GENERAL ELECTRIC Review

MARCH 1952

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GENERAL ELECTRIC

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MARCH 1952 • VOLUME 55 • NUMBER 2

GENERAL ELECTRIC Review

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

THIS MONTH'S COVER **is an illustration from the article "Nuclear Fuel for Power Production" which begins on page 8 of this issue. The design of nuclear reactors for power production is a subject which promises to be of considerable importance to our economic future, and one of the fundamental considerations in that field is nuclear fuel.**

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.

DR. W. R. G. BAKER

Vice President and General Manager
Electronics Division, General Electric Company
was awarded

THE MEDAL OF HONOR

of the
Institute of Radio Engineers
for his "*early technical contributions to the radio transmitter art, his long sustained and effective leadership of institute and industry engineering groups and his outstanding service to the Institute*":
at its National Convention in
New York City, March 5, 1952

DR. BAKER HONORED . . . Walter Baker joined General Electric in 1917; the following year he undertook his first work in radio. Since then his career has been intimately associated with electronics: first in the design and development of equipment; its application; and later in the shaping of the electronics industry. Thus he has attained his present stature as pioneer, producer, adviser, director, and valiant champion of electronics in its ever-expanding role as a dominant technological factor in modern life.

This Is the Year!

A HUNDRED years ago, in 1852, the first national engineering society was founded in the United States. It was the American Society of Civil Engineers.

In those early days the name of civil engineer was quite different from that of today, being applied to differentiate those in civilian engineering from the specialized work of the military. As engineering knowledge increased, bringing the expansion of great industries, specialization became necessary, and the various groups of engineers formed national societies of their own.

First to thus form was the American Institute of Mining and Metallurgical Engineers in 1871. The American Society of Mechanical Engineers was founded in 1880; the American Institute of Electrical Engineers in 1884. Our engineering neighbors to the north founded The Engineering Institute of Canada in 1887. In 1893 the teachers in the engineering schools founded the American Society for Engineering Education. The engineers in the chemical industries founded the American Institute of Chemical Engineers in 1908; the Institute of Radio Engineers was founded in 1912; and with the coming of the licensing of engineers, the National Council of State Boards of Engineering Examiners was founded in 1920, and the National Society for Professional Engineers in 1934. In 1946 the Instrument Society of America was formed.

This is neither a complete list, nor is the founding of engineering societies yet ended, for as new knowledge has brought new vision into being, so have the engineers in each new field formed an engineering society wherein they meet to describe to one another, for inspiration, for record, and for standardization, the contributions which have been made to the advancement of the knowledge in that field, and to the establishment of a high professional standing. This is a never-ending procession, until today there are nearly 100 national engineering organizations with their multitude of Sections and Student Branches throughout the United States and Canada, not to mention the over 200 state, regional, and local engineering clubs, councils, and societies; together with international engineering organizations and meetings with engineering societies of foreign countries to complete the picture. Thus have the engineers built strong, virile organizations for the advancement of engineering and the profession.

This is the engineering profession after 100 years. This is the unseen technical force behind management operating under the free enterprise system in a land of opportunity with abundant resources and with an impelling urge to provide the things of life for every man to have. This force has helped bring our country to the position it occupies in the world today as the champion of free peoples everywhere. In celebration the engineers will gather throughout the year. An important part of the Centennial of Engineering Celebration will be a convocation in Chicago, September 3 to 13. Many expect that this will be the greatest gathering of engineers ever assembled.

It will crown 100 years of opening new doors; 100 years of vision, hard work, and perseverance; 100 years of heartbreak; 100 years of inspiration; 100 years of glorious achievement; 100 years of service. It will also crown 100 years of engineering education which has trained students of ability so they could enter the profession and take their places among us.

But it seems that in progress for good there is usually a sacrifice. History informs us that no great movement was ever successfully undertaken, has ever survived without some pain, sacrifice, and even some injustice. And so it has seemed to many engineers, that as they have served they have not received the recognition their service justifies. They feel they do not enjoy the recognition by the public accorded the doctor, or the lawyer, or other professional men. And they feel that partly this is so because there is no over-all engineering organization to speak nationally for them. In building their separate engineering organizations they have not built a co-ordinated structure.

Nevertheless, separate engineering societies working alone or working together have made their mark in presenting the position of the engineer in many significant ways. But there is need for continuous attainment, and the work will go on.

During the two years past, a well-conceived committee has been exploring the opportunity for an engineering organization structure for effecting increased unity of the engineering profession. The committee report is hopefully awaited. May it be that in this 100th year of outstanding engineering society contribution each engineer will find inspiration in the formula toward achievement of the objective.

Then will the year 1952, as it closes a hundred years of outstanding engineering accomplishment, open a second hundred years with the inauguration of the extended organization. Let Chicago be the birthplace. Let September be the month. What an eminent year it could be if this unity were thus achieved.

Everett S. Lee

EDITOR

Nuclear Fuel for Power Production

By DR. J. F. FLAGG and M. J. GROSS

The design and operation of nuclear reactors for producing power is intimately associated with the development of suitable nuclear fuel. The fuel must meet strict physical and chemical, as well as nuclear, requirements in order to support a chain reaction in a reactor at relatively high temperature and energy levels. An understanding of these requirements is essential to an appreciation of the problems involved in designing the reactor.

The following material reviews these subjects, as well as the availability of fissionable material and the reprocessing of fuel. It also includes a brief discussion of the economics of nuclear power production.

Basic Concepts

Nuclear fission is a particularly violent type of nuclear reaction produced in the heavier elements by bombardment, usually with neutrons. In this reaction the element in question is split into fragments of lower atomic number. The total mass of the fragments almost equals that of the original element. The small difference in mass shows up in the form of radiation, kinetic energy, and eventually heat.

Of the isotopes found in nature in substantial amounts, uranium 235 (U-235) is unique with respect to fission. An atom of this isotope, under favorable conditions, not only divides but also liberates enough new neutrons to support a continuing chain reaction of fission with other U-235 atoms. This chain reaction is the key to the release of atomic energy.

Naturally occurring uranium contains only 0.7 percent of the U-235 isotope; the remainder is nearly all uranium 238 (U-238). U-238 is fissionable by fast (or high-energy) neutrons but this element is incapable of sustaining a chain reaction.

In U-238, however, an important alternate nuclear reaction with neutrons may occur: Through the capture of a neutron and the subsequent emission of beta rays, the U-238 is changed successively into uranium 239 (U-239), neptunium 239 (Np-239), and plutonium 239 (Pu-239).

The new element Pu-239 is both fissionable and capable of supporting a chain reaction. It is called a **secondary fuel**, because it does not exist in nature in significant quantity and because it is artificially produced in a nuclear reactor.

U-235 is called a **primary fuel**. It is obtained from natural uranium by isotopic separation. U-235 will even support a chain reaction without separation from natural uranium. (The first chain reaction produced by man was in a natural uranium "pile" at the University of Chicago in December, 1942.)

U-238 is called a **fertile material** to indicate that it can be converted into a nuclear fuel. Thorium 232 (Th-232) is another fertile material which, through neutron capture, may be changed into a secondary fuel, uranium 233 (U-233).

In the conversion of fertile material there is a theoretical possibility of producing more fuel than is consumed in supplying the necessary neutrons. This is called **breeding**.

Fission Products and Energy

The products of the fission of U-235 are isotopes of the 34 chemical elements from zinc through europium in the periodic table. Their total mass will be nearly equal to the mass of the fuel consumed. (The difference appears as energy).

The energy release from fission of an atom of U-235 amounts to nearly 200 million electron-volts. This results from the conversion of mass to energy in accordance with the Einstein mass-energy equivalence law.

Fission energy consists of:

Kinetic energy of fission fragments	83%
Neutron and gamma ray energy	6%
Radioactive decay energy	11%

It takes approximately 3.1×10^{10} fissions to release an energy equivalent to 1 watt-second. Stated in more familiar terms, the complete fission of 1 gram of U-235 releases 24,000 kw-hr. The combustion of 3.3 tons of coal would be required to produce the same amount of energy.

Although electrical terms have been used in the above comparisons because of their familiarity, the energy referred to appears primarily in the form of heat; it cannot, of course, be converted to electrical energy without appreciable loss. Furthermore, a portion of the energy is completely lost, for all practical purposes, because it is in the form of neutrons and radiation which are dissipated over a considerable amount of space.

Nuclear Fuels

By **nuclear fuel** is meant some fissionable material capable of supporting a chain reaction.

The term is applied not only to pure U-235, Pu-239, or U-233, but also to their chemical compounds, alloys, or mixtures with other elements. The fuel may be used for explosion in a bomb, production of radioisotopes, manufacture of secondary fuel, or generation of useful power.

The characteristics required of nuclear fuel depend upon its intended use. In this article, the term will refer to fissionable material in such chemical and physical form that it will support a controlled chain reaction in the proper

Dr. Flagg, Assistant Manager of the Chemistry and Chemical Engineering Section, Technical Department, Knolls Atomic Power Laboratory, has been with General Electric since 1946. His work is with chemical separations of fissionable materials, and the analytical chemistry of these and related elements.

Mr. Gross has been engaged in research and engineering with General Electric since 1928. At present he is Administrative Assistant to the Technical Manager, Technical Department, Knolls Atomic Power Laboratory. He also directs a radioactive remote-control testing laboratory and a mathematical calculations service group.

environment at *relatively high temperature and energy levels.*

Power Production

A knowledge of the factors influencing the physical and chemical form of nuclear fuel intended for power production is important to an understanding of nuclear fuel. At the same time, such knowledge also gives some appreciation of the problems of reactor design.

As far as we know today, the only practical way of converting fission energy into electricity is through the intermediate steps of heat and mechanical energy, and the use of a turbine-generator. Thus, the fission chain reaction becomes merely another way of getting heat, and in that case the nuclear reactor is simply a substitute for the firebox and boiler of a conventional power plant.

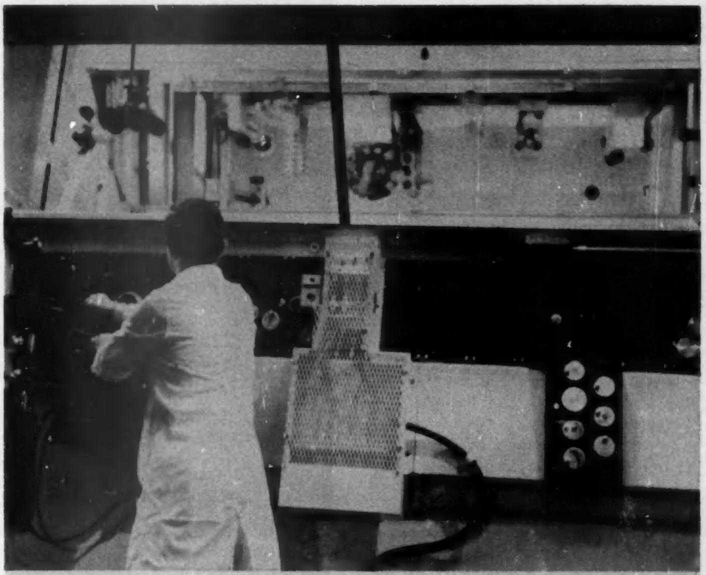
The reactor may be characterized as a very special assembly of (1) nuclear fuel, (2) moderating material to control the energy of the neutrons given off, (3) heat-transfer media to remove the heat, (4) shielding to confine the intense radiation, and (5) means to control the rate of fission.

The efficiency with which heat taken from the reactor can be converted into useful energy depends upon its temperature, in accordance with the well-known laws of thermodynamics. The higher the temperature, the more efficient the possible conversion into mechanical and electrical energy. (In a modern steam-turbine power plant using a temperature of 1050 F, net efficiencies of the order of 36 percent are obtained.)

Critical Mass

It is well known that a fission chain reaction requires a **critical mass** of fissionable material and a **critical size** of reactor. The required critical mass may vary from a few pounds of pure U-235 to several tons of natural uranium. It depends not only on the type of fuel but also on the amount of moderating (neutron-slowing-down) material, the amount of absorbing material, the presence or absence of a neutron reflector around the reactor—and their physical arrangement.

