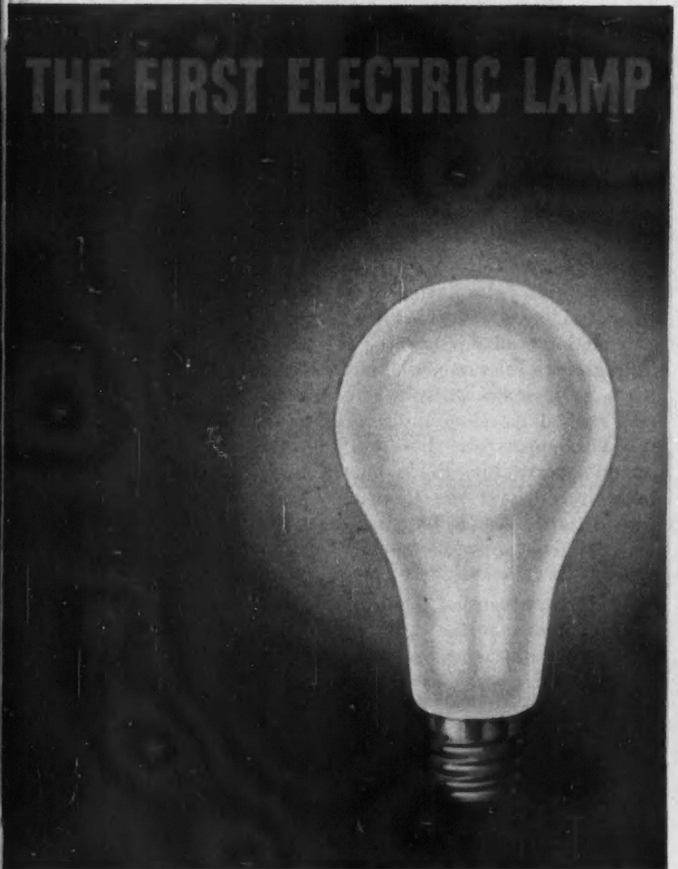
GENERAL ELECTRIC Review



75 Years of Electrical Progress

SEE PAGES 25–43

MARCH 1953

MY QUESTION TO THE G-E STUDENT INFORMATION PANEL:

"How does your business training program prepare a college graduate for a career in General Electric?"

...CHARLES O. BILLINGS, Carnegie Institute of Technology, 1954

The answer to this question, given at a student information meeting held in July, 1952, between G-E personnel and representative college students, is printed below. If you have a question you would like answered, or seek further information about General Electric, mail your request to College Editor, Dept. 123-2, General Electric Company, Schenectady, New York.

R. J. CANNING, *Business Training Course* . . . General Electric's business training program offers the college graduate the opportunity to build a career in the field of accounting, finance, and business management in one of the most diversified companies in the country.

Since its beginning in 1919, more than 3,000 students have entered the program—one of the first training programs in business to be offered by industry.

The program's principal objective is to develop men well qualified in accounting and related business studies, men who can become administrative leaders in the financial and general business activities of the Company.

Selection of men for the program is based on interviews, reviews of students' records, and discussions with placement directors and faculty members. Selection is not limited solely to accounting and business administration majors. A large number of men in the program are liberal arts graduates, engineers, and men with other technical training.

When a man enters the program he is assigned a full-time office position in accounting or other financial work and enrolled in the formal evening education program. This planned classroom work is a most important phase of the program. The material presented is carefully selected and well integrated for the development of an adequate knowledge of accounting and business theory, procedures and policies followed by the Company, acceptable accounting and business practices of the modern economic enterprise, and as a supplement to the practical experience provided by the job assignment.

In general, the program trainee is considered in training for three years during which time advancements are made to more responsible types of accounting work. After completing academic training the trainee's progress and interests are re-examined. If he has demonstrated an aptitude for financial work he is considered for transfer to the staff of traveling auditors or to an accounting and financial supervisory position. From here his advancement opportunities lie in financial administrative positions throughout the Company. Trainees showing an interest and aptitude for work other than financial, such as sales, purchasing, community relations, publicity, etc., are at this time considered for placement in these fields.

Today, graduates of the program hold responsible positions throughout the entire organization. Management positions in the accounting and financial field throughout the Company, such as Comptroller, Treasurer, finance managers, secretaries, and others, are held in large part by graduates of the course. Men who have transferred to other fields after experience in financial work include public relations executives, managers of operating divisions and departments, presidents of affiliated Companies, officials in personnel, employee relations and production divisions, and executives in many other Company activities.

This partial list of positions now filled by former business training men is indicative of the career preparation offered by the business training program, and of the opportunities that exist for qualified men interested in beginning their careers in accounting and financial work.

You can put your confidence in—

GENERAL ELECTRIC

MARCH 1953 • VOLUME 56 • NUMBER 2

GENERAL ELECTRIC Review

EVERETT S. LEE • EDITOR   PAUL R. HEINMILLER • MANAGING EDITOR

COVER—On October 15, 1878, Thomas A. Edison organized the first of the companies that, in 1892, became the General Electric Company. Two of the milestones of the past 75 years are portrayed on the cover; many more will be found in the special section that begins on page 25.

THE GENERAL ELECTRIC REVIEW IS ISSUED IN JANUARY, MARCH, MAY, JULY, SEPTEMBER, AND NOVEMBER, BY THE GENERAL ELECTRIC COMPANY, SCHENECTADY, NY, AND IS PRINTED IN THE U.S.A. BY THE MAQUA COMPANY. IT IS DISTRIBUTED TO SCIENTISTS AND ENGINEERS THROUGHOUT INDUSTRIAL, CONSULTING, EDUCATIONAL, PROFESSIONAL SOCIETY, AND GOVERNMENT GROUPS, BOTH DOMESTIC AND FOREIGN.

. . . THE CONTENTS OF THE GENERAL ELECTRIC REVIEW ARE ANALYZED AND INDEXED BY THE INDUSTRIAL ARTS INDEX, THE ENGINEERING INDEX, AND SCIENCE ABSTRACTS. . . . SIX WEEKS' ADVANCE NOTICE, AND OLD ADDRESS AS WELL AS NEW, ARE NECESSARY FOR CHANGE OF ADDRESS. . . . ADDRESS ALL COMMUNICATIONS TO: EDITOR, GENERAL ELECTRIC REVIEW, SCHENECTADY 5, NEW YORK.

ENGINEERING IS A GREAT ADVENTURE

It is always a joy to visit with students in engineering schools. To talk with them, to hear their questions, and to feel the enthusiasm of their eager interest in the future is to appreciate all over again the boundless potential of youth.

Every engineering student is continually wondering what is beyond his student life, what is ahead of him in the great adventure in which he has made a start. The step into industry looms large. The picture of the road ahead is never clear. Everything seems vast and complex. The answers to his questions seem unattainable.

And yet this need not be. If he will only realize it, he has been privileged to have the opportunity to obtain the finest education it is possible to provide. He has been associated with teachers who brought to him a knowledge of the fundamentals of engineering in practice and as a profession. And in these associations he has learned to live with his fellow men.

He has learned of the phenomena of Nature in his physics, which is fundamental. He has learned of the materials of Nature in his chemistry, and with these he will live throughout his engineering life. He has learned to write a phenomenon of Nature in the one-line equation of mathematics, to operate upon that equation to obtain a relationship of the variables involved, and to plot those variables in order to see the phenomenon in all its beauty and its usefulness.

For the phenomena of Nature are beautiful, and it is to the honor of the scientist and the engineer to search them out and make them available to mankind in the products of industry. These are the prize possessions of the engineering student; and industry provides him with the opportunity to make use of them. This is not new. It has always been that way.

Let's look at some cases. Edison was only 31 when Edison Electric Light Company was formed in 1878 to provide for him an opportunity to make his vision a reality. Elihu Thomson was but 22 when he operated the first radio set in history. And Charles Brush was 28 when he received his patent on the lamp which marked the birth of the arc-lighting industry.

Young General Electric engineers have continued the tradition ever since. Pages 25 to 43 of this issue carry a striking summary of General Electric technical contributions made possible by engineers who took advantage of their opportunities. These contributions range from power generation, transmission, and distribution through industry and transportation to electronics, appliances, chemicals, and lighting.

Yes, there is a place in industry today for every engineering student, according to his ability and his liking. To assure him that he is rightly located at the start, there are many General Electric courses and programs to show him the opportunities available in the Company. And a great variety of training programs allows him to continue his engineering studies along with the active engineering work in his new industrial life. Where he will advance later will depend upon himself as an individual and upon his relation to his associates as a member of a team.

The opportunities for new advances never cease. Even after 75 years of continuous engineering achievement, the engineer is still opening new doors. Whether these lead to the development of new products, or to the improvement of present ones they represent opportunities for every engineer. Of these there are no end. Engineering *is* a great adventure!

Everett S. Lee

EDITOR

REACTORS, LIKE THIS ONE AT BROOKHAVEN, LI, PRESENT MANY NEW PROBLEMS. AN IMPORTANT ONE IS . . .

Metallurgy for Nuclear Reactors

By DR. J. E. BURKE

Nuclear reactors are new, but many of the design problems facing the metallurgist are strictly old-fashioned. Such properties as strength, formability, thermal conductivity, resistance to corrosion at high temperatures, and of course, cost and availability, are as important in controlling the selection of materials for nuclear reactors as they are in controlling the selection of materials for other applications.

In addition to these properties, however, it is necessary to consider the interaction of the materials with neutrons. Everything enclosed in the heart of the reactor interacts to some extent with the neutrons, and a very careful control of materials that are included in the reactor is thus necessary.

Selection of Materials

The most important single factor controlling the selection of a material for use in a nuclear reactor is the extent to which it will absorb neutrons. For efficient operation the least possible number of neutrons should be absorbed in structural parts so that they can be available for continuing the chain reaction or, in some cases, for making desirable products such as plutonium.

All solids are relatively transparent to neutrons, but in passing through a solid a neutron will occasionally collide with a nucleus and stick. It is then no longer available for the desired use. The probability of such a collision depends upon the effective size or cross section of the nucleus; this area is usually expressed in units of 10^{-24} square centimeters (called the "barn" because it is so "large.") The cross section for absorption bears no relation at all to atomic sizes as determined from crystal structure data, and it varies tremendously from isotope to isotope, and also to some extent with the velocity of the neutrons themselves.

The absorption cross sections for a number of materials are listed in Table I, where they are arbitrarily divided into four groups.

All nuclear reactors have several components in common:

- Fissionable isotope or fuel
- Moderator (except in fast reactors), a light element that slows down the high-velocity neutrons produced at the time of fission to the energy that the reactor is designed to utilize
- Heat-transfer medium to permit removal of the heat generated in the reaction
- Shielding to control the intense radiations
- Neutron absorber that can be inserted or withdrawn to control the power level of the reactor

TABLE I

ABSORPTION CROSS SECTIONS OF SOME ELEMENTS FOR THERMAL NEUTRONS

LOW Cross Section $\sigma_c < 1.0$ Barn*

Element	σ_c
Hydrogen	0.32
Beryllium	0.01
Carbon	0.004
Oxygen	< 0.001
Sodium	0.48
Magnesium	0.07
Aluminum	0.22
Zirconium	0.4
Tin	0.6
Lead	0.18
Bismuth	0.015

INTERMEDIATE Cross Section $\sigma_c = 1$ to 5 Barns

Element	σ_c
Titanium	5.8
Vanadium	4.8
Chromium	2.9
Iron	2.4
Nickel	4.5
Copper	3.6
Zinc	1.0
Niobium	1.2
Molybdenum	2.4

VERY HIGH Cross Sections $\sigma_c > 100$ Barns

Boron	715
Cadmium	3000

HIGH Cross Sections $\sigma_c = 5$ to 100 Barns

Lithium	67
Cobalt	35
Tungsten	18

TABLE II

PHYSICAL PROPERTIES OF ANNEALED VANADIUM METAL

Tensile Strength (psi)	54,000
Yield Strength (psi)	36,000
Percent Elongation in 2 inches	25 to 35
Young's Modulus (psi)	18.4×10^6
Vickers' Hardness Number	120
Recrystallization Temperature (80 percent cold work—1 hour)	700 C
Density	6.11

* The effective cross section of a nucleus is usually expressed in units of 10^{-24} square centimeters, commonly called a "barn."

• Structural elements to support and contain all these components.

The structural materials should have the lowest possible cross sections for the greatest neutron economy and would normally be selected out of the low cross-section group of elements in Table I. However, if the reactor is operated with neutrons having higher than thermal energies, the cross sections are reduced somewhat, and it becomes possible to also consider metals such as vanadium, chromium, iron, nickel, zinc, and molybdenum and their alloys that appear in the intermediate cross-section list. It might be noted that cobalt and tungsten, which are common constituents of modern high-temperature alloys, have such large cross sections that their use in any quantity in a reactor is pretty much ruled out. This imposes great restrictions upon the development of suitable alloys for high-temperature reactor operation.

Moderators are used to slow down the neutrons produced at the time of fission to energies where they are efficient in producing further fissions. Moderation occurs when a neutron strikes a nucleus and bounces off instead of sticking. Part of its energy is transferred to the nucleus it strikes, exactly as a marble transfers its energy to another marble upon collision. The most efficient moderators are elements of low atomic weight because their mass more nearly matches the mass of the neutron. A marble is slowed down more by hitting another marble than by hitting a billiard ball; thus neutrons are slowed down more by colliding with a light nucleus than they would be by colliding with a heavy nucleus. Hydrogen, beryllium, carbon, and oxygen are good moderators—lithium and boron would be good moderators too, but their capture cross sections are so large that they would absorb too many neutrons.

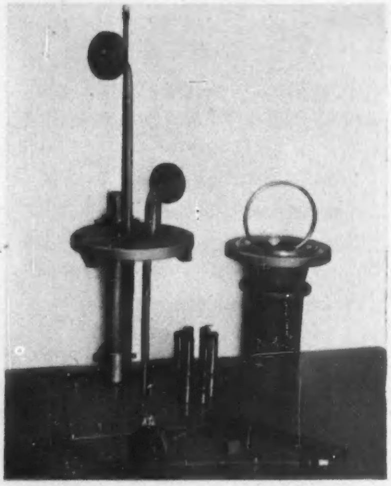
There is also a good use for materials having very large capture cross sections. The power level of a nuclear reactor is best controlled by inserting poisons that capture some of the neutrons, much like the burning rate of a fire is controlled by controlling the amount of oxygen to the fuel. Both boron and cadmium are useful for this purpose.

There is also the problem of heat removal from the reactor. High-velocity gases or water can of course be used but, as was pointed out by Thomas Trocki, (May 1952 REVIEW, page 22) liquid metals are also very good heat transfer agents. Of these liquid metals, sodium is one of the most promising.

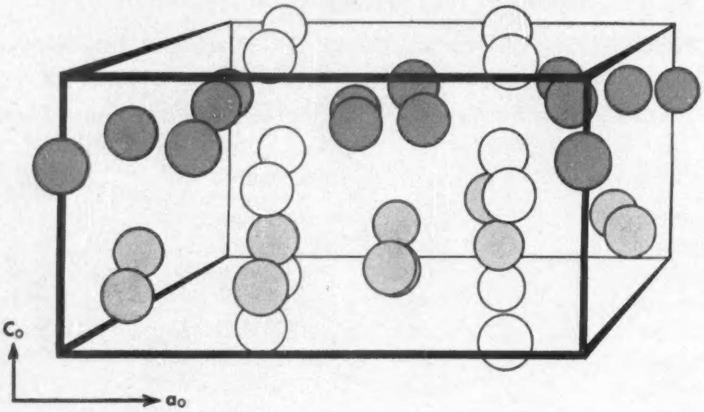
Development of Materials

The combination of nuclear and other engineering requirements and the wide variety of reactor designs that have been considered have required that at least some information be obtained about a great variety of new metals, and in particular about many of the less common elements such as beryllium, zirconium, titanium, vanadium, graphite, liquid sodium, and of course the most common fuel, uranium. The work that has been done at the Knolls Atomic Power Laboratory near Schenectady on the development of ductile vanadium is typical of work that has been done, sometimes on a larger scale, for many of these metals.

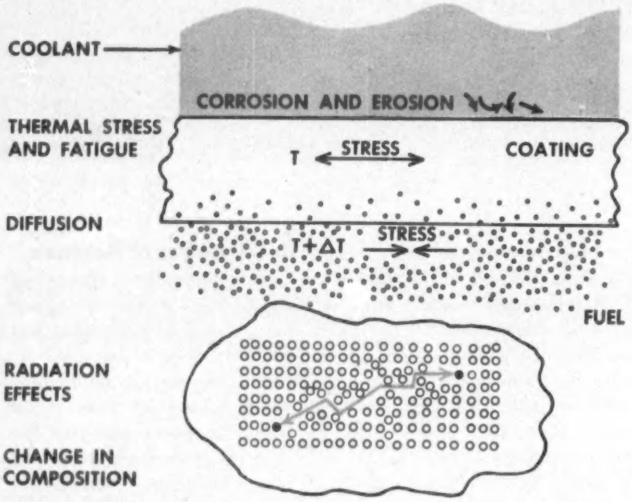
Since vanadium appeared to be a possible material for use in nuclear reactors, a program to investigate its properties was undertaken several years ago. Although nominally pure vanadium had been available for a number of years, it was brittle and could not be fabricated. Some ductile vanadium had been prepared by calcium reduction of the oxide, but only beads and small pellets were produced. In improving this product, additions of iodine were made to the mixture of V_2O_5 and calcium. Upon heating this charge in a closed



LIQUID SODIUM was tested in this device to determine its corrosiveness toward possible structural materials.



BETA PHASE of uranium has this complex tetragonal structure—one of the most complicated ever found for a pure metal.



JACKETING OF URANIUM in a nuclear reactor is necessary to prevent corrosion by the coolant. Thermal stresses and interdiffusion are other important problems.

pressure vessel, the additional heat provided by the combination of iodine and calcium raised the temperature enough so that a large ductile button of vanadium was obtained. Unfortunately, subsequent runs yielded buttons that were brittle. After extensive investigation it was finally found that the brittleness was due to nitride in the oxide, and the final procedure used involved a careful denitriding of the vanadium oxide by heating in moist oxygen for several hours. The product as now produced can be rolled into thin foil, drawn to wire, or given any of the standard metallurgical treatments except hot working. Because it avidly absorbs oxygen to become brittle, it can not be heated in air.

Some of the more important physical properties of annealed vanadium metal produced by this process are listed in Table II.

Processes and Techniques

A great part of the developmental effort on new materials has been devoted to improving processes and techniques for handling the materials. It has seemed almost axiomatic that the metals most useful in the construction of reactors react rapidly with air at elevated temperatures. This has given great impetus to the development of high vacuum and inert atmosphere melting and annealing furnaces. For example, vanadium, zirconium, titanium, uranium, and in fact almost all metals are best annealed under these conditions if great purity is important.

A very specific advance has been the development of methods of handling liquid sodium. One of the great barriers to the use of liquid sodium was a lack of knowledge about its corrosiveness toward possible structural materials. The large number of tests that have now been performed clearly indicate that liquid sodium is an excellent coolant, and that there are a number of materials that are resistant to it.

The apparatus shown at the top, left, of this page is typical of that used for a number of simple tests in static sodium. The tubular specimens are inserted in the pot and the lid is bolted on with a gasket. The whole apparatus is then heated and liquid sodium is forced into the pot with argon pressure, through the upper flanged tube. Both tubes are then capped with blind flanges and the pot placed in a furnace for the test. If dynamic tests are required, the specimens can be rotated by a shaft passing through a seal in an apparatus essentially like that described, or a convection loop can be used.

Tests such as these have indicated, for example, that specimens of stainless steel of types 302, 304, 316, 321, and 347 did not change in weight and were unattacked, visually and mechanically, after one year in relatively pure sodium at 500 C.

Another technique has developed from the desire to study solid state diffusion in metal couples that have been exposed in a reactor. The usual technique is to machine successive layers from a specimen such as an electroplated cylinder, and to determine the amount of interdiffusion that had occurred by chemically analyzing the turnings from each layer.

This is so very difficult to do if the specimen is extremely radioactive that new apparatus was developed. A specimen is made by electroplating a wire about 0.060 inches in diameter and one-half inch long. The successive "cuts" are made by cathodic sputtering. The sputtered layers are captured on an aluminum foil surrounding the specimen and subsequently undergo chemical analysis. The method has the great advantage that very small specimens can be used. Thus the total amount of radioactivity is small, the apparatus can be readily manipulated by remote control in a hot lab, and cuts of as little as 10^{-4} inches can be made. This means that diffusion can be observed over distances very small compared to those that can be observed using mechanical sectioning techniques.

Fundamental Work

Relatively few attempts were made to understand and explain the behavior of metals until a few years ago, and the interest in scientific metallurgy has increased markedly since World War II. By drawing on such fundamental work as has been done to date, metallurgists have made important contributions to the atomic energy program. In the long run it appears that in turn the requirements of the atomic energy program will lead to advances that are important to scientific metallurgy. These advances will result partly from the fact that the Atomic Energy Commission is supporting some 50 contracts for work in fundamental metallurgy at about 30 different institutions. In addition, the collection of information about a variety of new materials together with the new conditions of use that are encountered automatically broadens the foundation on which our present metallurgical science is based.

Uranium Metallurgy

One of the fields in which important work has been done is in studying the physical metallurgy of uranium. This relatively new metal exists in three crystallographic modifications. The alpha phase, stable up to about 660 C, has an orthorhombic structure that was determined a number of years ago. The gamma phase, stable above 770 C, has the simple body-centered cubic structure. However, until 1951 no satisfactory solution of the structure of beta uranium had been obtained. At that time, a technique was developed for preparing large single crystals of the beta phase of uranium in a chromium-uranium alloy in which the beta phase could be retained at room temperature. Using the powerful techniques available for the determination of structures of single crystals by x-ray diffraction, the structure shown on the opposite page was worked out. At the same time, people in a number of laboratories had been attempting to work out the structure of the sigma phase, a very brittle constituent that is frequently found in welded specimens of stainless steels. It quickly developed, when notes were compared, that the proposed structure for the beta phase of uranium was the same as the structure of the sigma phase, and the work on uranium thus aided materially in the final structure determinations of the sigma phase.

> **A NUCLEAR REACTOR . . .**
>
> . . . is a device in which certain substances such as the uranium isotope of mass 235 or the plutonium isotope of mass 239 are caused to cleave, or undergo fission, by bombardment with neutrons. The products of this "combustion" are heat, neutrons, the new atoms that result from the fission process, and large amounts of radiation. At the present time little use is made of the fission products or of the radiation; they are merely disposed of in the cheapest safe way. In some reactors heat is also an undesirable by-product that must be disposed of as cheaply as possible, but in power producing reactors heat is the important product and efforts are being made to use it efficiently to make steam to drive turbine-generators. Neutrons are of critical importance in all reactors because they are needed to produce fissions in other atoms and continue the chain reaction.

Fuel Elements

Many of the problems encountered by the metallurgist in the atomic energy field are illustrated by the difficulties encountered in designing a suitable fuel element. Suppose we take as a fuel one centimeter cube of uranium metal. This will weigh about 19 grams. If we cause 10 percent or about 1.9 grams to undergo fission in one year, the total energy generated will be about 45,000 kw-hr, or the power output of this little furnace will be about 5000 watts. Obviously it must be efficiently cooled or it will melt.

As mentioned in the Smyth report, uranium must be jacketed to prevent corrosion by the coolant. As shown in the diagram on the opposite page, a thermal stress will be developed between the jacket and the fuel. In addition, because the temperature is high, there is always the possibility of deterioration of either the fuel or the jacket by interdiffusion.

Finally, one of the most serious problems is deterioration of the mechanical properties of the fuel by radiation. The important advantage claimed for nuclear power is that an engine will operate for long periods of time on one fueling. Unfortunately this requires that the fuel be stored in the reactor during all of this time. Every time an atom of uranium undergoes fission two new atoms are produced, and they shoot out from their original location with tremendous energies, knocking atoms out of position all along their path. Thus, not only does the addition of new atomic species form an alloy that may have inferior properties, but the metal is subjected to an internal battering unparalleled in metallurgical experience.

Many Other Problems

There are of course a vast number of other metallurgical problems encountered not only at the Knolls Atomic Power Laboratory but also at other sites where reactors are being built; work on these problems is going on at many installations of the Atomic Energy Commission. As in other fields, improvements in materials are imperative if important advances in reactors are to be made. These require continuing work not only directly in the development of better materials but also on the fundamental studies that pave the way for the applied developments. Ω

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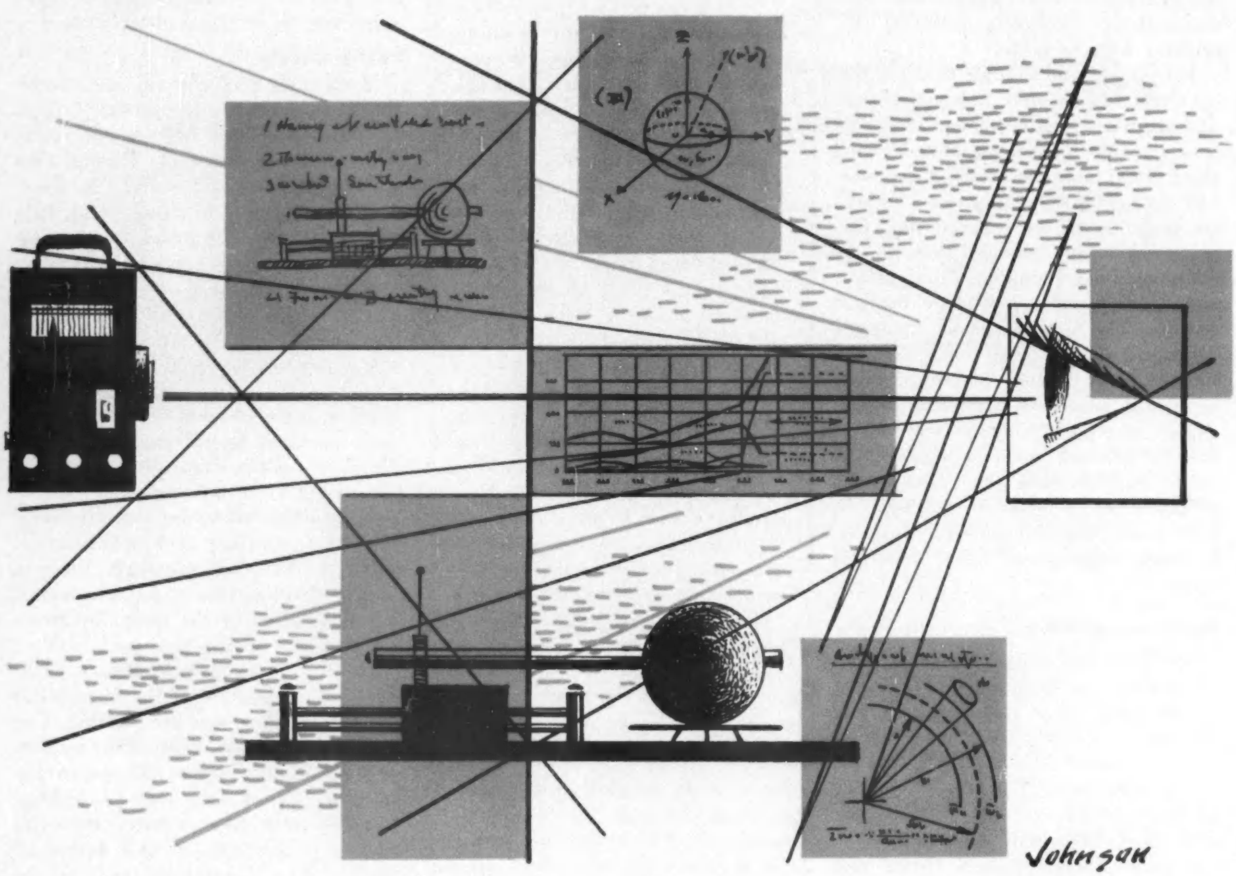
Dr. Burke came to General Electric in 1949 with a wide experience in atomic energy work. He is now Manager—Metallurgy Section of the Knolls Atomic Power Laboratory near Schenectady. The chief responsibilities of this section are to understand the behavior of nuclear reactors and develop improved materials for them.



How to Develop the Development Engineer

By I. F. KINNARD

The development engineer has one of the most difficult jobs in modern industry—bridging the gap between the scientific researcher and the design engineer.

Results of scientific research are seldom in a form that can be put to immediate practical use, but to the alert development engineer they may suggest solutions to practical problems. He takes these suggestions and develops them into ideas that can be used by industry, keeping in mind that the ideas must be sound in terms of engineering and economics.

Here lies the challenge of the job: Although he has full play in thinking up practical uses of research suggestions, he doesn't have quite the freedom of the research worker. Because he's close to the business world and the factory, he usually must solve a problem on schedule and frequently it requires some inventive solutions. Besides, he must stick to his objectives and keep his use of time, money, and materials within rigid limits.

The development engineer is also concerned with new and basic elements and materials; his activities are directed toward combining them into the prototypes of new products. This type of engineering requires the ability to think in terms of fundamentals—it requires a good theoretical and practical background coupled with strong imagination, plus analytical and creative ability.

Taking a functional view of the development engineer, his "input" is a new idea or concept, either his own or one that has been assigned to him for commercial development; his "output" is generally an operating sample, usually handmade, accompanied by enough data to prove that the idea is workable.

How Can Management Help?

What are some of the techniques that industrial management can use to further aid the development engineer?

In the first place, developments don't just happen. They must be planned and the proper conditions set up for their generation. Staff your development component with men who have enthusiasm that gives rise to ideas and possibilities—men of resourcefulness, ingenuity, and imagination—and give them a proper place to work.

A proper environment for creativity is important. This involves two areas: assignment and physical facilities. Wherever possible, give the development engineer no other responsibility than the development of new products. Experience has shown that he will work best in a laboratory atmosphere, away from the immediate problems of daily production. Do this not because the development engineer is a superman, above soiling his hands with manufacturing problems, but because any good engineer is better able to do creative work when free of distracting influences.

By working in a laboratory he will derive great stimulation from contact with other development engineers and scientists engaged in the attack on different but related problems.

The working conditions must be conducive to teamwork, because today many important developments are contributed by people working closely with each other. For example, three recent Coffin Awards (the highest award given by General Electric to its employees) in the field of measurements were joint ones: For developing the basic design of a new watthour meter, five men were cited; for a contribution to the art of insulating dry-type instrument transformers (molded butyl rubber design), three men; for a high-performance frequency-type telemeter, three men.

Another factor to watch is this: Don't attempt too rigid a distinction between development engineering and design engineering. The difference is one of degree and emphasis rather than kind. The design engineer takes the developments provided by the development engineer and adapts them for manufacture. His "input" is a handmade working sample; his "output" is a highly refined design suitable for manufacture. (In the course of his work the design engineer may do some development engineering to make improvements in existing products. But in this discussion a development engineer is one who spends all of his time in development work.) In other words, the development engineer is a practical man of science who uses empirical relationships whenever they will lead him to a solution more quickly than deductions from fundamental starting points, but who does not shy away from the fundamental approach when it is clearly indicated.

What Does Management Expect?

So far we have seen how management can help the development engineer to do a better job. Now, in turn, what are some of the characteristics that industrial management is looking for in a development engineer?

The development engineer constantly maintains interest in attaining his goal. He minimizes diversions and isn't sidetracked by subsidiary investigations. He analyzes his data for accuracy and for the effect of environmental influences. He knows the patent situation with regard to his project and recognizes patentable contributions when he makes them.

A man properly selected for this work spontaneously keeps up to date through reading or training courses, and he knows what is new in the field. Also, he intuitively selects the most economical path to his goal whether it be computation or empirical testing.

He has the intellectual honesty and straightforwardness to present disadvantages and shortcomings as well as advantages of proposed schemes. This is especially important when he turns the job over to the design group and advises them of pitfalls and marginal features.

He doesn't waste time and money in the support of a lost cause but knows that mistaken approaches should be recognized early in the game—not in the production phase. He takes schedules and commitments seriously and remembers that a profitable item starts earning only after it is in production.

Further Aspects

The importance of development engineering to business and industry in general can hardly be overestimated. Successful development engineers are constantly bringing along new products for a new age.

Studebaker started in business making wagons, continued with automobiles, and has now added jet engines to its line. And recently *Business Week* reported this situation: A large pharmaceutical house, specializing in production of a home remedy for the common cold, is busily seeking diversification of its product line against the day when medical science may banish this all too prevalent nuisance.

It is hard to imagine a faster changing industry than that of electrical manufacturing. Take the case of General Electric's Meter and Instrument Department—nearly 40 percent of current output is made up of products introduced no more than 10 years ago. For some products the market didn't even exist 10 years ago. A few examples are thermocouples especially designed to measure the operating temperature of turbojet engines, and nuclear radiation monitors and related instrumentation. Historically, the electrical industry has doubled about once every 14 years. This rate of progress would not be possible and cannot continue without a high level of development engineering.

Sometimes developments occur in time-tested and proved products, where they are least expected. Over the past half century GE has produced many millions of watthour meters. They have undergone a gradual evolution and refinement so that many considered this a barren field indeed for the development engineer. Yet, as recently as 1948, a completely new watthour meter was developed. It successfully employed for the first time in the engineering world the principle of magnetic suspension of a rotating part. The maintenance-free life of the meter was increased many fold by this development—a development that was the product of close collaboration of development engineers and materials specialists, particularly metallurgists working on new permanent magnet alloys.

Thus, we have seen that the development engineer's job is to take that believed to be possible and prove it practical. And in doing this job, he contributes significantly to the evolution of new and better products for a constantly rising standard of living. And whether he realizes it or not, he is one of the vital links in our American economy. His developments are helping to win acceptance throughout the world for the kind of system that brings them forth. Ω

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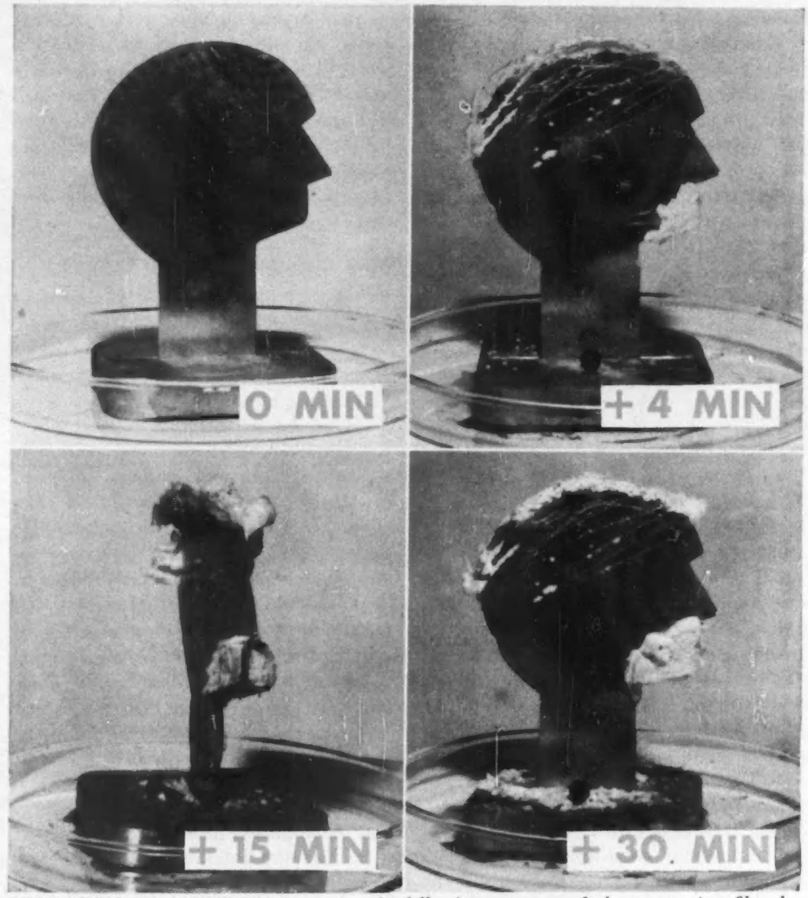
Mr. Kinnard, Manager—Engineering, Meter and Instrument Department, West Lynn, Mass., joined GE in 1922. A leader in measurements, he is responsible for development, design, and manufacturing engineering operations on hundreds of types of measuring instruments. He has many patents and was twice a Coffin Award winner.

Aluminum for Copper: Greater Corrosion Risks?

By DR. H. A. LIEBHAFSKY

and

DR. E. W. BALIS



CORROSION OF ALUMINUM in moist air following rupture of the protective film by scratching the aluminum head under mercury. Times shown are "minutes after scratching."

Will aluminum corrode significantly when it replaces copper?

This question is important when you consider the great strides aluminum has made in various fields where it is used for power cable, pipes and tubes, and various structural forms.

Fortunately for all concerned, the answer to the question is "No." Not an unqualified "No," for we must add that aluminum won't corrode significantly when it replaces copper *provided the thermodynamic driving forces can be restrained.*

It is important to know that under certain conditions the thermodynamic driving force for the corrosion reaction can be restrained enough to keep aluminum undamaged. Our purpose is to indicate just what these conditions are. Because if these conditions can't be maintained—you're in for trouble.

