George Grant* is personally in charge of the motor-test program. He has been at it since the program was started two years ago. Technical experience that fits him as grand inquisitor of silicone-insulated motors includes a B. S. in E. E. degree from M. I. T. in 1936, and periods of service with the Delco Appliance Division of General Motors, and as field engineer for the U. S. Graphite Company. When Grant wishes to relax from making it hot for motors he retreats to a cottage on a nearby lake.

After receiving his degree of B.S. in E.E. from the University of Kansas in 1938, *R. F. Horrell* spent the long, hot summer operating an electrical oil-detector in Arizona and New Mexico. History doesn't state whether he found any gushers or not, but, in any event, that fall he cast his lot with Westinghouse and commenced the student training course. He became interested in motor designing and was soon transferred to that department. Possibly the torrid months spent prospecting in the desert turned his thoughts to heat-resisting materials, for he was soon assigned the task of conducting heat tests on high-temperature insulation.

Horrell has a long list of hobbies that have interested him since student days. He has sung in glee clubs and choirs, done considerable amateur photography, been an active Boy Scout leader, and has an extensive victory garden.

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In the course of preparation of the article on testing of silicone-insulated motors we had lunch with *T. A. Kauppi*, one of the authors. He seemed at times deeply preoccupied.

Possibly he was concerned about the life expectancy of one of the motors he tortures alternately with heat and moisture. We learned later that Andy was worried about one of his crossbred great danes which had not delivered the new breed of puppies expected of her.

Kauppi received formal technical training at Brown University from which he was graduated in 1933 with a B.S. in Chemistry. He had nearly two years' experience in cellulose chemistry at the Institute of Paper Chemistry at Appleton, Wisconsin, before joining the Dow organization from which he was recruited for his present position with Dow Corning.

It is hard to guess where Andy's experimental turn of mind may lead. Five years ago he learned how to fly and now he is making his own landing field, literally in the back yard of the home he built in the timberland north of Midland, Michigan.

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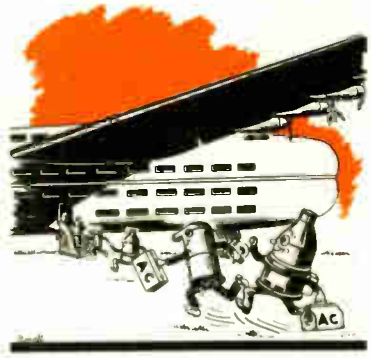
J. D. Miner comes from Rhode Island. He was graduated from Brown University in 1935 with the degree of B. S. in Electrical Engineering and came to Westinghouse the same year. He completed the Student Training Course and started his career as an industrial motor engineer. In 1938 he entered the field of small-motor engineering and was subsequently transferred to Lima, Ohio, where the small-motor activities are centered. Since 1942 he has held managerial posts in the Engineering Department of the Small Motor Division. He now is Manager of the Aviation Engineering Department. Many types of high-voltage a-c and d-c generators, dynamotors, radio power equipment (particularly for aircraft use) in current use are the product of his slide rule and design ability. His many contributions to the electrical industry led to his appointment to committees and subcommittees within the professional associations. For the 1944–45 sessions he is Chairman of the AIEE Committee on Air Transportation.



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Dr. Howard M. Elsey has had a busy career in the field of chemistry. His collegiate education was received at Stanford University where in rapid succession he received the degrees of A. B. and A. M., and, in 1919 his Ph.D. in chemistry. Thereupon he assumed a post as assistant professor in chemistry at the University of Kansas. In 1921 he was made associate professor and remained at the university until 1925 when he decided to enter private industry. He joined the research staff of Westinghouse as chemist, and has since become a consulting chemist for Westinghouse. Dr. Elsey has been active, for example, in the application of the mixture of halogen gases, flourine and chlorine, called freon to refrigeration problems. Later he developed a coating for transformer iron to protect it during the annealing process.

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Captain L. B. Loeb came to the United States from Switzerland when but a year old. His undergraduate collegiate years were spent at the University of California, Columbia, and the University of Chicago. From the last he received his B.S. degree in chemistry in 1912 and his doctor's degree in physics in 1916. After a period of work in the Bureau of Standards on such varied problems of phosphorescence, compressibility of liquid ammonia, and aviation-engine ignition, he joined the Army Air Forces. The war over he worked at University of Manchester as assistant in physics under Lord Rutherford. In 1919 he studied electronic mobilities at the University of Chicago, which studies he continued until he went to the University of California in 1923.

Loeb has always maintained an active interest in national defense and because he was convinced that another war was inevitable, undertook, in the early '30's research work for the U. S. Navy on such problems as sound locating and anti-aircraft fire. In 1941 he was in charge of the building and staffing of the Naval Proving Grounds and at the outset of war had much to do with degaussing of ships. After various special technical missions for the Navy into the war zone he became Assistant to the Officer in Charge of the Naval Ordnance Laboratory.

DIESEL-ELECTRIC LOCOMOTIVES are being used increasingly for both freight and passenger service. This newest 2000-hp locomotive has much larger motors to increase the loads hauled at low speed.