The critical mass of a reactor cannot be exceeded without loss of control of the reaction. However, in a reactor intended for large power output, the need for structural and heat-transfer materials, undesirable from a strictly nu-

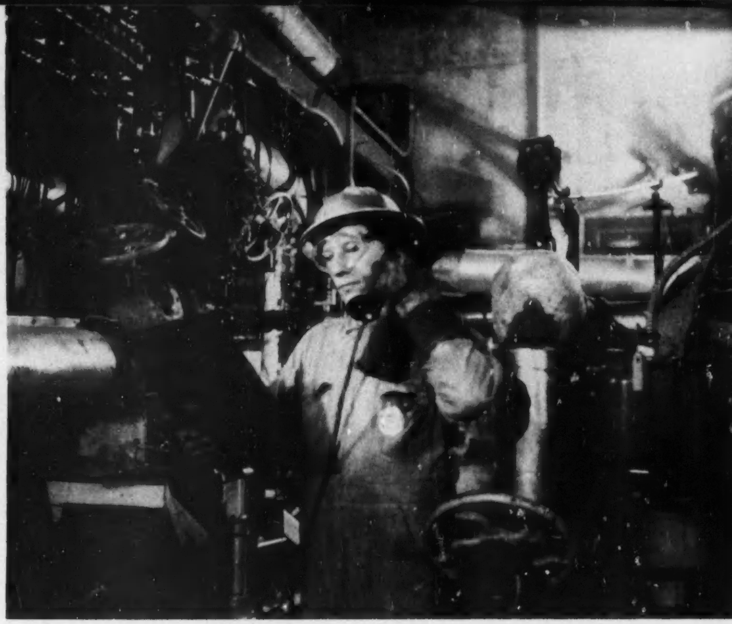


REMOTE CONTROL study of radioactive metals; mirrors beyond a heavy wall show apparatus whereby the operator opens capsules and analyzes samples

FISSION PRODUCTS after separation from unburned fuel are contained in shielded casks rolled out through the rear wall in an early step in disposal clear standpoint, influences the nuclear factors in the direction of larger critical mass and size. To a certain extent this is fortunate, because even with the increased size, heat must be removed from a limited volume and concentrated thermal fluxes must be dealt with which greatly exceed those found in ordinary heat-transfer processes.

It becomes evident, therefore, that in order to be useful for power production, nuclear fuel must be capable of operating at high temperature. Furthermore, it must be of such a nature and so arranged that heat can be readily removed by a heat-transfer medium.

Both of these factors have a great influence on the nature of the fuel, the way it is contained, and the way it is distributed through the reactor. Solid uranium metal conducts heat relatively well, but it has other limitations, including too low a melting point (1133 C) for some applications. Oxides, alloys, mixtures, liquids, and gases have all been considered as potential power-reactor fuel material, and in many different environmental arrangements.



CLOSE-UP OF EXPERIMENTAL liquid-sodium heat-transfer apparatus being used in the development of a submarine intermediate reactor.

Radiation Damage

High-energy radiation and high-kinetic-energy fission particles may permanently damage materials by the displacement of atoms, by ionizations, and even by particles remaining imbedded in the material as impurities. Radiation may break up chemical compounds, displace atoms in a crystal lattice and, in general, bring about quite important changes in the submicroscopic structure of any material within the reactor, including the nuclear fuel. There are good theoretical reasons to believe that in metals it may, among other things, increase the rate of creep and the rate of corrosion.

Now the control of corrosion in reactor materials is very important, particularly in the nuclear fuel itself and in any material jacketing the fuel. This control must take into consideration the possibility of radiation damage, the effect of high temperature, the use of unconventional engineering materials—and the difficulty of repairing the reactor, for intense radioactivity still prevails, even after the reactor has been shut down.

Burnup

The depletion of fuel due to fission is referred to as **burnup**. Obviously, it does not involve combination with oxygen as in ordinary fuel burning.

As burnup occurs, the fission chain reaction stops—unless compensating steps are taken or the burned and contaminated fuel is replaced. One such compensating step is to put a neutron-absorbing material such as boron into the reactor, and then to remove it gradually to compensate for the fuel depletion. A complication is the fact that certain of the fission products formed during burnup are good neutron absorbers, and these also interfere with the chain reaction and require compensation.

Some of the fission products have intense long-lived radioactivity. Although it is possible to handle new *unfissioned fuel* with only relatively simple precautions, the radioactive fission products so "contaminate" the used fuel that it can be handled only by remote control from behind protective barriers.

The fission products consist of both gases and solids, even at ordinary temperatures. In some cases, the objective is to keep them intimately a part of the nuclear fuel. The fuel must then be tightly jacketed.

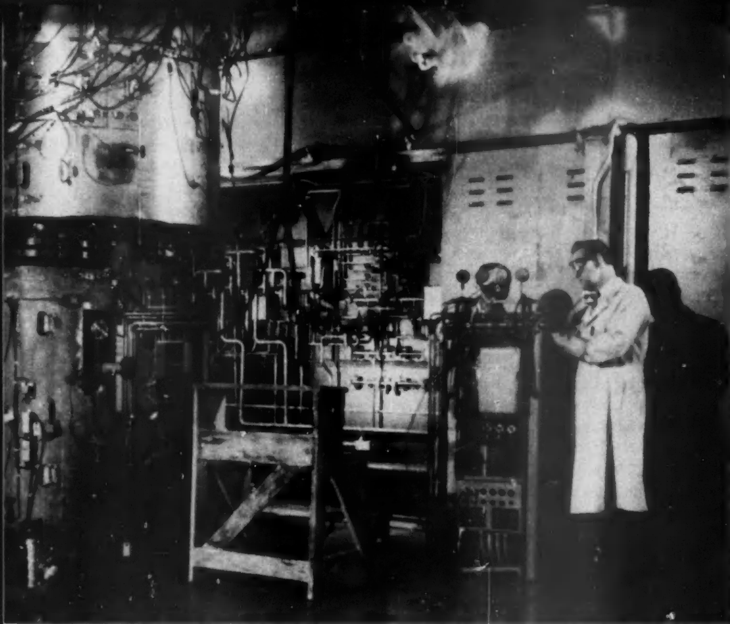
In other designs (such as the homogeneous reactor, in which fuel and moderator are mixed in liquid form), the fission products are removed from the reactor under controlled conditions.

Fuel Replacement

As fuel is burned up, then, new fuel must be added to maintain the fission chain reaction. In addition, because of fission-product poisoning, fuel may have to be removed long before it is completely burned up.

And there may be other reasons for removing old fuel, depending upon the design of the reactor. These might include preventing gaseous fission products from accumulating to the point where they produce too high a pressure in the space in which they are confined; the difficulty of maintaining uniform heat distribution within the reactor in spite of nonuniform fuel loading; and the necessity of removing valuable secondary fuel.

The fact that only a part of the fuel can be fissioned in a reactor influences its physical form, how it is contained, and the whole reactor design. After the fuel is removed, it must then be reprocessed to reclaim the valuable fissionable material still remaining. The process must be efficient and not too expensive. Whether it is feasible depends upon the suitability of the fuel for reprocessing—upon its chemical



MECHANICAL TEST APPARATUS for reactor control experiments being conducted at the Knolls Atomic Power Laboratory

form, its dilution with other materials, and its container, if any.

Radioactivity in Reprocessing

One of the greatest problems in reprocessing nuclear fuels is caused by the radioactivity of the fission products. Up to a certain time spent in the reactor, this activity is a function of the extent of burnup of the fuel. Then the saturation point is reached. The rates of production and decay of radioactivity are equal.

It might appear to be optional, in reprocessing, to shield all operations or to allow the fuel to "cool" until conventional reprocessing methods can be used without shielding. Unfortunately, this latter condition can never be met. Many of the elements formed abundantly in fission, such as cerium and cesium, have half-lives of many months or years.

Since 7 half-lives must elapse for an isotope to decay to roughly 1 percent of its initial activity, and since reprocessing requirements may call for removal of the fission products to as little as a millionth of the initial value, it is clear that reprocessing must be done on active material.

On the other hand, a number of the fission products, such as iodine and barium, do have half-lives of days or less. Hence, it is possible, by cooling for a shorter time, to reprocess und. r compromise conditions.

High levels of gamma radiation require at least several feet of concrete or its mass equivalent for shielding. The less penetrating alpha and beta rays are relatively easy to protect against, but handling such materials always presents a personnel-hazard problem. In addition, there may be a toxicity problem, as in the case of plutonium.

The time factor for cooling thus enters into the reprocessing picture in a complicated way, for we also have to consider the fuel inventory held up in reprocessing. To operate a reactor, with attendant fuel reprocessing, will require a greater fuel inventory for a 200-day cooling time than for a 100-day period. How much greater will be determined by other factors, such as the rate and amount of fuel discharge.

Still another factor to consider in this connection is the effect of fission products on process chemicals. The reagents used must be stable to radiation. For even water will be decomposed at an appreciable rate by alpha, beta, and gamma radiation, giving rise to gaseous products whose presence could affect the design of the equipment.

Parallel to this problem of the chemist is that of the chemical engineer. He must design equipment that will insure stability of process solutions and meet the shielding requirements in a particular area.

Recovery and Purification

The economic and strategic value of nuclear fuels makes high recovery important in reprocessing. Otherwise, reprocessing fuel losses may be greater than the loss through burnup in the reactor. The recovery can, of course, be made more efficient, but probably only at the expense of additional time and equipment. This must be balanced against the potential value of the material, and it is not always easy to decide the point of diminishing returns.

High chemical and radiochemical purity of the recovered fuels is as strict a requirement as high recovery. Impurities even in the parts-per-million range would reduce the efficiency of the chain reaction by parasitic neutron-capture reactions, or it would affect the physical properties of the fuel elements, or both.

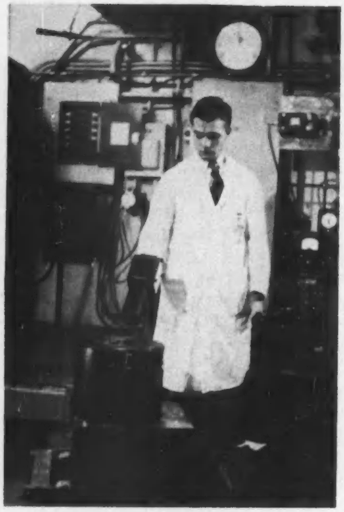
The large-scale preparation of high-purity uranium was a necessary forerunner of a successfully operating reactor. Similarly, in reworking the fuel, separation by a factor of a million or more may be required from the radioactive fission products. This again complicates the separation process and necessitates additional steps, with the attendant possibility of reprocessing losses. The development of remote-control metallurgical procedures could alter the entire reprocessing picture by permitting the refabrication of more contaminated products.

Reprocessing Methods

Combined with the problems of radioactivity, high recovery, and decontamination, the reprocessing of nuclear fuels introduces another problem wholly unique in the field of chemical processing: the problem of the critical mass. If it weren't for this, the size of a plant could be as large as necessary to accomplish the desired output.

(Even so, the plants would be regarded as small by ordinary standards. For process volumes may be equivalent to a maximum of only a few percent of the capacity of the newest type catalytic cracking units—which are reported to have capacities of upwards of 15,000 barrels per day.)

The amount of U-235 or Pu-239 that can be assembled without starting a chain reaction is definitely limited.



HEALTH PHYSICS inspector using instrument to determine radiation from material in lead cask

Indeed, recently declassified information indicates that under some conditions this may be of the order of a few pounds. Chemical reprocessing equipment must therefore be designed to prevent any possible accumulation of this critical amount of material.

Incidentally, the chemist must be certain that no side reactions occur in which material may accumulate. Such a restriction limits the amount of material which a plant may reprocess without resorting to numerous small-scale batch steps. Some of the unattractive features of this are overcome if reprocessing is made continuous, with correspondingly smaller fuel hold-up.

Actual reprocessing techniques are many and varied. Strictly physical methods are used when the problem is one of separating two isotopes of the same element; for example, U-235 from U-238. Chemical methods, such as precipitation, ion exchange, solvent extraction, and volatilization, are basically better adapted to the problem of separating low concentrations of materials, such as plutonium and fission products, from high concentrations of elements, such as uranium or thorium.