It's an attractive oversimplification to say that corrosion is Nature's way of reversing the process by which metals are won from their ores. And from this broad generalization it is tempting to jump to another even more specious: that any metal thermodynamically unstable in air is a poor corrosion risk. For example, the driving force for the formation of aluminum oxide at 25 C approaches 7000 calories for one gram of the metal. This is indeed a strong driving force; its very magnitude explains why the winning of aluminum from its ores requires so much energy. In comparison, the driving force tending to change copper into cuprous oxide is less than 300 calories a gram. This leads us to ask if aluminum is a poorer corrosion risk than copper. Not necessarily, for here as elsewhere thermodynamics seldom tells the whole story.

"Thermodynamically unstable" does not mean "actually unstable" provided some intervening factor makes the reaction rate infinitely slow. Is there such a factor for aluminum? Let's look at the evidence.

As early as 1855 the surprising stability of aluminum in air attracted much attention at the International Exposition of Paris. After half a century, aluminum medals made in 1891 and 1892 with no surface treatment are still bright, according to Dr. Max Schenk, Swiss author of a reference work on aluminum as an industrial material.

Also, the famous aluminum statue of Eros, mythical god of love, in London's Piccadilly Circus has survived the unkind atmosphere for almost 50 years. And aluminum cable has been used for high-voltage transmission lines since about 1895.

Today, aluminum windows and storm doors are commonplace and entire faces of buildings are made of aluminum or its alloys.

All of us know that aluminum pots and pans do well in our kitchens (more often than not the darkening that does occur inside them is mainly an optical effect produced by insignificant etching).

The Oxide Film

With these examples in mind, how can aluminum be actually stable though thermodynamically unstable? The factor responsible is an invisible oxide film. When allowed to form naturally in air at room temperature, this film is about one millionth of an inch thick. It has the important property of being self-healing in the presence of oxygen under many conditions. As long as the film is unbroken or spontaneously repaired, aluminum is protected against atmospheric corrosion—the thermodynamic driving forces are restrained. It is no exaggeration to say that this invisible film carries much of the aluminum industry upon its back.

What happens when the film is broken under conditions that delay effective repair?

For many years Professor J. H. Hildebrand of the University of California at Berkeley has "grown hair on a billiard ball" for his freshmen classes. Pure aluminum, properly amalgamated, oxidizes so rapidly in moist air that a fine head of "hair" can be grown during a lecture period. We duplicated this experiment (photographs, left) and also demonstrated that a beard can be grown as well. Amalgamation was accomplished by scratching the aluminum under mercury with a knife.

The preceding is an excellent demonstration of how disastrous the rupturing of the invisible protective film on aluminum can be. However, even under these special conditions, the growth of the corrosion product, though amazingly rapid, is not maintained for long. Within half an hour the long white streamers of hydrous aluminum oxide begin to fall away and reveal pits where they had grown. Though the metal surface is pitted and rough, rapid oxidation has ceased, the film has been repaired, and protection by the oxide has been restored so that the thermodynamic driving forces are again restrained.

Let's guess at what took place. During the amalgamation the film is so ruptured that mercury comes into atomic contact with aluminum. At this point the mercury dissolves in the aluminum and vice versa. The aluminum in these amalgams is exceedingly reactive—as reactive as the large thermodynamic driving forces would lead you to expect. If the air now contains enough water, the oxidation product will be a very porous and fluffy hydrous oxide that is incapable of protecting the metal from which it grows—incapable, that is, of shutting out oxygen.

Accordingly, oxygen continues to come in where the corrosion product and metal join so that more of the corrosion product forms at this interface and pushes the hair already formed out into space. But the hair carries mercury with it, and when the supply of mercury is exhausted (perhaps diffusion of mercury into the aluminum also contributes), the rate of oxidation decreases and a compact protective oxide film again forms.

This qualitative description ignores many of the complications. But it does serve to drive home the point that the oxide film on aluminum must remain intact if there is to be no attack of the metal when opportunities for oxidation exist.

Copper will not perform in the manner described for Professor Hildebrand's experiments nor are effects so drastic as this usually observed with aluminum. It is nevertheless true that contamination by mercury can be a serious corrosion hazard, not only to aluminum and its alloys but also to other nonferrous alloys such as brass.

QUALITY OF RESEARCH LABORATORY DISTILLED WATER

	Water	Maximum Total Solids (parts per million)	Resistivity (ohm-cm)	pH
1.	Distilled (at still)	0.2	550,000	5.6
2.	Distilled (tap)	0.2	500,000	5.9
3.	Schenectady (tap)*	192.0	3000	7.5

*Schenectady tap water included for reference. All samples dated March 28, 1952.

The Oxide Film and Water

So far we have shown how the oxide film protects the aluminum from the atmosphere. But it is also true that the oxide film on aluminum gives excellent protection when this metal is used in the distribution of distilled water. Here the primary concern is to guard against contamination of the water. Note that aluminum is "thermodynamically unstable" in contact with water even in the absence of oxygen, and that its successful use in distilled water systems is another proof of the protectiveness of the oxide film.

When the General Electric Research Laboratory was built at the Knolls near Schenectady in 1948, an aluminum distribution system for distilled water was installed, partly because of the favorable experience with a similar system used in the Aluminum Research Laboratories of the Aluminum Company of America. Tests made in 1950 showed the distilled water was of high quality; tests made a year ago are summarized in the table above.

Comparison of lines 1 and 2 of the table shows that the aluminum distribution system didn't contaminate the distilled water to any degree. Also, examination after nearly seven years of service of aluminum pipes carrying distilled water at the Aluminum Research Laboratories showed no visible signs of attack.

There is thus abundant evidence that the invisible film protects aluminum in contact with ordinary atmospheres, or with distilled water and oxygen. Further, there is evidence that in the absence of such protection, when the thermodynamic driving forces are unrestrained, the corrosion of aluminum can be rapid and serious.

As a freshman chemistry student you learned that aluminum is soluble in strong acids or strong bases, a behavior traceable to the solubility of the oxide film in acid or alkaline solutions. This, however, is another oversimplification. For example, aluminum is a preferred metal for handling concentrated nitric acid, because this powerful oxidizing agent even strengthens the natural oxide film.

Reinforcing the Oxide Film

In our discussion of the natural oxide film we have given a demonstration of how it can be destroyed; but it is equally important to know that this protective film can be *reinforced* by electrolytic oxidation, a process called "anodization." This process gives an externally porous, complex film whose thickness initially increases with the time of electrolysis. This makes it possible to form protective films that are many times thicker than the natural oxide film. (By the action of boiling water the external pores of the film can be sealed; such sealing is usually part of the coating procedure.)

Thick anodic coatings formed in a sulphuric acid electrolyte generally afford excellent protection to aluminum alloys, give them an attractive appearance, and make them resistant to discoloration. The aluminum alloy panels that sheathe the new Alcoa office building in Pittsburgh were given an anodic coating one mil thick.

Obviously, anodized coatings must increase electric resistance at the metal

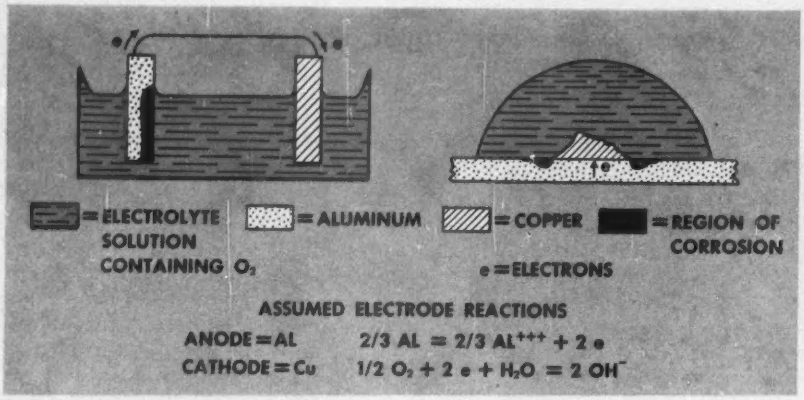


FIG. 1. Idealized corrosion cell showing an electrochemical process.

FIG. 2. Actual corrosion cell where copper has been rubbed onto aluminum.

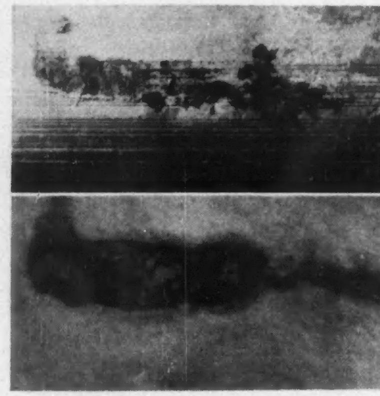


FIG. 3. Pitting of this aluminum tube followed transfer of copper to the aluminum by rubbing. The top picture shows the aluminum tube with scuff marks apparent at the left of the pits. Below is a map of the final distribution of copper (dark area) obtained from an electrographic print. (Both enlarged 15 times.)

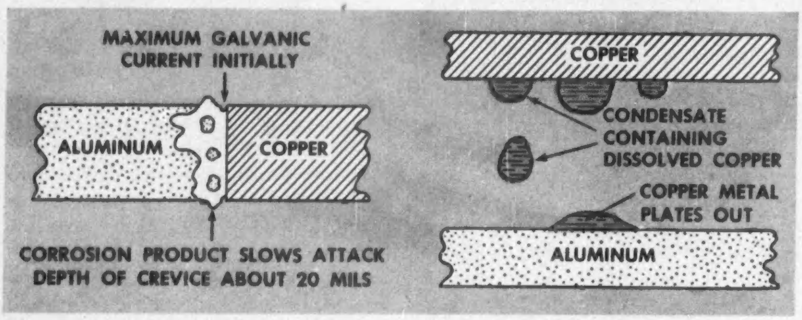
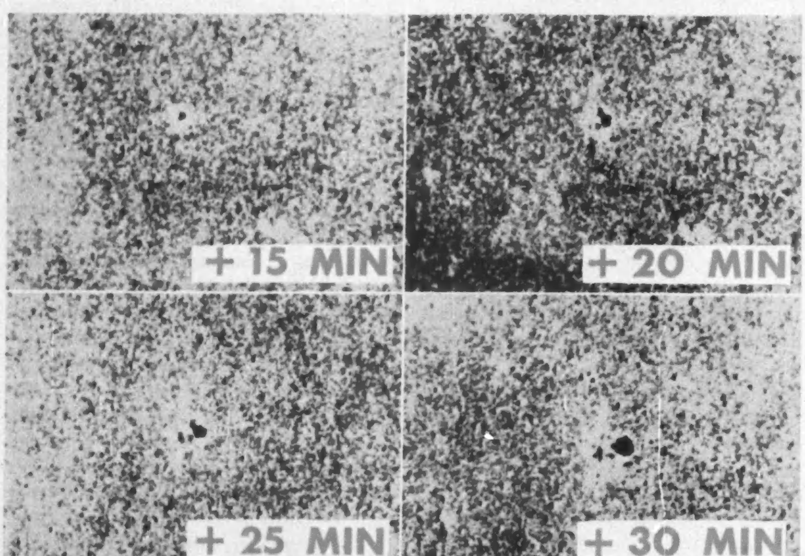


FIG. 4. Butt-welded aluminum and copper joint 30 days in salt spray.

FIG. 5. Deposition of copper out of solution onto aluminum.



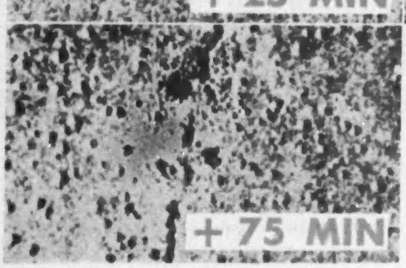


FIG. 6. Deposition of copper out of solution onto aluminum. The development of the pit is enlarged 10 times. An aluminum 2S specimen was exposed to a solution containing copper sulfate (10 grams per liter) and sodium chloride (1 gram per liter) and photographed after the time intervals indicated above. The mounds are metallic copper, while the dark spot near the center of each picture is the corrosion pit. This is further covered under the discussion of *CASE II* on page 16.

surface since alumina (aluminum oxide) is an insulator or semiconductor. Such coatings are therefore undesirable on surfaces through which current must flow easily. On the other hand, there is a possibility of using anodized coatings to insulate aluminum conductors.

Corrosion Cells

Many years ago Dr. W. R. Whitney, noted scientist and first director of the G-E Research Laboratory, pointed out that corrosion is an electrochemical process. The corrosion of aluminum by oxygen can therefore be represented schematically (Fig. 1) as occurring in an electrolytic cell. In the drawing the anode reaction is the solution of aluminum and the cathode reaction is the reduction of oxygen to the hydroxyl ion, in which hydrogen peroxide (not shown) may be an intermediate product.

For these reactions to proceed there must be a completed circuit—electrons must flow through metal from anode to cathode, and ions must be transferred through the solution. Anything that hinders this flow of electrons or of ions will reduce the corrosion rate. An oxide film on the aluminum anode could do this, as could reducing the concentration of ions in the electrolyte solution. (According to the resistivity data in the table, substitution of distilled water for Schenectady tap water could reduce the corrosion rate more than 150-fold, other things being equal.)

When anode and cathode are well separated as in Fig. 1, it's easy to measure the electric current associated with the corrosion process. Nature isn't so tidy however, and anodes and

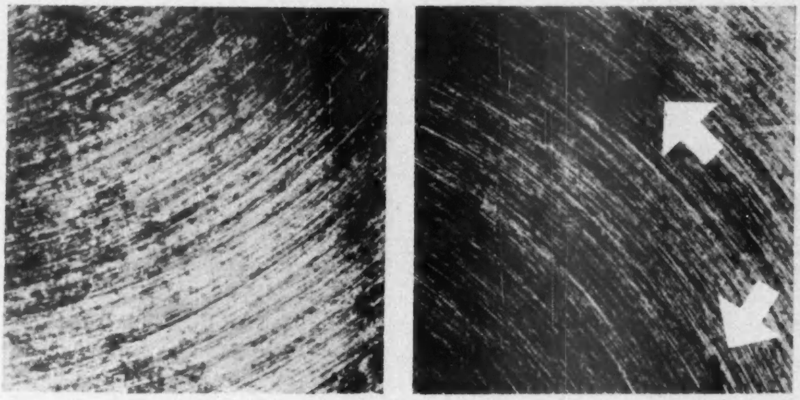


FIG. 7. Pitting of aluminum due to presence of heavy metals in Altoona, Pa., water (0.09 ppm copper, 0.08 ppm cobalt, 0.03 ppm nickel). Photograph at the left is a new aluminum 2S utensil after exposure to water of the same composition as Altoona water except that it was free of heavy metals. No pits are visible. At the right is a section from a similar utensil after exposure of one week to a water of the same composition as Altoona water with heavy metals included. Note black pits (arrows). Whenever aluminum is used, heavy metals like copper should, if possible, be kept out of water that touches it.

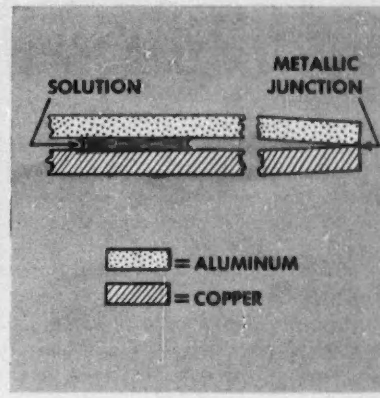


FIG. 8. Film of electrolyte between aluminum and copper in metallic contact. Note that the metallic contact can be at a considerable distance from the site of corrosion. This situation differs from others because no copper need be deposited on the aluminum. *CASE III* on page 16 describes this.

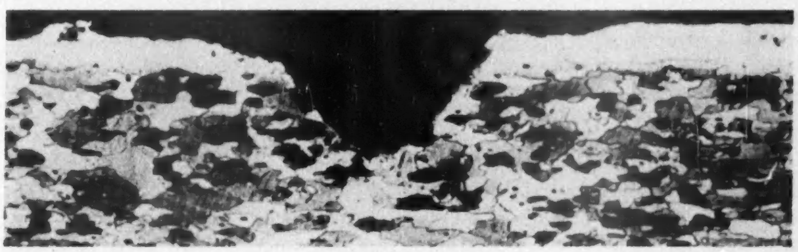


FIG. 9. This is the cross section of an alclad 17S-T4 (-T) sheet (0.040 inch thick) showing electrolytic protection of the core which was exposed by a deep scratch. No corrosion of the core occurred during six years' exposure to the atmosphere at New Kensington, Pa. Note sacrificial attack of coating adjacent to the scratch. (This cross section is enlarged 100 times and the sample was etched with HF-HCL-HNO_3.)

cathodes on a corroding specimen aren't usually so well defined as those in the drawing. Nevertheless, currents can often be measured in specimens that are corroding in the absence of an impressed electromotive force, and such currents are evidence that anodes and cathodes are present.

This being so, it follows that the metal will not corrode uniformly because corrosion ordinarily occurs only at anodes. Consequently corrosion currents imply the occurrence of localized attack, the kind most feared because it can lead to perforation. And perforation usually spells failure even though the mass of metal removed is insignificant.

Fortunately, localized attack doesn't necessarily lead to perforation. Film formation in the (anodic) pits often stifles the attack in a way reminiscent of the "hair-growing" experiment shown on page 12. The thicker the section, the more probable is such stifling. Of course, cost often limits thickness.

When a metal dissolves in acid, the attack is often uniform, or generalized. But from one point of view, even generalized attack involves anodes and cathodes. In this case, however, the anodes and cathodes are assumed to be numerous, close together, and small so that the measurement of corrosion currents is difficult or impossible.

The anodization of aluminum can also be described in terms of Fig. 1 provided an external electromotive force is supplied. As the drawing stands, the electromotive force of the cell is limited to the thermodynamic driving forces of the various possible reactions. Owing to the high resistivity of aluminum oxide, these internal electromotive forces aren't sufficient to thicken the film at a reasonable rate, and so an external electromotive force must be imposed. Also, anodization requires an electrolyte—such as strong sulfuric acid—in which the oxide film formed is, at most, sparingly soluble. Otherwise there would be no protection and too much aluminum would dissolve.

As practiced, anodization involves many other considerations, but this brief description will make clear to you that it is identical in principle with a corrosion process that is stifled by the formation of a protective film on the anode.

If a protective film does not form on an aluminum anode during anodization, the anode will be attacked, and the attack will often be localized. When there is no external electromotive force, localized attack is still possible owing to electromotive forces generated by the corrosion reactions. And because the driving forces of many of these corrosion reactions are large, this localized attack is the most serious corrosion hazard to which aluminum is subject. Such attack can be expected in any situation where the essential elements of Fig. 1 are present, provided the invisible oxide film has been destroyed at an anodic point and a protective film cannot form. In other words, localized attack of aluminum can be expected when all four of these requirements are satisfied:

- There is the possibility of a cathode reaction that, in conjunction with the anodic oxidation of aluminum, can give rise to an electromotive force.
- An electrolyte joins anode and cathode.
- Anode and cathode are in metallic contact.
- The natural oxide film on aluminum can be penetrated or destroyed, and a protective film cannot form.

Aluminum and Copper

Eighteen different situations have been listed elsewhere in which an electromotive force could arise to cause the corrosion of metals, including aluminum. But we'll discuss only three that could involve both aluminum and copper because these are of greatest interest.

In general, you may read "any metal nobler than aluminum" for "copper" in the following discussion. Remember, however, that many of these metals are less harmful to aluminum than is copper.

Three Cases

CASE I: Copper and Aluminum in Contact—Examination of Fig. 2 shows that the four requirements listed previously are all satisfied if oxygen is reduced at the copper cathode. Electrons flow from the aluminum to the copper mound. Because of the way in which the ion current distributes itself, attack of the aluminum will normally be greatest near the boundary between the two metals.

Practical examples of this are shown in Figs. 3 and 4.

Fig. 3 is a magnified view of an aluminum tube perforated by localized attack two months after copper was transferred to it by simple rubbing. There would have been no corrosion had the specimen remained dry.

Fig. 4 is a schematic representation of what happened to an aluminum tube butt-welded to copper. Localized attack of aluminum at the joint could have been avoided by keeping the joint dry, or by painting it—provided that significant electrolytic conduction between aluminum and copper could not occur over or through the paint film.

If moisture is unavoidable, one remedy for the specimen in Fig. 3 would be to make certain that copper cannot be transferred to the aluminum.

Sometimes it's feasible to insulate the metals from each other at the joint so that electron flow is interrupted; sometimes it helps to plate the copper with a more innocuous metal—such as cadmium or zinc. Cathodic protection is another solution, but it needn't concern us here.

CASE II: Deposition of Copper out of Solution onto Aluminum—Once the copper has been deposited (Figs. 5, 6, and 7), Case II becomes identical in principle with Case I. We have listed the two separately to emphasize that the amounts of copper involved in Case II may be so small as to escape even careful visual observation.

Aluminum beer barrels are subject to this corrosion hazard although it has been greatly reduced by making them of an aluminum alloy clad with the pure metal.

Also it's unwise to use aluminum for recirculating cooling systems when the coolant is liable to contamination by copper, or other heavy metals. We know of one example where aluminum piping in a cooling system was plugged with corrosion products that formed because the water contained a few parts per million of copper.

Just how damaging a little heavy metal can be is clear from Fig. 7. Whenever aluminum is used, heavy metals like copper should, if possible, be kept out of water that touches it.

The presence of Case I may set the stage for Case II. Consider what might happen to a domestic hot-water heater built of aluminum in a house that has copper pipes. Case I (copper and aluminum in contact) will exist where the piping joins the heater. And if the water dissolves small amounts of copper on its way to the tank, this copper would probably deposit on the inner aluminum surface and might produce a myriad of local cells. Failure, if it occurred, would probably not be at the joint, which would be cool, but through the wall of the hot tank. This illustration emphasizes that corrosion in Case I may not be serious because it is restricted to the neighborhood of the junction that causes it, but that Case I may lead to failure, according to the much more troublesome Case II.

CASE III: Film of Electrolyte Between Aluminum and Copper in Metallic Contact—This situation differs from the other two because no copper need be deposited on the aluminum. It is clear however that all the requirements of Fig. 1 are satisfied.

This case could involve crevice corrosion at a copper-aluminum joint, the crevice being at the joint and filled with electrolyte. (Crevices or re-entrant cavities of any kind should be avoided—aluminum or not.)

Or, as shown in Fig. 8, the metallic contact can be at a considerable distance from the site of corrosion. Perforation of an aluminum sheet very near the free end of a copper member in metallic contact with the sheet was explained in this way.

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Dr. Liebhafsky is Manager of the Physical Chemistry Section, Chemistry Research Department of the General Electric Research Laboratory, The Knolls, near Schenectady. He became associated with GE in 1934 when he joined the Laboratory staff. Dr. Balis has been with the Company 12 years and now heads the Analytical Chemistry Unit in Dr. Liebhafsky's Section. Neither author is a newcomer to the REVIEW. *In the September 1948 issue they collaborated on an article describing the electrolysis of cooling systems.*

Cladding of Aluminum Alloys

Some of the corrosion risks just described (like those in the domestic water heater) can be materially reduced by substituting *alclad alloys* for aluminum. These interesting materials consist of an alloy core clad with very pure aluminum, or with an aluminum alloy anodic with respect to the core. Their use has virtually eliminated the corrosion problems mentioned in connection with beer barrels, and they have become especially important in the aircraft industry. They provide the happy combination of a core alloy that gives strength with a cladding that reduces the risk of localized corrosion present with the unclad core.

A cross section of an alclad alloy is shown in Fig. 9. The cladding provides the core with physical protection followed ultimately by electrochemical protection. Until the core—more precisely the diffusion layer between cladding and core—is exposed, the product has the corrosion resistance characteristic of the cladding. This can be high if very pure aluminum is used for the outer layer. And if the cladding is eventually penetrated, it acts as a sacrificial (self-consuming) anode that will nearly always prevent perforation—especially if an aluminum alloy more anodic than aluminum itself is used for the cladding.

In Summation . . .

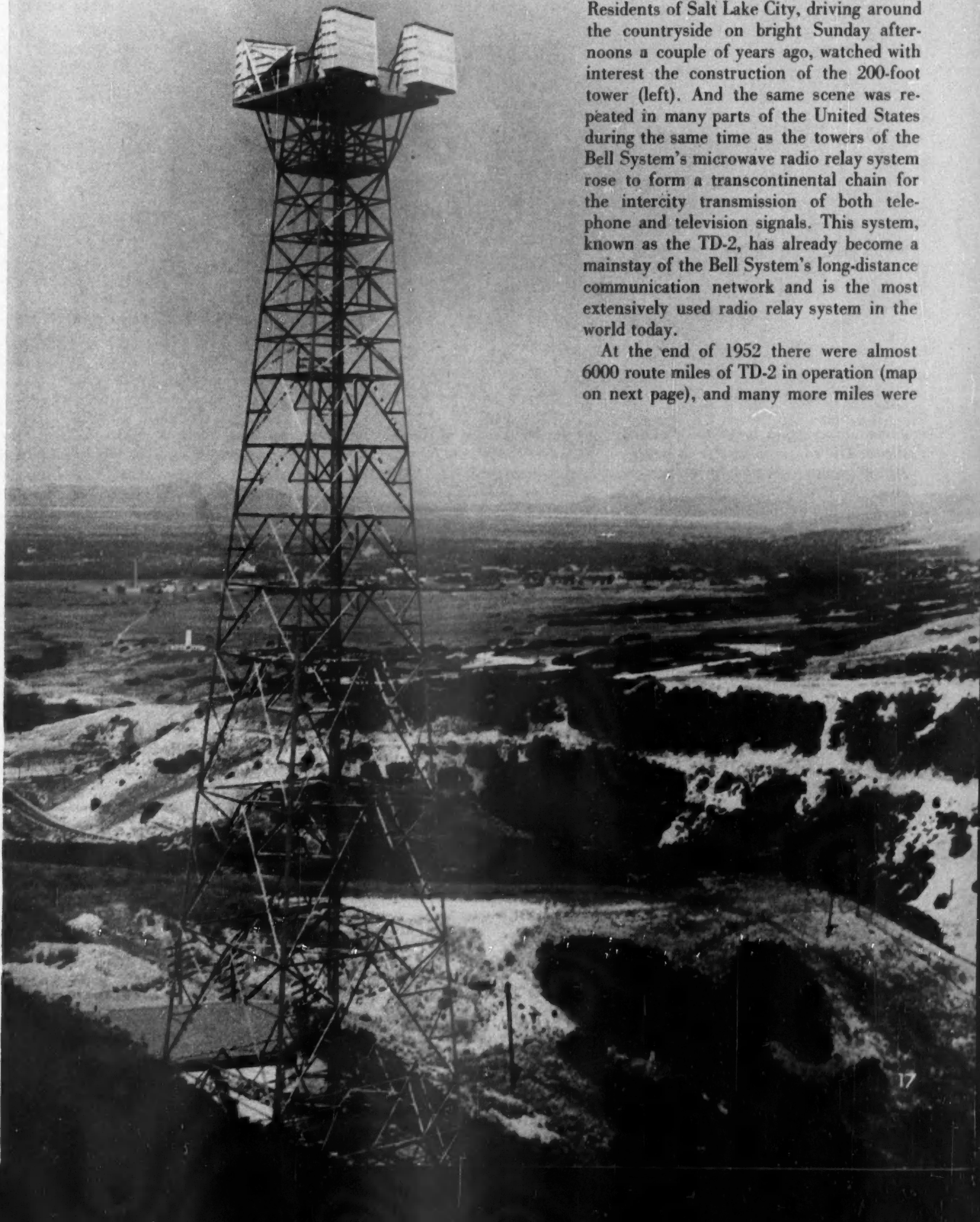
Regardless of the means adopted to control corrosion in any specific application of aluminum, you must give consideration to the natural driving force toward corrosion—and to the amazing invisible oxide film that can hold this force in check. For exposures to ordinary atmospheres and to distilled water, the natural film furnishes complete protection. But increased protection for different situations is available through anodization, a controlled oxidation of aluminum that produces a thicker, better oxide coating.

Under certain conditions, particularly where cells may occur that contain a heavy metal like copper, localized cor-

CONCLUDED ON PAGE 61

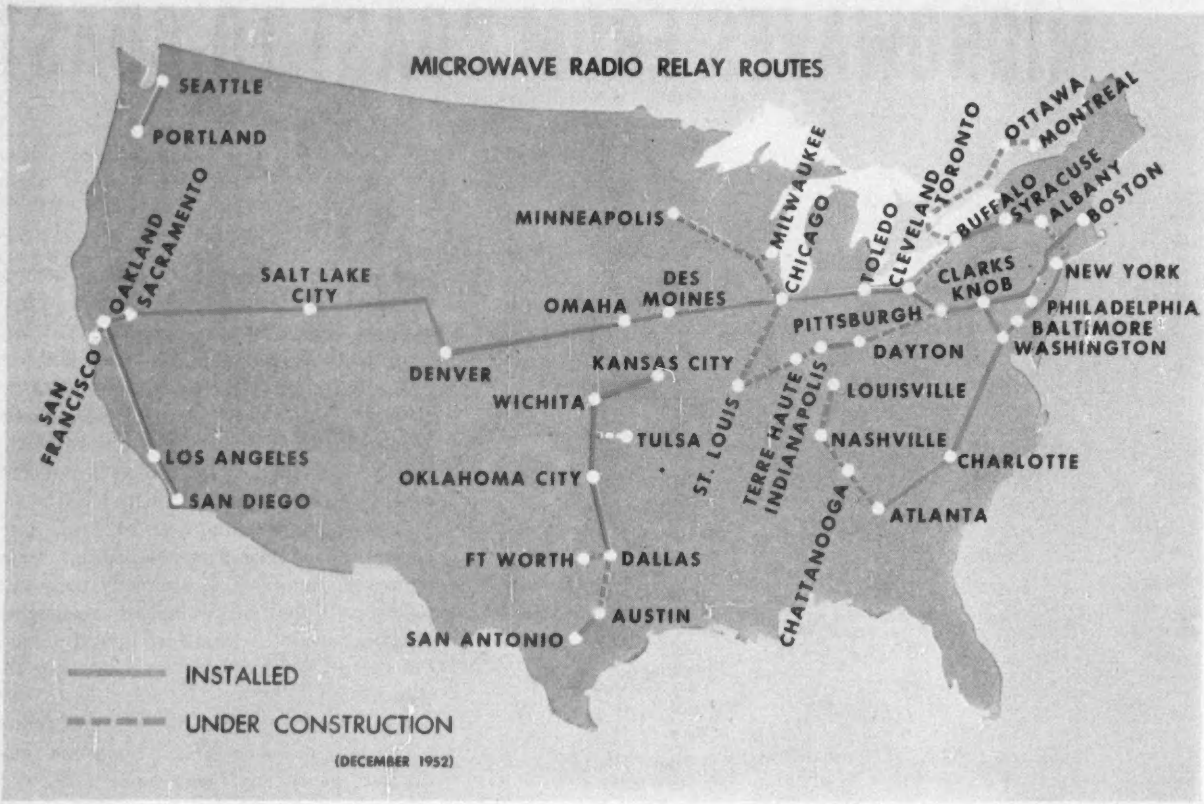
MICROWAVES FROM COAST-TO-COAST

By JAMES R. RAE



Residents of Salt Lake City, driving around the countryside on bright Sunday afternoons a couple of years ago, watched with interest the construction of the 200-foot tower (left). And the same scene was repeated in many parts of the United States during the same time as the towers of the Bell System's microwave radio relay system rose to form a transcontinental chain for the intercity transmission of both telephone and television signals. This system, known as the TD-2, has already become a mainstay of the Bell System's long-distance communication network and is the most extensively used radio relay system in the world today.

At the end of 1952 there were almost 6000 route miles of TD-2 in operation (map on next page), and many more miles were



under construction or in the planning stages. The routes in operation provide 36,000 miles of broad band radio channels that are utilized to furnish 17,000 miles of television circuits and about one million miles of two-way telephone trunks.

Microwaves

As generally used, the term "microwave" refers to radio transmission on frequencies of about 1000 megacycles or higher. (The standard AM broadcast range is 550 to 1500 kilocycles.) The TD-2 system operates in the vicinity of 4000 megacycles, or a wave length of about three inches.

The outstanding characteristic of microwaves, which makes them particularly suitable for multihop radio relay applications, is the similarity of their behavior to light waves. Like light, microwaves travel in essentially straight lines and require a path free of obstacles. At first glance this characteristic may seem to be a disadvantage in that it limits the length of hop. Actually it is helpful because it aids in confining radiations between two adjacent stations on a route, thus permitting re-use of frequencies at alternate stations. It also reduces interference between different routes. By the use of suitable antennas the waves can be concentrated in narrow beams similar to searchlight beams, thus permitting operation with very low power outputs.

Other advantages of microwaves are freedom from static and the availability of broad bands of frequencies, as compared with the lower end of the radio frequency spectrum. Unfortunately, microwave relays have some disadvantages too. We will discuss them later.

First Relay System

The American Telephone and Telegraph Company (AT&T) constructed its first multilink microwave relay system between New York and Boston. This system, known as the TD-X, was placed in service in 1947 and since then has been in regular use for the transmission of television programs. It operates on frequencies between 3900 and 4200 megacycles, and provides two channels in each direction. Each channel transmits a video frequency band of greater than four megacycles width. The TD-X system was also used for a telephone transmission trial during which a pair of radio channels satisfactorily carried 240 simultaneous telephone conversations. However, the principal benefit obtained from the TD-X system was the knowledge and experience gained that helped in the design and construction of the improved TD-2 system.

How the TD-2 Operates

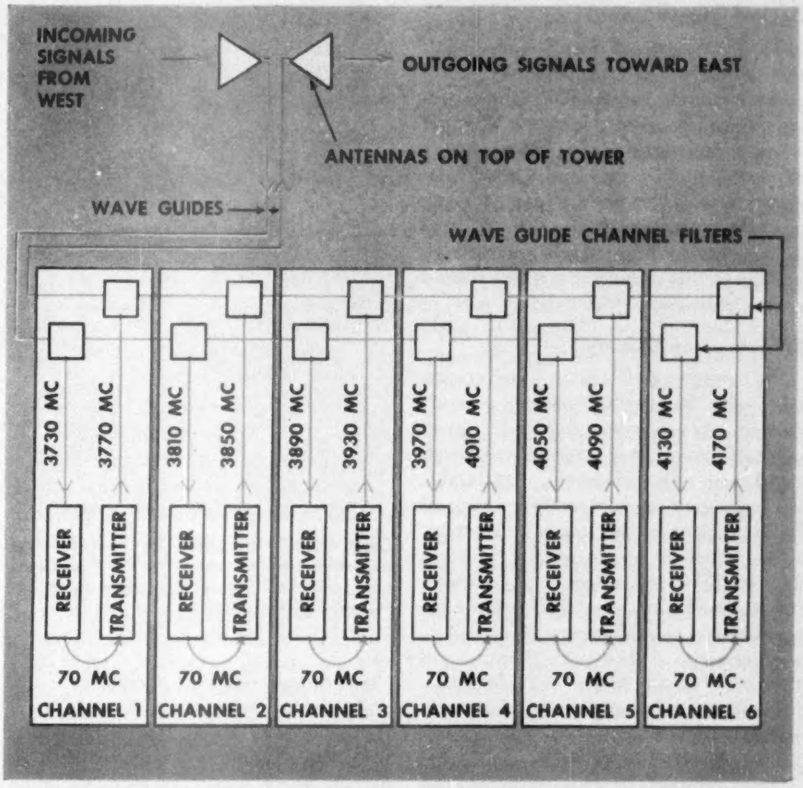
The TD-2 system operates in the band of frequencies between 3700 and 4200 megacycles, which has been allocated by the Federal Communications Commission (FCC) for "common carrier" operation. The microwaves are beamed from station to station by means of lens-type antennas that will be discussed later. Since the waves travel in essentially straight lines, it is necessary that adjacent stations be within "line of sight" of each other. As a result, stations are generally on hill tops and frequently make use of towers up to several hundred feet in height to increase antenna elevation. The average distance between stations on the routes so far constructed is about 30 miles.

The TD-2 system is capable of providing six wide band radio channels in each direction over a given route. To obtain these channels the available 500-megacycle frequency band has been divided into 12 channels with 40 megacycles separation between centers. Each channel utilizes a band 20 megacycles wide, leaving 20 megacycles between channels as a "guard band" to prevent interaction. (These guard bands are not wasted, however. On a spur route that is almost parallel to the main route, the guard bands are used as the channel frequencies, thus reducing possible interference between the two routes.)