The most desirable process for a given separation is, obviously, one in which the recovery is high, the decontamination is complete, and the wastes are in readily disposable form.

The physical form in which the fuel is used may determine to a degree the type or efficiency of the process used. The known fissionable materials may be prepared and used as metallic powders, rods, sheets, etc., or in the form of oxides or salts.

Except in the case of the so-called **homogeneous** reactors, in which the fuel is liquid—or dissolved in a liquid—the fuel must be covered to prevent gross contamination by escaping fission products. The first step in reprocessing, then, may consist of physical or chemical removal of this coating, followed by the separation techniques mentioned previously.

The largest amounts of radioactivity will be handled at the start of the reprocessing. After a few stages, this will be reduced to a point no longer requiring maximum shielding. The final product will be relatively inactive, although still requiring cautious handling because of toxicity.

For each separation method there are degrees of desirability. Precipitation processes may be made highly selective, but they are not adaptable to continuous operation. On the other hand, extraction and ion-exchange processes may be operated continuously, but critical mass and radiation stability factors may weigh against them. There probably is no single technique best suited for all types of fuel reprocessing.

Availability of Raw Material

It is not too optimistic to assume that good solutions eventually will be found to the many problems involved in utilizing nuclear fuel for power production. The extent of its use, therefore, will ultimately be determined by the availability of the raw materials from which it must be obtained.

The time may be many years away, but it is certainly pertinent to inquire into the availability of uranium—and also (for reasons discussed in subsequent paragraphs) into the availability of thorium.

According to estimates made by geologists, uranium makes up four parts per million of the earth's crust. The concentration of thorium is nearly three times that much. However, they are so widely distributed that significant concentrations in workable deposits are exceptional. From the information available before 1940, it appears that the world's commercial, or workable, deposits known at that time contained about 100 million pounds of uranium and perhaps a somewhat smaller amount of thorium. This is probably only a small portion of the total that might be available.

Today the bulk of our uranium comes, in order of available supply, from the Belgian Congo, the United States (particularly Colorado), and Canada. The chief sources of thorium are in India and Brazil, but it has been produced from minerals found in North Carolina, Virginia, and Florida.

Gordon Dean, Chairman of the Atomic Energy Commission, has recently stated that we now mine some deposits of uranium containing as little as one part of uranium oxide per thousand parts of ore.

Of obvious interest are deposits where uranium can be obtained as a by-product of the mining of some other valuable mineral. For example, the Atomic Energy Commission has announced that the United States and the United Kingdom have entered into an agreement with the Union of South Africa whereby uranium will be obtained as a by-product of gold production. A process has also been developed for extracting uranium from phosphate deposits as a by-product of fertilizer production.

Breeding

What the raw-material supply means in terms of potential power depends to a great extent on the success of the process of **breeding**. As previously explained, in the conversion of fertile material into nuclear fuel (Pu-239 or U-233), it is theoretically possible to produce more nuclear fuel than is consumed. This may sound like something for nothing, but it is not; the extra nuclear fuel comes from the fertile material. And, since there is a great deal more fertile material in nature (U-238 and Th-232) than there is of the primary fuel U-235, breeding would greatly increase the availability of nuclear fuel.

The theory behind breeding is that there are sufficient neutrons released in fission to provide: (a) one neutron to maintain the chain reaction, (b) another neutron to produce an amount of fissionable material just equal to that consumed, and (c) excess neutrons to produce fissionable material over and above the replacement of that consumed. Since the fission of a U-235 atom by one thermal neutron releases 2.5 new neutrons, there should be in this case—and under ideal conditions—2.5 minus 2.0, or 0.5, neutrons left over for breeding.

Actually, because of parasitic capture and reprocessing loss, it is impossible to make use of all the excess neutrons. Nevertheless, the process of breeding is very attractive as a possibility for greatly increasing the available fuel supply.

Economics of Nuclear Power

Much has been written of a speculative nature about the economics of nuclear power, but it necessarily has been based on very nebulous information. Many more years of work may be required before the economic aspects are clear.

For some years to come nuclear fission is certain to be an expensive source of electrical power which will not compete with conventional fuel—except in certain specialized fields where advantage may be taken of its unusual properties. This is not intended to be discouraging—on the contrary, nuclear fuel may, before too long, contribute greatly to progress in those specialized fields.

Even the cost of fissionable material is hard to determine accurately, because of the military conditions under which the plants have been built for its production. Whatever this material cost, it is only a part of the total cost of nuclear power. The over-all figure must include the operating and fixed costs of (1) the fuel fabrication, (2) the nuclear reactor and associated heat-transfer system, (3) the turbine and electric generating equipment, and (4) the chemical reprocessing of the fuel. Compared with the costs of plant facilities for the conversion of ordinary fuels, estimates of these costs range considerably higher today.

Unusual Properties

The unusual properties of nuclear fuel that may be valuable in special fields include: (1) an extremely high energy potential per unit of mass, (2) the release of this energy without consuming oxygen as with other fuels, and (3) a potential ability to produce simultaneously both energy of commercial value and secondary fuel of military value. The first property is of great interest for ship propulsion, where the weight of conventional fuel is a limiting factor in cruising range.

For the same reason, nuclear fuel is being given serious consideration for airplane propulsion. In this case, the reactor must operate at an even higher temperature than for ship propulsion and must not require excessively heavy radiation shielding.

For submarine propulsion the release of energy without oxygen consumption is an added advantage. The Atomic Energy Commission has announced that work is in progress on two nuclear power plants for this special application—one at the Knolls Atomic Power Laboratory (operated by the General Electric Company) and the other under the joint direction of the Westinghouse Electric Corporation and the Argonne National Laboratory.

Electric Power

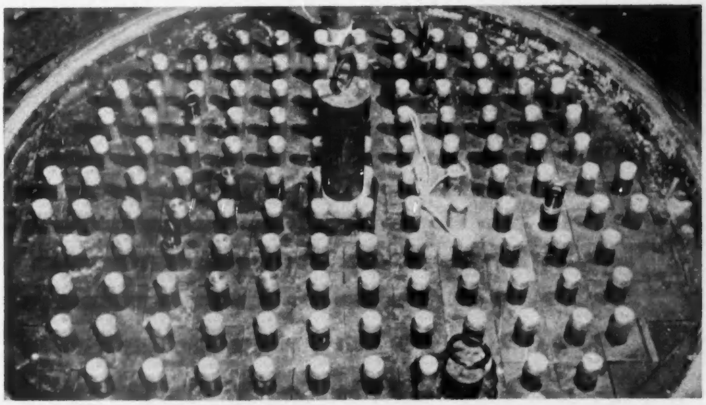
The potential ability of nuclear fuel to produce power and secondary fuel simultaneously may offer the best opportunity for the initial economic and large-scale generation of electricity. It is interesting to note that the Atomic Energy Commission last year signed agreements with four industrial groups* for studies of the possibility of private industry's building and operating reactors which are intended for this dual purpose.

It is probable that the reactors for large-scale generation of electricity will be built in locations that would preclude the possibility of endangering populated areas through malfunction or sabotage. If so, this would be only a temporary limitation, until more experience is obtained with the new hazards involved. Eventually, there is no reason to believe that such reactors cannot be made safe enough for operation anywhere.

The development of nuclear power has been in progress for about five years—and on a rather intensive basis, by industrial standards. It has benefited, of course, from the great effort directed toward military ends The fact that as yet no significant electric power has been produced is an indication of the magnitude of the scientific and technological problems involved. Progress is being made, however, and before too long nuclear power plants should be a reality. At first they will be expensive and of specialized value only, but as time goes on they undoubtedly will find an increasingly valuable place in our power economy.

*(1) Monsanto Chemical Company and Union Electric Company, both of St. Louis; (2) Detroit Edison Company, of Detroit, and Dow Chemical Company, of Midland, Michigan; (3) Commonwealth Edison Company and Public Service Company of Northern Illinois, both of Chicago; (4) Bechtel Corporation and Pacific Gas & Electric Company, both of San Francisco.

The opinions expressed in this article are those of the authors and do not necessarily reflect policies or judgments of the Atomic Energy Commission.



HEAVY WATER research reactor. Uranium rods are suspended in tank of heavy water. The uranium weighs nearly 3 tons, the heavy water 6½ tons; 300 kw is removed as heat from the water

The Story of Electric Time

By IRA A. TERRY

Time measurement and indication have come a long way in accuracy and availability since the days of our oldest written records when man had to content himself with a concept of days and nights, moons, seasons, and years. The oldest known method of measuring and indicating time is the use of sun dials, dating back to about 4000 BC The first basic mechanical timekeeper known to be developed was the "clepsydra" water clock (circa 1000 BC), fitted with gears that moved a pointer on the dial. It was later (about 300 BC) that hour glasses, notched candles, and graduated lamps formed the basis of time indication.

The first recorded mechanical clock was built in 1360 by Henry deVick for the Palais de Justice in Paris; and the next and most basic discovery, making possible truly accurate clock regulation, was the principle of the pendulum by Galileo, who is credited with this discovery in 1581. Christopher Huyghens and Robert Hooke are credited with the application to clocks.

Next followed the development of balance-wheel and hairspring escapements, coil springs, and jewels. Then American ingenuity came to the front in the Connecticut Valley with the manufacture and sale by Eli Terry* of several thousand wooden-movement clocks for $4 each.

Electric Time

Very shortly after the discovery of the principle of electromagnetism, experimenters recognized the possibilities of a new source of energy for driving clocks. To Alexander Bain, of England, goes the credit for the first electrically driven clock, developed in 1840. It used the pendulum as its basic timekeeping system. Then, for over 70 years, electric time systems were based upon the use of direct current either to drive pendulums directly or to wind springs for pendulum or balance-wheel escapements.

Henry E. Warren of Ashland, Massachusetts, who has come to be known as the father of modern electric time, experimented with clocks as a hobby. In 1912, after several years of experimenting, the Warren Clock Company was organized to build and sell an ingenious and accurate battery-operated clock. The manufacturing operation was housed first in an outbuilding, and later in a barn on his farm.

But Warren was not satisfied with his product at that time. The clock was battery-operated and it was rather tricky to install and maintain in operating condition.

He had a vision of a vast network of electric clocks—a time service available at every socket in the home, factory, office building, and every other place of business. He realized, of course, that alternating current would have to be used to make accurate time available conveniently to such a mass market. Not only would it provide greater availability but also, with accurate control of frequency, it contained the required element of basic time indication which is not present in direct current.

He started experimenting, therefore, with synchronous motors, hoping to obtain one which could be unidirectional with positive starting characteristics and which would maintain synchronism with a power system. By 1916, he developed a synchronous motor which would start by itself, run on alternating current, and carry the load of the gear train and clock hands without difficulty.

The completion of the synchronous motor demonstrated that further developmental work was necessary. For the timepiece was a failure—it varied as much as 10 to 15 minutes a day on the alternating current supplied to the farm workshop. Warren concluded correctly that the frequency of the alternating-current system was in error. The following quotation from an interview with Warren in the *Boston Herald* in 1936 describes the subsequent developments:

> This first crude motor was connected by tiny gears to the hands of a clock which had a small dial. Then followed weeks of observation to determine the behavior of this clock, which was connected continually to the Boston Edison System. It was off as much as 10 to 15 minutes per day.
>
> One day, after verifying my records, I telephoned the Edison Power Station and said as tactfully as I could that the frequency at that time was in error approximately half a cycle. I was politely told that according to their instruments it was correct. Then I suggested that the standards must be in error, which probably made the operator at the other end of the wire think I was foolish. Nevertheless this unusual message from a stranger was taken seriously, and I learned later that the meters at the power station were rechecked with the laboratory standards.
>
> The experiments in measuring continued at Ashland for many weeks. At the same time development work on the motor was rushed until there had been built four or five clocks that looked as though they could operate for a long time. My apparatus and experiments were rechecked very carefully at the Edison Laboratory under the direction of Mr. R. S. Hale, in charge of research and laboratories, a man of clear vision and progressive ideas to whom I feel much indebted.
>
> After some months the way was made clear by him for an experimental demonstration, at the L Street power station at Boston, of a regulating instrument I had de-

Mr. Terry is manager of engineering of General Electric's Telechron Department. In 27 years of GE engineering, he has worked with motors of all sizes—from the largest to the smallest.

*The author claims no relationship.

signed and built. This instrument was intended to eliminate errors in frequency of the current which had so far prevented my clocks from keeping time. It was designated as a master clock but differed radically from any other form of master clock formerly used for such work.

After it had been set up I explained to the operators and engineers what it was intended to accomplish and how it might guide them in controlling their frequency.

I never dreamed that they would make any use of it (the master clock) until there had been time to regulate it and observe its behavior.

However, the men at the switchboard were curious to try regulating by the new kind of indicator. Before any of us realized what had happened, the great Edison system began sending out accurately timed alternations. That was on October 23, 1916, and from that day to this the same service has never been interrupted except for a few minutes by reason of accidents.

There was a tremendous outside interest in the new idea. Representatives of other big power companies came to consult with me at Ashland, and soon the master clocks were controlling the frequency of current which was flowing into a million homes.

And so, at this time in 1916, the principle of the synchronous electric clock system—the master clock supervising the frequency, and the self-starting, unidirectional synchronous motor—became an accomplished fact.

In 1917, the year following the successful demonstration of the master clock and clock motor, work began in earnest in a factory converted from a barn. Personnel increased from three men to eight. But space was inadequate, and more operators were needed to handle the backlog of orders. So more space was leased, machine tools were obtained, and 20 more people were hired. The business grew by leaps and bounds. So in the space of 35 years, an industry was built around a revolutionary principle that made comparatively accurate electric time available to homes and other places that needed it.

TYPE A—one of four types of master clock for regulating frequency in alternating-current systems

Today there are four general classes of products in production: master clocks, timing motors, clocks, and timers. Each has an interesting story behind it.

Master Clocks

Master clocks, the instruments responsible for modern electric time, are accurate, convenient, and scarcely ever require attention by the user. Yet they regulate, it is estimated, over 95 percent of all alternating current generated in the United States and much of that produced elsewhere. They are today basically the same as the original design, a tribute to the thoroughness of the initial engineering.

Power producers and consumers have obtained a threefold benefit:

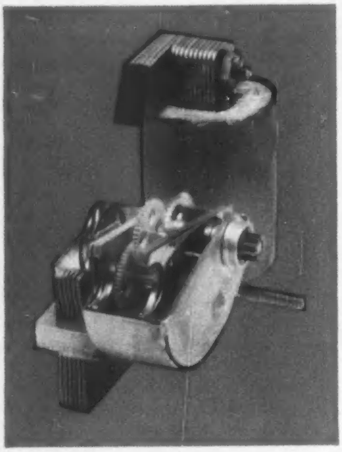
1. Improved service is furnished to manufacturing companies, insuring more uniform speed of motor-driven machinery and, as a general result, assuring better product quality.
2. More accurate and better synchronized records are provided at lower maintenance cost, by enabling power companies to use synchronous-motor movements in maximum-demand meters and graphic recorders.
3. Interconnection of large and of small power systems is facilitated through frequency standardization. In fact, it is probable that the use of master clocks received its greatest impetus because of this utility when, during the Twenties, the great need for such interconnection became so apparent.

There are four types of master clock. Type A is a time-error indicator for manual control. Type B is a differential time-error indicator for manual control. Type D is a recording master clock for use in conjunction with manual equipment. Type E, an automatic frequency-control clock, integrates the time error over a two-second interval and actuates a governor control device to correct the frequency.

Most of the principal elements of master clocks are combined in Type A. This consists of a very accurate pendulum-driven clock movement and a separate timing mechanism actuated by a Telechron synchronous motor. The clock mechanism is a very carefully made timekeeper with a 60-beat pendulum and a Graham "deadbeat" escapement. The pendulum rod is made of Invar, so that the rate of the clock is not affected by normal variations of temperature.

The large operating dial has two concentrically mounted hands of different colors. The indicating hands rotate once in five minutes. One, colored black, shows "true" time. The other, colored gold and driven by a synchronous timing motor, shows "system" time. Once set together, the two hands will move together around the dial and remain in coincidence as long as the average frequency is correct. But any variation from normal in the average frequency will cause the system hand to lag or lead the true-time hand.

Below the operating dial is a 12-hour dial, which permits the operator to tell



SYNCHRONOUS MOTOR and gear train, sealed within a case with oil for lubrication, are basic mechanism for timers and clocks used in home and industry

the time of day and the five-minute interval during which the main dial is operating. An auxiliary dial, mounted above the main dial, has but one hand, actuated by a second motor. This permits control of a second separate system, or it may be used for auxiliary purposes.

In order to maintain absolute accuracy, the time of the pendulum-control clock movement may be checked daily, or as frequently as desired, with reliable radio time signals.

Supplementing the thorough construction of the clock movement and its initial accurate setting, there are two sensitive means of regulating the pendulum:

1. By small weights on a pan attached to the pendulum rod;
2. By rheostatic control of a magnetic field through which a permanent magnet in the base of the pendulum bob passes.

A vibratory standard master clock has been developed for supplying precisely controlled frequency to drive a large telescope. It does not use a swinging pendulum for the time standard. Instead, a vibrating wire, compensated for temperature changes and amplitude of vibration, produces controlled frequency variations in an electromagnetic system coupled to a vacuum-tube circuit. This circuit amplifies the energy to provide power for operating a master clock system having great accuracy and ease of rate control.

Timing Motors

Timing motors also are basically as originally developed: a hysteresis-shaded-pole type operating at 3600 rpm on a 60-cycle system with suitable gear reduction to 3.6 rpm or other speeds required in various movements.

They have a single field coil on the lamination cross pieces, with copper shading coils arranged on one-half of each pole face in the bipolar field. This provides a rotating magnetic field.

The rotors are made of thin tungsten steel, with magnetic and mechanical proportions to obtain acceleration to synchronism in a few cycles of the 60-cycle system. The rotor design was developed by Warren after painstakingly making and testing over 1000 shapes.

The rotors, with the gear-case assembly, are sealed within a case with the right amount of oil for lubrication. This assures dust-free operation and controlled lubrication for the life of the motor. Capillary action in the spaces between each bearing and capillary plate keeps the bearing and pivot surfaces constantly covered with a thin coating of oil drawn from the reservoir at the bottom of the sealed case. Oil creepage along shafts, pinions, and gears maintains complete, continuous lubrication.

This unique construction also allows easy replacement of the rotor unit.

There are essentially three types of motor. Type H motors are for light-duty purposes, such as in household clocks and timers and in timing, switching, and controlling devices. Type B motors are for medium-duty applications, such as switches, combination recording and controlling mechanisms, and various types of control equipment. Type C motors, designed with sturdy gear train construction, are for heavy-duty applications. There are modifications of these motors for terminal shaft speed, frequency, voltage, reversible characteristics, and for instrument and chart movement mounting.

Although many other types of motors have been developed for timing uses, some with permanent-magnet rotors and others with induction-reaction rotors, none has the combination of inherent simplicity, positive unidirectional starting characteristics, long, noiseless life with sealed-in lubrication, and virtually instantaneous synchronization with applied voltage that has distinguished the high-speed Telechron motor.

Electric Clocks

Telechron and General Electric Clocks driven by synchronous timing motors have gone through a series of developments in features and in appearance. The earliest ones were wall clocks. These were followed by mantel, banjo, kitchen, and display clocks. Then, in 1929, came the alarm clock.

The first alarm clock had a bell signal. By means of a 24-hour alarm dial, it could be set to ring automatically 24 hours later. This automatic feature was eliminated a few years after with the development of a twelve-hour movement. However, the soundness of the idea persisted, and an improved automatic alarm without the confusion of the auxiliary dial was put into production in 1950.

Another important step in electric alarm clock development was the buzzer alarm. While this has not replaced the bell alarm, it is used in the major production. It is simply a magnetic vibrator, actuated by the magnetic flux of the motor field and restrained mechanically from motion when the clock setting is not in the alarm position.

An interesting modification of the buzzer alarm is the tone control. This permits the user to adjust the alarm intensity.

As alarm clocks are principally used in bedrooms, there was an early need for sufficient illumination to see the time in the dark. The earliest solution to this was the use of a tungsten lamp so located that the light was reflected upon the dial. Later, radium-treated hands and dials were introduced. Another development has a neon lamp at the edge of a transparent plastic dial; the light-conducting characteristics of the plastic help to provide the illumination. A telltale light has also been developed for use on the dial to indicate when the alarm has been set.

Electric clock appearance has undergone a great change from the early intricate shapes wrought from natural materials—wood, copper, alloys, aluminum, steel, zinc, plated materials, leather, glass, and onyx. Phenolic and urea synthetic materials were used as compression molded parts in early production.

But all these, with the single exception of wood, have quite generally been replaced by modern injection moldings, resulting in improved appearance plus greater design and manufacturing flexibility and ease. Color combinations and shapes previously difficult to obtain have now become commonplace, not only in the large-production alarm and kitchen clock models, but also in the prestige lines of occasional, chime, and grandfather clocks.

Electric Timers

Telechron electric timers were among the earliest applications of synchronous timing motors. These included graphic recording charts, recycling and interval timers, sports and audible signal timers, and devices such as time switches to control or actuate industrial operations. Multistation preselectors were developed for radio programming. Later the pull-pin ON-OFF cased timers were developed, and also the "reminder" timer with a buzzer. The pull-pin timer is today the deluxe item of the timer line, and it is used in many applications because of its great versatility.

There is a considerable demand for uncased timers for ranges and radios. Range timers provide combinations of electric clock, switch, and signal-timing operations for convenient intervals up to 3½ hours—or they may be set on a time-of-day basis, permitting the operation to be actuated at any time within the following 12-hour period.

Radio timers include the "auto-on" feature, which presets a time to turn on the radio automatically. Then there is a radio-alarm-clock ON switch, for using the "wake-up-to-music" principle. This has a delayed-action buzzer alarm for the user who isn't awakened by the radio program but needs something more insistent. Also, there is a "sleep switch" timer. All of these features may be combined into one radio timer which:

1. Indicates the time of day;
2. Permits the user to drop off to sleep to soothing music that plays up to an hour before it is turned off automatically;
3. Turns on the radio automatically in the morning at a preset time to awaken user gradually and gently;
4. Insists, by means of a buzzer signal 10 minutes later, that the sleeper get up.

What of the Future?

In 1949 the 50 millionth Telechron timing unit was produced. At the present rate of production, the 75 millionth will be made sometime during 1952.

Seventy-five million Telechron motors require a generating capacity of over 150,000 kilowatts to drive them. This is the capacity of a *very* large steam turbine generator.

Is the market becoming saturated—does a future market exist? The answer to this question is directly related to the future of America. Surveys have indicated that there are approximately 40 million electrically wired homes in the United States, and there are about 40 million Telechron timing units in use. Many of these are in industrial applications, leaving less than one timing unit per home in household use.

Three-eighths of the wired homes do not have even one electric clock, and over two-thirds do not have a conventional kitchen clock. Nine-tenths do not have a clock radio. Similar large proportions of the homes do not have range-oven control timers, automatically timed washing machines, automatic dishwashers, or other useful household appliances which offer volume opportunities for electric timing.

So, in the consumer market alone, there are many opportunities for electric timing. The great American urge for more convenience is not restricted to just one clock or clock radio in each home, but of one or more in every room. When we include the literally hundreds of uses of Telechron motors and instrument movements in industrial business, transportation, hospital, and office building applications, and also the many new industrial uses discovered each year, it is apparent that the great market for Telechron electric timing devices is just beginning to unfold.

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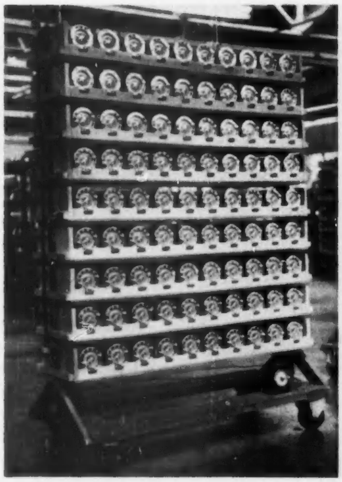


ELECTRIC TIMERS on portable test rack

SAMPLING product quality. Clocks are selected at random from production lines

Pump Motors at Grand Coulee

Design Features of the Largest Motors Ever Built

By E. P. SMOOT and J. E. TILLMA

The two 65,000-hp motors installed by General Electric last year at the Grand Coulee Dam pumping station are the largest motors ever built for any purpose anywhere. For this reason a description of the features of their design is of outstanding interest.