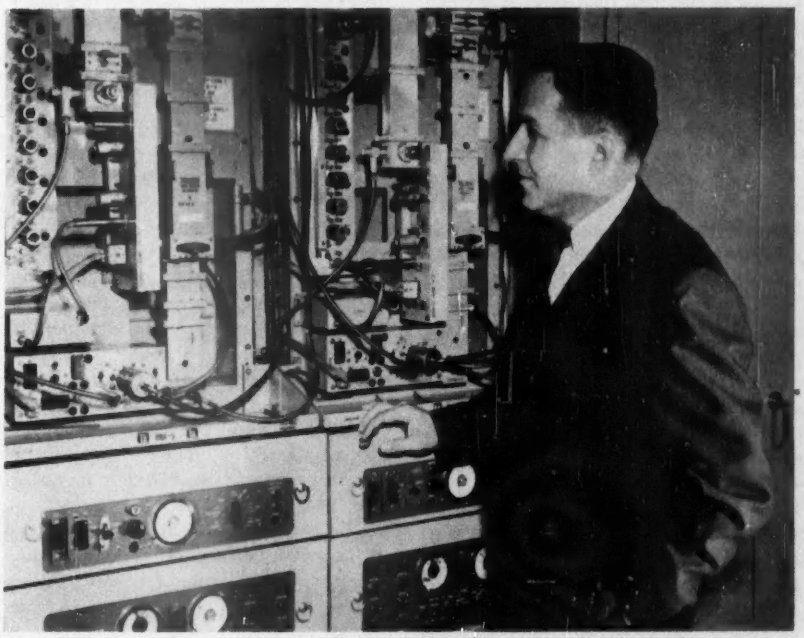
Of the 12 available channel frequencies, each station uses six for transmitting and six for receiving, since it is not practicable to transmit and receive on the same frequency at a given station. The frequencies used for transmitting and receiving are alternated station-by-station along the route. Thus, channel No. 1 will be transmitted from station A to station B on the frequency 3730 mc. From station B to station C it will utilize the frequency 3770 mc, and from station C to station D will again be on 3730 mc.

At relay stations each channel requires its own bay of radio receiving and transmitting equipment. The combined energy of the six channels picked up by the receiving antenna is transmitted through a group of wave guide filters located at the tops of the repeater bays, each of which picks off its own channel frequency and passes the others with negligible loss. Similar filters combine the energy emitted by the six radio transmitters. (At the top of this page is a diagram of a typical repeater station.) It shows one direction of transmission only; the opposite direction is handled in identical manner by a second pair of antennas and another line of repeaters. At adjacent stations the same arrangements are used except that transmitted and received frequencies are interchanged.

Each of the individual radio channels is capable of providing a TV channel with a band width greater than eight megacycles. This can be used for the transmission of one television program or 600 telephone circuits that are multiplexed by means of the same frequency-division multiplex system as is used on coaxial cables. Thus, since one of the six radio channels is normally held in reserve as a standby protection channel, leaving five "working" channels, the TD-2 system is capable of providing either 10 television circuits (five in each direction) or 3000 two-way telephone circuits, or various combinations of television and telephone facilities, as required.



REPEATER BAY arrangements and frequency translations at a typical TD-2 relay station. For transmission in the opposite direction duplicate arrangements are used.



MR. RAE INSPECTS microwave repeater equipment (TD-2) in New York's Long Lines terminal. Transmission aspects of the communications business—both wire and radio facilities—have been Mr. Rae's chief interest during his career with the Bell System that began in 1929. Prior to his recent appointment as General Methods Engineer in the Long Lines Engineering Department, American Telephone and Telegraph Company, he was Engineer of Transmission in the same Department.

Design Objectives

The TD-2 system was designed with the objective of providing as many radio channels as possible in the frequency space available. Each channel was to be capable of transmitting a television picture or hundreds of message channels, with negligible impairment, over distances as great as 4000 miles. Furthermore, reliability comparable to that of buried or underground cable facilities was desired.

Transmission Quality

To enable each radio channel to carry the number of message circuits desired, it was realized at the outset of development that a means of providing broad radio channels, very stable in frequency and essentially free of both amplitude and phase distortion, would have to be provided. It did not appear that the klystron or magnetron tubes used in previous microwave transmitters would meet the necessary requirements. This was because of the very small noise and distortion tolerances permissible at each individual station if as many as 150 stations were connected in tandem.

The solution to this problem was found in the development of an improved planar triode vacuum tube, known as the 416, that made it possible to build amplifiers that would operate satisfactorily at 4000 megacycles. Ordinary vacuum tubes will not function at such high frequencies because their electron transmit time (the time for an electron released from the cathode to reach the plate) is too great in comparison with the period of the microwave frequency. The walnut-size 416 tube solves this problem by the extremely close spacing of its three elements. The distance from cathode to grid is only 0.0005 inch, while that from grid to plate is 0.0012 inch. The grid wires are 0.0003 inch in diameter, spaced 1000 to the inch.

The development and commercial production of this tube was a project of great magnitude. A number of completely new techniques had to be devised because of the fineness of the work and the extremely small tolerances permitted. The successful outcome of this project was the most significant factor in making possible the outstanding transmission qualities of the TD-2 system.

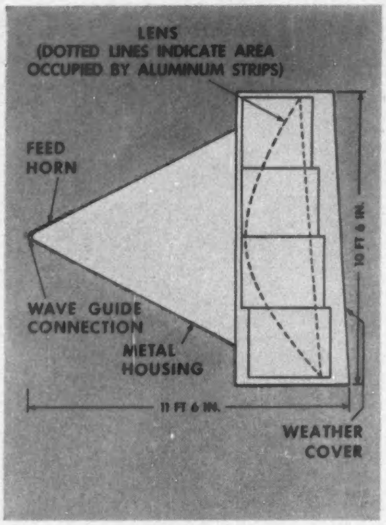
Antennas

Another problem solved was that of suitable antennas. It will be recognized that, unless different frequencies are utilized for transmitting in each direction from any given station, resulting in a requirement for doubling the frequency space used, the antennas must have excellent "front to back ratios." The reason is that energy radiated by a transmitting antenna or picked up by a receiving antenna in the backward direction is one cause of interference and signal distortion. In a relay system of relatively few sections, such spurious couplings might be tolerated, but in a 4000-mile system where there may be 150 such couplings, they must be reduced to negligible proportions.

A second requirement was that the antenna give uniform performance over the entire 3700- to 4200-megacycle frequency range. This applies to its performance as a wave guide termination, as well as its gain. A good "impedance match" between antenna and wave guide over the entire frequency band is essential to avoid reflections that cause loss of definition in television signals and interchannel modulation in multiplex telephone signals.

The conventional parabolic dish type of antenna, while producing satisfactory gain over a limited frequency range, would not meet the other requirements.

A type of antenna known as a "shielded delay lens" antenna was successfully developed. (Cutaway on this page.) The wave guide is connected to a short horn that terminates it properly and guides the signal toward the lens. The lens consists of strips of aluminum imbedded in polyethylene foam blocks, the number of such strips being greatest at the center of the lens, thus reducing the velocity of waves passing through the center as compared with those nearer the edges. The lens is designed to focus incoming waves at the apex of the horn. In the transmitting case the radial wave front emanating from the wave guide is changed by the lens to a plane wave front. The metal housing of the entire antenna acts as a shield and minimizes radiation or reception in other than the desired direction.



DELAY LENS ANTENNA has metallic lens that concentrates outgoing energy in a narrow beam and focuses incoming energy at the apex of the feed horn.

Reliability

The problem of getting a high degree of reliability has been one of the most serious facing designers of microwave systems. To compare with existing coaxial cable systems, which have transmission capabilities comparable to TD-2, total trouble outage time per 100 miles of radio channel should be in the order of 0.02 percent. This amounts to only 10 minutes per month for 24-hour per day service.

The use of the 416 triode furnished a solution for one of the most serious problems affecting the reliability of most microwave systems—the provision of a stable power supply. Radio relay systems using klystrons require high voltages that are normally derived by stepping-up and rectifying the a-c power supply. Even very short interruptions of the a-c supply therefore cause "hits" on the radio signals.

Experience in the operation of such relay systems showed that power interruptions at remote relay stations are one of the most serious causes of service outages, even when stand-by engine generators are provided. Although this condition can be improved by the use of a constantly running motor-alternator at each station (operated from storage batteries when a-c power fails), such arrangements are expensive.

Stand-by Power

In the TD-2 system a much simpler solution was possible because the maximum voltage required for the 416 tubes is only 250 volts. This is low enough to be supplied directly from storage batteries. Such power supplies were built into the TD-2 system—a 12-volt storage battery provides heater power, and a 250-volt battery plate power. As a result, failure of commercial a-c power has no effect on the radio equipment.

While emergency engine generators are provided to take over when commercial power fails, the cutover interval is not critical. If, for any reason, the stand-by engine generator fails to take over, the batteries can carry the station for at least eight hours.

Fading

Another serious problem affecting the reliability of microwave systems is fading. The first line of defense against fading is adequate engineering of proposed routes with respect to station sites and tower heights.

In general, it is believed that there are three principal causes of fading on microwave systems:

Path Blocking may occur when atmospheric conditions of temperature and moisture content cause radio waves to be refracted upwards. As a result, it is energy leaving the transmitting antenna in a slightly downward direction and following a bowed path that finally reaches the receiving antenna. In effect, the earth between appears to bulge upward and may partially or totally block the radio path.

Ground Reflections are caused by bodies of water or by flat pieces of the earth's surface. The reflected energy from these may arrive at the receiving station in phase or out of phase with the direct beam, depending on the difference in length of the direct and reflection paths. Changes in atmospheric conditions change the relative lengths of these paths so that the received signal varies with time.

Multipath Interference is caused by rays arriving at the receiving station from somewhat higher angles than the direct beam. They are apparently produced by reflection or refraction from atmospheric discontinuities and arrive at the receiving station in ever-changing patterns, causing rapid changes in the total received energy.

There appears to be little that we can do to prevent fading from the third cause. However, as these rays are generally small in magnitude compared with the direct signal, their effect can be minimized by preventing fading from path blocking and ground reflection, so as to keep the direct signal at its normal strength at all times.

Path blocking can be prevented by adequate tower heights. But towers cannot be heightened indiscriminately because of cost, transmission losses in wave guides, and because higher towers may increase the effects of ground reflections.

To obtain maximum insurance against fading on TD-2 routes, every proposed path is subjected to microwave testing before acceptance. These tests, performed with portable microwave equipment and antennas that may be varied in height from ground level to 200 feet, provide accurate information as to heights of intervening obstructions and the presence of reflecting surfaces. Analysis of the results enables the determination of optimum tower heights. In addition to fading considerations, of course, the route engineering must also take into account such other factors as the economic spacing of stations while maintaining adequate signal-to-noise margins, accessibility of sites, availability of power supply, and zoning or other property restrictions.

Despite the most careful route engineering some fades of serious magnitude will still occur. And even with the most conservatively designed equipment there is always the possibility of vacuum tube failure or other equipment trouble. The only sure safeguard against interruptions due to these causes is the use of an automatic switching system that will provide either frequency diversity or space diversity reception to guard against fading, and substitute stand-by equipment to guard against equipment failure.

In the TD-2 system both of these objectives can be accomplished by setting aside one channel of the six in each direction as a protection channel and providing automatic switching, at intervals of 100 to 200 miles, that will substitute this channel for any that fails. The operation is fairly complex, since the failed channel must not only be detected at the receiving end, but an identifying signal must be sent to the transmitting end of the section to connect the stand-by channel in parallel with the failed channel. After this is done the switch can be made at the receiving end.

The apparatus to perform such switching is not yet installed, but it has been designed and is now in process of manufacture. It is expected that a switching interval of about 40 milliseconds can be realized. In most cases of fading this interval should be sufficiently short to switch out the affected line before service becomes unsatisfactory.

Maintenance

Maintenance charges for a radio relay system are likely to be a serious item of expense, largely because of the considerable amounts of travel time required to visit many of the stations. It is important therefore that unnecessary trips be minimized by providing means for control offices to diagnose troubles, to determine where the trouble is, what it is, and whether it is sufficiently serious to dispatch a repair man immediately.

On the TD-2 routes an alarm and control system is installed, operating over paralleling wire circuits, that connects each remote station with its maintenance center and provides as many as 84 indications of conditions at each station and permits the maintenance center to perform 34 different operations at each station by remote control. Thus it is possible for the maintenance center not only to diagnose troubles accurately but also to perform routine operations, such as testing the emergency engine generator or interchanging working and protection channels, without sending a man to the remote station.

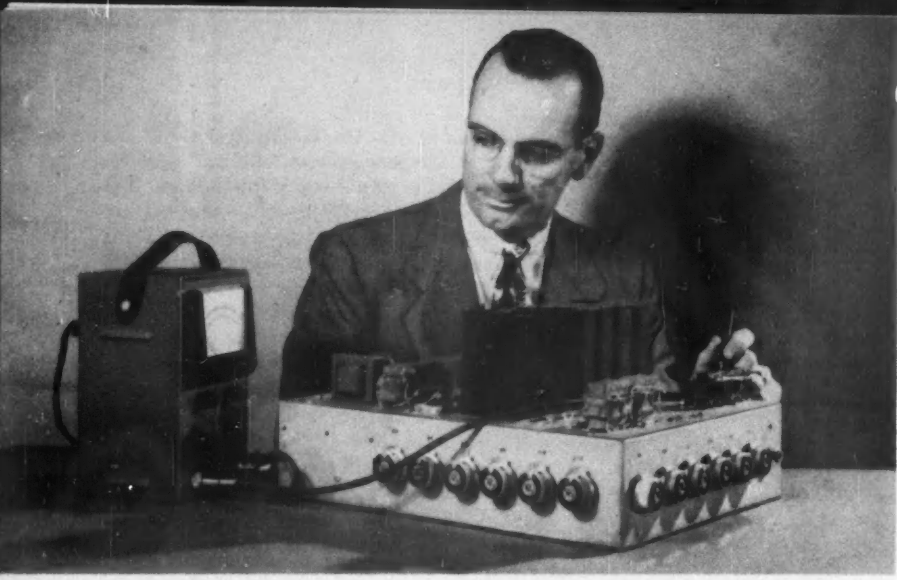
Are Results Satisfactory?

Transmission quality over the existing TD-2 routes has been very satisfactory.

Cross-continent transmission of television pictures introduces so little impairment that it is difficult to distinguish between remote and local originations. The telephone circuits derived from TD-2 likewise provide excellent quality.

Interruptions on TD-2 routes due to fading and equipment troubles have thus far been materially greater than on cable facilities, but these are expected to be effectively reduced by application of the automatic switch mentioned above.

The Bell System's experience to date indicates that microwave relays are a practical and economical way of handling many long-distance communication needs. They are not as inexpensive as might be thought upon first study of microwave principles, chiefly because of the costs of the features that give quality and reliability. In the case of the TD-2 system, however, the total cost appears to be reasonable in view of the large volume of communication facilities obtained. Even so, work goes on in the Bell System, both on improvement of the present TD-2 system and on development of still more advanced radio equipment which will eventually provide even better communication systems. Ω



GAS-TURBINE CONTROL—A 12-STAGE MAGNETIC AMPLIFIER—IS CHECKED BY AUTHOR.

The Magnetic Amplifier

By V. J. LOUDEN

The magnetic amplifier is a variable-inductance device that controls the flow of power to a load. It differs from the vacuum tube—a variable-resistance device—in that its operation depends on the nonlinear magnetization of ferromagnetic materials.

The principle of its operation is shown on the opposite page.

Fig. 1 is a simplified representation of a half-wave magnetic amplifier that consists of: 1) an iron-core reactor, of high inductance and low resistance; 2) a rectifier, permitting current to pass in one direction only; 3) a load resistor, in series with a supply voltage across the reactor's terminals; 4) a signal winding to control current flow through the reactor, in series with a variable d-c voltage.

Fig. 2 is the magnetization curve of the iron core. This is a plot of magnetic flux density B in lines per square inch of cross section versus magnetic-field intensity H in ampere turns per inch of core length.

Fig. 3 is a plot of the a-c supply voltage and resultant load current through the winding—with and without a control signal applied.

Let's look first at the reactor's operation without a d-c voltage across the signal winding. (Hysteresis effects are omitted for simplicity.)

When a cycle of a-c supply voltage is applied to the reactor, its iron core goes through a magnetic excursion of the B-H curve. In other words, the core is operated in the *unsaturated* region between b and c, as well as in the *saturated* region above b. Because the load current's flow is impeded in direct proportion to the slope of the B-H curve, the reactor presents essentially two values of reactance. Steep slope means high inductance, flat slope means low inductance.

This, then, is what happens to the current when the supply-voltage cycle is applied: At the beginning of the cycle t_0 the current is zero and, of course, the magnetic intensity—proportional to the current—is also zero. From t_0 to t_1, the current and magnetic intensity build up at a slow rate. The reason is that the core is in the unsaturated region; consequently, current flow through the winding is greatly impeded since the effective inductance is high.

The current, lagging behind the supply voltage, continues to build up slowly until the core is magnetized to point b. At this time t_1, the current takes a big jump. For the core is now saturated with magnetic flux, the current being limited mainly by circuit resistance. Effective inductance of the reactor has dropped to a low value.

The reverse is also true: As the supply voltage passes its peak and begins to decrease, the current decreases with it until point b, corresponding to time t_2, is again reached. Here the current has the same value as at time t_1.

Any further decrease of current through the winding at time t_2 is opposed because the core is now operating in the unsaturated region below b, where the reactor's effective inductance is high. The current therefore decreases slowly, lagging the voltage, until finally at time t_3 the current and the magnetic intensity are zero.

Next let's see what happens when a d-c voltage is applied across the signal winding.

A d-c signal current raises the magnetic intensity H and premagnetizes the core. In effect, then, you can control the degree of magnetization, fixing the time at which the core will saturate when the supply voltage is applied.

If, for instance, you apply a positive d-c signal that corresponds to point a of the B-H curve, the magnetic intensity H to saturation has only to change from H_a to H_b when the supply voltage is applied. Load current then need only build up to a smaller value—shown by the dashed curve—for saturation to take place earlier in the cycle. Likewise, a negative d-c signal saturates the core at a later time in the cycle—the current's surge being retarded.

So it is through means of the d-c control signal that a reactor is converted to a magnetic amplifier. For by regulating the time in the supply voltage cycle that saturation takes place, the *average* value of load current is controlled.

The magnetic amplifier isn't a new device. It was used in this country more than 30 years ago for high-speed telegraphic and telephonic transmission (October 1920 REVIEW, page 797). Then, during the second World War, the German military forces further developed and used it to make up for their acute shortage of trained personnel to service electronic control equipment.

German scientists believed then that the magnetic amplifier could be installed and subsequently forgotten because its service requirements are negligible. But the war ended before many of their new control systems could be put into service, so they didn't reap full benefit from their idea.

•

Mr. Louden joined General Electric five years ago. During this time he has been engaged in the development of electronic and magnetic control systems. Presently in charge of magnetic amplifier component and system development, he is in the Servo Section of the Aeronautic and Ordnance Systems Division, Schenectady.

When American specialists later examined German warships, they found magnetic-amplifier systems used for various controls—gunfire, ship-steering, voltage—and computers. They were impressed with the potentialities of this device. And so the United States Armed Forces set out on a program calling for development of magnetic-amplifier control systems.

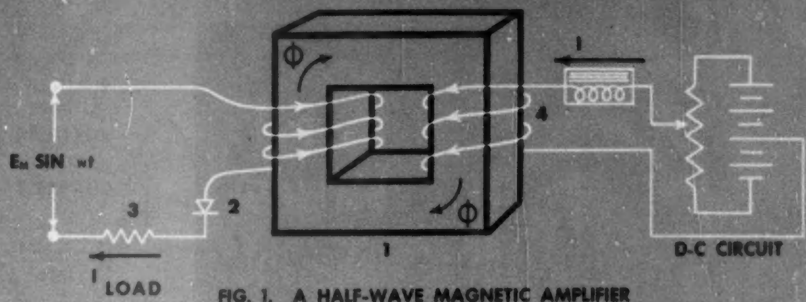


FIG. 1. A HALF-WAVE MAGNETIC AMPLIFIER

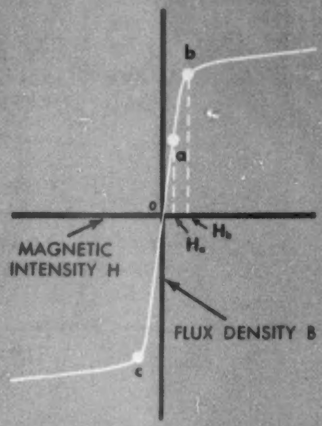


FIG. 2. B-H CHARACTERISTICS OF THE CORE MATERIAL

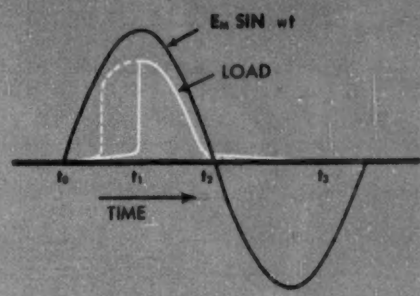


FIG. 3. SUPPLY VOLTAGE AND LOAD CURRENT WAVE SHAPE

Electronic Counterpart

In many respects a magnetic-amplifier is similar to a thyratron control circuit. A gas-filled triode, the thyratron is usually connected in series with a load across an a-c supply-voltage source. In its normal state the gas acts as an extremely high impedance to passage of current. But when the gas is ionized—grid voltage controls ionization—it conducts current so well that the voltage drop across the tube is small and almost independent of the amount of current through it.

A comparison of the thyratron circuit with a half-wave magnetic-amplifier circuit is shown on page 24.

The thyratron appears as a high impedance in its circuit, and during the first part of the supply-voltage cycle, current flow through it is low. But at some later time in the cycle the thyratron's grid receives a pulse or other firing signal that ionizes the gas. Load current then surges through the tube. Because the voltage-drop inside the tube is small, most of the supply voltage appears across the load resistor. And as you can see, the wave form of load current in the thyratron circuit is approximately a portion of a sine wave.

A half-wave magnetic-amplifier circuit operates in a like manner. During the first part of the supply-voltage cycle, current flow through the load resistor is small because, as mentioned earlier, circuit inductance is high. However small, the current increases until at some later time in the cycle—determined by the d-c control signal—the core is saturated and circuit inductance becomes low. Current flow is then limited primarily by resistance in the circuit. Notice the similarity of the load-current's wave form with that of the thyratron circuit.

Although we've discussed the half-wave magnetic-amplifier circuit thus far, it isn't practical for most applications. This is so because a high inductance or resistance is needed in the control circuit to minimize the flow of undesirable induced currents. But the introduction of a high inductance makes the amplifier's speed of response slow—the use of a high resistance reduces the amplifier's gain.

The more practical circuit is also illustrated on page 24, lower left. In essence, there are two half-wave circuits with their reactors adjacent so that one signal winding links both cores. With this arrangement, the undesirable harmonics are not induced in the signal circuit, and a high impedance or resistance isn't required.

Use in Aircraft

Good performance is achieved with many complex magnetic-amplifier control systems, such as the aircraft gas-turbine control shown on page 22. Twelve stages of magnetic amplification are contained in this system. They are so co-ordinated that a jet-aircraft pilot automatically gets thrust proportional to his selector position.

The device also prevents the engine from stalling during rapid accelerations. It does this for various flight conditions by computing the maximum rate at which fuel can be supplied without stalling the engine. Fuel flow is then limited to a safe value slightly less than the computed rate.

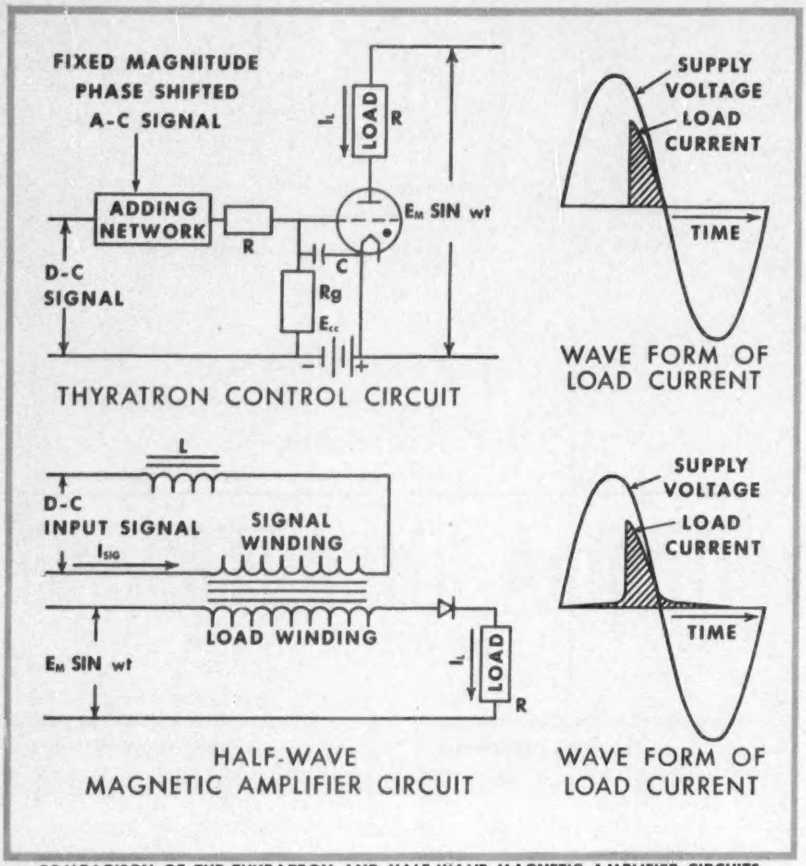
Other functions of the control are to prevent the jet-engine's combustion burners from being blown out during rapid deceleration, and to limit the tail-pipe temperature to a predetermined maximum during acceleration. Many other duties otherwise required of the pilot are also performed by the aircraft gas-turbine control.

Some additional magnetic-amplifier systems developed are azimuth and elevation controls for air-borne radar and naval gun mounts, naval ship-steering controls, autopilots for aircraft, voltage and frequency controls for aircraft alternators, and a control system for a nuclear power plant.

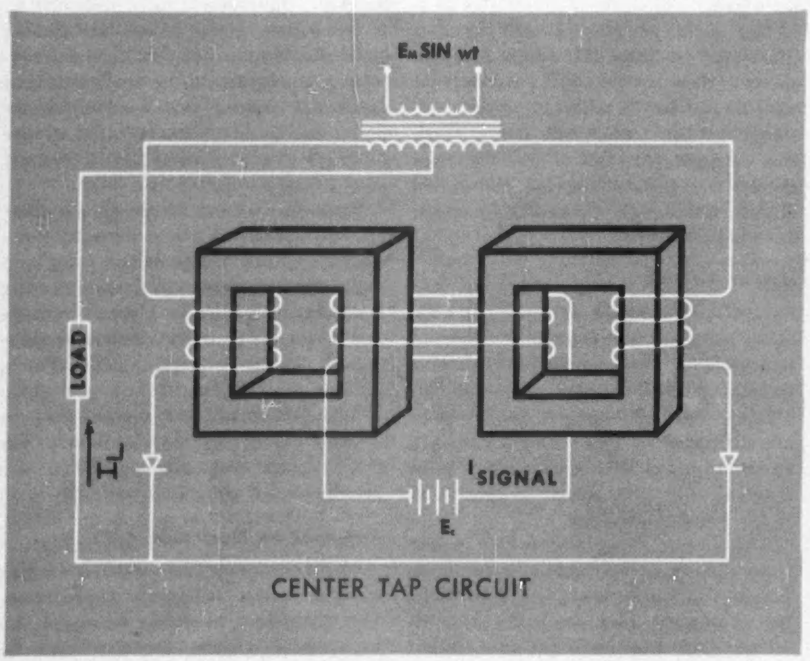
More often than not, control systems operate under adverse conditions. For this reason magnetic amplifiers are usually sealed airtight.

Magnetic vs Electronic

Magnetic amplifiers are replacing vacuum tubes in many applications. You shouldn't, however, interpret this to mean that they are substitutes for vacuum tubes. Rather, they are direct



COMPARISON OF THE THYRATRON AND HALF-WAVE MAGNETIC AMPLIFIER CIRCUITS.



PRACTICAL MAGNETIC AMPLIFIER HAS TWO HALF-WAVE CIRCUITS, ONE SIGNAL.

competitors to be used where their advantages warrant application.

Size and weight are factors that influence application. Where these are of prime importance, magnetic amplifiers shouldn't be considered if the available power is at a frequency of 60 cycles per second. On the other hand, vacuum-tube and magnetic-amplifier systems are comparable in size and weight when the power supply is at 400 cycles per second. At this frequency it's sometimes possible to make the magnetic-amplifier system even smaller than the electronic system. The reason is that low-power magnetic amplifiers have low stand-by losses and small internal-temperature rise, and as a result can be mounted close together.

Warm-up time, maintenance, and ruggedness are other advantages over the vacuum tube. For the magnetic amplifier operates almost immediately after power is applied. And in addition, it gives long maintenance-free life even when subjected to high shock and vibration.

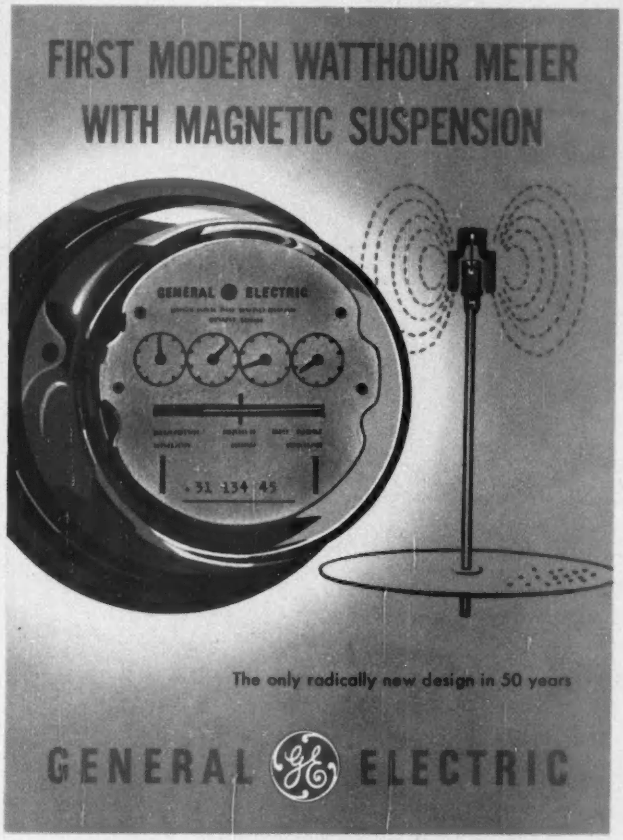
But magnetic amplifiers shouldn't be used at extremes of temperature. At present their maximum temperature range is −55 to +100 C. When these limits are exceeded, the extreme temperatures change the properties of the core materials and metallic rectifier.

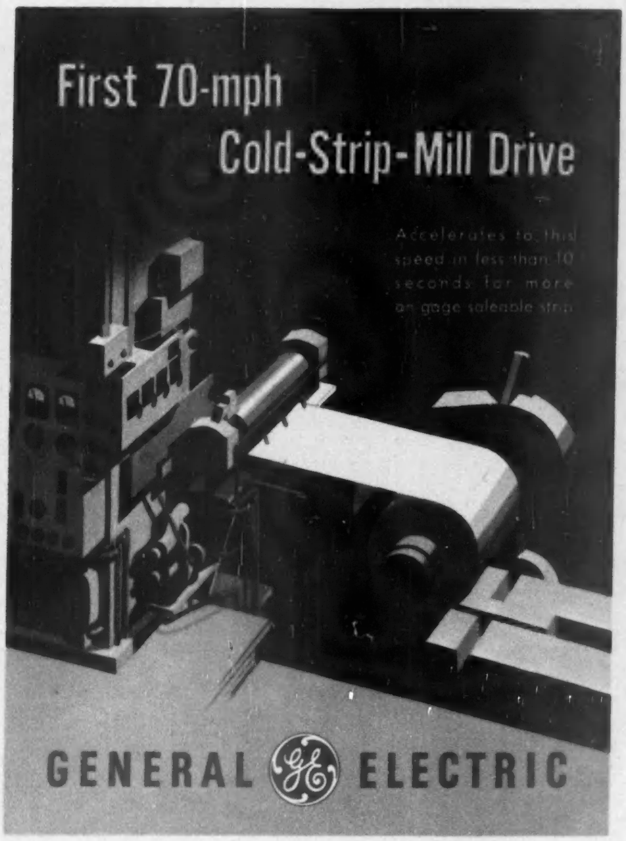
For extremely high-performance control systems, the magnetic amplifier requires a power supply at a frequency of 2000 cycles or better. This restriction exists because magnetic amplifiers have an inductive signal-input winding and their speed of response is slow compared to a vacuum tube. As the frequency of the power source is increased, however, the amplifier's speed of response for a given gain becomes proportionately faster.

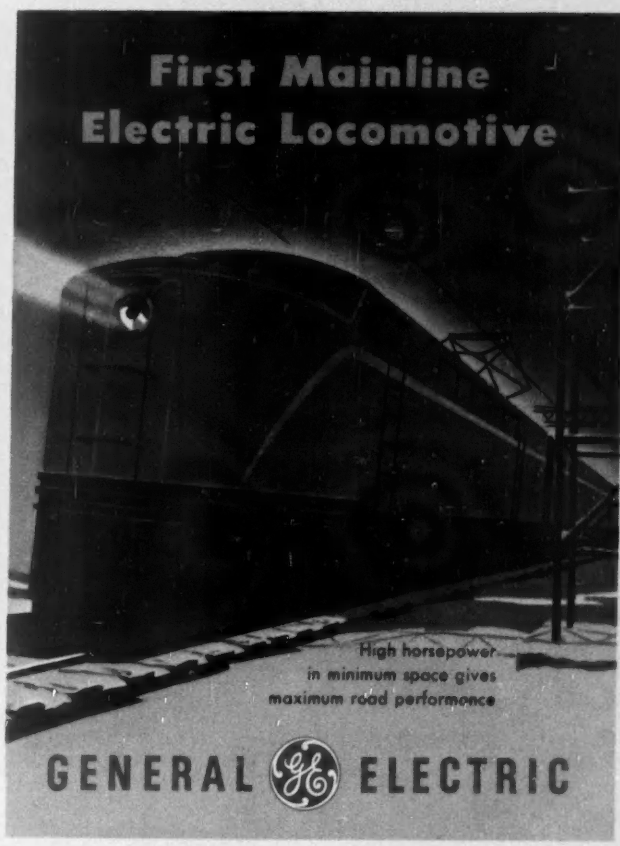
In some places where a vacuum tube would prove inadequate, the magnetic amplifier can be used—for instance, where input and output circuits must be electrically isolated from one another. Still another application would be where the output must respond to the sum of several input signals. Here again the magnetic amplifier comes in handy because a number of signal windings can be utilized.

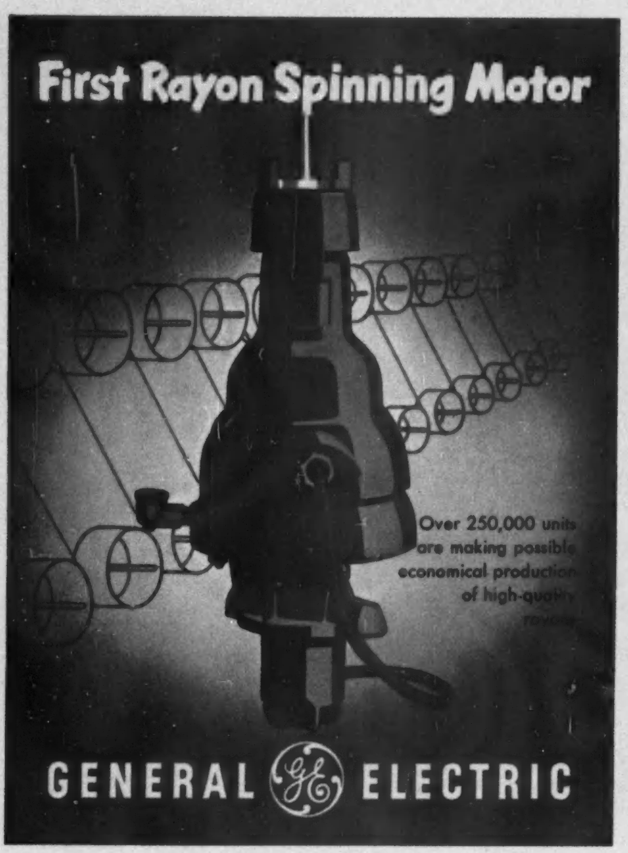
The magnetic amplifier is a highly useful device for the design and development of control systems. Responsibility for its proper use rests with engineering. And if properly applied, you can be sure that better and more reliable control systems will be available in the future. Ω

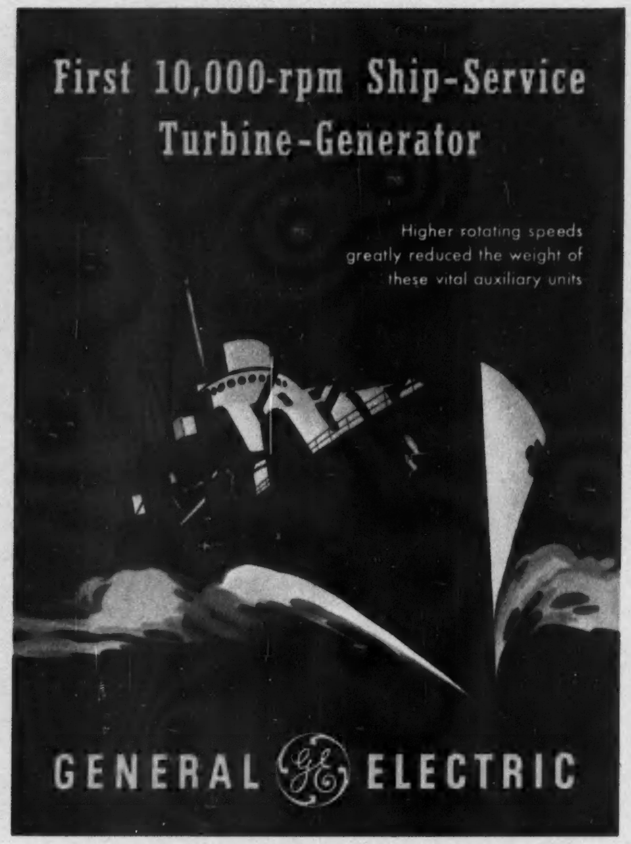
75 Years of Electrical Progress

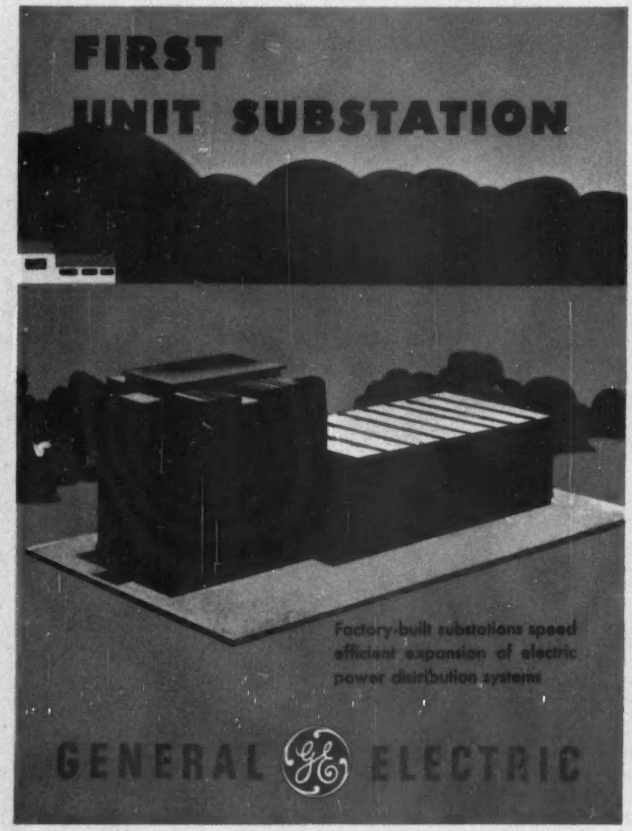




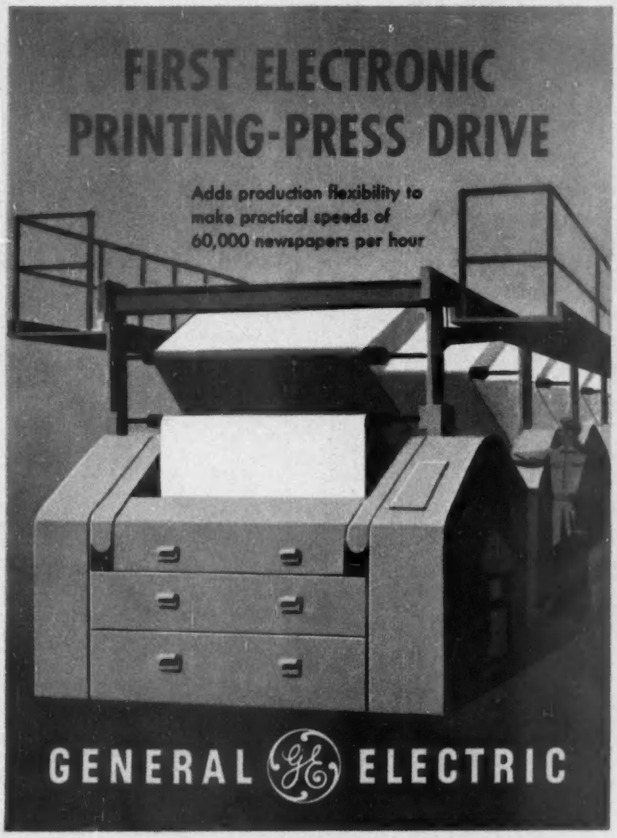


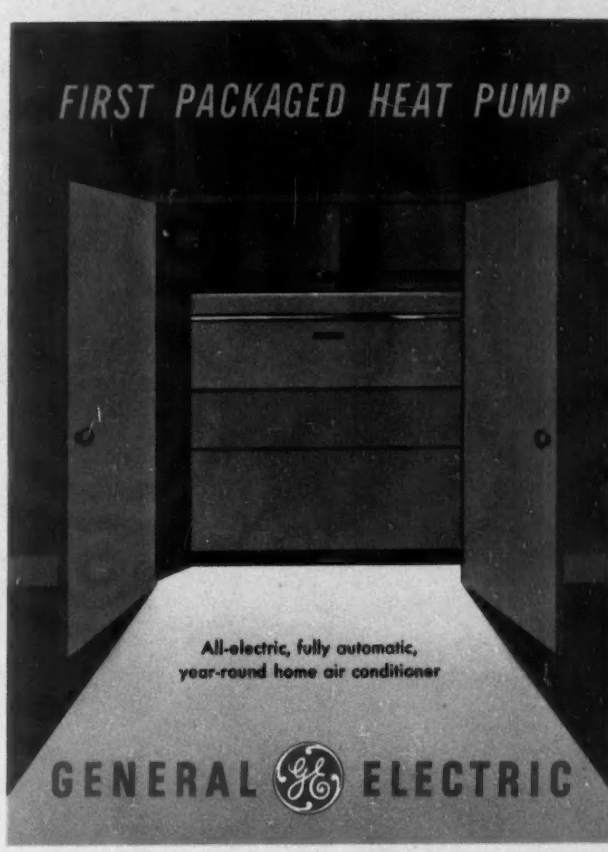

First Rayon Spinning Motor
Over 250,000 units
are making possible
economical production
GENERAL ELECTRIC

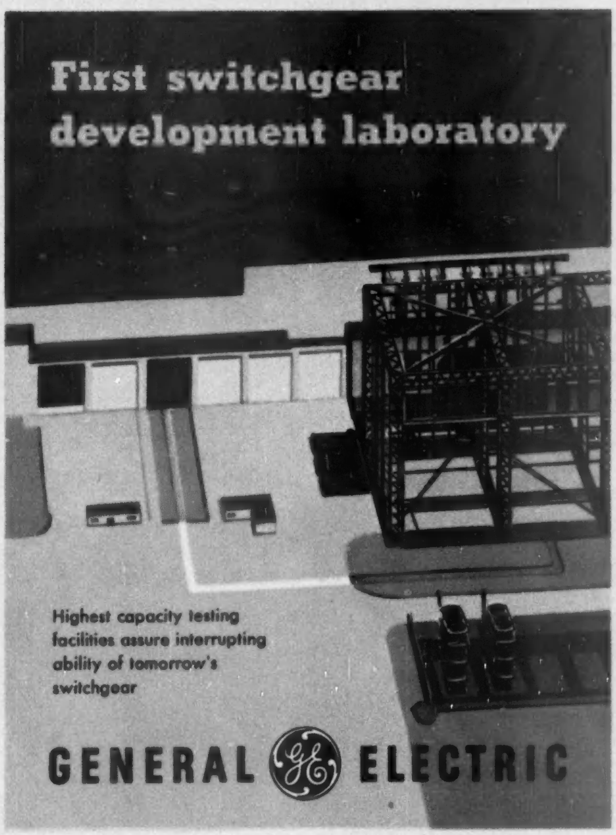

First 10,000-rpm Ship-Service
Turbine-Generator
Higher rotating speeds
greatly reduced the weight of
these vital auxiliary units
GENERAL ELECTRIC


FIRST
UNIT SUBSTATION
Factory-built substations speed
efficient expansion of electric
power distribution systems
GENERAL ELECTRIC


First Metal-Clad Switchgear
with Flame-Retardant Insulation

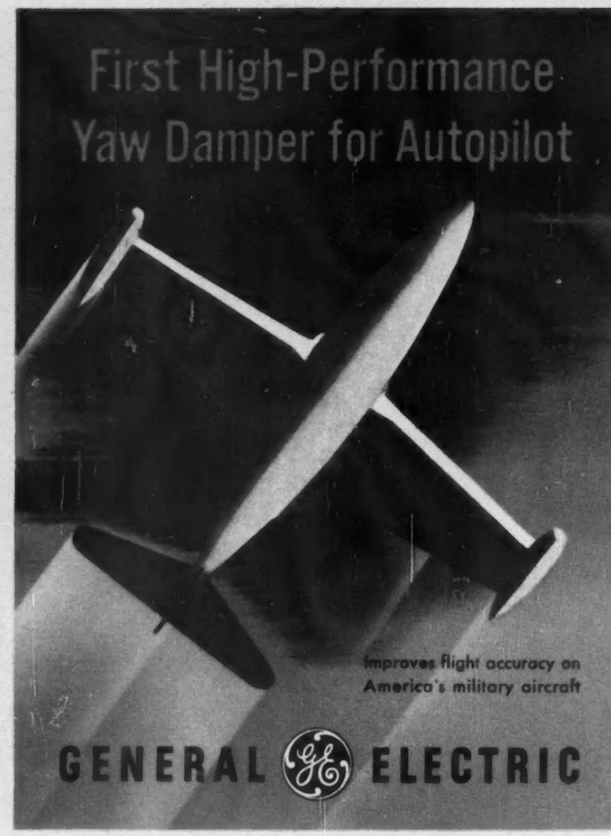

FIRST ELECTRONIC
PRINTING-PRESS DRIVE
Adds production flexibility to
make practical speeds of
60,000 newspapers per hour
GENERAL ELECTRIC

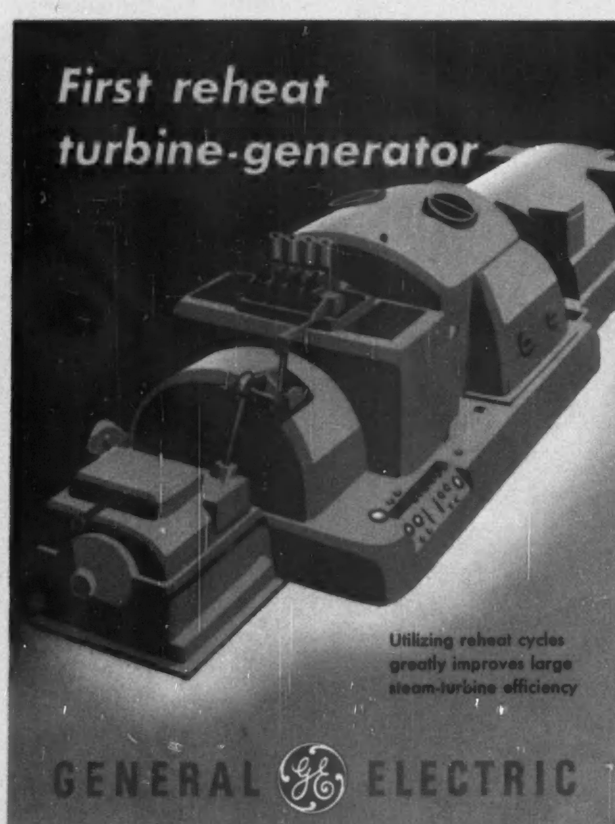

FIRST PACKAGED HEAT PUMP
All-electric, fully automatic,
year-round home air conditioner
GENERAL ELECTRIC

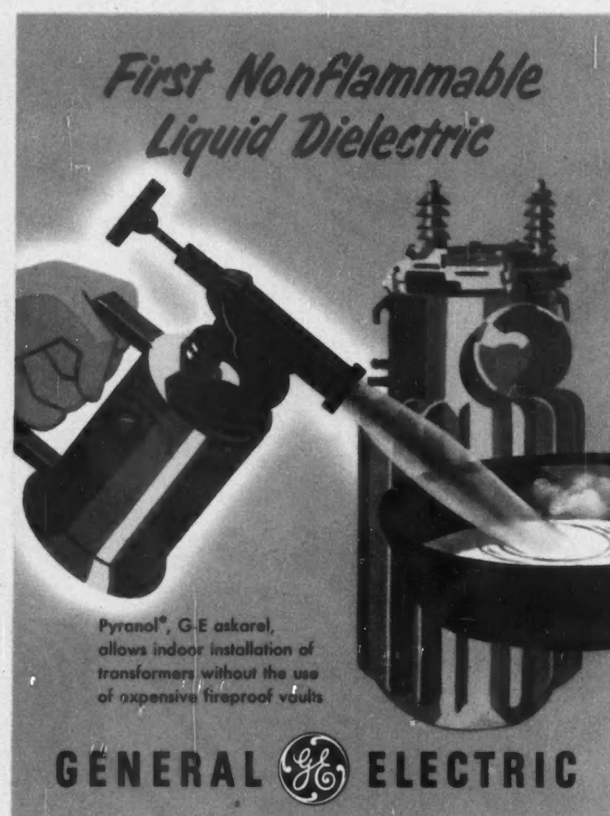

First switchgear
development laboratory
Highest capacity testing
facilities assure interrupting
ability of tomorrow's
switchgear
GENERAL ELECTRIC

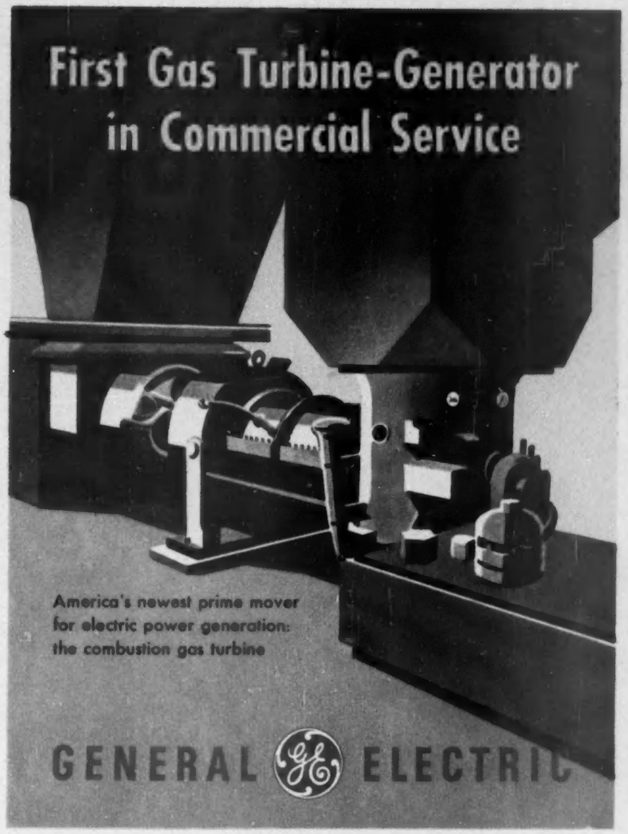

FIRST FORCED-OIL-COOLED STATION
TRANSFORMER WITH DIRECTED FLOW
Reduced size, weight, and cost—
made it practicable to ship
high-capacity units upright,
completely assembled
GENERAL ELECTRIC


FIRST SINGLE-PHASE CAPACITOR MOTOR
Now smaller, lighter for more versatile machine drives, 1/6 to 5 hp
GENERAL ELECTRIC

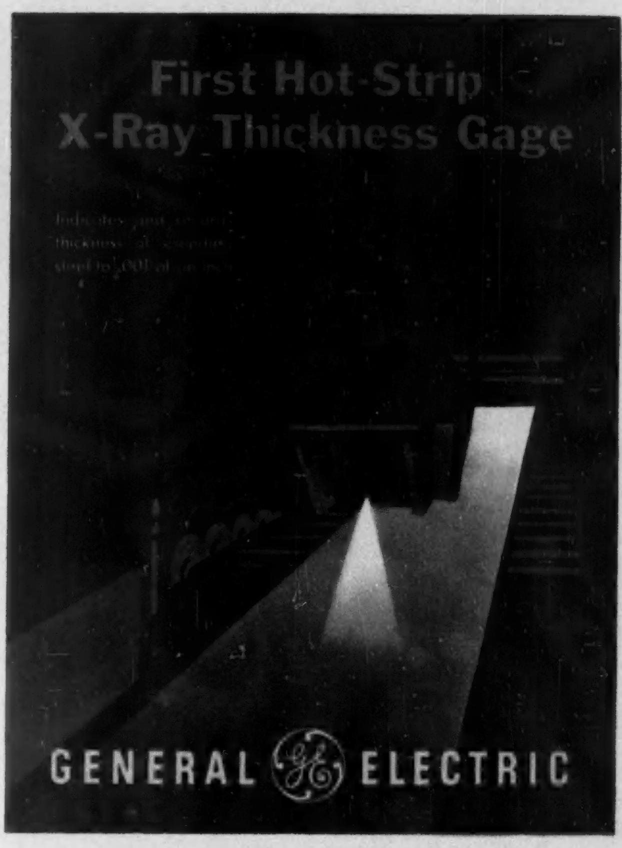

First High-Performance Yaw Damper for Autopilot
Improves flight accuracy on America's military aircraft
GENERAL ELECTRIC


First reheat turbine-generator
Utilizing reheat cycles greatly improves large steam-turbine efficiency
GENERAL ELECTRIC


First Nonflammable Liquid Dielectric
Pyranol®, G-E askarel, allows indoor installation of transformers without the use of expensive fireproof vaults
GENERAL ELECTRIC



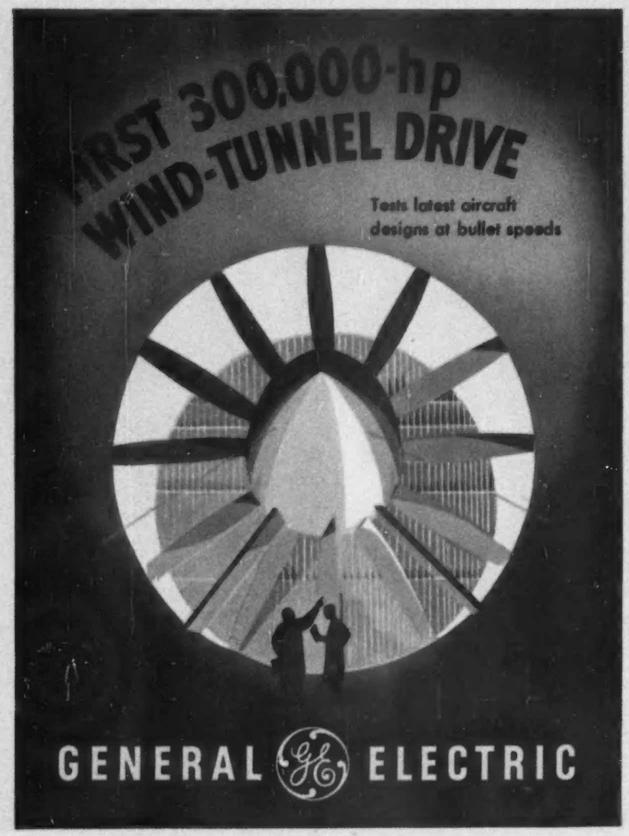
First Gas Turbine-Generator in Commercial Service
America's newest prime mover for electric power generation: the combustion gas turbine
GENERAL ELECTRIC

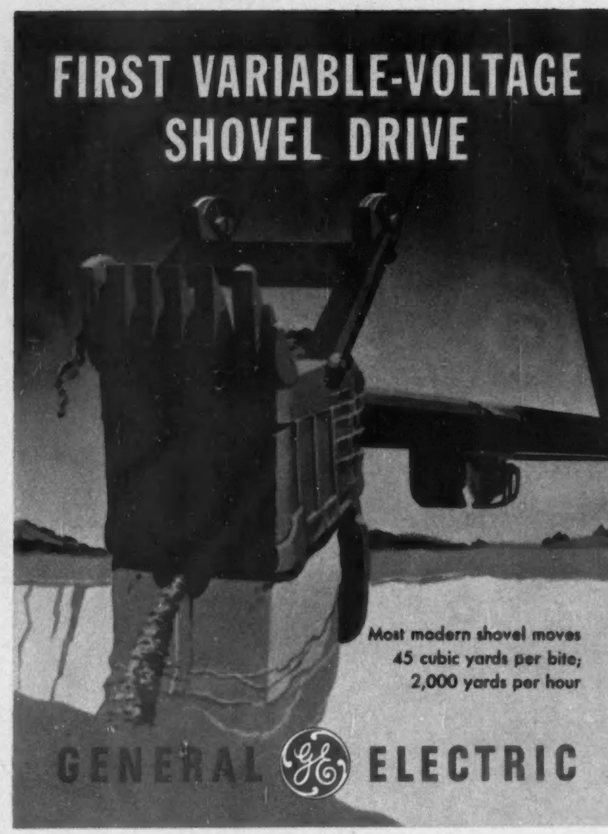


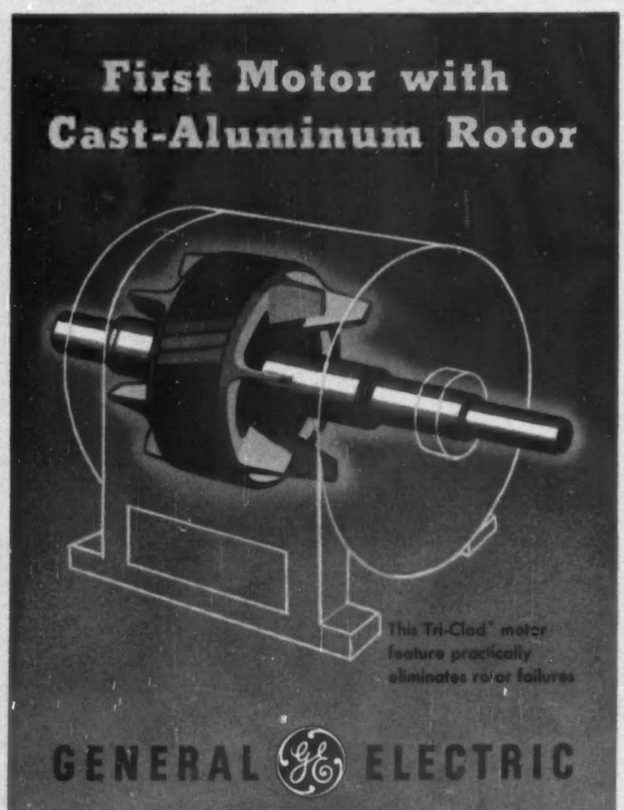
First Hot-Strip X-Ray Thickness Gage
GENERAL ELECTRIC

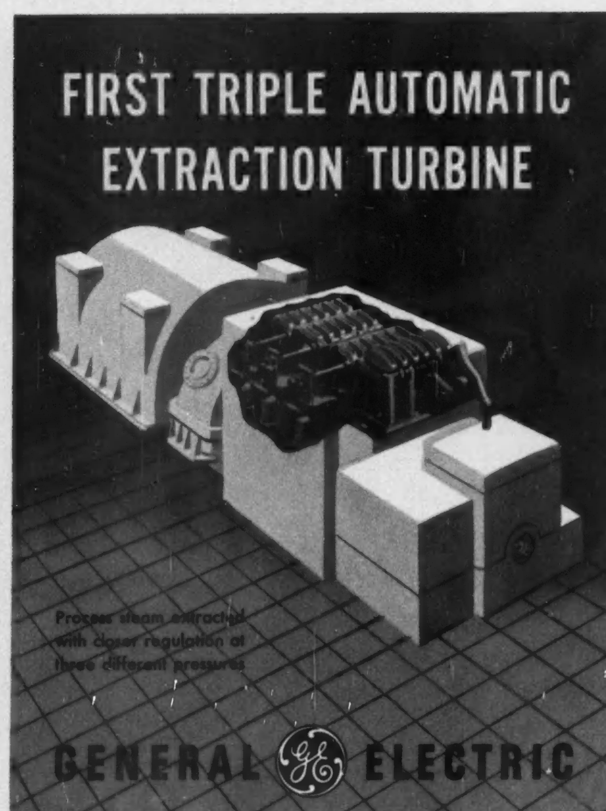
First Successful Diesel-Electric Locomotive
Nearly 20,000 diesel-electrics now operating on America's railroads stem from the pioneer locomotive built by General Electric, American Locomotive and Ingersoll-Rand
GENERAL ELECTRIC

FIRST AIRCRAFT TURBOSUPERCHARGER
Made possible high-altitude bombing in World War II
GENERAL ELECTRIC


IRST 300,000-hp
WIND-TUNNEL DRIVE
Tests latest aircraft
designs at bullet speeds
GENERAL ELECTRIC

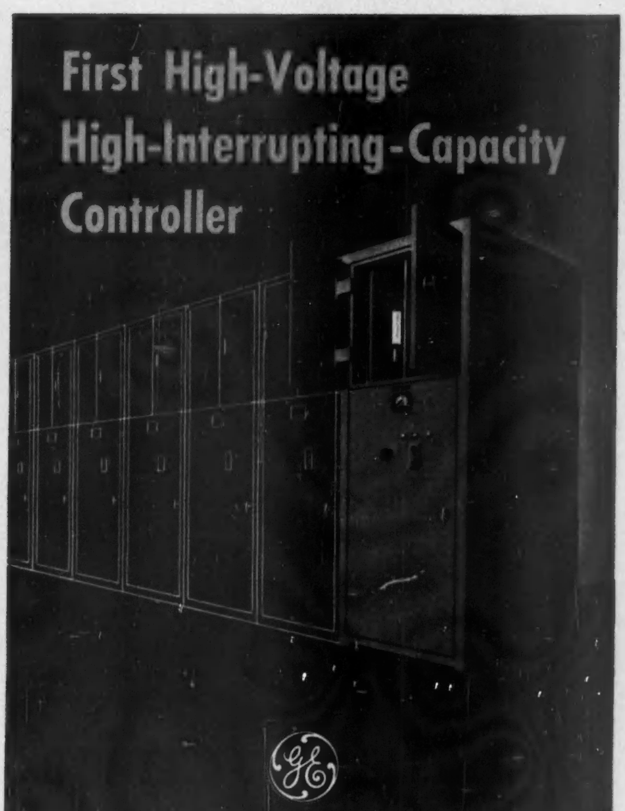

FIRST VARIABLE-VOLTAGE
SHOVEL DRIVE
Most modern shovel moves
45 cubic yards per bite;
2,000 yards per hour
GENERAL ELECTRIC


First Motor with
Cast-Aluminum Rotor
This Tri-Clad* motor
feature practically
eliminates rotor failures
GENERAL ELECTRIC

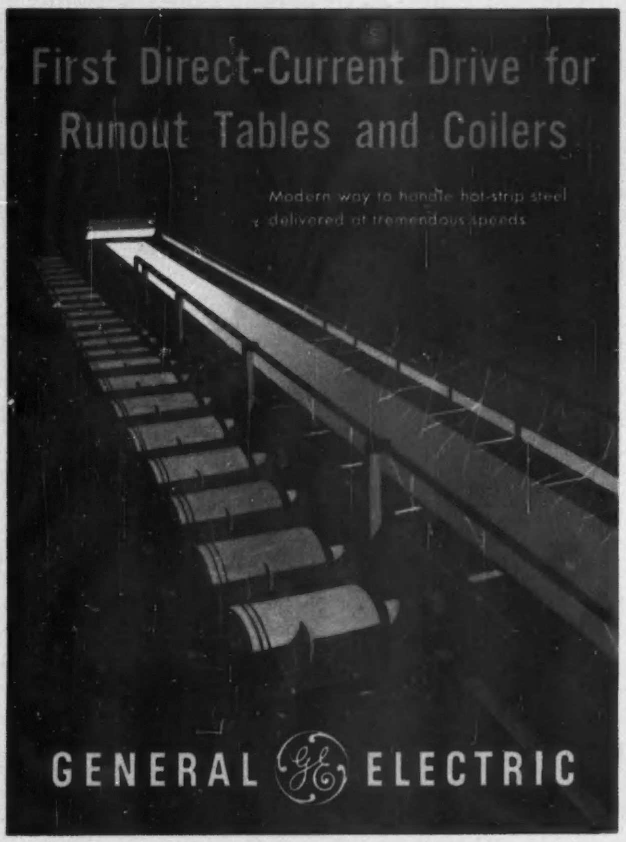

FIRST TRIPLE AUTOMATIC
EXTRACTION TURBINE
Process steam extracted
with closer regulation at
three different pressures
GENERAL ELECTRIC

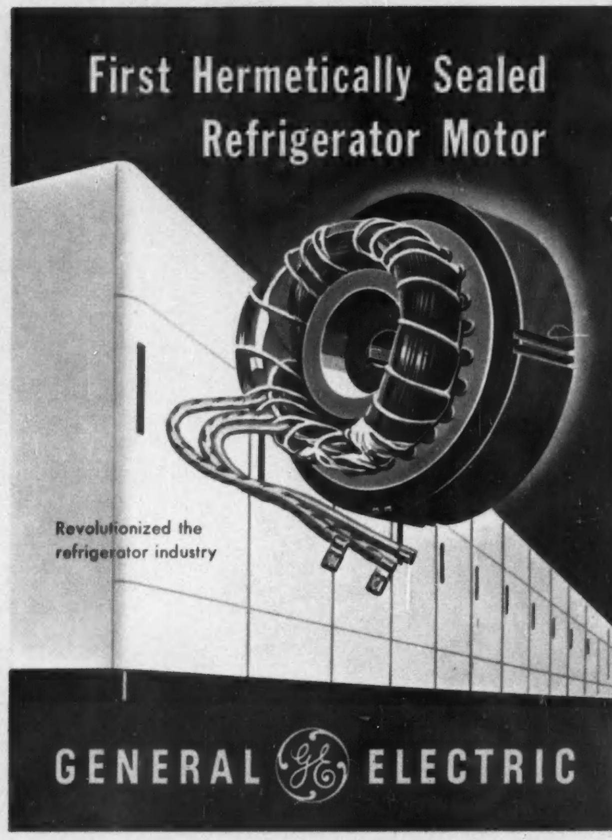

First Turbine Generator with Oriented-Grain Strip Steel Laminations
Electrical losses in the laminations reduced as much as 30%
GENERAL ELECTRIC

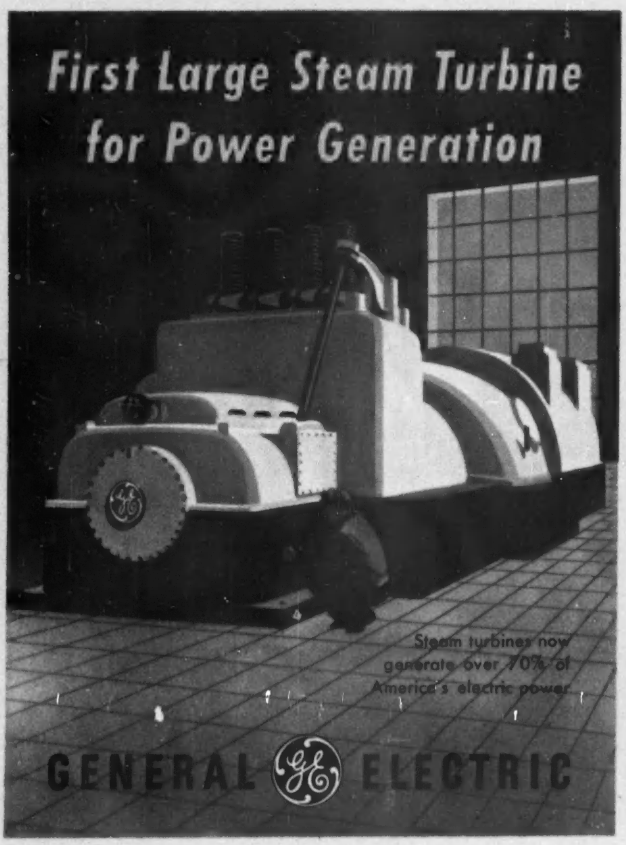

First Fluorescent Street Light
Virtually glareless illumination provides ease of viewing never before attained
GENERAL ELECTRIC


First High-Voltage High-Interrupting-Capacity Controller

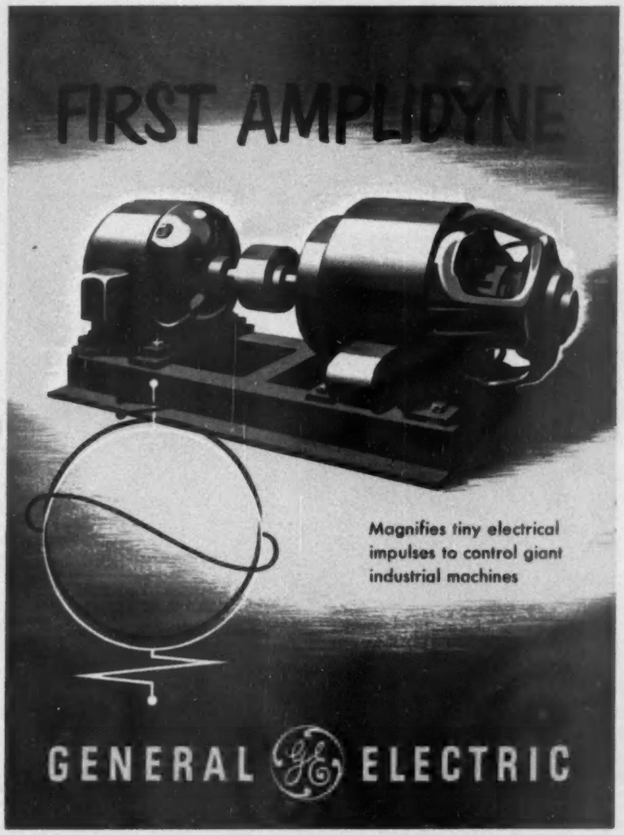

FIRST DISTRIBUTION TRANSFORMER WITH ORIENTED-GRAIN STEEL

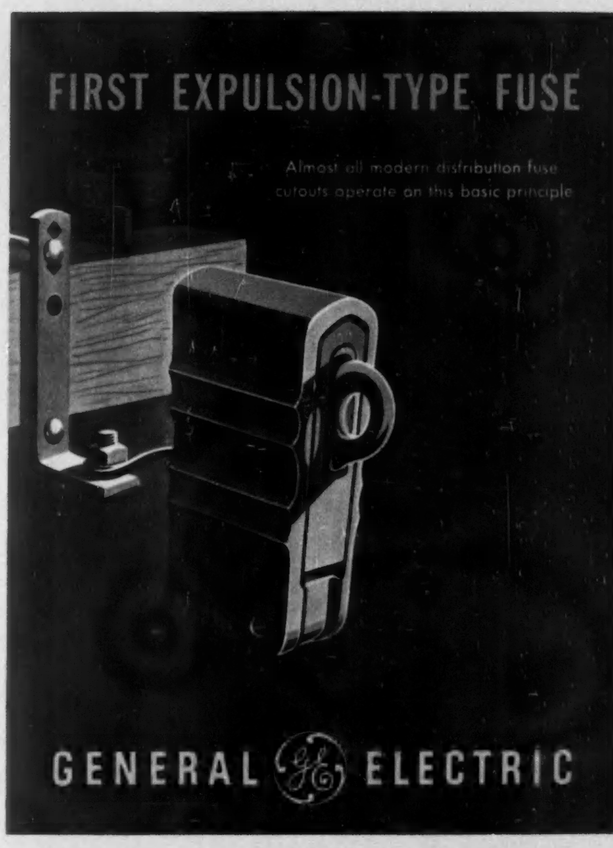

First Direct-Current Drive for Runout Tables and Coilers
Modern way to handle hot-strip steel delivered at tremendous speeds
GENERAL ELECTRIC

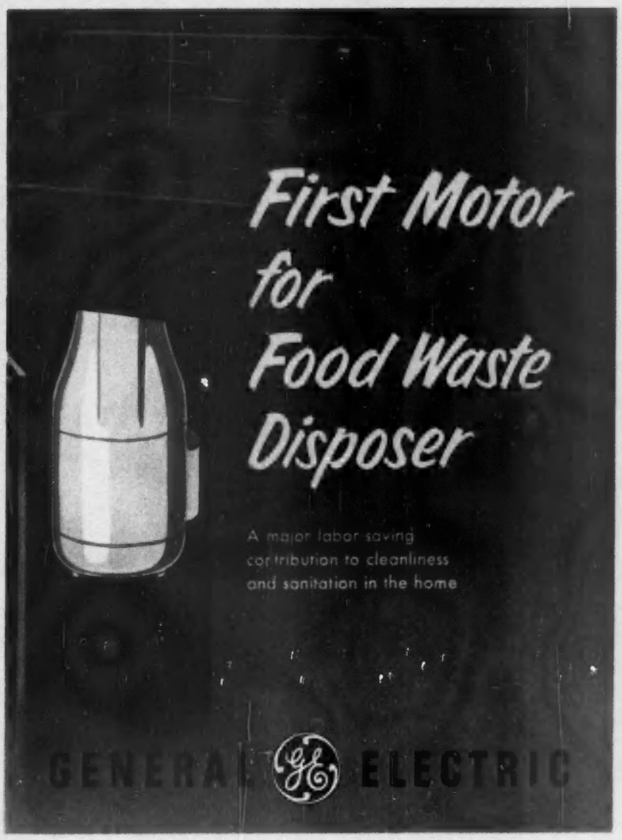

First Hermetically Sealed Refrigerator Motor
Revolutionized the refrigerator industry
GENERAL ELECTRIC