When, in prehistoric times, the Columbia River formed the great gorge known as the Grand Coulee, about 30 cubic miles of silt were removed and deposited on a large area of flat land in central Washington. Today the silted area could be very fertile land with a long growing season—but, without irrigation, it lacks sufficient moisture to support agriculture.

The surface of the reservoir at Grand Coulee Dam is normally about 350 feet above the original river level. It is necessary to lift the irrigation water 280 feet above this point and then carry it some 60 miles in canals, tunnels, and inverted siphons to the edge of the irrigable land.

When the Grand Coulee Dam was built, the base for a pumping plant was built at the same time. Positions were provided for 12 pumps. Ten of these would be sufficient to meet the water requirements of the 1,029,000 acres that are ultimately to be irrigated. The remaining two would be standby pumps.

Present construction plans call for the installation of six pumps. The first two have been installed, and these are the ones driven by the motors which are the subject of this article.

Each of these record-breaking motors is a synchronous unit rated 65,000 hp, 50,000 kva, unity power factor, 3 phase, 60 cycles, 13,600 volts, 200 rpm. Power can be supplied by six of the nine hydroelectric generators in the west powerhouse at the dam. Each generator is capable of supplying power for two pump motors.

At rated output, each motor will require about the same amount of energy per hour as is used in 250 homes in a month. Each pump at normal capacity will pump over a billion gallons of water per day—approximately the amount required by New York City.

With a few exceptions, the General Electric pump motors are identical in construction with conventional vertical hydraulic turbine-driven generators of comparable rating. The three major exceptions are as follows:

1. The conventional hydraulic turbine-driven generator has its exciter mounted on top, and the exciter is driven directly from the top of the generator shaft. The methods of starting the Grand Coulee motors require field excitation with the motors at standstill or at greatly reduced speed. The direct-driven exciters are therefore omitted, and separate motor-driven exciters, each rated 175 kw, are provided.
2. One of the methods of starting is an induction-motor type, and an extra-heavy-duty amortisseur winding is required for this service.
3. Water draining out of the outlet pipe when a motor is shut down will cause the pump to act as a turbine and accelerate the unit to something above rated speed in the reverse direction. The bearings are therefore made for rotation in either direction.

The motors are of the vertical-shaft type, and each contains a thrust bearing that supports not only the entire weight of the rotating parts of the motor and pump but also the hydraulic thrust of the pump. This amounts to a maximum of 300,000 pounds for the weight and hydraulic thrust of the pump, and 330,000 pounds for the weight of rotating parts of the motor, making a total of 630,000 pounds to be supported by the thrust bearing.

Each of these thrust bearings is located in a housing above the upper bearing bracket, a structure that rests on top of the motor's stator frame. This structure transmits the force on the thrust bearing to the stator frame. The stator frame, in turn, transmits the force to the motor foundation.

Also located in the upper bearing bracket is a separate housing containing a guide bearing, which provides radial restraint to the shaft.

Just below the motor rotor the lower bearing-bracket structure is located. This contains the lower guide bearing, which provides radial restraint to the shaft below the motor rotor. The combination motor brakes and jacks are mounted on this lower bearing bracket.

The motors are completely enclosed in a housing and provided with surface air coolers for removal of the heat created by the motor losses. Water is circulated in the coolers to take the heat away from the machine.

Each motor has an over-all height of 21 feet 11 inches above the station floor.

Stator

The stator frame for each motor provides a support for the armature core and the armature coils. The complete frame is 24 feet 4 inches in diameter. Its height is 9 feet 1 inch, from the bottom of the base ring that rests on the foundation sole plates to the top of the upper flange.

Shipping and handling requirements made it necessary to build these motor frames in four sections. The frame sections were bolted together in the pumping plant, and it should never be

Mr. Smoot, in charge of bearing design for General Electric's large motors and generators, has served as a consultant in the installation of generators at many well-known hydroelectric developments. Much of his 22-year career with GE has been spent in designing large frequency-changer sets, synchronous condensers, and generators.

Mr. Tillma joined General Electric in 1942 on the Test Course. He later spent several years designing industrial motors and generators, and is presently a designer of hydraulic-turbine-driven generators in the Large Motor and Generator Engineering Department, responsible for both the electrical and mechanical design.

necessary to open these split joints again.

The stationary flux-carrying portion of each motor is the stator core. This is made up of slightly over 100 thousand individual punchings, approximately two feet long in the circumferential direction.

Rotor

Each rotor has 36 poles, and each pole with its coil weighs a little over 1½ tons. The motors are designed to withstand a maximum runaway speed of 295 rpm. At this speed each of the poles has a centrifugal force of 397 tons, or about 265 times its weight. To hold the poles on the rotor rim against this force, the poles are dovetailed to the rim and held by tapered keys.

The rim of each rotor is constructed of layers of sheet-steel segments bolted together to form a solid structure. It is fixed in position with respect to the rotor spider by means of keys. The keys provide restraint against tangential movement of the rim with respect to the spider, but they do not restrict the outward radial movement of the rim, which is, therefore, said to be a free or floating rim. With this free-rim construction, the principal stress that due to centrifugal force is carried on the rim alone and is, therefore, uniformly distributed and capable of definite calculation.

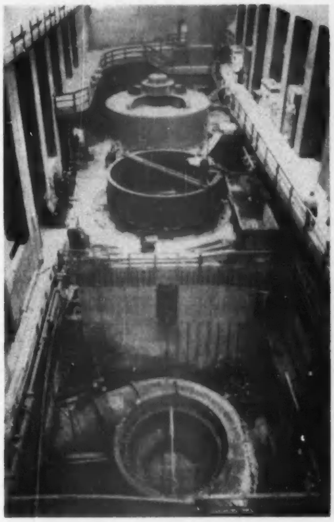
The motor shaft has an over-all finished length of 24 feet 4 inches. At its lower end is an integrally forged coupling flange 48½ inches in diameter for connecting the motor to the pump.

Upper Bearing Bracket

The upper bearing bracket is a very rigid structure, bridging a span of approximately 25 feet and weighing in the order of 25 tons. It is capable of supporting its required load with less than one-twentieth of an inch deflection. It is composed of a cylindrical hub 10 feet in diameter and nearly 6 feet high, to which four radial arms more than 7 feet long are attached. Two of these arms are permanently attached to the hub, and two are removable. It was necessary to make these removable to keep the shipping dimensions of the bracket within railroad clearances.

Lower Bearing Bracket

Although the primary purpose of the lower bearing bracket is to support the lower guide bearing, it also provides a support for the combined brakes and jacks. When fitted with cover plates, it provides a seal to enclose the lower end of the machine.



THREE STAGES of erection at the Grand Coulee pumping plant. From front to back can be seen a scroll case before motor foundation has been poured; a motor stator frame; a completed motor

This bracket is not attached directly to the motor frame; it rests on a separate ledge on the foundation. The bracket was built to dimensions that will allow it to be lifted through the motor stator to provide a clear passage for removal of the pump impeller for maintenance purposes.

For maintenance operations it may be necessary to lift the rotating parts slightly and remove the weight from the thrust bearing. Jacks for this purpose are provided on the lower bearing bracket, which must therefore be capable of supporting the weight of the rotating parts of the motor and pump.

The braking and jacking functions are combined in the same equipment. Air pressure at approximately 100 psi is used for braking, and oil pressure at approximately 1000 psi is used for jacking. The high oil pressure required for jacking is supplied by a motor-driven pump mounted on the lower cover plates.

Thrust Bearings

The thrust bearings consist of the following parts: (1) a rotating plate or "runner" without grooves, rigidly attached to the shaft by means of a thrust collar; (2) a set of relatively thin and flexible babbitted stationary segments; and (3) a flexible support consisting of a number of precompressed springs.

The operation of the bearing depends upon the combination of these parts, but its distinctive feature is the combination of the flexible stationary member and the distributed, individual springs which support it. These function to supply what every bearing needs; namely, an adequate oil film between the rubbing surfaces under all conditions.

Special procedures were followed in finishing the runner, to insure proper flatness of the plate as a whole, and to insure suitable smoothness of the bearing surface.

High local pressures may develop in the bearing without the knowledge of powerhouse attendants, foundations may settle, and the proper alignment of shaft and bearing may be disturbed. Under such conditions, high local pressures are automatically relieved by a slight yielding of the flexible support.

Each of the individual springs which support the stationary member is precompressed. Theoretically, a precompressed spring will not deflect until the loading reaches that of the precompression. Measurements show, however, that where the precompression is obtained by means of a screw in a tapped washer, a desirable characteristic of small amplitudes of motion with small variations in loading is obtained. The result is a regular deformation as determined by the film requirements.

The screw and threaded washer which provide the precompression of the spring are brazed together, to lock them securely against loosening, and then machined to close tolerances to assure uniform length.

Thrust Bearing Lubrication

Several General Electric bearings having smooth runners and segmental babbitt plates were put into successful operation in the period 1914 to 1916. These were small low-speed bearings. As larger sizes with higher losses were developed, grooves were provided in the runner to augment the volume of oil circulated, and this design, plus a grooved stationary plate, became standard for a long period of years.

In 1938, in anticipation of this motor application, it seemed desirable to again consider the feasibility of a smooth runner. The fact that these motors were to be started electrically made it desirable that the breakaway torque be held to a minimum. One way to accomplish this was to design the thrust bearing for high-pressure oil lubrication during the starting period, and a smooth runner was desirable to prevent the escape of high-pressure oil through runner grooves.

Factory tests were made to determine the effect of high oil pressure during starting on the coefficient of friction, the best means of introducing the pressure, the optimum shape of the grooves in the babbitt, the optimum pressure, etc.

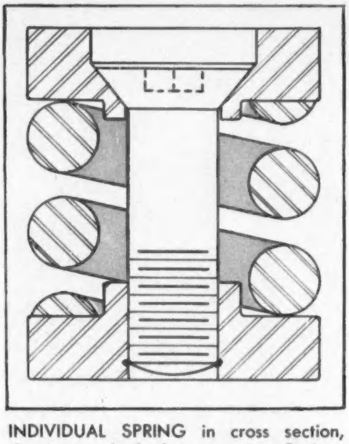
Based on these tests a bearing was designed and, with the co-operation of the Corps of Engineers, installed in a unit at Bonneville Dam.

This developmental installation was successful in every way. It indicated the possibilities of improved operation with a smooth runner and individual segments for all applications. As a result, this type of bearing, without oil-pressure starting equipment, was installed in all the other Bonneville units and in several other plants, and in 1945 it became the General Electric Company's standard design.

The high-pressure oil-starting equipment for the thrust bearing consists of a motor-driven positive-displacement pump, located on a bearing-bracket arm near the thrust-bearing housing, and the necessary piping to conduct the high-pressure oil between the running surfaces of the thrust bearing. An adjustable relief valve is located at the pump, and a check valve is located in the high-pressure line to the oil header in the thrust-bearing housing.

Field tests indicate that, a few seconds after the oil pump is started, an oil film is formed between the bearing surfaces, effectively floating the 330,000-pound rotor. The bearing friction is thus reduced so that, when the oil pump is started, the slight static unbalance of the rotor causes it to move to its "dead" spot. After a few pounds pull at the coupling periphery has moved the rotor and this pull has been released, the rotor again moves to this "dead" position.

The oil pump can be started and left running while preparations are completed for starting the motor and the generator that drives it. The rotor is thus floated on an oil film and is ready to be started at any time, even though considerable time is consumed in delays. This feature can be extremely important, since unlimited time is thus made available for correlating the starting operations.



INDIVIDUAL SPRING in cross section, showing method of compression. Springs like this support the stationary member of the thrust bearing

Housing and Ventilation

The air housing which encloses the motor is 31 feet 3 inches in diameter and stands 10½ feet above the station floor level. Two standard office-size doors provide ready access to the interior. Lights are permanently so mounted inside that the interior may be easily inspected at frequent intervals.