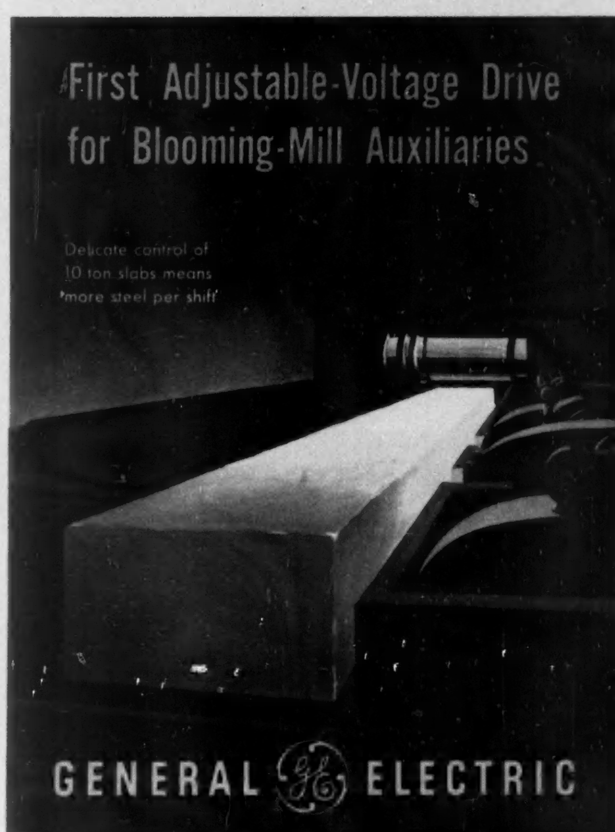

First Large Steam Turbine for Power Generation
Steam turbines now generate over 70% of America's electric power
GENERAL ELECTRIC

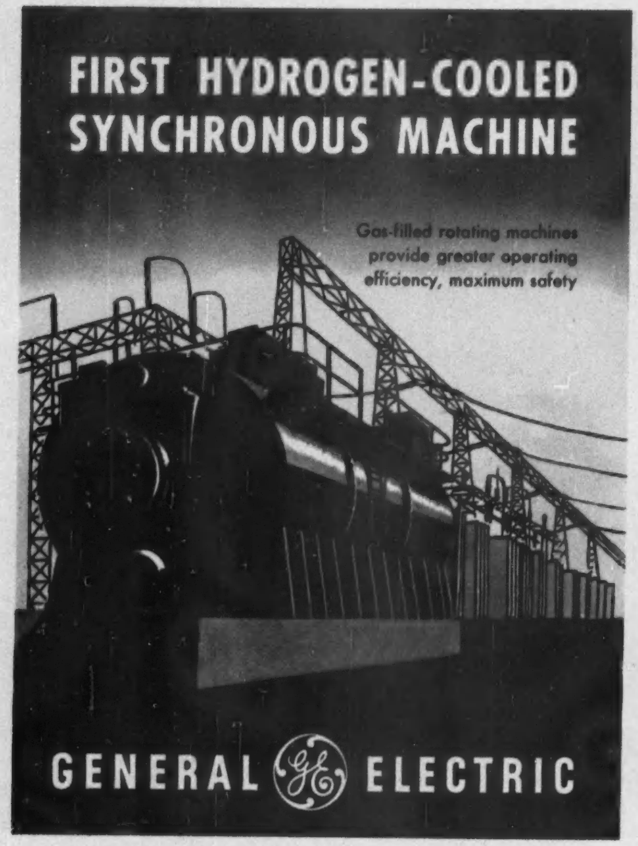

FIRST HIGH-OUTPUT AIRCRAFT GENERATOR
Helped make possible complete electrification of America's military aircraft
GENERAL ELECTRIC

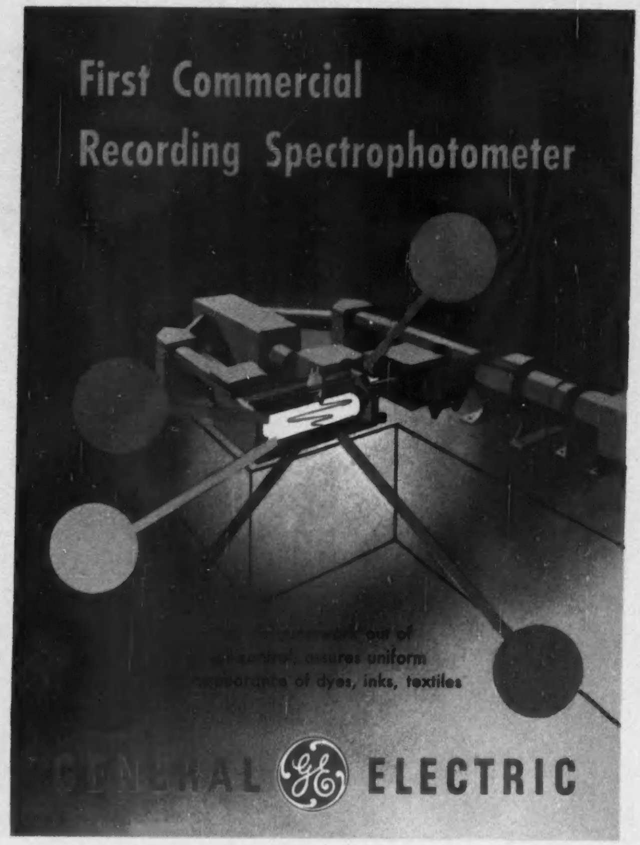

FIRST AMPLIDYNE
Magnifies tiny electrical impulses to control giant industrial machines
GENERAL ELECTRIC

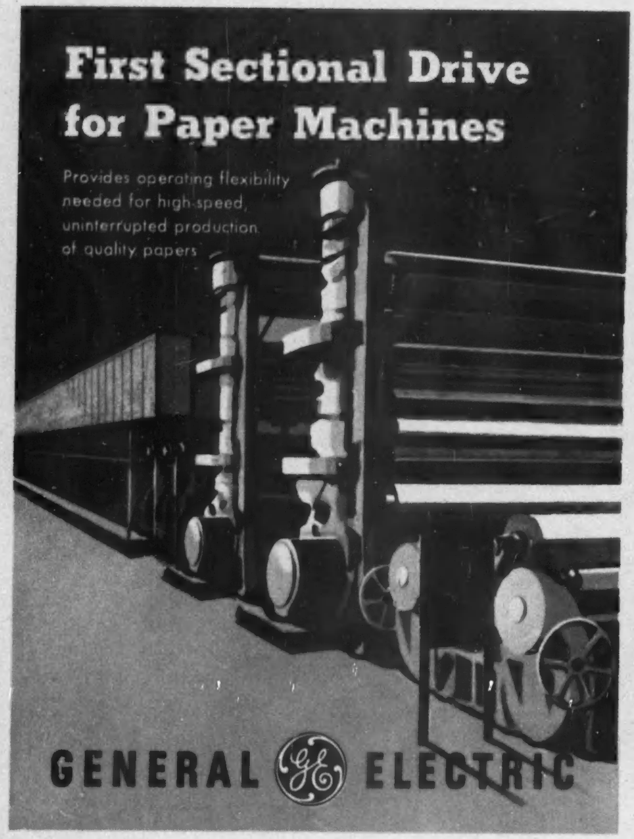

FIRST EXPULSION-TYPE FUSE
Almost all modern distribution fuse cutouts operate on this basic principle
GENERAL ELECTRIC

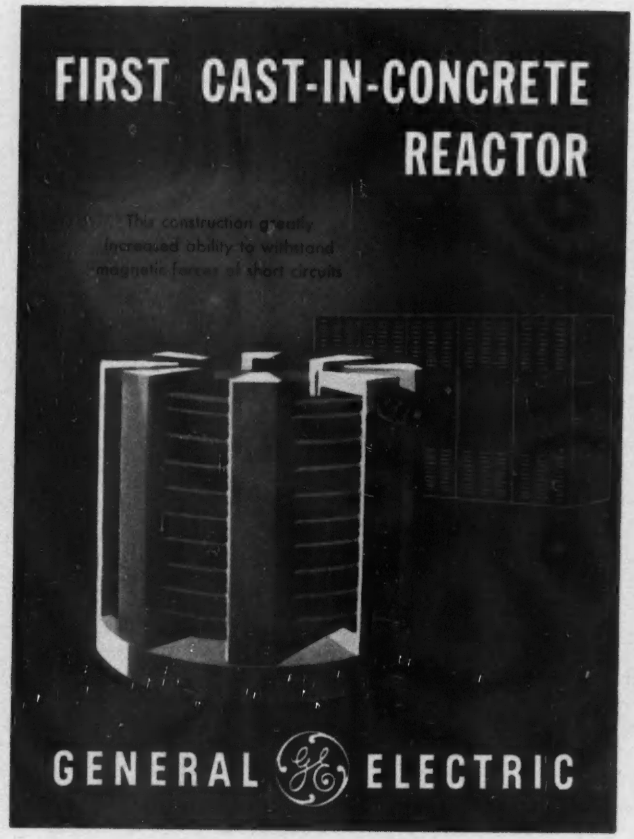

First Motor for Food Waste Disposer
A major labor saving contribution to cleanliness and sanitation in the home
GENERAL ELECTRIC

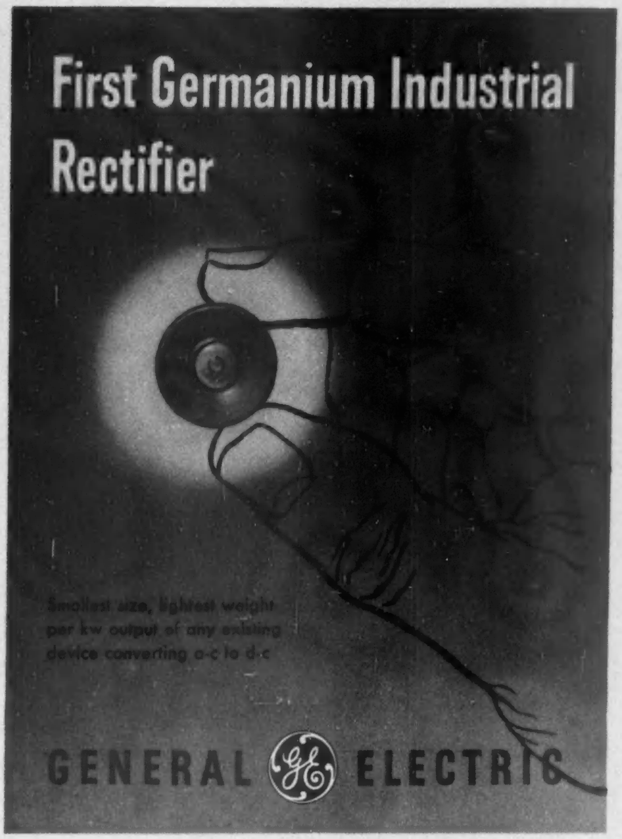

First Adjustable-Voltage Drive for Blooming-Mill Auxiliaries
Delicate control of 10 ton slabs means "more steel per shift"
GENERAL ELECTRIC

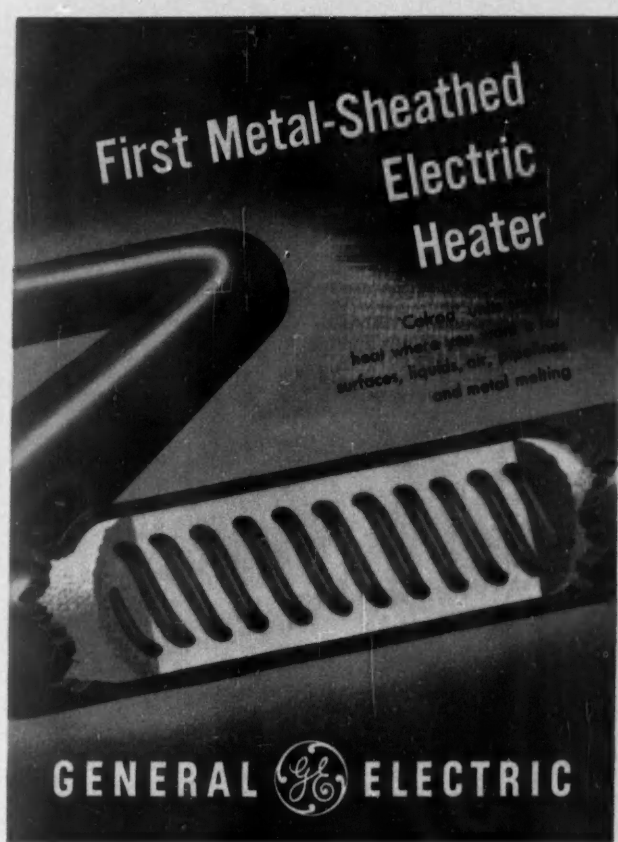

FIRST HYDROGEN-COOLED SYNCHRONOUS MACHINE
Gas-filled rotating machines provide greater operating efficiency, maximum safety
GENERAL ELECTRIC

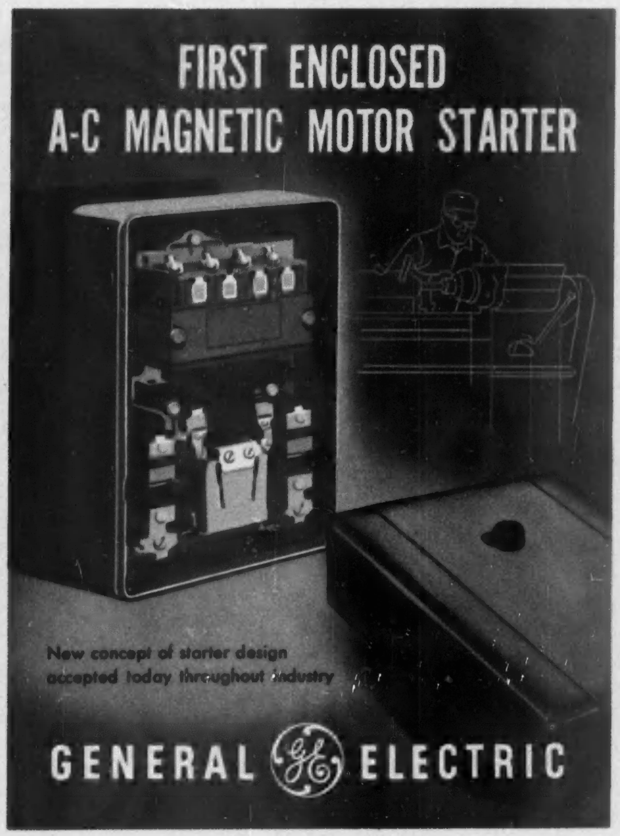

First Commercial Recording Spectrophotometer
work out of
assures uniform
of dyes, inks, textiles
ELECTRIC

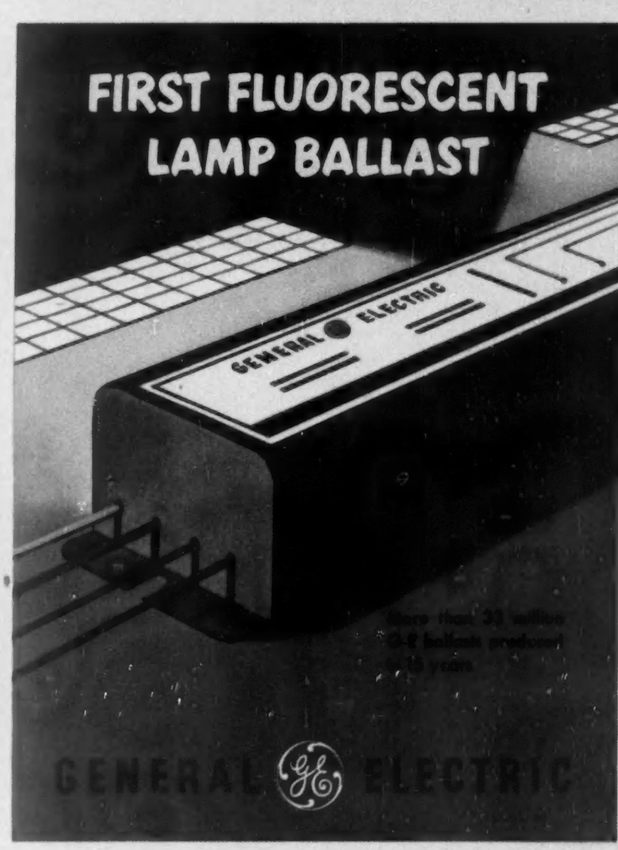

First Sectional Drive for Paper Machines
Provides operating flexibility needed for high-speed, uninterrupted production of quality papers
GENERAL ELECTRIC


FIRST CAST-IN-CONCRETE REACTOR
This construction greatly increased ability to withstand magnetic forces of short circuits
GENERAL ELECTRIC

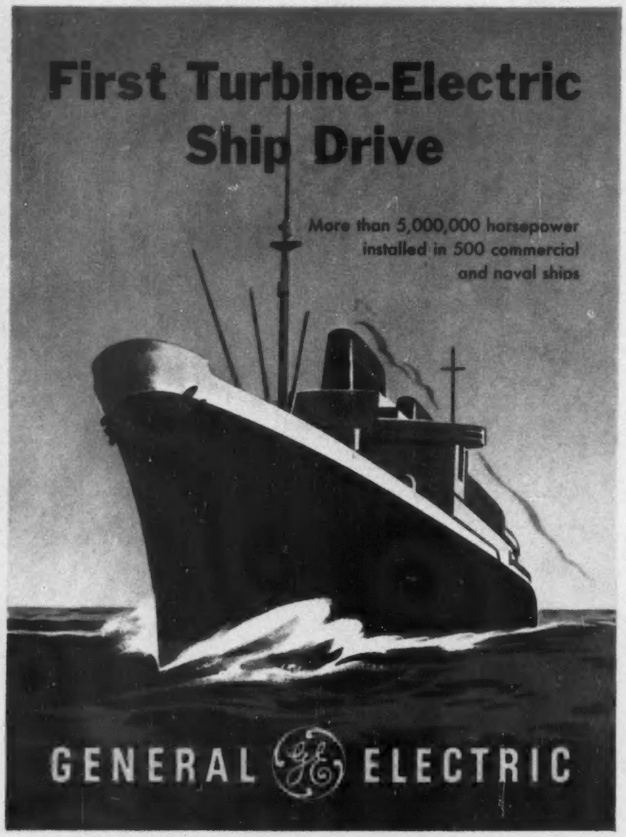

First Germanium Industrial Rectifier
Smallest size, lightest weight per kw output of any existing device converting a-c to d-c
GENERAL ELECTRIC


First Metal-Sheathed Electric Heater
surfaces, liquids, air, pipelines
and metal melting
GENERAL ELECTRIC

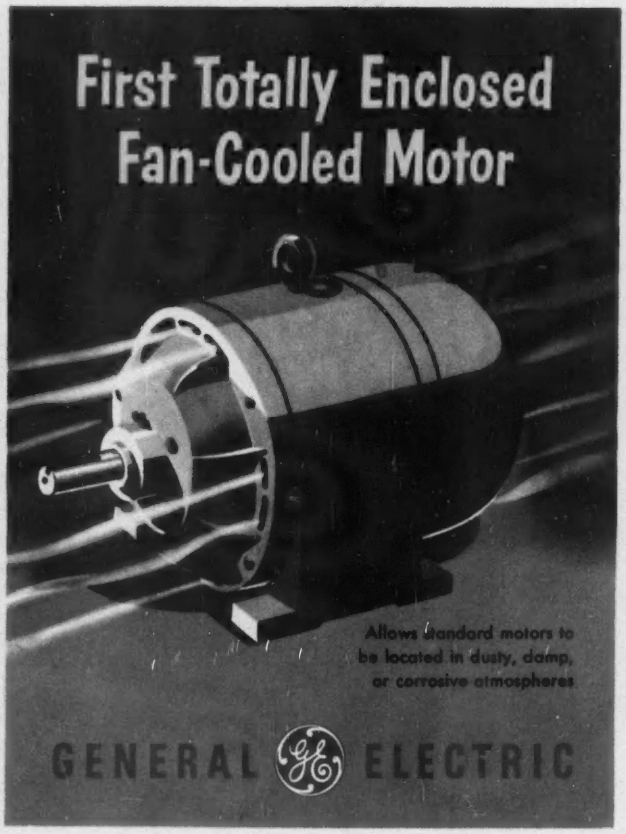

FIRST ENCLOSED A-C MAGNETIC MOTOR STARTER
New concept of starter design accepted today throughout industry
GENERAL ELECTRIC

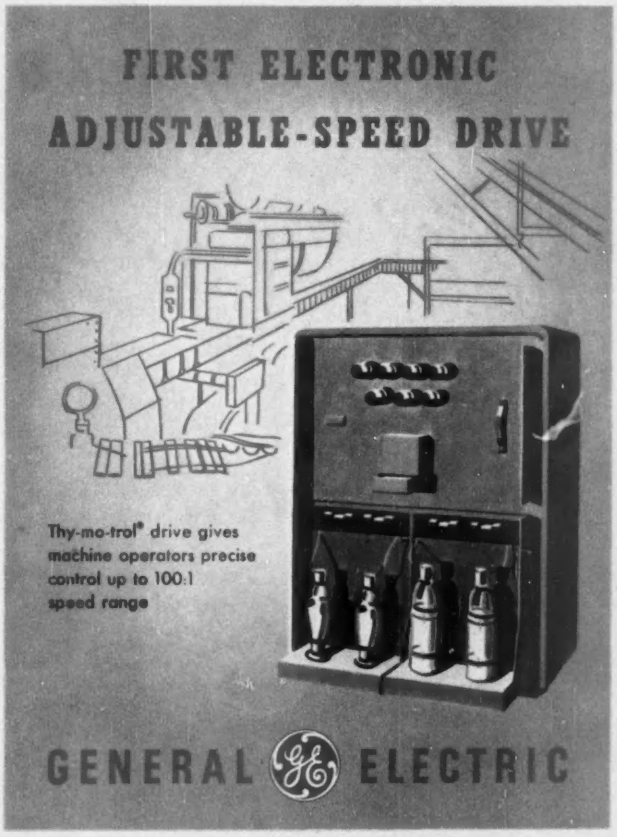

FIRST FLUORESCENT LAMP BALLAST
GENERAL ELECTRIC
GENERAL ELECTRIC


First Gas Turbine
Electric Locomotive
All new prime mover marks another step in the evolution of tomorrow's railroad motive power
GENERAL ELECTRIC

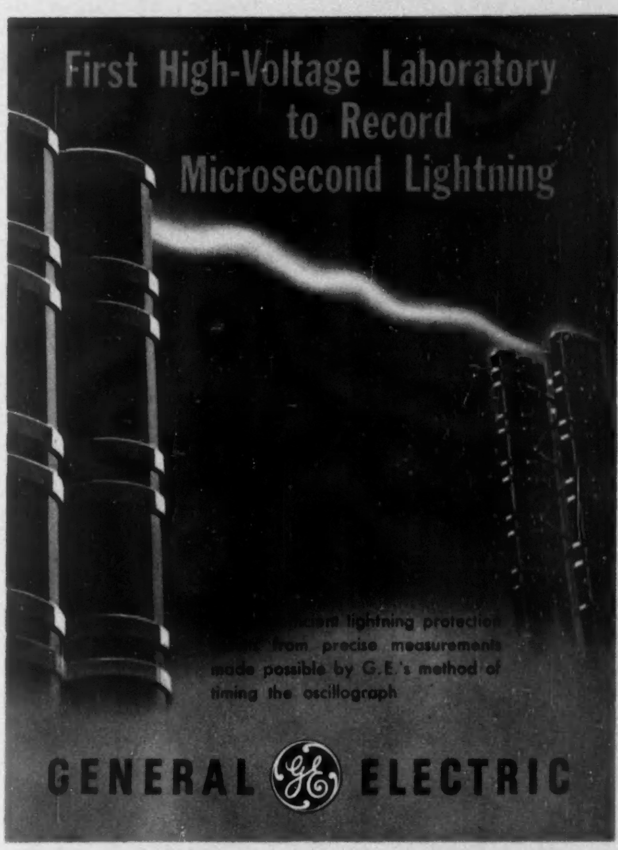

First Turbine-Electric
Ship Drive
More than 5,000,000 horsepower installed in 500 commercial and naval ships
GENERAL ELECTRIC


FIRST PRECISION REMOTE CONTROL
FOR AIRCRAFT ARMAMENT
GENERAL ELECTRIC


First Totally Enclosed
Fan-Cooled Motor
Allows standard motors to be located in dusty, damp, or corrosive atmospheres
GENERAL ELECTRIC

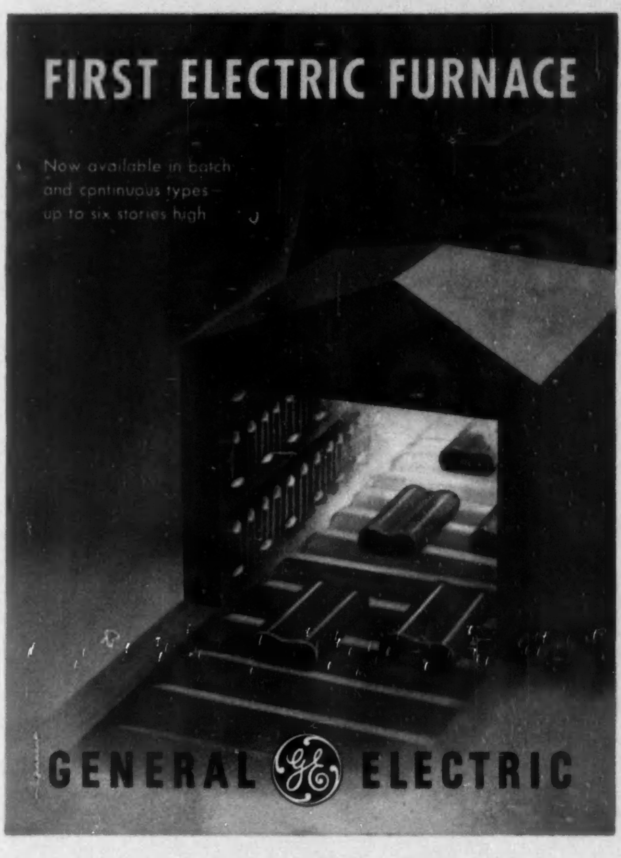


FIRST ELECTRONIC
ADJUSTABLE-SPEED DRIVE
Thy-mo-trol* drive gives machine operators precise control up to 100:1 speed range
GENERAL ELECTRIC

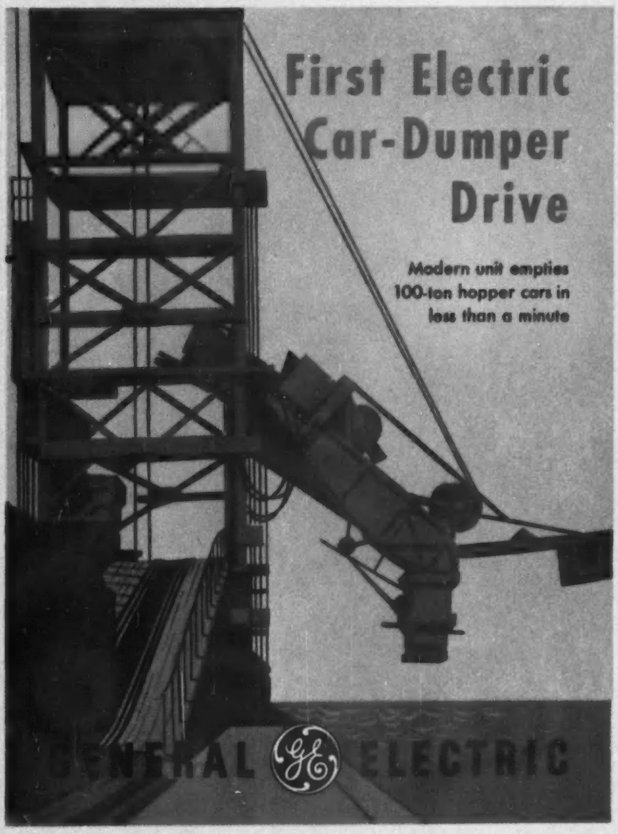


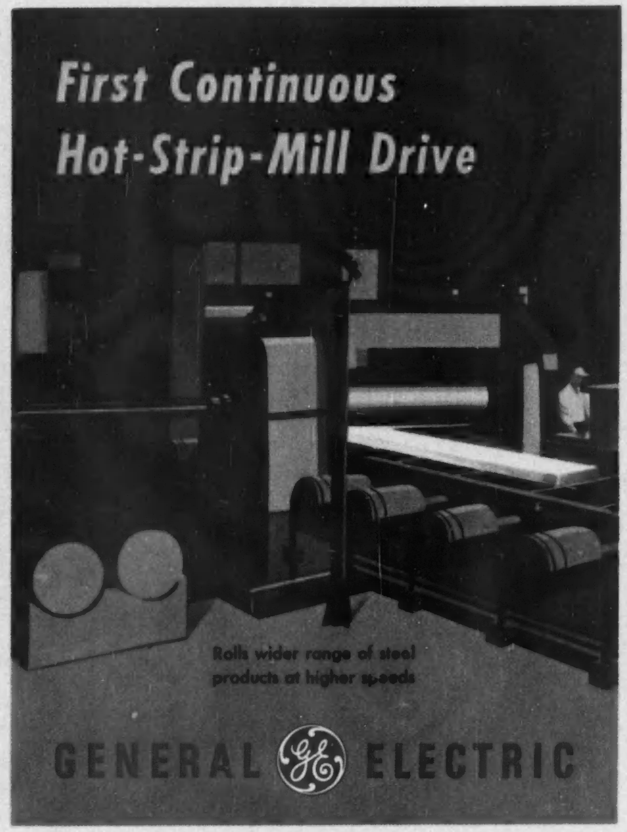
First High-Voltage Laboratory to Record Microsecond Lightning
lightning protection
from precise measurements
made possible by G.E.'s method of
timing the oscillograph
GENERAL ELECTRIC

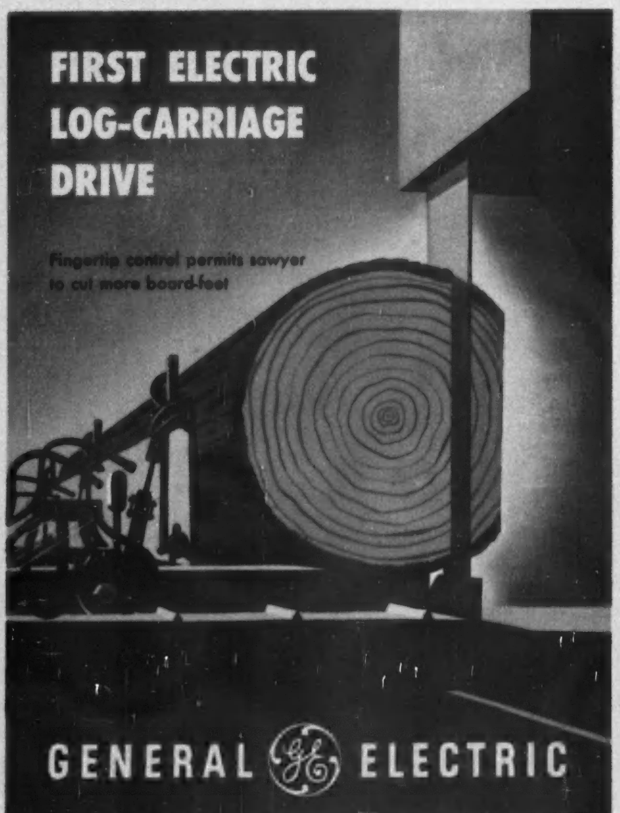
FIRST STEP VOLTAGE REGULATOR
Made it more economical to distribute power over larger areas for better consumer service
FIRST INDUCTION VOLTAGE REGULATOR

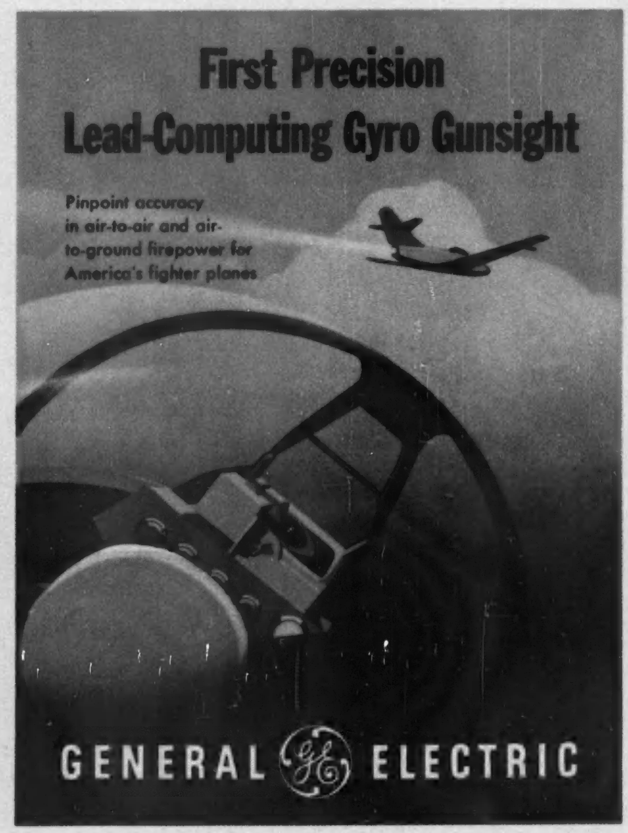


FIRST ELECTRIC FURNACE
Now available in batch and continuous types—up to six stories high
GENERAL ELECTRIC

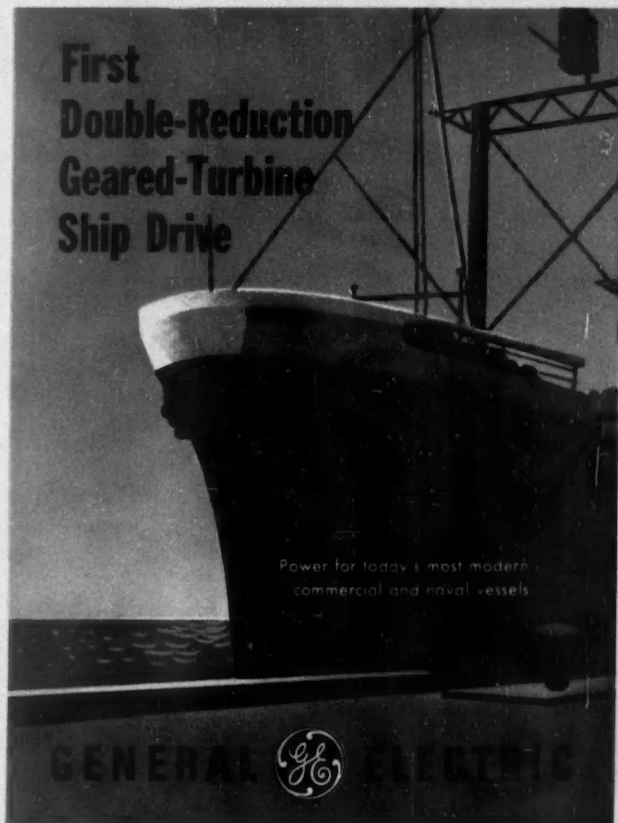

First Electric
Car-Dumper
Drive
Modern unit empties
100-ton hopper cars in
less than a minute
GENERAL ELECTRIC

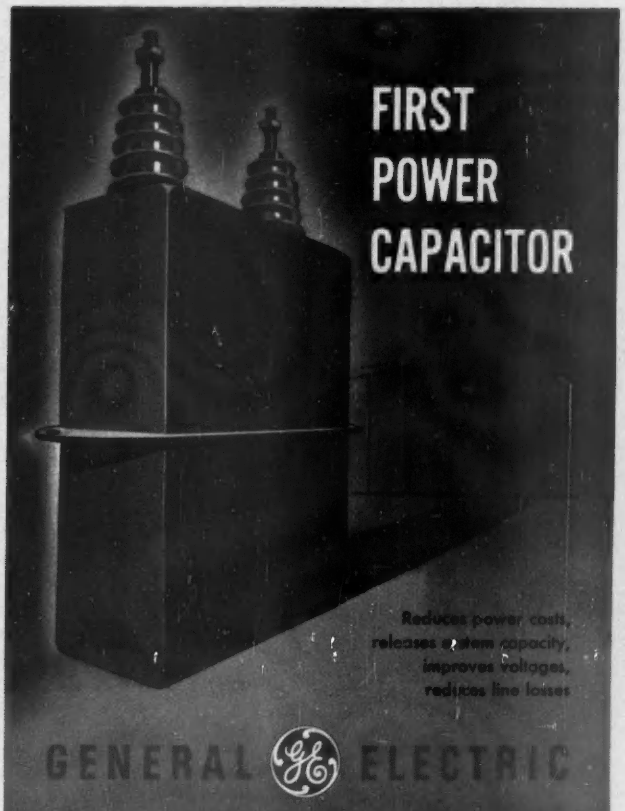

First Continuous
Hot-Strip-Mill Drive
Rolls wider range of steel
products at higher speeds
GENERAL ELECTRIC

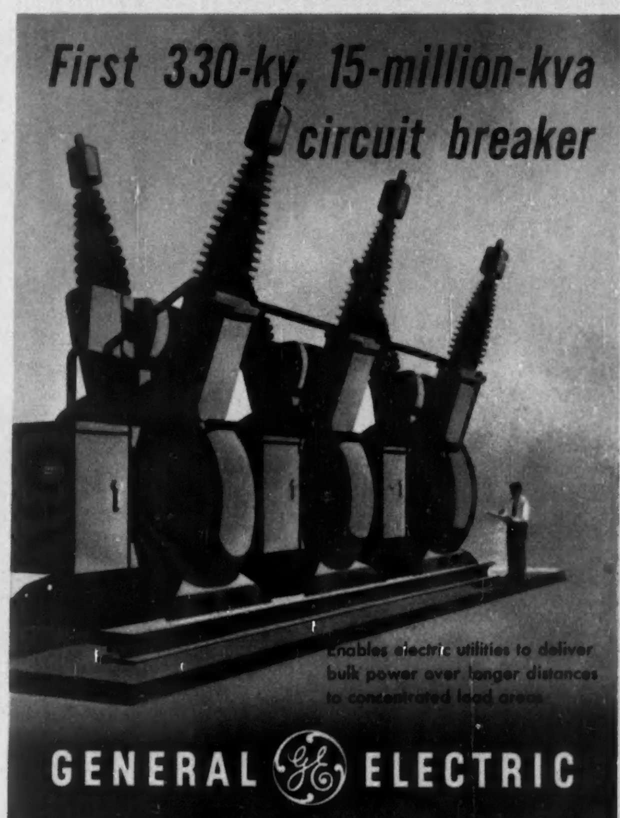

FIRST ELECTRIC
LOG-CARRIAGE
DRIVE
Fingertip control permits sawyer
to cut more board-feet
GENERAL ELECTRIC

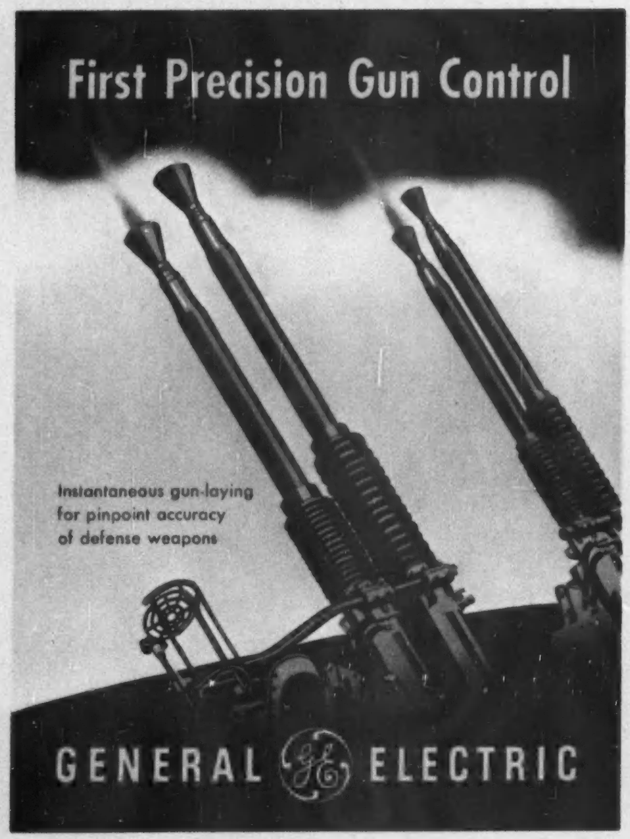

First Precision
Lead-Computing Gyro Gunsight
Pinpoint accuracy
in air-to-air and air-
to-ground firepower for
America's fighter planes
GENERAL ELECTRIC


First Modern-Type
Load-Ratio-Control
This circuit … of contactors
and tap … now in general use
on many … transformers
GENERAL ELECTRIC


First
Double-Reduction
Geared-Turbine
Ship Drive
Power for today's most modern
commercial and naval vessels
GENERAL ELECTRIC


FIRST
POWER
CAPACITOR
Reduces power costs,
releases system capacity,
improves voltages,
reduces line losses
GENERAL ELECTRIC


First 330-kv, 15-million-kva
circuit breaker
Enables electric utilities to deliver
bulk power over longer distances
to concentrated load areas
GENERAL ELECTRIC



1878 75 1953
YEARS OF ELECTRICAL PROGRESS

On October 15th, 1878, Thomas A. Edison organized the first of the companies which, in 1892, became the General Electric Company. A few milestones are portrayed here, first brought to American business and industry by General Electric men and women.

Some of these developments grew from the combined research of many G-E laboratories; some were engineering triumphs; some are credited to progressive manufacturing or marketing techniques; many were performed in cooperation with our customers. But all had this in common: they helped to improve America's products and productivity which in turn raised our standard of living and secured the nation's defense.

As a part of our 75th anniversary celebration, all the people of General Electric are resolving to provide you—our valued customer—with even better service. We hope you will challenge us as to ways we can better serve your business.

You can put your confidence in—

GENERAL ELECTRIC

Here's another G-E "First" to start the next 75 years . . .

FIRST LARGE GENERATOR WITH LIQUID-COOLED CONDUCTORS

Review **STAFF REPORT**

Shortly after the first of the year a report came to the Review *office that some highly significant developments in the field of large generators were under way. A* Review *editor was immediately assigned to the story; here is his report of a development that will prove to be one of the most important of the* next *75 years . . . .*

In the mammoth turbine manufacturing plant at GE's Schenectady Works, I learned of a new development in the design of generators for large turbine-generator units.

For the first time in the history of the electrical industry, General Electric will manufacture a large generator with liquid-cooled conductors.

A new method of circulating a liquid through hollow conductors will be used in the stator.

The present method of cooling large generators is to circulate hydrogen gas through passages in the magnetic portions of the rotor and stator. Developed by GE, this method is highly efficient for units up to approximately 230,000 kva capability at 3600 rpm.

Engineers told me that the new method of cooling will be used in a turbine-generator set for the new Eastlake Power Plant of the Cleveland Electric Illuminating Company.

The unit, consisting of a tandem-compound turbine rated at 208,000 kw, and a generator rated at 260,000 kva, will be one of the largest in the world. This generator alone will be capable of supplying the household electrical needs of 600,000 people.

It was further emphasized that this type of liquid cooling makes possible a significant increase in capability of generators without increasing physical dimensions of the units. The higher capability results from more efficient removal of heat produced during the generation of electricity.

Other technical features of the Cleveland machine include direct cooling of the rotating-field winding with hydrogen, a new and improved grain-oriented strip steel in the magnetic portion of the armature, and an improved type of insulation.

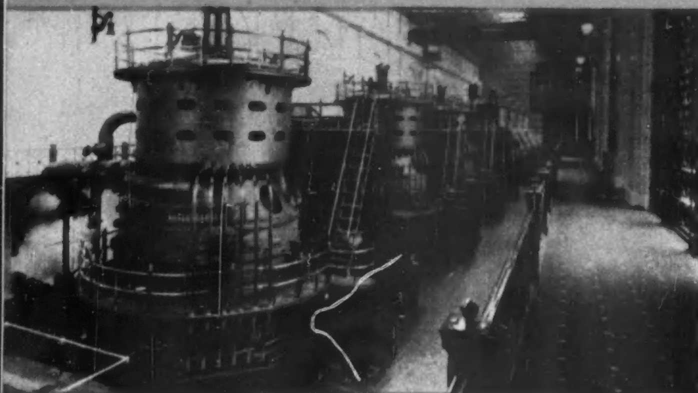
General Electric is also supplying three conventional hydrogen-cooled units, each of 125,000-kw capacity, for the Eastlake Plant that will go into operation this summer.

The 208,000-kw generator is scheduled for installation by the end of 1955. Ω

1878 75 1953 YEARS OF ELECTRICAL PROGRESS

50 Years of the GENERAL ELECTRIC Review

In March 1903 the *General Electric Review* began publication. For 50 of the past 75 years the significant developments of General Electric engineers and scientists have been reported in its pages. And on the preceding page you read about one of the most important advances of the *next* 75 years . . . On pages 25 through 40 of this issue you saw 63 "firsts" that commemorate 75 years of electrical progress; on these two pages are some of those same developments as they were presented over the years to *Review* readers.—EDITORS

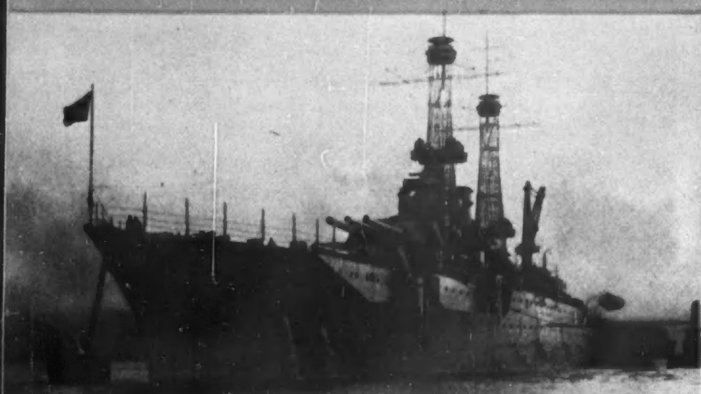


1910 STEAM TURBINE FOR POWER GENERATION

". . . . Modern steam turbine practice has advanced so rapidly that quite startling changes have been effected . . . . Improvements in . . . construction . . . speed . . . greatly reduced the size and weight per kilowatt. About six years ago the first large steam turbines were installed . . . three machines were vertical two-stage machines of 5000-kw capacity, and the fourth . . . of the five-stage type . . . these four machines have been removed and replaced by four vertical machines of 12,000-kw continuous capacity . . . the Curtis turbine has been built and placed in successful operation in sizes from 5-kw to 14,000-kw . . . even larger machines are under consideration."

—G. R. Parker, February 1910

The first large steam turbine, rated 5000 kw at 500 rpm, was installed for the Commonwealth Edison Company of Chicago in 1903.

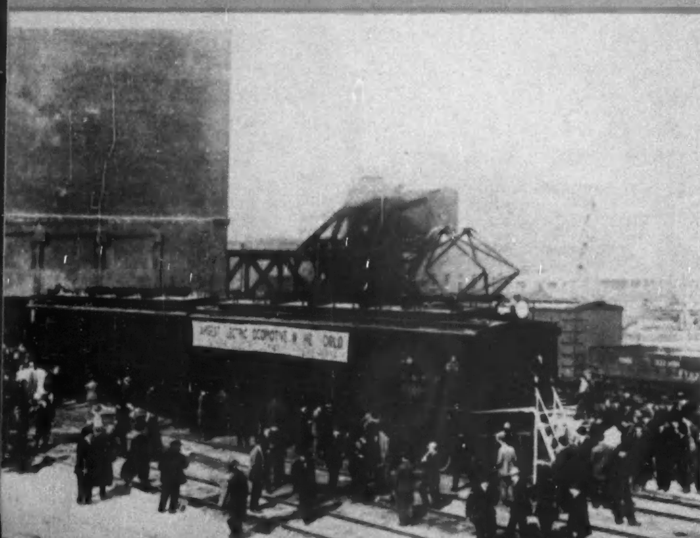


1912 TURBINE-ELECTRIC SHIP DRIVE

"In July, 1911, the United States Government closed a contract with the General Electric Company for the equipment of the new naval collier *Jupiter* with electric propelling machinery . . . . In this contract the manufacturers are required to guarantee under penalty time of delivery, water rate for shaft horsepower at 14 knots and 10 knots, and that the weight of the electrical equipment will not exceed that of the [reciprocating] engines proposed . . . . The electrical equipment was therefore made to conform with engine layout . . . without doubt one of the main reasons why the Government felt justified in trying this new method of propulsion . . ."

—Eskil Berg, Lighting Engineering Department, August 1912

U.S.S. New Mexico *of 1919, first electric-propelled battleship. Method was adopted by Navy after success with the collier* Jupiter.



1915 MAINLINE ELECTRIC LOCOMOTIVE

"The flexibility in design and operation of the electric locomotive afforded by the use of electric motors renders this type of motive power especially well-suited to the hauling of trains, either high-speed passenger or slow-speed freight . . . the electric locomotive possesses inherent qualifications for haulage . . . fundamental reason for bringing about the change from steam to electricity . . . compare the capacity of the new electric locomotives and the [steam] engines they will replace . . . comparison indicates that the electric locomotive has a hauling capacity one-third greater than the steam engine and tender of the same total weight . . ."

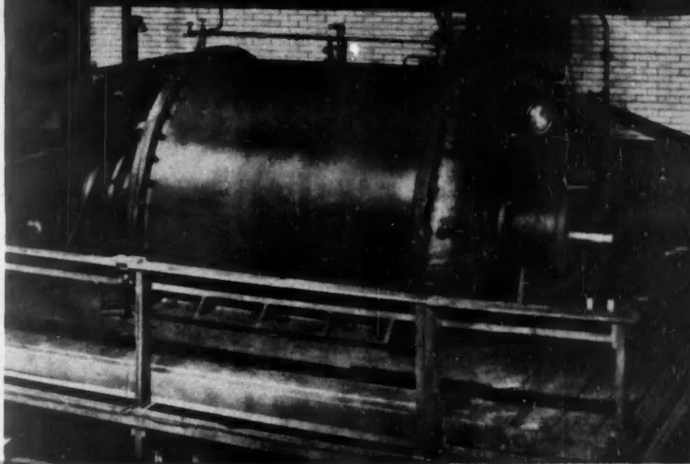
—A. H. Armstrong, Railway and Traction Department, July 1915

"Largest Electric Locomotive in the World," exhibited in Chicago. Its 3000 hp hauled passenger and freight trains over the Rockies.

1927 HYDROGEN-COOLED SYNCHRONOUS MACHINE

"... it is an essential part of his [designer's] work to get more kilowatts output from less energy input and from less material. The years of intensive study that have been given to this ambitious feature of machine [dynamoelectric] design have produced such great improvements in electrical, magnetic, and structural materials ... as to reduce the apparent possibility of further remarkable gains. And now comes the means of converting one-third of the losses into useful output and of simultaneously increasing the capacity of the machine about 30 percent—all by the substitution of hydrogen for air as the cooling agent ..."

—*Review* Editorial, November 1927



Tight oil seals around the rotating shaft of this early hydrogen-cooled dynamoelectric machine eliminated possibility of explosion.

1932 PACKAGED HEAT PUMP

"No attempt is made in this article to say what the first cost of electric heat-pump apparatus would be, since cost of apparatus depends so much on the stage of development and the quantities produced. All new devices come on the market at relatively high prices, and then the prices come down as the field is developed ... from an operating cost standpoint alone ... the electric heating and cooling of homes is practical .... The public must be 'sold' on the need for cooling .... Having thus sold a cooling equipment, it would be possible to call attention to the fact that ... this same cooling equipment could be used to heat the house in winter ..."

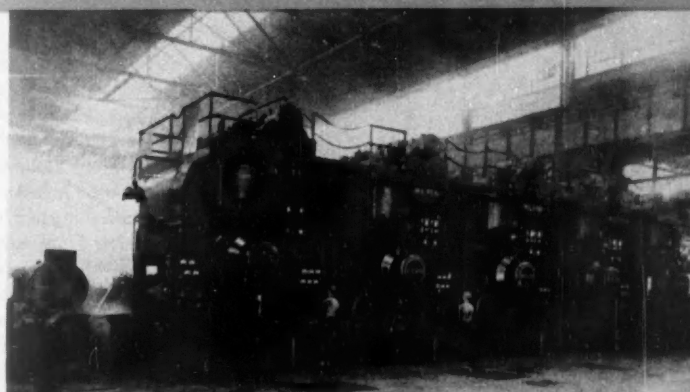
—A. R. Stevenson, Jr., F. H. Faust, E. W. Roessler
Engineering General Department, March 1932

By 1950 General Electric had installed 16 packaged heat pumps throughout the country—the home pictured is near Providence, RI.

1940 AMPLIDYNE

"A dynamoelectric amplifier, called an amplidyne generator, has been developed .... It is a two-stage amplifier incorporated in one dynamoelectric machine ... characterized by a pair of short-circuited brushes at right angles to the power brushes .... The first stage of amplification is from the control field to the short-circuited brushes, and the second stage from the short-circuited brushes to the power brushes .... A high ratio of amplification, of the order of 10,000 to 1, can be obtained .... When a control system is desired which demands a still higher ratio of amplification ... it is possible to introduce a first stage of electronic tubes ..."

—E. F. W. Alexanderson, M. A. Edwards, K. K. Bowman
Consulting Engineering Laboratory, March 1940

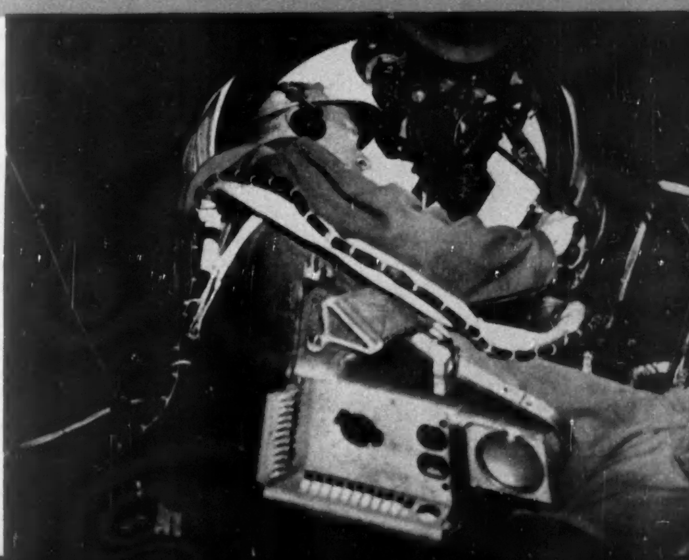


A hot-strip mill installation where an amplidyne exciter is used for constant-tension control of strip-tension at the reel.

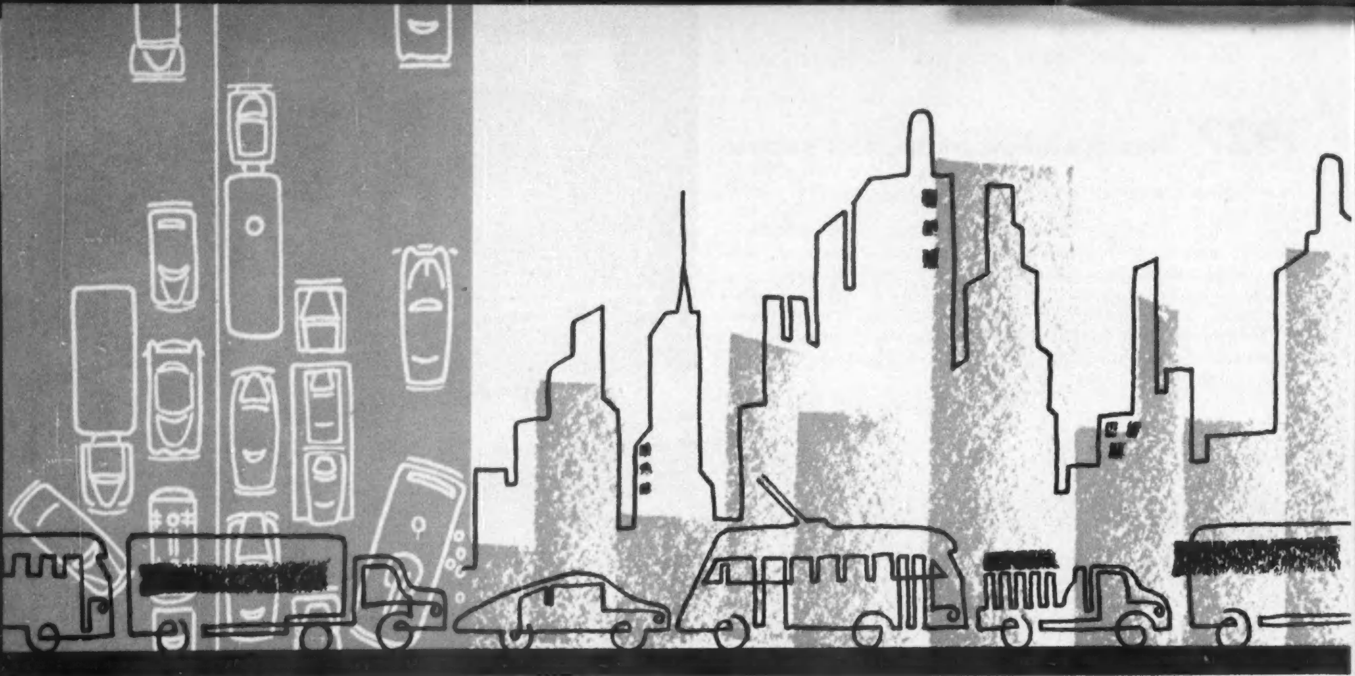
1945 REMOTE CONTROL FOR AIRCRAFT ARMAMENT

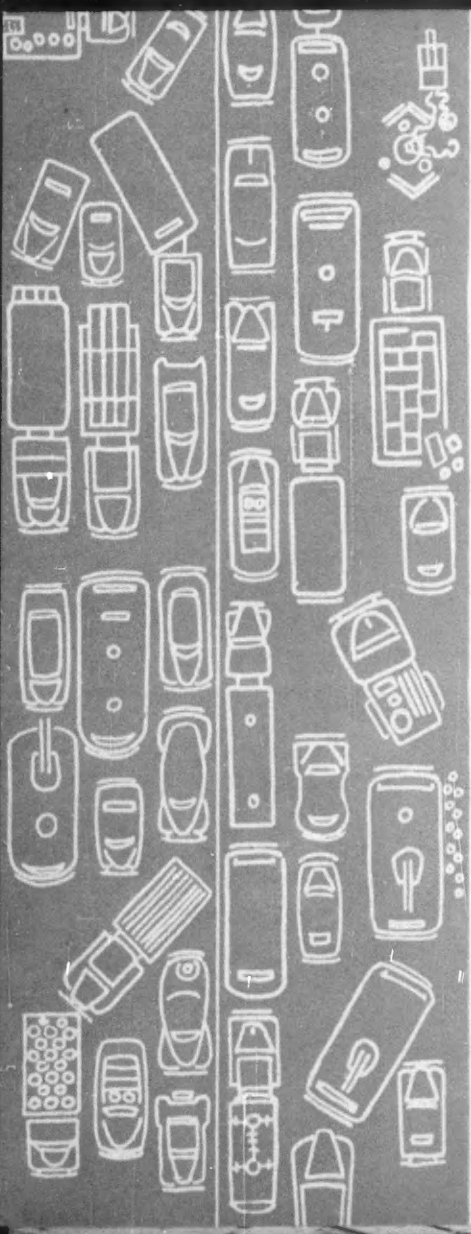
"Even before the United States was attacked, the Army Air Forces and the General Electric Company had been developing airplane armament for the future .... Then came the day. The B-29 [Superfortress] was selected for mass production .... A good turret is the first essential of a good fire-control system .... The gunner uses a sighting station to aim at the enemy fighter, range him, and fire at him .... To solve all the correction problems automatically, and make the guns point to hit the enemy fighter when the gunner aims at him, the B-29 computer was designed .... He aims his sight directly at the target and knows his bullets will hit ..."

—H. T. Hokanson, T. S. Lisberger, March 1945



Parallax, wind, gravity, and lead were automatically compensated for when the B-29 gunner centered enemy fighter in his gunsight.





Congestion Engineering

By C. A. CHURCH

Crooked narrow streets and the associated traffic congestion in our cities are often blamed on the cow. Some pointed engineering reflection indicates that although "ole bossy" couldn't tunnel through a hill or bridge a ravine, she knew the easiest and most practical way to go from one point to another. But basically our present urban traffic difficulties arise more from inefficient use of streets than from having unwittingly built our towns along the cowpaths.

Congestion is not solely a 20th century American problem—it is as old as the first system of good stone roads built by the Phoenicians in 700 BC. And in medieval England a law was passed to prohibit the use of the street for a stable.

Nor is the problem unique to the automobile. In 1920 the city council of Chicago worried about the multitude of dray wagons that clogged streets in the Loop area. The problem of traffic congestion simply goes hand-in-hand with city growth. Essentially the engineering aspects of this problem can be, and have been, easily solved by using available space *more* efficiently.

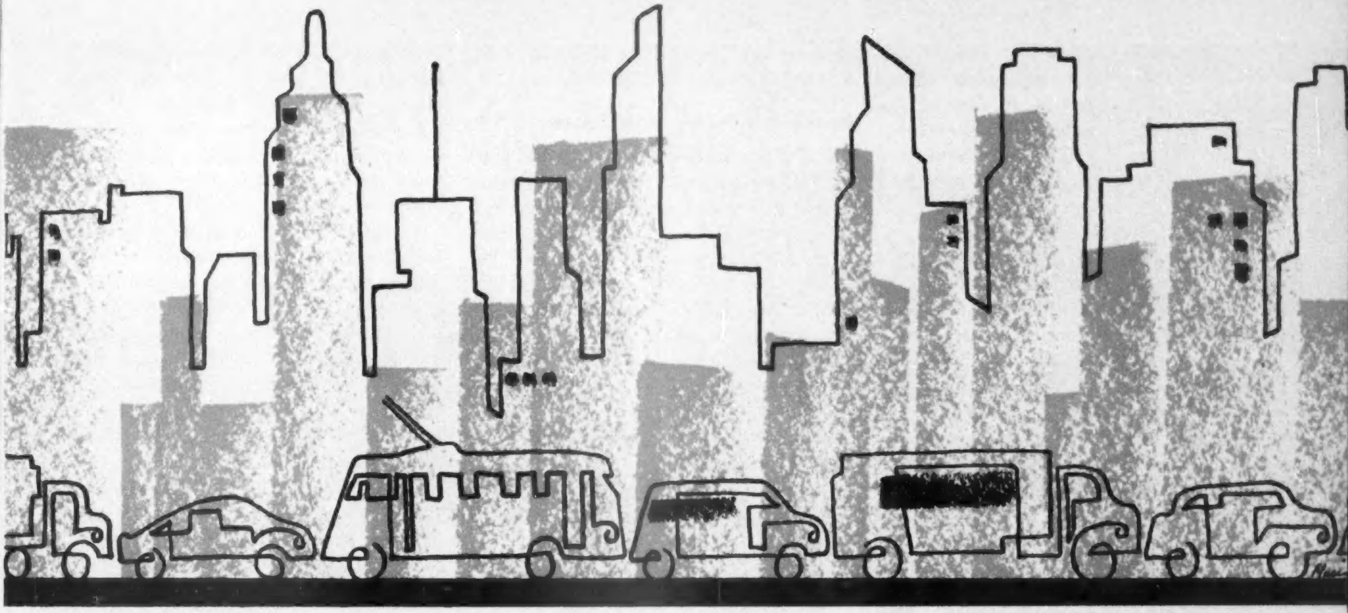
The city is continually becoming a better place in which to live—at least more and more people are moving there. And more and more people mean more and more places to obtain goods and services—thus the movement of people and goods has increased steadily.

Three Solutions

The arithmetic of increasing the carrying capacity of a city's transportation system to meet a growing demand is quite simple. There are three basic solutions, and down through the years the engineer has made wise use of all three by . . .

- Increasing the scope and size of the system
- Using present facilities more efficiently
- Installing a more efficient "vehicle."

Increasing the scope and size is the most obvious and more or less continuing measure employed to keep up with slow consistent city growth. Extending service to new areas by cutting through new streets is generally a simple matter. This is soon followed by increasing the size of the arteries, such as adding traffic lanes.



Using present transportation facilities more effectively gives immediate although limited gain to their carrying capacity. But this method alone is more or less a stop gap unless the peak of growth is in sight. To meet continual and extended growth, this approach is best combined with increased size, or with an improved or new type of equipment or system.

The greatest gains—both in capacity and efficiency—that engineers have made in city transportation systems have come from radically new and different systems and equipment. For example, the development of the electric trolley to replace the horsecar greatly expanded the residential areas of cities.

Habit to Blame

But even the carying out of the three solutions outlined doesn't always result in a perfect answer to the traffic problem. For the workings of a transportation system involve people, and the engineer usually has had more immediate success in improving the movement of *goods* (faster elevators, larger pipelines) than the movement of *people*. The tenacity of man's habits—accustomed to the convenience and chrome of his automobile—has far more to do with today's traffic congestion than the apparently erratic engineering of the cow.

City folks weren't too reluctant to leave their horses once better modes of transportation were devised. A horse has definite limitations and involves many nasty chores.

But man and his car are almost a psychological case. The car's speed, flexibility, glitter, and oblivion to fatigue have all but blinded man to the simple arithmetic of the situation. Obviously many advantages of collective effort can be enjoyed in the city only at the expense of some of the individual freedoms of rural living.

Unfortunately for man's ego, one of these curtailed freedoms must be the limited use of the private pleasure car in heavily populated areas. As the general public gradually accepts this annoying fact, the engineer can do some effective "congestion" engineering by providing the more efficient and higher capacity transportation systems that are needed today in most cities. The solution will vary with the demands of the particular metropolitan area, but the three basic engineering approaches will take these general forms . . .

• Wider streets and more parking facilities have popular appeal as a solution to traffic congestion because people are unusually sensitive and responsive to measures that have immediate advantage for themselves. Both these measures have a limited and often illusory effect in increasing the flow of people and goods in and out of busy trading areas. First, practically all goods and the majority of the people come and go by means *other* than the private car. For example, most goods move by pipe, truck, or rail; and a recent survey revealed that more than 90 per cent of the shoppers come into downtown Philadelphia either on foot or by public transit. Second, the economic division of space between the street, the sidewalk, the store, and the parking area has been well engineered through the years. The net gain in transportation capacity by wholesale street widening at the expense of sidewalk space, and the establishment of parking areas by removing buildings, is questionable indeed.

Traffic congestion is just as bad in newer cities as in older ones, indicating that street width has little bearing on the problem. Experience suggests that wider streets and bigger parking areas attract additional automobiles into an already crowded area, aggravating the overcongested condition. Thus little is gained in capacity for the time and money expended.

• More efficient use of existing transportation facilities—a time-honored engineering approach to the overload problem—can effect some appreciable over-all gains. The vehicle-moving capacity of what appears to be a typical "loaded" downtown street can be nearly doubled by prohibiting parking. This not only adds two useful lanes but also speeds traffic flow in center lanes by removing the confusion of parking and standing.

The money and space saved by using existing streets more efficiently can be very effectively utilized to provide off-street loading and unloading areas. Routing trucks and buses out of the traffic stream to deliver goods and discharge passengers not only improves the speed and convenience of their own services but frees the street for other vehicles.

The engineer can also get considerably more use out of existing facilities by working them nearer to capacity over longer periods of time. Because a large percentage of the people and goods enter and leave the business area at the same time, space and vehicles are consistently jammed only a few hours during morning and afternoon peaks. Now the cow could truthfully comment that in our "herding habit" practice we are behaving like most of her bovine associates. After this twice-a-day stampede is over, the transportation facilities are idle or partially loaded. This "load" factor can be greatly improved by spreading working and shopping hours, and by delivering more goods during the time when fewer people are moving, and vice versa. The engineer who can encourage this practice not only will improve the performance of the city transportation system but also will relieve high blood pressure and frayed nerves.

• In his endless job of providing more transportation in the same limited space, and thus sustaining continued growth of the modern city, the engineer is always seeking new techniques or equipment that either carries more pay load in the same space, or does the same job faster. For example, he solved the big city delivery dilemma of the early twenties with the automotive truck—it occupied less space and moved faster than a dray wagon. Moreover, by consistent and steady improvement in these vehicles he has kept them abreast of requirements over the last 30 years.

According to this appraisal the automobile has limited value in congested areas for it uses expensive space with relative inefficiency. With current riding habits one auto passenger requires seven times as much space as one bus passenger. Public transit vehicles require no downtown parking space whereas every auto requires 250 square feet of parking space. The parking area required for a worker's car is equivalent to the floor space he occupies while at work. Thus as cities grow in size, the transportation job increases. And it becomes an engineering certainty that while the role of the pleasure car is growing on the open road, it must diminish in congested business areas.

Increasing Premium on Space

Population growth and technological improvements will continue to increase both the size and density of cities—and consequently the volume of transportation. The larger the city grows, the greater the premium on efficient use of space, especially in those areas where transportation requirements for housing, shopping, manufacturing, and recreation merge into one. Here the most people and goods must be moved, yet the space in which to do it is the most constricted.

1878 75 1953
YEARS OF ELECTRICAL PROGRESS

. . . see pages 25 to 43

Smaller cities, now depending on the automobile, will have to install public transit systems on their main streets. Cities that now have a few bus lines will expand and increase their surface lines and change building codes to include off-street loading and unloading of goods. Cities with trolley coaches and streetcars will add rapid transit trains. Population centers—like New York and Boston—will extend their subways and private right-of-ways farther into growing suburbs that must have fast, dependable access to the business districts.

A two-track rail system can carry as many people as would normally travel by car on a 300-foot wide street, yet after rush hours it stands idle a great percentage of the time. Such a system has a great potential also as a carrier of goods, and it daily serves the very areas that use the most goods. In his quest to provide more and more transportation, the engineer will undoubtedly better utilize these rail lines by moving goods in and out of downtown areas at night when passenger traffic drops off.

In sparsely settled areas where the transportation requirements are light and space is cheap, the automobile is unquestionably the most practical and economical mode of transportation. Yet in many cities these areas are also being served by public transit as a carry-over from old franchises, or at the insistence of government bodies. Ultimately the engineer will correct this misapplication of transportation equipment. The effort and money now spent on unprofitable lines will be applied to improve operation in more densely populated areas where buses and trolleys are the most economical and efficient way to move people. He will install new and improved transit equipment that will increase the speed, convenience, and comfort, thus attracting more riders. This will act as an inducement to get automobiles off busy city streets, and justifies even better public transit facilities.

The engineer will also better coordinate the interchange of people between the various methods of transportation to improve the service, speed the flow, and please the people. More perimeter parking and downtown express service will encourage the use of the private auto and public transit in those areas where each can do the best job.

For the Future . . .

Down through history, people have been drawn toward urban living by the time-tested benefits of group action. Transportation is one of man's basic needs.

Therefore, the impact of a major technological advance—like the automobile—is felt in every aspect of city life as well as in the transportation system.

An engineering analysis indicates that the automobile has unquestionably brought some immediate benefits to the city. But like the Australians and their rabbits, the more observing Americans are realizing that there is such a thing as having too many automobiles in business districts. As this understanding spreads, the engineer will be able to absorb the true and lasting advantages of this modern vehicle into the city's transportation system. Ω

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In charge of the Technical Service Division, Mr. Church is responsible for advertising, sales promotion, and related activities of the Locomotive and Car Equipment Department, Erie. This article is an outgrowth of his work on developing and promoting plans for over-all advancement of the transportation industries.

TEXAS Heat pump fits snugly in cubicle off patio and warms or cools home the year round.

OHIO "Young America" home conditioned by heat pump for modern soot- and ash-free living.

Heat Pump—New Load on Utility Horizon

By P. F. O'NEILL

In most of the southern regions of the United States, home air-conditioning equipment is being installed in increasing numbers. It promises soon to be as commonplace as the electric refrigerator. But as more and more of this equipment is tied into power systems, it will change the pattern of the electric utility's summer residential load. Its effect in some areas will be to develop a greater spread between peaks of the utility's summer and winter electric loads; this is undesirable because the extra system capacity needed isn't utilized the year round.

But heat pumps, by their very nature, will help the situation by keeping seasonal electric loads in a more favorable balance.

Capacity and Performance

Known as "YR" (Year-Round) models, the air-to-air heat pumps referred to are standard-production 3- and 5-hp packaged units. And although they will conform to certain commercial applications, they are primarily for the residential market.

The 3-hp unit is powered by a 3-hp compressor motor, a ⅓-hp indoor-fan motor, and a ½-hp outdoor-fan motor. Used where greater heating capacity is wanted, the 5-hp unit has a 5-hp compressor motor, a ½-hp indoor-fan motor, and a ¾-hp outdoor-fan motor. (Reason for larger outdoor-fan motors is the greater mass of air moved by them.) They are produced for three-phase 220- and 208-volt operation and single-phase 230-volt operation.