The top of the housing is located at about the mid-point of the upper bearing bracket. This arrangement allows ventilating air to pass over the top of the motor frame. Another path around the bottom of the machine is created by holes cut in the lower portion of the motor frame.

The enclosing housing, being larger in diameter than the motor frame, creates a space about 3½ feet wide between the frame and the housing. The ventilating air from the motor discharges into this space through eight large surface air coolers mounted around the periphery of the frame. The air thus discharged into the housing is therefore cooled air ready to return to the top and bottom of the motor for additional cooling. A recirculating system of ventilation is thus accomplished.

The ventilating air is circulated through the machine by the blower action of the rotor. This blower action is aided by fan blades attached to each end of the rotor. The fan blades are so placed to direct the air between the rotor poles. The action of the rotor and the fan blades mounted on its supplies all the force needed to circulate the ventilating air; no additional external blowers are required.

The surface air coolers have sufficient capacity to maintain the temperature of the air entering the motor at 40 C or less with one cooler out of service and the motor delivering rated output. In normal operation, the coolers require approximately 1200 gallons of water per minute to maintain desired operating temperature.

Motor Starting

The establishment of a suitable starting procedure for a motor of this large size required very careful study in the design stage. In addition to the task of bringing its own inertia up to rated speed, the motor has to start a load that requires rated motor output as rated speed is approached. No provisions are made to unload the pump during the starting cycle.

Most synchronous motors in use today are started by applying voltage of rated frequency to the terminals. Many are started with full-rated voltage applied. Full-voltage rated-frequency starting of the Grand Coulee motors would require approximately 250,000 kva from the supply for each motor. It would not be practical to attempt to maintain the full-rated voltage at the motor terminals during starting, and it would be difficult to make provisions for the very heavy currents involved.

The torque to accelerate a synchronous motor to nearly synchronous speed for the applied voltage frequency is developed by the induction-motor action of an amortisseur winding. For a start of this nature, the energy input to the amortisseur winding appearing as I^2R loss in the winding is equal to the kinetic energy of the rotating parts at the synchronous speed, plus the energy required by friction and windage and the load in coming up to speed. Most of this energy loss appears as an increase in amortisseur-winding temperature.

The torque required to drive the pumps increases very rapidly as the pump speed increases. Therefore, starting with voltage of rated frequency applied would require a large amount of torque to be developed by induction-motor action as the motor and pump approach rated speed. An amortisseur winding with a very large heat capacity would also be required to absorb the energy input for a start of this type. These factors made it desirable to use other methods of starting, and two alternatives were included in the final arrangement: (1) a synchronous method of starting with the motor and driving generator in synchronism from rest; and (2) an induction-motor type of starting on the amortisseur winding with reduced frequency-voltage applied. The torque available for starting with the synchronous method of starting is substantially greater than that available with the induction-motor method.

It is anticipated that the synchronous method of starting will normally be used. With this method, one or two motors are started with one generator, depending on how many motors are to be started. The sequence of operations is as follows:

With the generator at standstill, the motor-driven exciter sets for both the motors and generator are started, and the pilot exciters are set at rated voltage. The rheostats in the main-exciter field circuits are set to give proper generator and motor excitation, but the circuits are left open. The generator main-exciter armature is permanently connected to the generator field. A field breaker in the circuit between the motor field and its main exciter armature is closed. The circuit breaker connecting the generator to the motors is closed. The turbine gates are then opened. At the same time, the pilot-exciter voltage is applied to the main-exciter field circuits, causing the predetermined value of excitation to be applied to the motors and generator. As the generator starts to rotate, the motors start in synchronism with it. When the generator and motors have been accelerated to normal 60-cycle speed, the turbines are placed on governor control, and the excitation on the units is adjusted for normal operation.

Although the induction-motor method of starting at reduced frequency will probably not be used to any extent, the motors are equipped with an amortisseur winding suitable for this starting service, should it become desirable to use it. The starting sequence for this method is as follows:

Excitation is removed from the generator, and the turbine gates are adjusted to maintain 65 percent of rated speed. The field breaker in the motor field circuit is opened. When this breaker is opened, a suitable discharge resistor is placed across the motor field. The generator main-exciter field rheostat is adjusted to give the required generator excitation for starting. The circuit breaker connecting the generator and the motor is closed, and the generator main-exciter field breaker is closed. Voltage builds up, and the motor starts and accelerates by induction-motor action. Since the turbine gates have been adjusted to maintain 65 percent rated generator speed with no load, the turbine supplies a negligible amount of torque for accelerating the motor. Therefore, as the motor accelerates, the generator decelerates, the energy for accelerating the motor coming from the kinetic energy of the generator rotor.

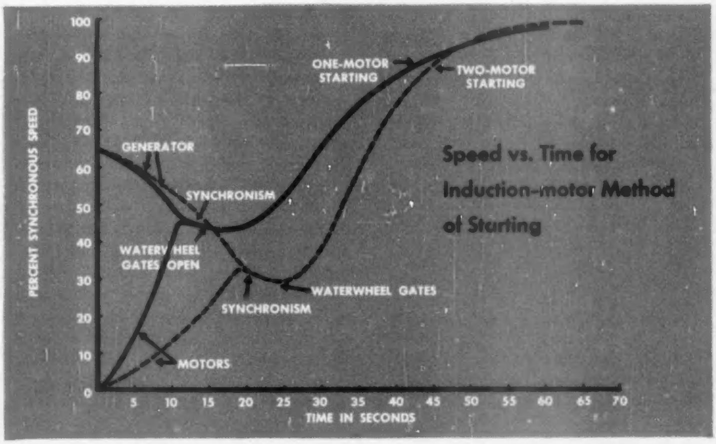
For the starting of one motor, calculations indicate that the generator and motor will approach synchronism and will be synchronized at approximately 45 percent of rated speed and in about 11 seconds after the starting cycle has been initiated. Calculations for starting two motors simultaneously by this method indicate synchronism will be reached at approximately 32 percent rated speed and in about 17 seconds after the cycle has been started.

Application of motor excitation for synchronizing is accomplished by automatic control. After synchronizing, the turbine gates are opened and the units are accelerated to rated speed. The excitation of the motors and generator is then adjusted for normal operation.

The induction-motor method of starting has the advantage of not requiring the generator to be stopped. It will take less time to place a pump motor in operation by this method, if it is necessary to use a generator that is running.

A very heavy amortisseur winding is required for the induction-motor type of starting. This winding is formed by embedding heavy rods in the pole faces. These bars are all connected together at each end. During the starting period, the rate of expansion of the amortisseur winding is high because of its rapid change in temperature. A flexible connection is used to make the connection between poles to allow for small differences in the expansion rates between poles and to compensate for the rapid heating of the end-ring connection to the bars.

The amount of material contained in the amortisseur winding (and, therefore, its heat capacity) is more than double that which would be used in a hydraulic-turbine-driven generator of comparable rating.



Erection

Installation of equipment of this size involves a considerable amount of assembly work at the site. Approximately 40 railroad cars were required to ship the parts of these two motors from the factory at Schenectady to the pumping plant at Grand Coulee. Approximately six months was required for their erection and assembly.

The Engineer . . . and the Team

By DR. W. R. G. BAKER

Presented at the joint AIEE-IRE Student Branch meeting, Rensselaer Polytechnic Institute, October 18, 1951

On several occasions recently I have been asked the question, "How can engineers win success?" It seems almost as though the world were full of engineers seeking a simple mathematical formula for success. If there is such a formula, I'm certain it is just about as simple as Einstein's theory of relativity.

In quite a few of the engineering offices of the General Electric Company you will find printed cards on the walls carrying this message by Lord Kelvin:

I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science, whatever the matter may be.

If we attempt to apply Lord Kelvin's remarks to the commonly accepted tokens of success within the engineering profession, it is apparent that anything as fleeting as fame, or as temporary as riches, cannot be measured in scientific terms. If you would define success (as the dictionary does) as the favorable termination of a venture, then perhaps some method of measurement, some appropriate yardstick, can be found.

Initiative is often cited as one of the prime requisites of success; so we can appropriately take a quick look at the type of initiative demanded of us today. In a compendium recently published by Harvard University Press of several score talks by executives from various fields of industry, Neil H. McElroy, president of a soap company with annual sales of approximately three quarters of a billion dollars, discussed the question, "What is initiative?"

As one example, Mr. McElroy pointed to the creation of research laboratories by the management of industrial concerns, and to what he called "the prospects for improved living for everyone which can result from an untrammeled utilization of the product of these fine technical minds." He went on to say: "Yes, truly, management, through many types of research activity, is exercising initiative of its own which can't help contributing to our over-all objective of expanding production in the interest of an improved standard of living."

To his way of thinking, today's engineer is engaging in a venture whose goal is an improved standard of living for mankind. Surely this is a creditable venture, and one that be can measured adequately in many ways that are not related directly to individual or national income. It can be measured in the raising of educational standards, and in the lowering of the death rate. It can be measured in the health statistics and the growth charts of our children.

Because as engineers we are accustomed to thinking and dealing in numbers, we readily recognize that the standard of living is dependent upon the productivity of the individual worker. We take pride, as engineers, in having helped to increase productivity, and we point to the larger number of kilowatts or horsepower we have placed at the command of the individual worker in his daily tasks.

I do not believe that many will quarrel with the thought that the long-range objective of the engineer is to create a better standard of living. But the long-range objective may be lost sight of in the striving for the immediate objective, whether it be the creation of a better sparkplug, a better television set, a better bridge, or a better heating system for the home. In the United States, we possess a better standard of living than most other countries because, through engineering efforts and initiative, we have lowered the real cost of the goods and services we utilize in our daily lives.

Dr. Baker—pioneer in radio—is a Vice President of General Electric Co., and General Manager of the Electronics Division. Under his direction as chairman of NTSC, standards for black-and-white telecasting were developed, recommended, and adopted by the FCC. Co-ordinating research and development work in the color-television industry is a present concern.

This may sound academic, but I assure you I am still talking about success in the engineering field—success in the terms of the definition I mentioned a moment ago, "the favorable termination of a venture."

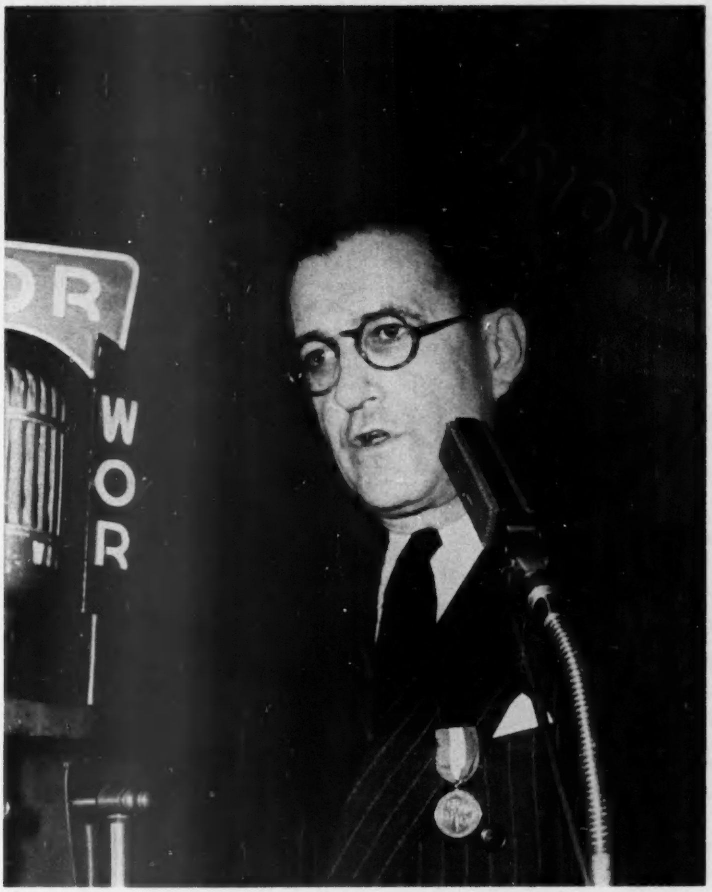
In the engineering profession, as in almost every other profession, there are those who bemoan the passing of the "good old days." The simple discoveries have all been made, they say, and there no longer exist opportunities for an Edison, a Ford, or a Fulton. The engineer, they say, as well as the chemist and the physicist, is now only a cog in a large machine. He works in one small field, on one small part of the whole. He is submerged by management, they claim, and he reaps neither the recognition for his contribution, nor a just monetary award.