Shown in Tables I and II, pages 48 and 49, are the heating and cooling capacities for the larger of the two units (5-hp). Included with the heating capacities versus outdoor temperatures are the corresponding kilowatt demands. You'll note that the heating output and power consumed drop off as the outdoor temperature decreases. On the cooling cycle however, the variation of electric demand with changes of outdoor temperature is much less. For that reason only the maximum and minimum figures are given. (In connection with heat pumps the *coefficient of performance* should be mentioned. For a given condition of temperature and humidity, it equals heat output of the pump divided by the heat equivalent of electric input. This factor varies above and below three with outdoor temperatures, and accounts for the difference between tabulated values of Btu per hour output and equivalent kilowatt-input. For details of the heat pump's operation, see December 1950 REVIEW.)

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For the past 14 years Mr. O'Neill has been engaged in all phases of utility engineering and operating functions. And during World War II while in the Navy he was active in research on electronic equipment and naval aircraft. With the General Electric Company since 1951, Mr. O'Neill is now Manager of Utility Services, Heat Pump Department, at Bloomfield, NJ.

Capacity Booster

During the heating cycle, heat output drops off with decreasing temperatures, and supplementary heating in the form of electric resistance heaters may be required. If so, these supplementary heaters are supplied as an integral part of the pump, installed in its indoor-circuit air-plenum chamber. But whether supplementary heating will be necessary depends on the degree of insulation of the home, its size, and the outdoor temperature in its particular region.

House construction greatly influences heat-pump size and need for supplement-

TABLE I—HEATING CAPACITIES BTU/HR AND KW-INPUT FOR A 5-HP HEAT PUMP (1 KW-HR = 3413 BTU) OUTDOOR AIRFLOW 3400 CFM, INDOOR AIRFLOW 2000 CFM

Air Temp Entering Indoor Coil (degrees F)		Air Temperature Entering Outdoor Coil (degrees F) 0	5	10	15	20	25	30	35	40	45	50
65	Btu/hr	34800	36800	39300	42000	45200	48700	52600	56900	61500	66500	71600
	kw-input	4.3	4.5	4.7	4.9	5.1	5.3	5.5	5.8	6.0	6.2	6.4
50	Btu/hr	38500	40800	43200	46100	49200	53000	57000	61300	66000	71000	76000
	kw-input	3.8	4.0	4.2	4.4	4.6	4.8	5.1	5.3	5.5	5.7	5.9
60	Btu/hr	36200	38200	40700	43400	46700	50200	54000	58300	63000	68000	73000
	kw-input	4.1	4.3	4.5	4.7	4.9	5.1	5.4	5.6	5.8	6.0	6.2
70	Btu/hr	33500	35500	38000	40600	43800	47200	51200	55500	60000	65000	70300
	kw-input	4.4	4.6	4.8	5.0	5.2	5.5	5.7	5.9	6.1	6.3	6.6

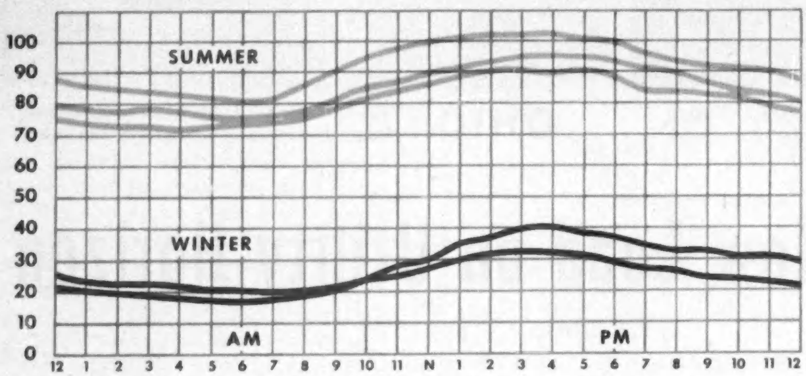


FIG. 1. HOURLY OUTDOOR TEMPERATURES of some of warmest summer days and coldest winter days in a southern location. Lowest temperatures usually run from six to seven am.

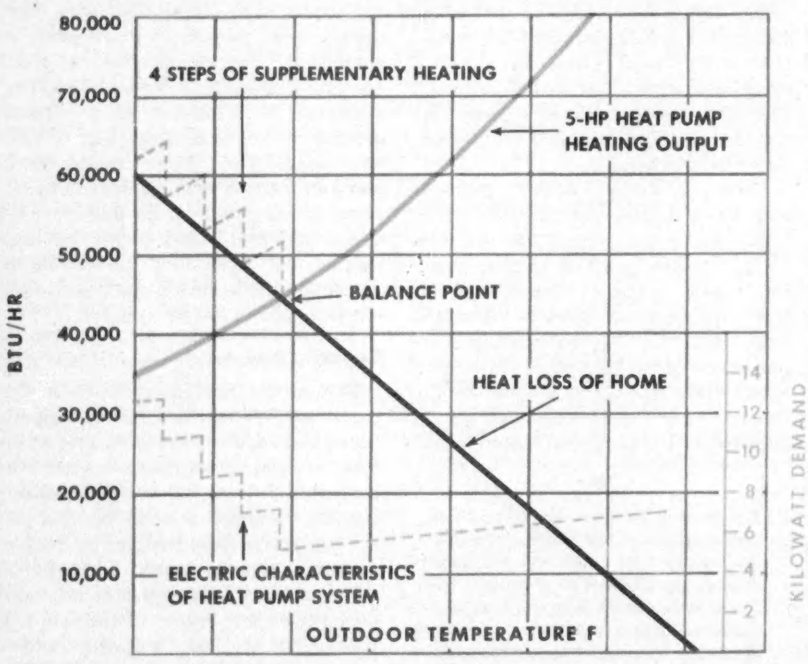


FIG. 2. HEAT BALANCE DIAGRAM for a heat-pump system applied to a home in Southern location. At the design temperature of zero F the home's heat loss is 60,000 Btu/hr.

ary heaters. For example, the uninsulated crawl space of a basementless house has little or no effect upon the *cooling* load of the home. But it does have considerable effect on the *heating* requirements. Such an uninsulated crawl space might result in the need for supplementary heaters, whereas the insulation of this crawl space would reduce or eliminate that need. Complete insulation of the home will therefore go a long way toward reducing or eliminating supplementary heating.

When supplementary resistance heaters are employed in a heat pump, their degree of usage coinciding with the electric utility's peak electric load in winter is limited by two factors. Consider first that the wintertime peak electric load generally occurs in the late afternoon between five and seven. At that time the electric range and other home appliances are being used to prepare the evening meal, thereby reducing the heat pump's output requirements. But in addition, outdoor temperatures during this period are usually near their warmest for the day.

Weather Outlook

A study of hourly outdoor temperature cycles (Fig. 1) for the Southern area will show you how the variation of outdoor temperatures exerts a major control on the heating and cooling of a home. In most areas the warmer part of the day is from eight in the morning to nine in the evening—the highest temperature usually occurs at midafternoon. On the other hand, the colder temperatures occur near midnight and during early morning hours.

The hours that temperatures were at or below different levels during the 1951–52 winter heating season are shown in Table III. A tabulation such as this is highly important because it illustrates, depending on the application, the number of hours supplementary heating may be needed. And having average values of the time at which these temperatures occurred, you can pretty well determine how many hours supplementary heating will coincide with the utility's daytime electric load. A tabulation of this kind is therefore valuable not only in predicting the heating season kilowatt-hour requirements of a heat pump but also in getting an over-all picture of these requirements.

Facts and Figures

The heat balance diagram (Fig. 2) is a "moving picture" of a 5-hp YR

TABLE II—COOLING CAPACITIES BTU/HR, AIR ENTERING OUTDOOR COIL 95 F, OUTDOOR AIRFLOW 3400 CFM, INDOOR AIRFLOW 2000 CFM

Air Entering Indoor Coil Wet Bulb (degrees F)	Total Cooling Capacity* (Btu/hr)	Air Entering Indoor Coil, Dry Bulb: 75 F Heat		80 F Heat		85 F Heat		90 F Heat	
		Sensible	Latent	Sensible	Latent	Sensible	Latent	Sensible	Latent
65	54400	30750	23650	36000	18400	41800	12600	47200	7200
67	56800	29100	27700	34800	22000	40100	16700	45600	11200
69	59500	27700	31800	33000	26500	38600	20900	44000	15500
71	62200	26100	36100	31400	30800	37000	25200	42500	19700
73	64800	24600	40200	29800	35000	35200	29600	40800	24000

*Total cooling capacity = sensible heat plus latent heat. Latent heat is that required to dehumidify indoor air. Kw-input on cooling cycle = Maximum 7.2-kw; minimum 6.7-kw.

TABLE III—HOURS OF OUTDOOR TEMPERATURES IN SOUTHERN AREA IN 1951-52 HEATING SEASON

Outdoor Temp (Degrees F)	Hours Temp was at or below that value at any time	Hours Temp was at or below value 8 am—8 pm
30	295	141
28	204	96
26	145	67
24	113	53
22	79	33
20	65	26
19	61	25
18	56	22
17	49	18
16	41	14
15	30	10
14	21	7
13	19	5
12	15	4
11	14	3
10	11	2
9	10	2
8	9	2
7	9	2
6	8	2
5	6	1
4	4	
3	2	
2	1	
1	0	

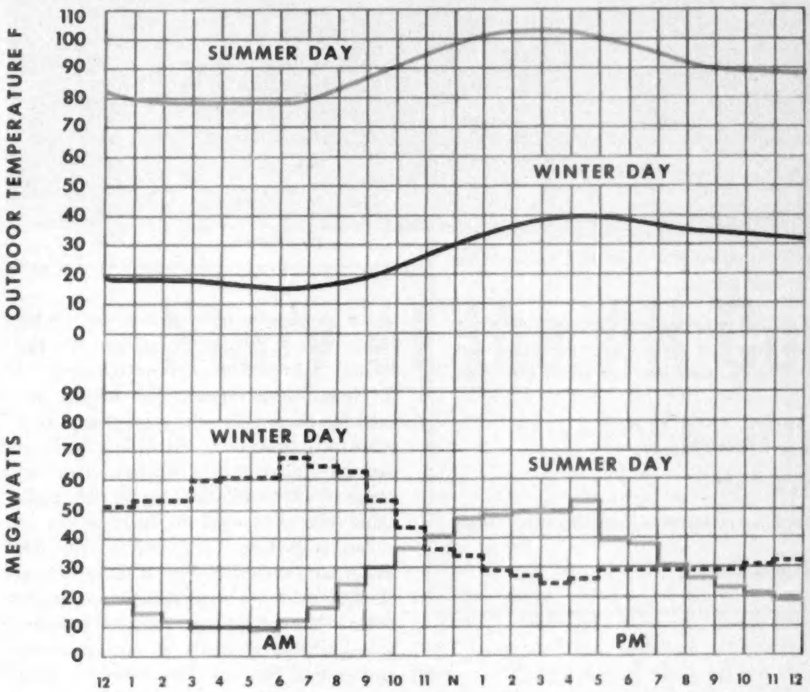
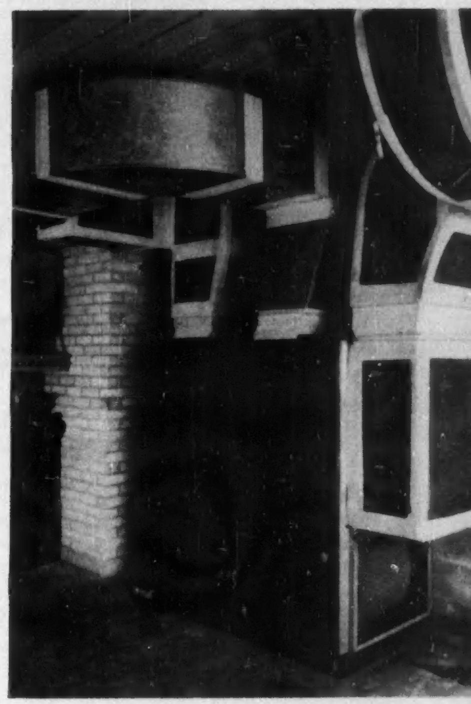


FIG. 3. ELECTRIC LOAD CURVE calculated for 8000 all-electric homes with heat-pump systems. In Southern locale, daytime energy consumption is greater in summer than winter.



HEAT PUMP can be housed in basement, garage, or in a household utility room.

heat-pump system installed in a home with a 60,000 Btu per hour loss—design temperature for this particular Southern location is zero F. In this application, and as recommended in all other applications, supplementary heaters are thermostatically controlled by outdoor temperatures in two-kilowatt steps. They work this way: the first two-kilowatt heater is cut in when the outdoor temperature is 19 F, and the outdoor thermostat calls for heat. Next, the second two-kilowatt step (making a total of four kilowatts of supplementary heat) cuts in when the temperature is 14 F. And so the process continues until all four steps are cut in. With this form of control the use of supplementary heat is kept minimized. (You can check the number of hours each supplementary heater operates by cross reference to Table III.)

On the assumption that the Southern location had approximately 8000 heat-pump systems—1400 3-hp units and 6600 5-hp units—their combined electric load characteristics (Fig. 3) were calculated. Notice that for this location the summer load is greater than the winter load during normal daytime hours. In the winter the electric load generally peaks near midnight and during the early morning hours.

Setting the thermostat back to a lower temperature at night, as is customary with other types of heating equipment, isn't recommended for the heat pump. In the first place, it would take the heat pump too long to bring the house up to morning comfort during periods of low outdoor temperature. And second, such forced operation could result in an *over-all* higher electric demand by the pump, with possibly greater operating costs. When such oper-

TABLE IV

HEATING SEASON KW-HR REQUIREMENTS OF HEAT PUMP FOR HOME OF 60,000 BTU/HR LOSS, AT ZERO F DESIGN TEMP, IN AREA OF 2367 DEGREE DAYS

	Sequence of Supplementary Heating Steps (Fig. 2)	Total Hours of Operation (Table III)
1)	First step cuts in at 19 F	61
	Second step cuts in at 14 F	21
	Third step cuts in at 9 F	10
	Fourth step cuts in at 4 F	4
	Total	96

2) Each step of supplementary heating is rated 2 kw. Therefore, if each had operated 100 percent of the above hours, (2) (96) or 192 kw-hr would have been used. Since the heat pump and supplementary heaters exceed the heating needs of the home for some outdoor temperatures (Fig. 2), a correction factor must be applied. This factor is in the order of 91 percent.

Therefore, kilowatt-hours used by supplementary heaters equals (91 percent) (192 kw-hr) or 174.7 kw-hr, which is equivalent to 0.596 million Btu.

3) Total heating season Btu requirements of home based on 2367 degree days are

$$\frac{(60{,}000 \text{ Btu/hr})\ (24 \text{ Hr})\ (2367 \text{ degree days})}{70 \text{ F}}$$

equals 48.6 million Btu for this heating season. (70 F equals house temperature minus design temperature.) Subtracting 0.596 million Btu from 48.6 million Btu leaves 48 million Btu to be supplied by the heat pump.

4) Weather bureau figures show the average annual temperature during this heating season was 54.7 F. At this average temperature the performance factor of the heat pump is 3.15 when transient and defrosting operations are taken into consideration.

$$\frac{48 \times 10^6 \text{ Btu}}{(3.15 \text{ performance factor})\ (3413 \text{ Btu/hr})}$$

equals 4480 kw-hr to be supplied by heat pump alone.

5) Total heating season requirements equals heat pump plus supplementary heat, equals

$$4480 + 174.7 \text{ or } 4654.7 \text{ kw-hr.}$$

TABLE V

HEAT PUMP ON COOLING CYCLE—ESTIMATED NUMBER OF OPERATING HOURS IN VARIOUS CITIES

City	Hours
Baltimore	700
Boston	200
Buffalo	125
Chicago	400
Cincinnati	850
Columbus	650
Cleveland	300
Dallas	1200
Detroit	500
Duluth	100
Ft. Wayne	600
Grand Rapids	500
Houston	1450
Indianapolis	800
Milwaukee	300
New Orleans	1650
New York	300
Pittsburgh	500
St. Louis	1150
Washington	700

ation is absolutely required, an automatic control is recommended. It restores the temperature setting to normal daytime level at an early morning hour.

The step-by-step method of calculating the *heating* season kilowatt-hour requirements of a heat pump is given in Table IV. Chosen for the example is a home with 60,000 Btu per hour loss at zero F, located in the Southern area for which temperature data are listed in Table III. When the summer cooling needs for this home are included, the heat-pump system uses about 13,000-kw-hr annually. (You can make the same calculation on a monthly basis by obtaining from the weather bureau the degree-days—average daily temperature subtracted from 65 F—and outdoor temperatures for the month.)

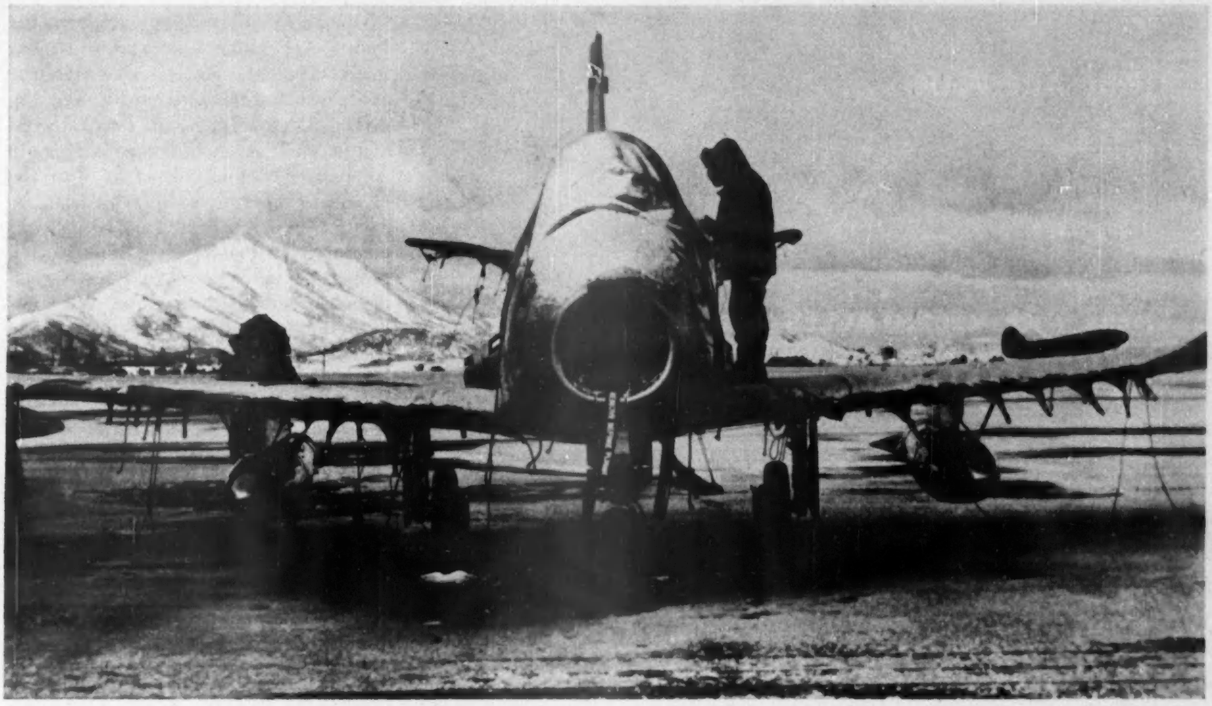
Interested people might also like to know the monthly kilowatt-hour requirements of the *cooling* season. These are again a function of outdoor temperatures and many other factors. However, the development of such data isn't sufficiently established for presentation at this time. It can be calculated but the method now used is detailed and laborious. Table V shows the heat pump's anticipated hours of cooling-season operation for various parts of the country.

Crystal Gazing

The size of a house, its construction features, and the design temperature—winter and summer—in its particular area, have a major influence on the annual kilowatt-hour requirements of the heat-pump system. No definite annual figure can therefore be affixed to a given size house in all areas. Still, it can be stated that a system uses between 2500- and 3500-kw-hr for each rated horsepower of the heat pump.

But regardless of the area, the YR heat-pump system is a good thing for the electric utility. For as mentioned at the outset, the growth of straight summer air-conditioning loads is changing the season and time of the electric burden on the utility's system. Straight winter electric heating-loads, too, can create similiar seasonal problems. Both these conditions require extra system capacity—capacity that must at times stand idle because it's not fully utilized the year round. The introduction of YR heat pumps to the residential horizon, with subsequent growth of their characteristic year-round load, will tend to minimize this seasonal unbalance.

Many comfort, safety, and convenience features are inherent to the heat pump. And because of its ability to utilize the *free* air as a heat source in winter, with its three-to-one performance factor in extracting this heat, the heat pump is a major step toward the era of all-electric living. Ω



Story of the AN Connector

By G. R. LAWSON

U.S. Air Force F-86 *Sabrejets*, like the one above at a 4th Fighter Interceptor Wing forward airstrip in Korea, depend on AN connectors, as do all modern aircraft. And working in conjunction with connectors are miles of wire servicing every conceivable kind of electric device. Still, the importance attached to connectors is somewhat overshadowed by the remarkable technological state of today's military equipment. Yet the interconnection of electric components within the equipment grows increasingly complex and critical.

Through common usage the term "AN" is applied to all electric connectors meeting joint Air Force–Navy specifications. Their history begins several years prior to World War II. Then the need for a series of quick-disconnect plugs arose with the development of portable Signal Corps equipment. When the war broke, there was a sharply increased demand for electric connectors and, because they were to be made by more than one manufacturer, some standard was needed. A military specification resulted that has since been revised, improved, and co-ordinated.

There are two types of AN connectors—plugs and receptacles—as shown on page 52. They are made in sizes ranging from one-half to three inches in diameter, and the number of circuits that can be accommodated varies from one to over 60, with a current capacity of up to 200 amp. At present there are about 250 different contact arrangements, making it possible to select a connector for just about any requirement.

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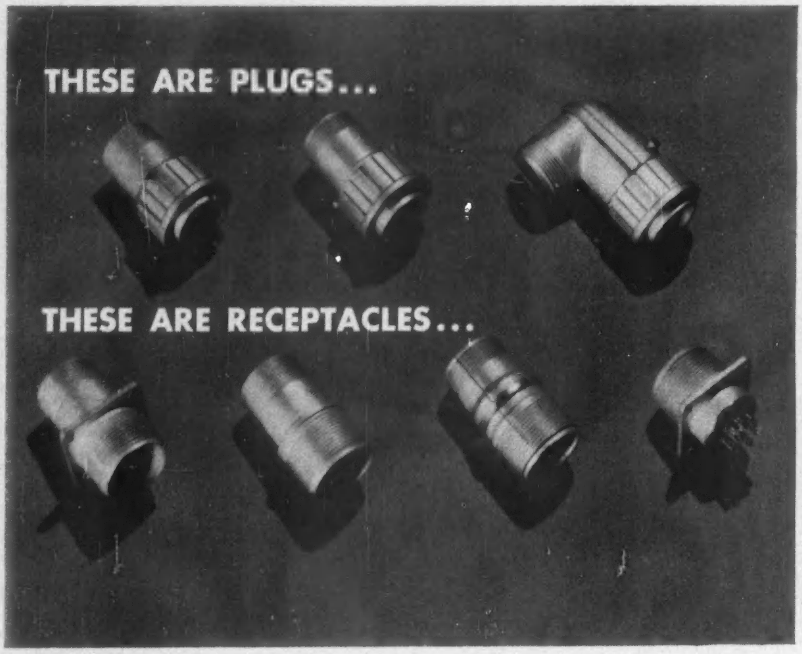
Mr. Lawson works on AN connector design, development, and application for Monowatt Department, General Electric Company, Providence, RI. He represented Monowatt at recent Air Force–Navy–Industry conferences held in Washington, DC, and Wright Field, Dayton, to revise connector specifications to meet present requirements.

That half of an AN connector with a coupling nut is called a *plug;* that half with external coupling threads is called a *receptacle.* In other words, the half with the coupling nut is always called a plug whether it has pin or socket contacts. And the half with external coupling threads is always a receptacle. (This is contrary to conventional usage where you invariably call that half with pin contacts a plug.)

Plugs are made in two styles: straight plugs for normal use and right-angle plugs for close mounting. Receptacles come in three styles. One has a square mounting flange, with its back diameter threaded to receive standard conduit fittings or cable clamps. Intended for wall or bulkhead mounting, it eliminates need of a junction box. Another receptacle—used as a free-end cable connector—is identical except that it has no mounting flange. The third type—mounted in a junction box or in an enclosed wiring assembly—is again similar, but for the absence of conduit threads on the back diameter.



Durability Plus

All AN connectors, as mentioned before, must meet a certain specification and be approved for use by the custodian and qualifying agency for this specification—the Navy Bureau of Aeronautics. That is to say, before you can make, advertise, or sell connectors for use in military equipment, they must meet certain physical, electrical, and performance requirements. Samples must be tested and qualified by a government testing laboratory as directed by the Bureau.

Tests are performed on four samples. Two connectors are consecutively subjected to all the tests of one group, while the other two are subjected to all the tests of a second group.

Designed to check performance under various extremes of environmental conditions, the first group of tests include . . .

- Five complete cycles of a half-hour's duration at −67 F and +185 F
- Exposure to 95 percent humidity and 160 F for 14 days
- Salt spray exposure for 50 hours.

Before proceeding with successive tests, connectors are checked for contact resistance. This is done by measuring the millivolt drop of the contact while it carries rated current. In addition, connectors are also subjected to high-voltage tests.

The second group of tests is mostly for checking mechanical performance . . .

- Resistance between adjacent contacts or between any contact and the metal shell must measure at least 5000 megohms.
- During continuous vibration of the connector at high frequencies for five hours, maintenance of electric conductivity is checked.
- Subjected to a shock of 50 *G*'s—*G* is a force equivalent—the connector is examined for any change in contact resistance.
- To simulate actual service conditions the connector is mated and unmated 500 times, after which contact resistance is again checked.

Design Materials

You can think of a connector in terms of three groups of component parts—housings, contacts, and inserts.

Housings—Ordinarily, housings are made of aluminum. They may be either wrought-alloy machined parts or aluminum die castings, though the greater portion are die castings. Chosen for their ability to cast well in relatively thin and intricate sections, all metal parts of the die-casting alloys are cadmium-plated for corrosion protection.

Contacts—Of the two types of contacts—pin or socket—the pin contact presents less of a materials problem.

Pin contacts are made of an extremely high-conductivity copper-alloy, such as tellurium, selenium, or leaded copper. Any of these materials has a conductivity of about 99 percent.

On the other hand, the requirements for a socket contact—the spring member that receives the pin contact—aren't so easily satisfied, materials-wise. For the principal requirement of a socket contact is this: it should have as high a conductivity as is consistent with the physical properties necessary to get the desired spring action. But most high-conductivity metals have poor spring properties, and those that have good ones are difficult to machine. With few exceptions therefore the choice of a socket contact material is something of a compromise.

Accordingly, two design approaches are used, each with merits of its own. In one design the socket contact is fabricated from bar stock—brass, bronze, beryllium-copper; in the other, from sheet stock—copper, commercial-bronze.

Inserts—By far the greatest amount of research and investigation has been directed toward finding a suitable material for inserts. As used in today's connectors, the insert material is an attempt to meet electrical requirements that have accumulated over the past 15 years.

The problem is essentially one of finding a high dielectric strength material that has arc, insulation, heat, cold, humidity, and moisture resistance to a high degree. Some additional requirements are that the material be unaffected by corrosive atmospheres and solvents, be adaptable to molding techniques, and have post-mold dimensional stability.

In view of all the plastics materials available you might think the solution to the insert problem relatively simple. But several years of search and compromise were necessary, and the history of this search is practically the history of AN connectors.

Earliest inserts were molded of plastics materials that provided excellent dimensional stability, good electrical resistance, and ease of molding. But their use was ruled out by subsequent requirements of the Navy specification. Insert materials must withstand at least 115 seconds arc resistance, and have a minimum dielectric strength of 100 volts per mil. These requirements severely restricted the field of possible materials. And those that did meet them were still further restricted because they were prone to post-mold shrinkage. (Post-mold shrinkage apparently continues for an indefinite period of time. It's undesirable because the inserts become loose in their housings and the dimensional locations of contacts change.)

CONCLUDED ON PAGE 61

The Institute of Radio Engineers

By E. K. GANNETT

Since earliest times, man has sought to devise means to communicate over long distances. The African drum, the Indian smoke signal, even the lantern in the tower of Old North Church which sent Paul Revere on his famous ride—all were evidences of man's never-ending struggle to extend his range of direct communication.

From the beginning, experimenters in electricity and magnetism were intrigued by the idea that their investigations might provide them with a unique and complete solution to this problem. Consequently, considerable effort was spent during the early 1800's to devise communication systems utilizing such means as the conductive properties of water, magnetic induction, and conducting wire.

The most ingenious answer to the problem was provided by James Clerk Maxwell in 1867 when he postulated the theory of existence and behavior of electromagnetic waves. Not until 19 years later, however, was Maxwell's theory confirmed by Heinrich Hertz, who proved experimentally that electromagnetic waves could indeed be transmitted through space at the speed of light.

During the period prior to 1900 when these dramatic developments were unfolding, other important discoveries were in the making: Crookes demonstrated the properties of cathode rays; Braun constructed the first cathode-ray oscilloscope; Nipkow invented the television scanning disc; the basic principles of facsimile were conceived by Bain; Edison observed that a heated filament would cause an electric current to flow through space in an incandescent lamp; and Thomson discovered the electron.

To a civilization not yet accustomed to the new era of scientific and technological progress, the significance of these fundamental discoveries was not fully apparent. But in 1895 when a 21-year-old youth named Marconi announced that he had transmitted and received signals by wireless, the significance of such an announcement was apparent to all.

Poulsen, Fessenden, Lodge, and other engineers set about to perfect equipment by which messages in code could be transmitted without wires and over long distances, and in 1901 Marconi succeeded in spanning the Atlantic by wireless. To this achievement was added the transmission of speech by Fessenden, Flemming's electronic valve detector, and de Forest's three-element amplifying tube, so that by 1907 the infant "radio" was beginning to emerge.

IRE Founded

In Boston, Mass., on February 25, 1907, John Stone Stone, renowned radio pioneer, formed the first radio engineering society—the Society of Wireless Telegraph Engineers (SWTE). An outgrowth of seminars held by members of the Stone Wireless Telegraph Co., the SWTE recruited members from the Stone staff and only one or two other companies in the Boston area. In 1908 another society, known as the Wireless Institute, was formed in New York City by Robert H. Marriott, drawing its members from many companies. However, an intense rivalry existed then between wireless companies, to the point where fraternization by engineers of competing firms was frowned upon. Partly as a result of this situation, by 1912 the two societies still had less than 50 members each despite an encouraging start.

At this time Robert H. Marriott and Alfred N. Goldsmith, both representing the Wireless Institute, and John V. L. Hogan, active in the SWTE, held an informal meeting to discuss the status and plans of both societies. Out of this meeting came a plan to consolidate the two organizations, forming a single society to advance the art and science of radio communication and to promote the professional welfare of its engineers. As a result, 46 members of both societies met on May 13, 1912, at Columbia University, to adopt a constitution and elect officers. And the name selected for the new society was The Institute of Radio Engineers.

Growth of IRE

The four decades since the formation of the IRE have seen a spectacular growth in radio. From the activities of a small group of wireless experimenters has grown an established field of engineering which provides employment for tens of thousands of radio engineers and scientists. In its early stages, radio was used primarily in connection with maritime shipping operations. Commercial radiobroadcasting was initiated in the early 1920's, and by 1930 experimental television stations were on the air. This new-found knowledge opened the doors to applications in other fields, such as industrial control equipment, manufacturing processes, and scientific and medical instruments.

With the advent of World War II, electronic research activities were increased 100-fold, resulting in radar, loran, the proximity fuse, and a host of other developments. To this list were soon added printed circuits, transistors, color and uhf television, electronic computers, and nuclear instruments, so that at the present time radio is already a broad and varied field of engineering and is continuing to expand at a rapid rate.

The growth of the radio engineering field has been closely paralleled by a corresponding expansion of the IRE. The original membership of 46 located in a 200-mile area has swelled in only 40 years to approximately 32,000 radio engineers and scientists in all parts of the globe.

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*Mr. Gannett has recently been appointed Administrative Editor—*Proceedings of the IRE*—the Institute's official monthly publication. He was formerly Technical Editor of the magazine.*

IRE HEADQUARTERS BUILDING, CORNER FIFTH AVENUE AND 79TH STREET, NEW YORK CITY.

The first and most important service instituted by the IRE was the establishment of its technical journal, *Proceedings of the IRE*, which began publication in 1913 under its present editor, Alfred N. Goldsmith. In it were published the papers and discussions presented at the monthly meetings. The *Proceedings* quickly established itself as one of the world's leading publications devoted to the radio engineering field.

Since 1913, standardization activities have played a permanent and prominent role in Institute affairs, resulting in the eventual formation of more than 20 technical committees which originate standards on radio subjects at frequent intervals, bringing conformity and clarity to all branches of the radio electronic field.

As membership increased, the activities of the IRE—originally confined to the New York area—rapidly spread to other cities where local Sections were organized. The first Section, formed in Washington, DC, in 1914, was followed by the formation of Sections in Boston, Seattle, and San Francisco during the next three years. These were all large coastal cities where maritime radio predominated just prior to World War I. In 1925 as the broader aspects of radio engineering began to materialize and the IRE influence was felt in other countries, Sections were formed in Philadelphia, Chicago, and Toronto. The growth of this important grass-roots activity has continued unabated so that today there are over 75 Sections and Subsections in the United States, Canada, Hawaii, and Argentina.

In 1947 the Board of Directors authorized the establishment of Student Branches in schools of recognized standing to give this important segment of Student members official and direct support of the Institute. Now Student Branches are functioning in 110 colleges in the United States and Canada.

Perhaps the most important change in the Institute's structure during its 40 years of growth was the establishment of the Professional Group system in 1948—it meets the diversification of membership interests resulting from wartime expansion of the radio engineering field. The Professional Group system provides for technical subsocieties within the IRE enabling the individual member to follow even more closely and in greater detail the technical advances in his specialized field. This development, although still in its formative stages, has already led to the formation of 19 Professional Groups. These Groups have been active in sponsoring meetings on subjects of special interest to their own members and many are issuing their own technical publications, called *Transactions.*

IRE Today

Membership in the IRE is open to persons interested in the theory and practice of radio engineering or the allied arts. Membership is divided into five grades, each with its particular professional requirements, privileges, and dues. The grade of Student is open to those taking a regular course of study in engineering or science in a college or technical institute of recognized standing. Associate grade is available to persons over 18 who are interested in the theory and practice of radio and allied arts. The grades of Member and Senior Member require the equivalent of three and eight years of professional experience, respectively. The Fellow grade is the highest order of membership in the IRE and is awarded solely by the Board of Directors to those who have made outstanding contributions in the field.

Publications

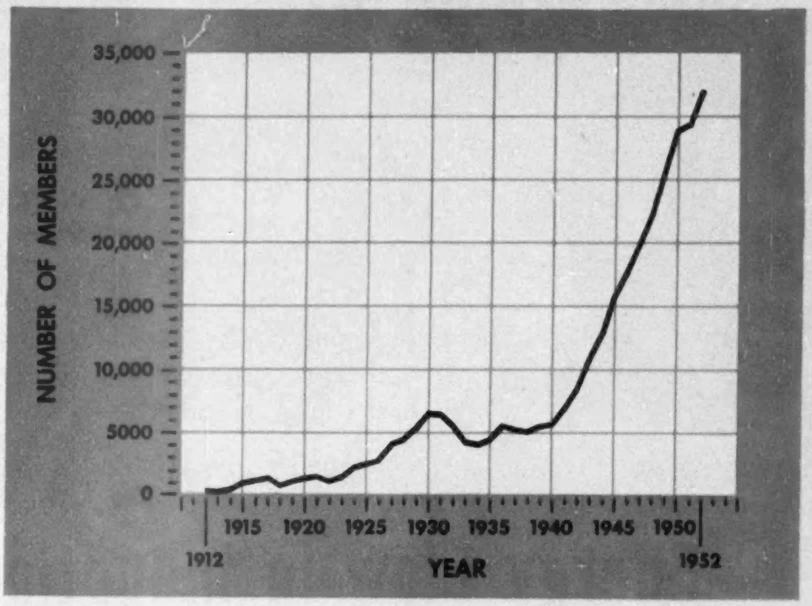
The *Proceedings of the IRE*, the official monthly publication of the Institute, is sent free to members in good standing. In addition to technical papers, items are published concerning IRE activities, its members, and the industry; IRE technical standards; book reviews; abstracts of technical papers published in periodicals the world over; and a listing of job opportunities. To fully inform its membership of the most important developments in the field, special issues of the *Proceedings* are published in expanded form as the need arises.