These men who are looking backwards are like all others who pine for the good old days. I can think of no man living today, including these complaining engineers, who would for one moment exchange life today, with what he describes as lack of opportunity, for life not too many years ago. Ask yourself if you would be happy with wells that became contaminated, with kitchen hand pumps that froze when the wood fires went out during the night, with outhouses that bred flies and odors, with milk that soured because of inadequate refrigeration, with kerosene lamps that created a fire hazard and gave insufficient light. I am sure you can think of many more homespun examples of life in the good old days that you would prefer not to undergo today.

These men who bemoan the system that has provided them with a far more comfortable existence, that has almost doubled their life expectancy—these men speak and think in half-truths. They are not cogs in the machine, but members of the team, and important members.

I have mentioned teamwork and co-operation as being made necessary by the complexity of our industrial life today. And we all recognize that complexity and interdependence are inherent parts of increased productivity and its resultant higher standard of living. But there is no single team that plays a dominant role in this economy of ours. There is, for example, the management team, made up of specialists in production, in sales, in advertising, and in engineering. Then there is the research team, a comparatively new concept in our industrial life, made up of specialists in related or even divergent fields of science, and of engineers. And there is also the industry team, made up of engineers from many companies, brought together for the common purpose of hastening the development and utilization of new discoveries.

I would like to explain how these three types of teams have all proved their worth. In each case, although individual engineers made noteworthy contributions, the venture could not have been carried through to a favorable termination without the help of other members of the team. And neither would the work of the team have been successful without the best efforts of the individual engineer.



W. R. G. BAKER surrounded by some symbols of his particular field of engineering

Let me give you first an example of the management team, drawn from General Electric history. Some time previous to 1931—more than twenty years ago—someone conceived the idea that there must be a better method of disposing of food wastes in the home than had yet been discovered. Laboratory engineers in Schenectady then began work on the idea of grinding up the garbage so it could be washed down the kitchen drain into the sewage system. The advantages were obvious. These wastes could be disposed of long before they could serve as a breeding place for one of the common carriers of disease, the housefly.

By mid-1935 the work was sufficiently advanced so that the laboratory turned it over to the appropriate operating unit for production and sale. The cost of the laboratory's services up to that point was approximately $100,000.

But here was a new product, for which neither public acceptance nor demand had been created. Two other members of the team then took over: the advertising and sales members.

In 1935, 235 Disposall* units were sold, at a loss of $9000. For five succeeding years, even though the engineering members of the team continued to make marked improvements, this new product showed a loss. In the year 1941 a small profit was made.

Then came the war, and production was halted. In 1946, the Company went back into production and experienced a loss of nearly $500,000. It was not until 15 years after its introduction on the market—not until a quarter of a million units had been produced and sold—not until the cost of development and promotion had reached a total of nearly one and a half million dollars, that the Company was able to show an over-all profit on that one development.

I believe it is obvious to you that the contribution of the engineer was only the starting point. It was initiative by the whole management team, backed by the enthusiasm of the engineer who believed he had developed a product for which there was a definite need, that brought the venture to a successful conclusion.

My second example demonstrates that the engineer, as a member of the research team, can make contributions of great value by working in close cooperation with the scientist.

Just before the war, a National Defense Research Council group at Purdue University observed the high back-voltage characteristic of germanium, a grayish-white, brittle, metallic element. The importance of this characteristic was

*Reg. trade-mark G.E. Co.

ELOQUENT EXAMPLE of engineering design, manufacture, and application typifying products for a new era of living

recognized immediately, and some work was done to produce a commercial diode for low-frequency use. But no great progress was made, because of the war.

From 1940 to 1945, research work was carried on by several of the NDRC groups, including General Electric, to investigate the possiblities of using germanium at S, X, and K bands. Low-frequency commercial development slowed down considerably during this period.

Toward the end of the war, intensive work on a commercial-type high back-voltage germanium diode was revived, and one or two companies ventured into the business in a small way, but the unit cost was high. General Electric did not immediately produce a commercial unit, but continued development work in the Research Laboratory which resulted in a number of different units and particularly a metal and glass unit which showed considerable promise.

Early in 1946, engineers of a specialty group in the Electronics Division took over the job and quickly began limited production. By the middle of the year they had redesigned the unit to utilize a plastic casing into which the element could be force-fitted and sealed with a thermosetting cement. This appreciably reduced cost and increased production. The idea of force-fitting the parts into a plastics case, while it may have seemed trivial at the time, was a factor of prime importance later. This made it possible for engineers to design machines with which to assemble the diodes at a commercially advantageous rate and cost level. Production was increased from about 1000 per month in 1947 to approximately 5000 per month by the end of 1948.

Then we ran into trouble; the first of two major difficulties developed. In the spring of 1949, during a high-humidity period, we began experiencing failures of the diodes in the field. Upon investigation we found that the diodes were abnormally sensitive to moisture; they were absorbing a microscopic amount of water vapor through the wood-flour plastics case. Within a very short time, engineers found a better plastics case material, using powdered glass instead of wood flour as a filler, and the effects of moisture were overcome.

As a result, progress became so satisfactory that we were able to cut prices and turn the manufacturing over to the factory. During the remainder of 1949 and the early part of 1950, an extensive tooling program was carried out. One outstanding contribution was a high-speed assembly machine developed in the Engineering Laboratory. We raised production to nearly two million diodes during 1950.

But in January of 1950, we experienced our second setback. The germanium, which must be of an exceptionally high degree of purity, suddenly became contaminated to the point at which diode yield dropped to an extremely low value. Immediately, help was requested from all sources. This resulted in an intensive effort on the part of one of the engineers in the laboratory, and he was successful in developing a means of purification.

This accomplishment firmly established the need for a thorough study of the whole field by a group closely allied to the manufacturing operation. As a result, an electron physics section was set up in the Electronics Laboratory at Syracuse, to handle research in the germanium field and similar activities.

The physical makeup of this electron physics section well illustrates the high degree of teamwork which is producing results today. The original group consisted of two engineers with inclinations toward physics, plus an organic chemist with essentially no electronic background but a doctor's degree in chemistry, an interne's status in medicine, and a master's degree in physics. Unfortunately, the organic chemist was lost to the organization, but the concept of his diversified backgrounds was continued in expanding the section. Since the major work to be undertaken was in the field of solid-state physics, one man was chosen who had specialized in that field. The remainder of the section was formed from the personnel of the divergent backgrounds. The present group includes, therefore, in addition to the original two engineers, a physical chemist, a crystallographer, and a physicist with considerable background in solid-state work.

I believe the whole concept of the research team will result in the more rapid development of new basic discoveries than otherwise would be possible. The presence of the engineer on that team leads to a quicker utilization of basic discoveries. But perhaps it serves an even more useful purpose. For the engineer becomes a guide, leading the pure researcher toward discoveries that have more immediate promise of usefulness.

My third example of teamwork involves the field of television, and here I must give you briefly some of the historical background.

After early experiments, black-and-white television had been so far developed that early in 1940 one company made plans to market television receivers and to place commercial television broadcast stations on the air. That proposal was considered by the Federal Communications Commission of the United States as tending to freeze the standards of television operation and to discourage research and experimentation with systems based on, or requiring, standards other than the proposed 441 scan lines per picture. Other companies favored other standards.

The Commission decided that no standards should be established at that time, and that there should be no commercial broadcasting until "the probabilities of basic research" have been fairly well explored. The Commission also stated that, as soon as the engineering opinion of the industry was prepared to approve any one of the competing systems of broadcasting as standard, the Commission would consider the authorization of full commercialization.

Because of the recommendation, the concept of the National Television System Committee was born, the first of four major industry committees that have dealt with television standards since 1940. The monumental work of the engineers who unselfishly and unstintingly gave their time and effort is a matter of record. In the less than six months needed to draw up standards and report to the Commission, the 168 members of the committee and its technical panels of experts produced reports and minutes totaling 600,000 words, devoted 4000 man-hours to meetings and an equal time to travel, and witnessed 25 demonstrations of technical matters. The standards for black-and-white television proposed by these industry engineers were adopted, and television was off to a successful start, although delayed by the advent of World War II.

Perhaps the best measure of the success of this almost unparalleled co-operation among industry engineers is the fact that a number of countries have adopted television standards based upon those recommended by the Committee with only minor variations.

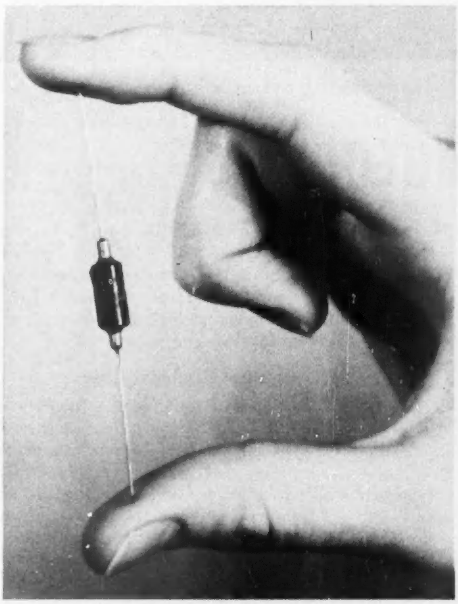
The current National Television System Committee is today studying color television, and I hope that shortly it will be ready to propose color-television standards. I sincerely believe that the teamwork of this group can evolve an acceptable, workable, compatible, color-television system.

Please do not misunderstand me. I am not saying that the day for individuality and individual initiative has passed. But there is a need for the engineer to broaden his outlook and his background, to recognize the problems of modern civilization, and then to take his place as a member of the team working towards a common goal.

If I have left the impression that success in the engineering field—like virtue—is its own reward, let me point out that opportunities for engineers have never been greater than they are today. It is certainly no secret that the electronics engineer is as popular as a beauty queen stranded on a desert island with a shipload of men. As the field of electronics expands, the need arises for more and more well-trained engineers. And as the electronics industry expands, more and more opportunities are created for chief engineers, managing engineers, and of course leaders in the industrial laboratories.

This is not a political article—but let me point out that, in the nondemocratic bloc of nations, many of these opportunities for engineers do not exist. For example, if radio manufacturing is controlled by the government to the extent that one design, and only one design is accepted, then competition between companies as we know it is lacking. And the need for engineers is far less. We can be grateful, too, for the fact that the penalty for engineering mistakes in this country does not consist of being sent to labor in the uranium mines with a pick and shovel.

Today's engineer should look ahead, not backwards. His opportunities are not limited, but limitless. But to be successful, to carry his venture to a favorable termination, he needs the support of the team on which he is playing, even as the rest of the team needs him. His success can be measured in the advancement of civilization.



GERMANIUM DIODE, through engineering and research, was made a commercial product by teamwork

MODERN TELEVISION is a significant example of a development requiring co-operation in each phase of design, utilization, and improvement

Fig. 1. TYPICAL PHOTOCELLS—Germanium photocell *(left)*; selenium photocell *(center)*; and vacuum photoemission cell

Germanium Photocells

By DR. W. C. DUNLAP, JR.

Photoelectric cells are widely used in science and industry as a means for measuring and controlling light of varying intensities and wave lengths. Counting and sorting objects on production lines, and opening and closing doors, are typical applications in which photoelectric cells are utilized.

Among the types of cells in general use are the vacuum photoemission cell, and the semiconductor photovoltaic cell, such as the selenium photocell so widely used in the popular exposure meters that are carried by nearly every photographer. Semiconductor cells are also made in which the active material is based upon cuprous oxide, thallous sulfide, lead sulfide, and silver sulfide. And recently germanium photocells (Figs. 1, 2, and 3) have been developed; they show tremendous promise for a variety of applications.