The IRE's annual Directory contains the names, addresses, and business affiliations of all members above Student grade, and a valuable alphabetical listing of radio-electronic firms, together with their products, a product index, and a catalogue section. In 1952 during the first year of publication of *Transactions*—an increasingly important activity of the Professional Groups—nearly 200 specialized papers were published in 10 branches of the radio field. Plans are currently under way to substantially augment this valuable service.

This year the Institute is supplementing its publication program by publishing the more than 200 papers which will be presented this month at the IRE National Convention in New York City. The *Convention Record of the IRE* will be issued in several parts, divided according to subject matter.

Professional Groups

Membership in the IRE Professional Groups is open only to members of the Institute. Each Professional Group may levy assessment fees on its members to meet the costs of publishing *Transactions* and *Newsletters*, conducting meetings and conferences, and other operational expenses. The 19 Professional Groups which have been organized to date cover the fields of airborne, industrial, and medical electronics; audio, antennas and propagation; broadcast, and television receivers; broadcast transmission and communication systems; circuit, microwave, and information theory and techniques; electron devices and electronic computers; engineering management; radio telemetry and remote control; instrumentation; nuclear science; quality control; and vehicular communications.



IRE MEMBERSHIP CURVE SHOWING ITS RAPID GROWTH, ESPECIALLY DURING THE LAST DECADE

Meetings and Sections

The largest engineering meeting and exhibition in the world is the annual IRE National Convention held in March of each year in New York City. The 1953 convention will be held from the 23rd through 26th of this month at the Waldorf Astoria and at Grand Central Palace. Besides presentation of technical papers, some 350 exhibits of the latest radio electronic apparatus will be on display. More than 28,000 persons registered at the 1952 convention.

The Professional Groups supplement the conventions by numerous meetings devoted to one topic of broad interest; the Sections by conferences of regional interest. And hundreds of local meetings are held each year by the various Sections and Subsections.

Committees

The IRE's standardization work has contributed much to the orderly expansion of the communications and electronics field. Through its 23 technical committees, the IRE issues standards on definitions of technical terms, test procedures, and measuring methods for judging the performance of electronic apparatus and phenomena, graphical symbols for engineering drawing, and abbreviations of technical terms. These standards are made available to all members through publication in the *Proceedings*. The standards activities also include co-operation with other engineering societies, and with national and international standardization organizations.

Committees also handle such subjects as education, professional recognition, Armed Forces liaison, awards, public relations, and preparation of an annual review of the significant developments of the preceding year for publication in the *Proceedings*. Each committee effectively contributes to the progress of radio engineering within the scope of its own activities. For example, the IRE in conjunction with the Radio-Television Manufacturers Association sponsored the formation of the Joint Technical Advisory Committee, composed of leading radio engineers. This committee acted in an advisory capacity to the Federal Communications Commission in the allocation of additional frequencies for television broadcasting, and provided the Commission with the most recent authoritative technical data—without which a suitable allocation plan could not have been drawn up. And it has recently prepared and arranged for the publication of a basic and valuable study of radio spectrum conservation.

Awards

The IRE annually bestows six awards to persons who have made substantial and important contributions in the field of radio engineering . . .

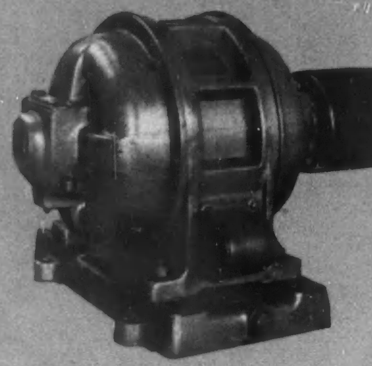
- Medal of Honor—the Institute's oldest and most prized award—for outstanding scientific or engineering achievement. A few of the engineers thus honored include: E. H. Armstrong, E. F. W. Alexanderson, and Guglielmo Marconi; Balth van de Pol, Melville Eastham, and A. G. Lee; Lloyd Espenchied, A. N. Goldsmith, and Haraden Pratt; and Ralph Brown, W. R. G. Baker and J. M. Miller
- Morris Liebmann Memorial Prize—specifically for work of IRE members
- Harry Diamond Memorial Award—to persons in government service
- Zworykin Television Prize—for advances in television
- Browder J. Thompson Memorial Prize—for the author under 30 whose IRE paper best combines technical contribution and clear presentation
- Editor's Award—for literary excellence
- Founders Award—newly established this year—will not be given annually but only on special occasions to persons who have achieved eminence through leadership in the planning and administration of technical developments.

Advancing the Profession

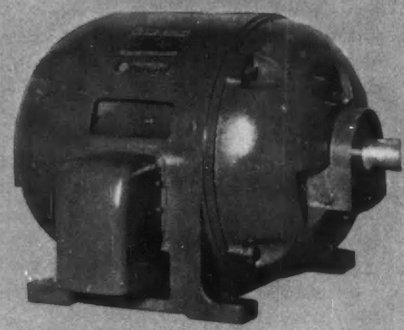
It is thus that an engineering society advances the profession it serves—through its publications, meetings, and committees. It might be likened to a catalyst by which the exchange of ideas and information is stimulated, and the reaction between theory and technique is directed toward a useful conclusion. The substantial services which have been rendered by the engineering societies of this country are a tribute to the past, a credit to the present, and hold great promise for the future of mankind. Ω

Same Frame Size . . . More Horsepower

1902 5 HP



1922 20 HP



1941 30 HP

Energy Flow in Induction Machines

By P. L. ALGER and W. R. ONEY

The polyphase induction motor still presents challenging problems, both practical and theoretical—this despite the progress made in the 66 years since Telsa invented it. A present-day 30-hp motor is built in the same over-all dimensions as the 20-hp motor of 25 years ago or the 5-hp motor of 50 years ago. It's more reliable, versatile, and better in every respect including looks. Yet, customer demands and economic pressures require that progress continue. To this end better *theories*, as well as better materials and methods, are needed.

Torque Is the Problem

The chief *problem* in induction-motor design is obtaining high torque all the way from rest to full speed, and along with it also obtaining low starting current, low losses, and quiet operation. A first step in the solution is to employ some form of double-squirrel-cage rotor winding. This consists of two squirrel cages placed one outside the other. The outer winding has a high resistance and low reactance; the inner winding has a low resistance and high reactance. In this way the rotor current at standstill is made to flow chiefly in the high-resistance outer bars, while at speed the current takes an alternate path through the inner bars of low resistance but high inductance. The effective rotor resistance therefore is high at start and low at speed, giving high starting torque with low I^2R losses in normal operation.

After taking this first step, however, there is still a big way to go before the torque problem can be solved. The stator and rotor windings of an induction motor are located in slots separated by a small air gap. The air-gap magnetic field therefore has a highly *ragged* wave shape. Besides the *fundamental* flux rotating at synchronous speed, there are many *harmonic* fields with large numbers of poles that rotate at low speeds. These produce *parasitic* torques that somehow must be held within limits.

The three speed-torque curves, shown in Figs. 1, 2, and 3, illustrate the wide variations that can occur in motor performance with seemingly minor changes in design. All three curves were taken on 30-hp 4-pole motors built in the same size frame, with the same over-all core dimensions, and with cast-aluminum double-squirrel-cage rotor windings. Fig. 1 is for a motor with 48 stator and 56 rotor slots, giving excellent torque over the whole speed range.

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Author of The Nature of Polyphase Induction Machines, *Mr. Alger—Consulting Engineer—has been engaged in the development of dynamoelectric machinery since he entered General Electric's Test Course in 1916. Mr. Oney joined the Company in 1948 and is with Induction Motor Engineering doing analytical work. Both are with the Small and Medium Motor Department.*

Fig. 2 shows how the accelerating torque is reduced when a 76-slot rotor is used with the same stator. The severe dips in torque are caused by two stator-slot harmonic fields that rotate at 1/23 speed backward and 1/25 speed forward. Fig. 3 is for a 60-slot stator and the same 56-slot rotor as in Fig. 1. It exhibits a smooth torque curve, but there is a subsynchronous crawling torque (a torque that varies greatly without change in speed) at 1/14 speed backward. Besides these torque differences, the three motors differ markedly in losses and noise.

A Deeper Understanding

Usually, motor theory is taught, and design calculations are made, with equations expressing the torque as the product of rotor current by magnetic flux density in the air gap. You can gain a deeper understanding of the performance however by the *energy method* of analysis. This method traces the flow of electric energy over the incoming power lines; its transformation into magnetic energy in the air-gap space; and its final delivery in mechanical form to the shaft of the driven machine. The procedure is based on the fundamental principle expressed by Kelvin's law—

When in a singly excited magnetic circuit without saturation a deformation takes place at a constant current, the energy supplied from the electric circuit is divided into two equal parts. One half *increases the stored energy of the magnetic field; the other half is converted into mechanical work.*

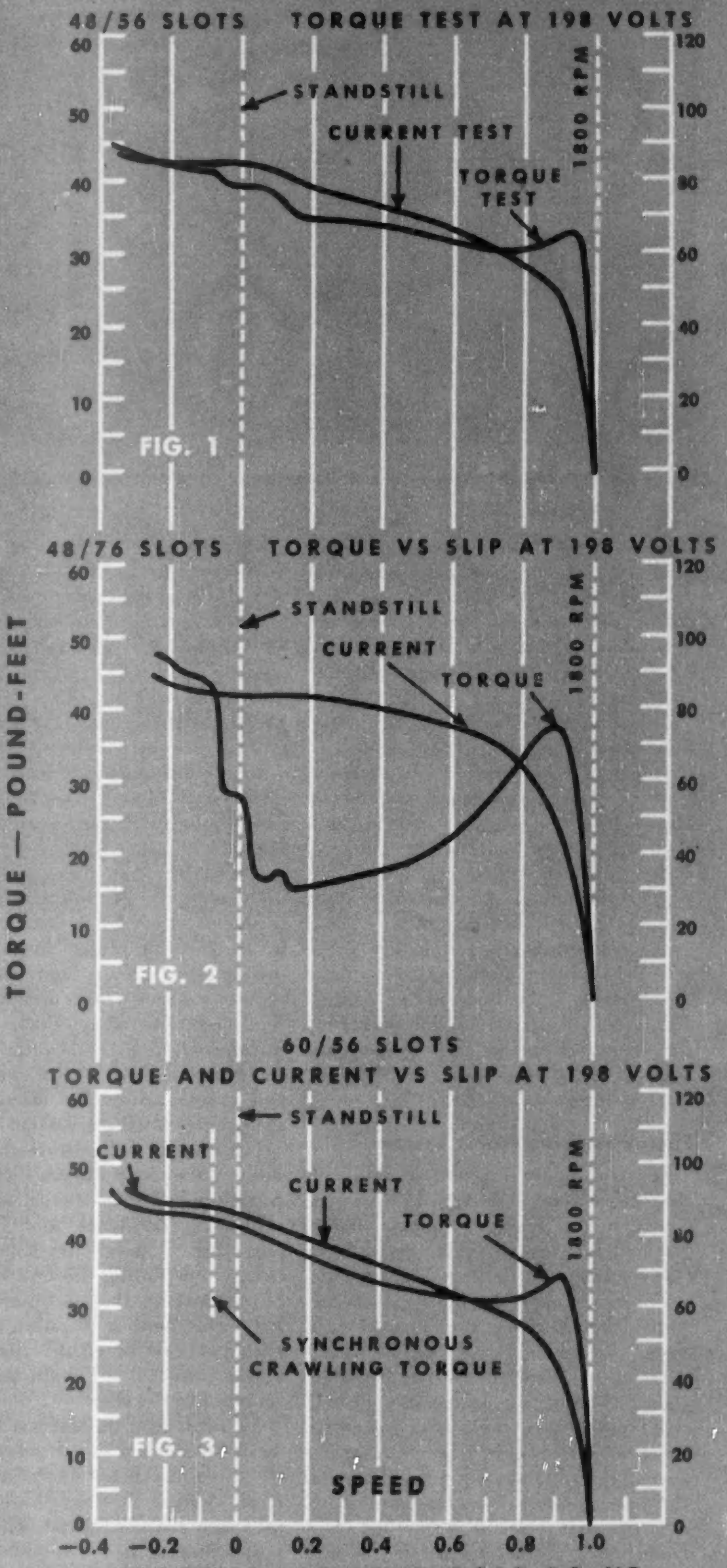
In other words, the work done by a magnetic force acting across an air gap is only possible because energy is stored in the magnetic field itself. The magnetic force acting at any point in the air gap equals the corresponding space derivative of the stored magnetic energy. By dealing with the total magnetic energy in the air-gap space of a motor, expressions for the forces can be obtained that include all of the harmonic-field effects. The magnetic energy is also a direct measure of the reactance.

What follows is an outline of this energy method of analysis. Our purpose is to indicate its advantages for teaching, as well as design purposes.

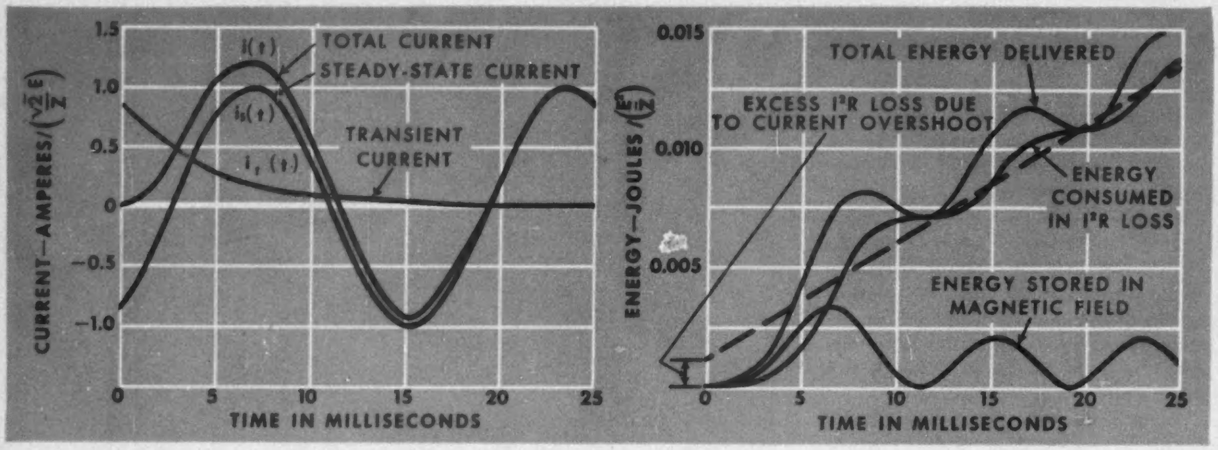
Energy Method of Analysis

It is easy to see how a force pushing down on the piston of an automobile engine turns the crankshaft. It's not easy to *see* how the air-gap magnetic field of a motor creates a turning effort by taking hold of the rotor currents. Let's therefore replace the intangible magnetic fields by imaginary elastic bands of force. Think of energy being stored in these elastic bands just as it's stored in stretched rubber bands. Consider them to stretch from the magnetic poles of the stator to those of the rotor; and to slide along their surfaces as the field moves. Finally, think of the field slipping over the rotor surface as creating a frictional drag, or torque, manifested by the I^2R losses of the induced rotor currents. The magnetic force is given by the derivative (rate of change) of the stored elastic energy—with respect to the space angle between the field and the rotor current.

The flow of energy across the air gap of a motor is governed by *precisely* the same laws as the transmission of radio-broadcast waves over thousands of miles of space. In either case the *carrier* for the useful power flow is the magnetic energy stored in the air spaces (a result of the magnetomotive force impressed by the sending-end currents). In a turbine the important thing is the *flow* of energy-containing gas or fluid through guided paths. Similarly, in an electric machine the important thing is the *flow* of energy through the magnetized air spaces. A proper model of an induction motor is one formed therefore by first immersing the machine in a plastic compound, and then dissolving out all the metal parts with acid—leaving a



THREE-PHASE FOUR-POLE 30-HP
60-CYCLE 440-VOLT MOTOR



FIGS. 4 AND 5. INSTANTANEOUS CURRENT AND ENERGY COMPONENTS IN A SINGLE-PHASE RL CIRCUIT WITH 0.5 POWER FACTOR AT 60 CYCLES.

structure representing only the air and dielectric (insulating) spaces. The motor designer must shape these air spaces—just as the turbine designer shapes his nozzles and buckets—so that the energy flow will be as frictionless and easy as possible.

To apply these concepts to an induction motor it is logical to consider in sequence: the incoming electric energy from the power system; the magnetic energy stored in the air-gap field; and the mechanical energy transmitted across the air gap.

With the locations and flows of magnetic energy throughout the air spaces in the machine clearly established, it is a relatively simple matter to determine the torques and forces at all points. These are obtained by differentiating the energy stored in each locale with respect to the direction in which the force occurs.

Energy from the Power System

It's convenient for you to think of the flow of electric current in a wire as similar to that of water in a pipe. When the switch is closed (valve opened) at the sending end, voltage (hydrostatic pressure) is applied to the conductor (pipe). Free electrons (water) then rush along the conductor. These electrons build up a pressure of electric potential (bursting pressure) against the insulation (pipe wall) along the way—and create magnetic-field energy in the space around the conductor (kinetic energy of the moving water). Two conditions arise:

- If the receiving end is *open* the electrons meet a potential barrier of air. This barrier throws them back against the oncoming electrons—resulting in a wave of reflected voltage and current that returns to the source. After a series of reflections the system settles down to a steady state with no current flowing. The conductor is now full of electrons pressing against the enclosing wall of insulation.
- If the receiving end is *closed* a similar process of current reflections occurs until equilibrium is reached. With a steady-state current now flowing, some of the voltage pressure is used up along the line in overcoming resistance and reactance drops.

In an a-c circuit the transient current is limited chiefly by the reactance. That is, the current creates magnetic fields linking the circuit; and these fields induce voltages which oppose the current flow. In this process, energy is transferred from the electric circuit to the magnetic field as the current rises and is returned to the electric circuit as the current falls, in each cycle.

Figs. 4 and 5 illustrate this. Fig. 4 shows the current build-up when an a-c voltage is suddenly applied to a circuit containing resistance and inductance only. Fig. 5 shows the corresponding energy flow during the first few cycles. Superposed on the continuous flow of I^2R loss, there is a pulsating *double-frequency* flow of energy that is alternately stored in the magnetic field and returned to the line.

In a balanced three-phase circuit the double-frequency power components of the three phases are displaced 120 electrical degrees in time phase, giving a zero sum at each instant. The only net power flowing in the combined circuits is the I^2R loss, or active power, divided equally among the phases.

Energy Stored in the Air Gap

You have seen that there can be no net power flow across an air-gap space: unless and until a store of magnetic energy is first created in the space to act as a carrier for the energy flow. This is likewise true of radiobroadcasting, as mentioned earlier. The numbers are different but nature's process for transferring energy across a 20-mil air gap is the same as for a space of 1000 miles. In the small air gap of a motor however the proximity of iron and copper (with permeability and conductivity vastly greater than that of free space) leads to much greater energy densities and correspondingly greater rates of power flow than for radio waves. To calculate this magnetic energy—

Let the effective length of a magnetic path be g centimeters, its permeability be μ, the area be A square centimeters, and the number of turns in the magnetizing coil be N. When i amperes flow through the coil, the steady-state flux density produced in the path will be

$$(1) \qquad B=\frac{4\pi\mu Ni}{10\,g}\text{ gauss}$$

The voltage induced in the coil at any instant during the buildup of the flux $\phi=BA$ is

$$(2) \qquad e=-N\frac{d\phi}{dt}10^{-8}=-NA\frac{dB}{dt}10^{-8}$$

The energy stored in the field as the flux density rises from *zero* to B is

$$(3) \qquad \frac{W}{Ag}\int_o^t\frac{eidt}{Ag}=\int_o^B\frac{BdB}{4\pi\mu10^7}$$

$$=\frac{B^2}{8\pi\mu10^7}\text{ watt sec per cu cm}$$

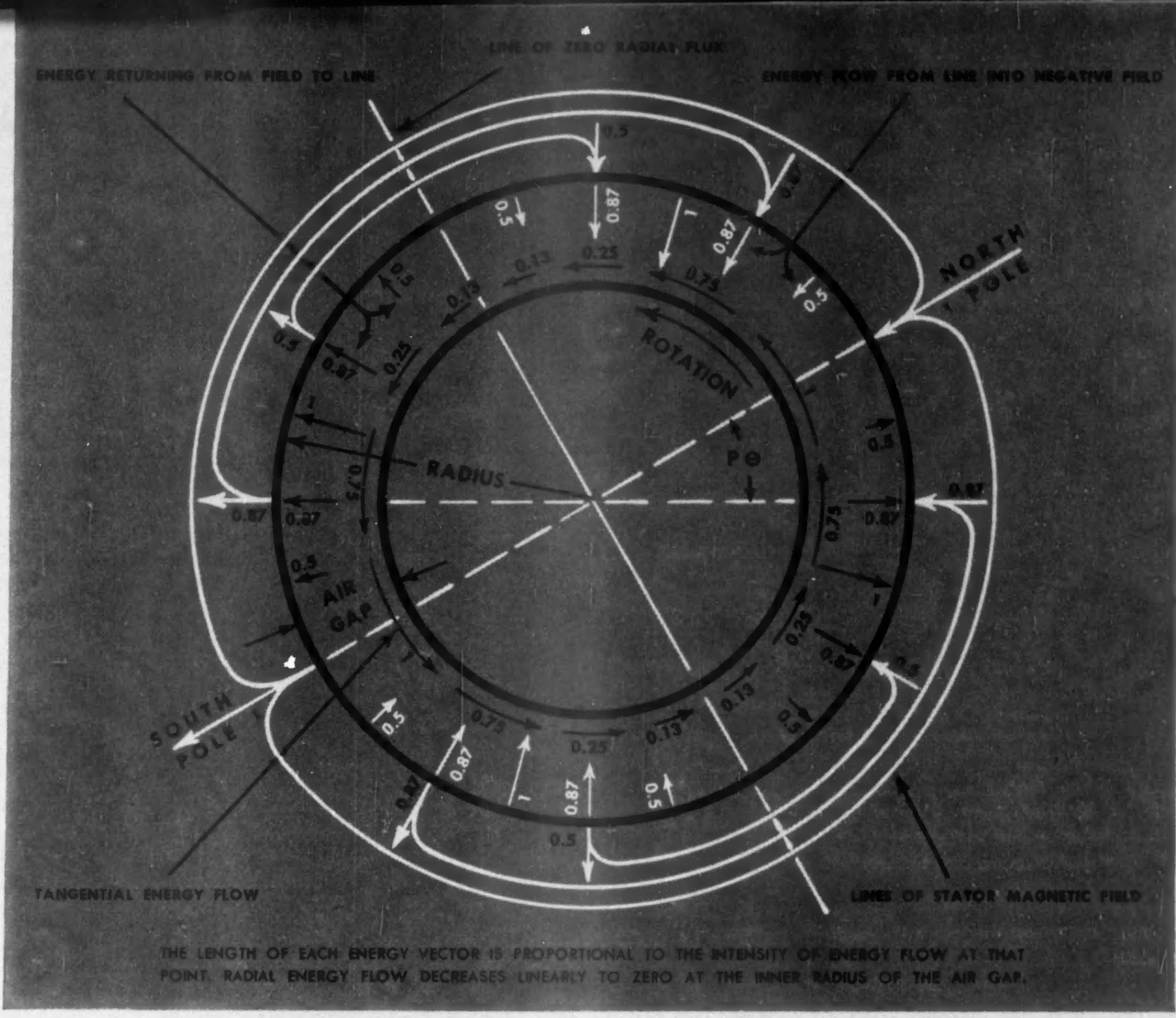


FIG. 6. FLOW OF MAGNETIC ENERGY IN NO-LOAD FIELD OF POLYPHASE (TWO-POLE) INDUCTION MOTOR.

At a density of 10,000 gauss this gives for $\mu=1$, or in air

$$(4) \qquad \frac{W}{Ag}=\frac{10}{8\pi}=0.398 \text{ watt sec per cu cm} = 4.81 \text{ ft-lb per cu in.}$$

This is a very important result. Every cubic inch of air—or vacuum or nonmagnetic material—that is magnetized to a density of 10,000 gauss contains 4.81 foot-pounds of stored energy. The energy stored in iron is negligible by comparison. For the permeability of steel in usual flux density ranges is of the order of 1000 or more, making the value of W less than 0.1 percent of its value in air at the same B.

In a three-phase motor, the rotating no-load magnetic field in the air gap preserves a constant magnitude, so that the total stored energy is constant. From equation (3) it is equal to the volume of the air gap in cubic centimeters times the square of the RMS flux density in gausses divided by $8\pi 10^7$. To maintain this steady revolving field equal volt-amperes must be delivered to each of the three phases in turn. From this relation is derived an expression for the total magnetic energy stored in the air-gap field—

$$(5) \qquad W_g=\frac{0.239}{f}EI \text{ watt sec}$$

where

E = RMS phase voltage

I = RMS amperes no-load phase current

f = line frequency in cycles per second

Equations (3) and (5) enable the air-gap flux of any motor to be calculated directly when the no-load volt-amperes and the air-gap dimensions are known. For example, if a three-phase 60-cycle 440-volt Y-connected motor (phase voltage =254) has a no-load current of 6 amp, and measurements show it to have an air-gap radius of 4 inches, a core length of 4 inches, and an air gap of 0.020 inch: then the magnetic energy stored in the air gap is

$$W_g=0.239\ (254)\ (6)/60=6.07 \text{ watt sec}$$

The volume of the air gap is $8\pi(4)(0.020)(2.54)^3=33$ cu cm so that the peak value of air-gap flux density (assuming no magnetic saturation) is

$$B_{max}=\sqrt{\frac{8\pi(6.07)10^7}{33}}=6{,}800 \text{ gauss} = 43{,}900 \text{ lines per sq in.}$$

Energy Crossing the Air Gap

There is a well-known theorem in physics, derived from Maxwell's equations that states:

The flow of electromagnetic energy through (penetrating) any surface is equal to the integral of the Poynting vector EH sin α over the surface where E and H are the electric-and-magnetic-field intensities in the plane of the surface, and α is the angle between their directions. The direction of the vector is at right angles to both E and H.

This theorem describes the flow of energy across the air gap of a motor, as well as the propagation of radio waves through space. To calculate the power flows let—

R = outer radius of the air gap (radius of the stator bore) in centimeters

$R-g$ = radius to any point in the air gap

G = length of air gap in centimeters

g = distance from stator surface to any point in air gap

θ = angular position of any point in the air-gap space in mechanical radians

α = mechanical angle of displacement

P = number of pairs of poles of the air-gap fields

v $= (R-g)\dfrac{d\theta}{dt}$ = tangential (counterclockwise) speed of the field in centimeters per second

B_g, B_θ = radial and tangential flux densities at any point $R-g$, θ in lines per square centimeter

Q_g, Q_θ = radial (outward) and tangential (counterclockwise) power flows at $R-g$, θ, in watts per square centimeter

All the magnetic lines of force lie in radial planes so that the electric field E is always in the axial direction and is

(6) $E = v\, B_g\, 10^{-8}$ volts per cm

B_θ does not contribute to E because it is parallel to v.

The magnetic field intensity H is $10/4\pi$ times the corresponding flux density B. The radial component of flux density B_g gives rise to a Poynting vector in the tangential direction (at right angles to E and to B_g) equal to

(7) $Q_\theta = EH_g = \dfrac{v\, B_g^2}{4\pi 10^7}$ watts per sq cm

But from equation (3) the stored magnetic energy of the radial magnetic field at $(R-g)$, θ is

(8) $W_g = \dfrac{B_g^2}{8\pi 10^7}$ watt sec per cu cm

Therefore, the tangential flow of energy, equation (7), in the direction of the field rotation is equal to twice W_g multiplied by the speed of the rotating field.

B_θ, the tangential component of B, gives rise to a Poynting vector in a radial direction equal to

(9) $Q_g = EH_\theta = \dfrac{v\, B_g B_\theta}{4\pi 10^7}$ watts per sq cm

This represents a flow of energy out of or into the stator winding; whereby the load energy is transmitted to the rotor, and the magnetic energy of the air-gap field is delivered by—and returned to—the power system through each phase.

Evaluation of these energy flows enables the process of energy transference across the air gap to be clearly seen. The power supply system serves as a reservoir into which the magnetic field energy is alternately delivered and received each quarter cycle. In free space the electrostatic field energy serves this purpose. In the motor however the magnetic-field strengths are multiplied many fold by the proximity of the power currents and the iron, making their energy vastly exceed that of the associated electrostatic fields.

Formulas for the flux densities B_g and B_θ can be developed, in accordance with Maxwell's field equation, and substituted in the foregoing. The tangential energy flow, equation (7), considering only first order terms representing the fundamental air-gap field and the load power, is found to be

(10) $Q_\theta = EH_g \dfrac{VB^2\ (R+g-2G)}{8\pi R10^7}\ (1+\cos 2P\theta)$ watts per sq cm

where B is the peak radial flux density at the rotor surface.

The radial energy flow inward from the stator is

(11) $Q_g = EH_\theta = \dfrac{PVB^2}{8\pi R10^7}\Big[(G-g)\sin 2P\theta + CG\ (\sin P\alpha + \sin P\ (2\theta+\alpha)\Big]$ watts per sq cm

where C = ratio of the rotor current (load component of stator current) to the no-load magnetizing current, and $P\alpha$ is the electrical angle of displacement between them.

Fig. 6 illustrates the energy flows expressed by these equations at no load ($C=0$). The magnetic field indicated by the outer curved lines is rotating counterclockwise at synchronous speed. The tangential energy flow, nearly uniform across the length of the air gap, is indicated by the curved arrows in the middle of the air-gap space. The length of each of the arrows indicates the energy density at that point, proportional to $1 + \cos P2\theta$, by equation (10). The radial arrows indicate the energy flow from the stator winding into and out of the field, proportional to $\sin 2P\theta$, and varying across the gap length from a maximum at the outer radius to zero at the inner radius.

The first term of equation (11) represents the radial flow of energy between the stator (supply system) and the air-gap magnetic field. The third term represents the variation in the flow of active power to the rotor, which creates torque pulsations in a single-phase machine, but adds to zero around the periphery of a polyphase machine. The second term of equation (11) is a uniform, radial power flow proportional to $\sin P\alpha$. Integrating this term around the periphery, the net power delivered to the rotor is found to be

(12)

$$\text{Useful power } R = \int_0^{2\pi} Q_g d\theta = \frac{CGPVB^2 \sin P\alpha}{4\ (10^7)} \text{ watts per cm of axial length}$$

By equations (1) and (6) this reduces to

(13) Useful power $= \pi PE(CNI) \sin P\alpha$ watts per cm axial length

which is the familiar expression for the output of a motor with a peak voltage of E volts per cm of core length, CNI peak ampere turns per pole, P pairs of poles, and a field displacement of $P\alpha$ electrical degrees.

Significance

When equations (10) and (11) are expanded to include the numerous second order terms representing the flow of energy of the leakage reactance fields (especially the space harmonics that cause the crawling torques indicated in Figs. 2 and 3), many interesting relations are brought out. The stator and rotor leakage fluxes can be distinguished from each other by noting from which side of the air gap their magnetic energies are supplied. Radial forces that cause magnetic noise can be determined as the radial derivatives of the total magnetic energy at any point. The energy method thus provides an over-all approach to the motor performance that is quite distinct from the equivalent-circuit and harmonic-analysis methods.

Designers require exact values. To this end they rely on equivalent-circuit calculations. They will find the energy method of analysis provides a key to the calculation of the finer points of motor performance, as well as a deeper understanding of its behavior.

Teachers need to give their students complete understanding of fundamental theory. To this end they point out the universal application of basic physical laws to machines, as well as electronic phenomena. They will find the energy method has a greater appeal to the student's imagination and is better understood than the usual textbook procedures. Ω

AN Connectors—

(*Concluded from page 52*)

Finally, after much research and development, we found the material that most nearly meets all the aforementioned requirements—a diallyl phthalate formulation. A member of the polyester group of plastics, it has an arc resistance of approximately 140 seconds, a dielectric strength of about 180 volts per mil, a moisture absorption of only 0.108 percent, and a post-mold shrinkage of 0.002 inches per inch.

The requirements of military equipment become more stringent each day. You'll recall how, during the last World War, theaters of operations extended all the way from the subzero regions of the Arctic Circle to the hot, humid, and fungus-laden atmosphere of the tropics. In modern warfare therefore practically any combination of ambient conditions may prevail.

Added to this we now have the jet-engine age. Equipment in aircraft must function at altitudes up to 70,000 feet. It must operate under moisture condensation conditions caused by rapid changes in altitude, with the attendant changes of temperature, humidity, and pressure. Yet there's still another consideration: the very complexity of a modern plane's electric system sometimes makes the location of trouble extremely difficult when it does occur.

With these things in mind you are in a position to weigh the importance of dependability in AN connectors. Their versatility and adaptability point up the large amount of research and development devoted to bringing them to their present high level of performance. Ω

CREDITS . . .

Page 10, Myron Johnson; pages 14, 15—Figs. 6, 7, and 9—Aluminum Company of America; pages 44, 45, Paul Marince; page 51, U.S. Air Force.

. . . AND A CORRECTION

Referring to the historical review of the American Society of Civil Engineers, September 1952 REVIEW, we received a letter from Prof. D. L. Snader, Norwich University, in which he quotes from the book *History of Rensselaer Polytechnic Institute 1824–1934* by Dr. Palmer Ricketts that "no well-defined courses in civil engineering were formulated at RPI until several years after 1828."

Aluminum for Copper—

(*Concluded from page 16*)

rosion can be disastrous. Even this situation can be met however if cell action is prohibited by eliminating any *one* of the four essentials. No electrolytic action will occur, for example, at a dry copper-aluminum joint. Alclad alloys too should find extensive application for they carry added insurance against perforation—because the coating of pure aluminum or anodic alloy is consumed when corrosion takes place, while the core is protected.

Overwhelming evidence shows that you can substitute aluminum or alclad alloys for copper without necessarily increasing corrosion hazards. So long as the invisible oxide film on aluminum remains intact, the metal will not corrode at ordinary temperatures. But if the natural film is penetrated or broken and a protective film can't form, corrosion may begin—and it may proceed rapidly because the thermodynamic driving force is usually large. Our advice to you is: don't use aluminum blindly. Ω

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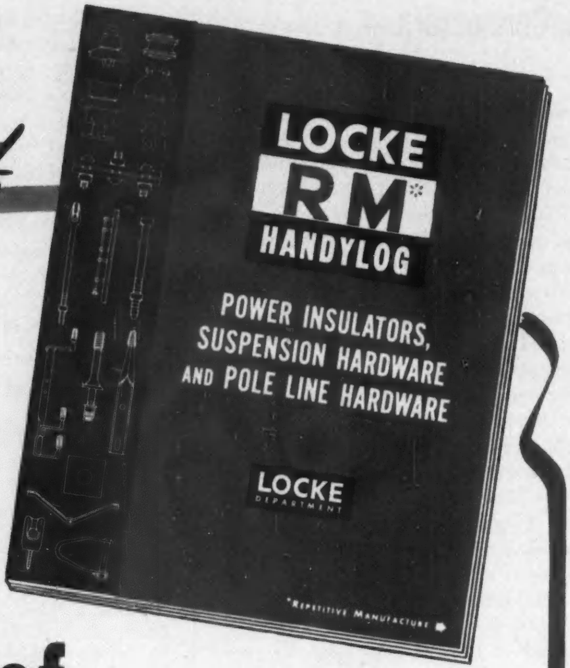

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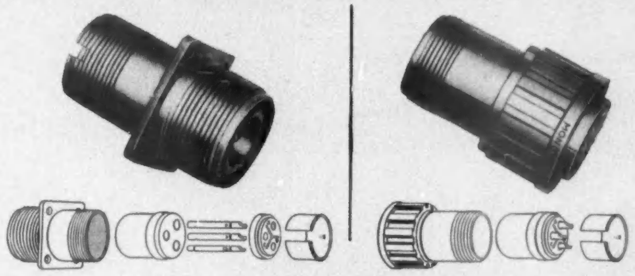

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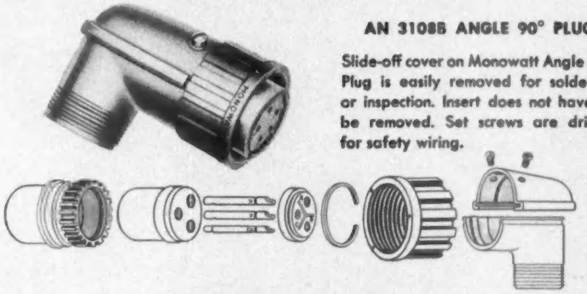

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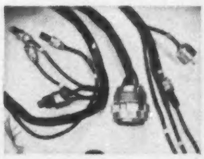

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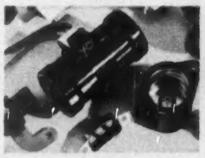

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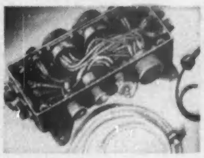

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