Germanium photocells are of interest in several respects. They are very small, have relatively large power-handling capacity, and are sensitive to infrared radiation. Even more important, however, to the whole field of photocell technology is the insight into semiconductor mechanisms that can be gained because of the fact that we can build germanium cells that very accurately obey simple theories of semiconductors. Many of the uncontrolled factors that have obscured the reasons for the operation of other photocells are removed because germanium cells can now be made of germanium crystals, whose composition and structure are under close control.

Principles of Semiconductors

The idea of the existence of energy bands in which the various electrons in the atoms of a solid crystal can move about has now become widely established. Energy bands are not to be thought of as physical bands, like a layer cake. Rather, there are certain energy levels that contain electrons moving at definitely limited speeds.

These energy bands are formed by the interaction of neighboring atoms upon each other. The energy levels generally remain separated by a "forbidden" energy region in which there are no electrons. Forbidden is a good word, because electrons just can't be in these energy regions.

These energy bands are characterized by an important property. If they are completely filled with electrons, no current can pass when a field is applied. However, no current can pass if the bands are completely empty either, for the simple reason that no carriers are present. Thus, an insulating crystal is one in which all the bands are either completely full of electrons or completely empty.

Metals, on the other hand, have bands that are not filled all the way. These unfilled bands contain a large number of electrons, in the order of one per atom. Semiconductors are materials in which one of the bands may be completely filled with electrons, while another band in the same semiconductor contains relatively few electrons. The electrons may be present because of impurities within the semiconductor, or they may be "excited" electrons that have been produced by thermal excitation across the forbidden energy region.

A band can permit conduction by two methods: if there are a number of electrons in the bottom, or if there are a small number of unfilled spots in the top of a filled band.

These two situations lead to conduction of two types: N and P.

In N-type conduction, the carriers are free electrons present in small numbers at the bottom of a band (conduction band). In P-type conduction, the carriers are vacancies of electrons —usually called "positive holes"—in the top of a normally filled band. Even though a hole is "nothing," it is an entity as an electrical carrier. The picture of a vacancy, or a hole, having character almost as definite as the electron itself, is very strongly established in semiconductor work.

If an impurity that tends to shed electrons easily is present in the semiconductor, it is represented by a dotted line close to the conduction band in any schematic representation of a semiconductor (Fig. 4). However, if the impurity tends to take up electrons easily from the germanium atoms, it is represented by a dotted line close to the filled band.

Each impurity atom then tends to furnish one electron, or one hole carrier, depending upon its chemical nature. In germanium, antimony is an N-type impurity (donor), whereas indium is a P-type impurity (acceptor).

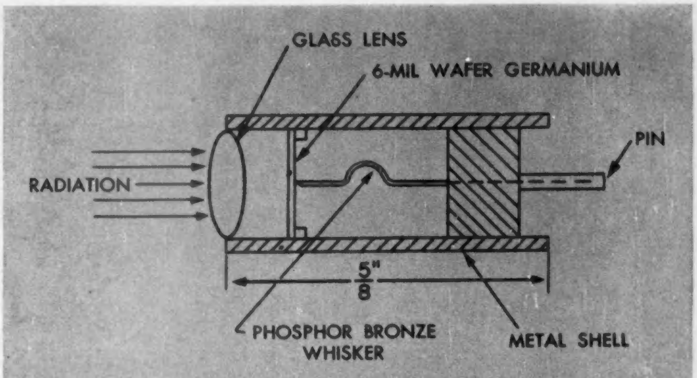


Fig. 2. COAXIAL PHOTOTRANSISTOR: germanium cell of the type shown in Fig. 1

Electrical conduction can also take place when an electron is excited with sufficient energy to jump across the forbidden zone. This is "intrinsic" conduction, and is neither N-type nor P-type, since both a free electron and a free hole are produced. Excitation in a photoelectric cell involves the same formation of a free hole and a free electron. Thus, the photoelectric threshold for a semiconductor should be the same as the energy gap, as measured from the temperature dependence of the intrinsic conduction of germanium. This has been found to be the case for both germanium and silicon.

The long wave-length response of semiconductor cells arises because in some materials the forbidden band is very narrow. Lead sulfide is responsive to infrared wave lengths of about 3 microns, lead telluride to about 5 microns. In these materials, the band gap is narrow, and the intrinsic electrical conduction is correspondingly large.

The current that is continually flowing through a photocell when the cell has no light shining on it is known as "dark" current. A problem involved by using infrared cells arises because this dark current, as a result of intrinsic conduction, may be greater than the photocurrents—unless the cell is refrigerated.

Dr. Dunlap, research associate in the General Electric Research Laboratory, has been engaged in research on germanium and other semiconductors for six years, studying such phases as the Hall effect, P-N junctions in semiconductors, and the rectifying characteristics of transistors. He is now serving as chairman of the Subcommittee on Semiconductors and Transistors of the AIEE.

Dark currents are a chronic problem with photocells. It's not always a question of what output you can get with light shining on the cell; it's a question of how much change there is relative to the situation with no light.

What is most desirable is to hold the dark current to a small fraction of the value of the output current when light strikes the cell. It can be compared to the signal-to-noise ratio in a radio receiving set. The sensitivity doesn't depend on how much output you get; it's a question of how much output you can get over the fluctuations and the "background." Thus, in effect, the dark current is the photocell background.

Germanium has a band gap that is just about as narrow as it can be without having the intrinsic conduction so large that refrigeration, with all its complications, is required. This value is 0.75 electron volts, which corresponds to a photoelectric threshold of about 1.5 microns. The experimental value for the threshold is about 1.9 microns.

Only in a very few characteristics is there any distinction between the behavior of an N- and a P-type semiconductor. But these characteristics are important. They include the Hall effect, the thermoelectric effect, and the electrification characteristics. Here again,

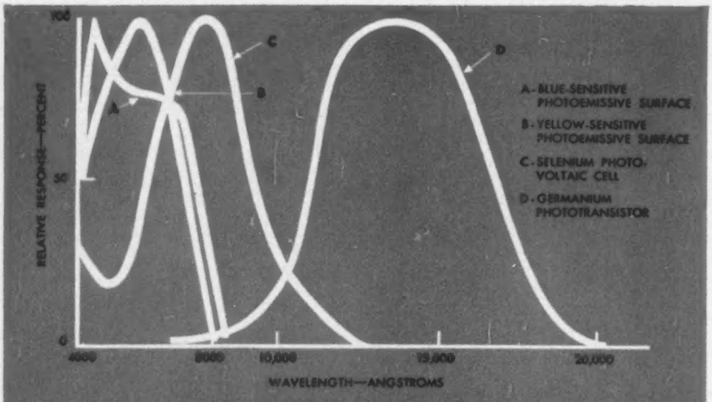


Fig. 3. WAVELENGTH-RESPONSE for four photocells: A and B are for surfaces widely used in vacuum photocells; C selenium cell and D germanium cell in Fig. 1

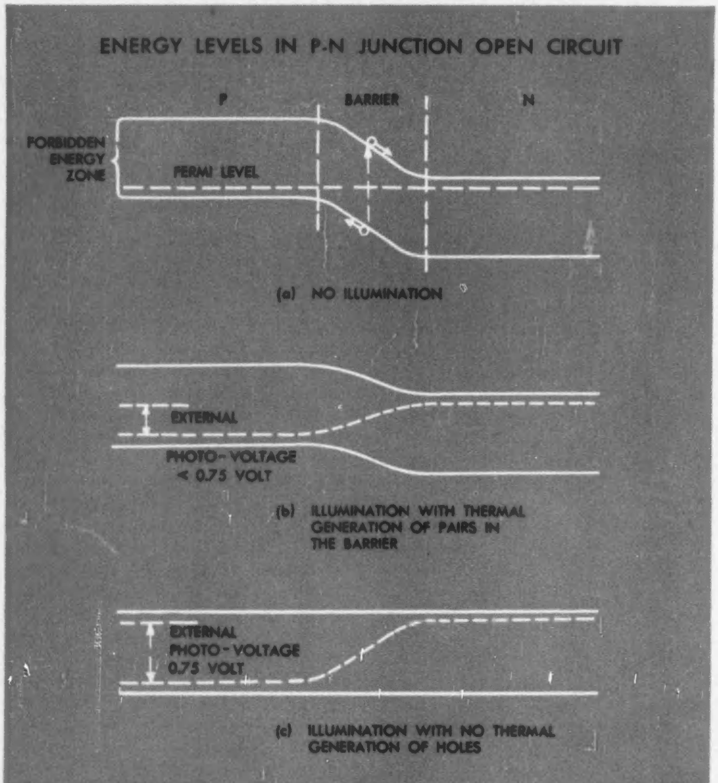


Fig. 4. ENERGY BANDS through a P-N junction, the boundary between N- and P-type semiconductor, for various illumination. Max. output for germanium, 0.75 volt

the general nature of the properties is the same for the two types, only the sign is *reversed*.

The Hall effect, for example, involves the production of a transverse emf when a magnetic field is applied to a plate of material carrying current along the plate. For an N-type material, the voltage is of one sign; for the P-type material, the observed voltage, everything else being equal, is of the opposite polarity.

P-N Junctions

Some of the important properties of semiconductors appear not in the homogeneous material of either N or P type, but at the boundary between the two—the P-N junction. These important properties include rectification, the amplifying action of a transistor, and photoelectric effects.

A transistor consists of a wafer of germanium soldered to a metal plug, with two fine metallic whiskers touching the face opposite the plug at points separated only a few mils from each other. These two contacts act like the elements of a "point-contact" diode, one operating in the forward direction, the other in the reverse. Interference by the forward element, or emitter, with the reverse element, or collector, leads to a transfer of power from the emitter circuit to the collector circuit.

When a P-type sample of semiconductor is placed in contact with an N type, the energy bands (Fig. 4) are distorted. This distortion is equivalent to a space-charge region between the two conductors.

One way of looking at the space-charge barrier follows: In the P-type region at room temperature, the semiconductor is neutral in charge at all points. The number of free holes moving about is just balanced by the number of negatively charged impurity ions (acceptor ions).

In the N-type region, the number of free electrons is just balanced by the number of ionized donors.

Let's think now of the transition from P to N being caused by the gradual increase of the number of donors over the number of acceptors. A charge situated in the middle of the barrier will tend to feel the electric field of the acceptor ions and also the field of the positively charged donor ions. Both these fields urge the charge in the same direction. This means that any charge located at the exact center of the barrier region tends to be swept out by the space-charge field of the ions that are responsible for the change from P to N type.

It is easy to see that a positive charge will always tend to be swept into the P-type region; a negative charge, into the N-type region. Thus, the simultaneous formation of an electron-hole pair in the region of the barrier leads to the separation of the two. The electron goes off to the N-type region, and the hole goes off to the P-type region. This separation leads to the formation of a voltage when light strikes such a barrier. This is the basic mechanism for the photovoltaic effect such as is used in an exposure meter.

One of the important properties of the P-N junction is the rectification characteristic (Fig. 5). When an electric field is applied in one direction, the bands tend to come together. Holes from the P-type side, and electrons from the N-type side, tend to flow into the region of opposite type of conductivity. This is the phenomenon of "hole emission" that was brought into prominence by the discovery in 1948 of the "transistor."

The simultaneous coexistence of electrons and holes in the same region is possible. Many transistor experiments have shown this to be possible—but only to the extent that electrons and holes will eventually cancel one another out, since the hole is only a vacancy in a sea of electrons. If it is filled by an electron, both the electron and the hole play no further role in the conduction process.

The mean time that an electron can exist in the P-type semiconductor before filling up one of the holes, or that a hole can exist in an N-type semiconductor before being filled up by one of the electrons, is called the "lifetime" of the carrier. The lifetime is an important property of germanium that is to be used for rectifiers, transistors, or photocells. For, if the lifetime of a carrier is short, it leads to a reduced output of the photocell.

When an electric field is applied in the back direction, the current is reduced to small values. This reduction takes place because there are no electrons in the P-type material to move into the N-type material. The holes in the P-type material, which might have served for conduction, are now urged in the opposite direction by the electric field. The same situation applies in N-type germanium. The only carriers available are those that arise from the "intrinsic conduction." As these arise, they are swept away by the field.

There is another important property involved here; namely, the rate of generation of electron-hole pairs. Theory indicates that in a perfect semiconductor crystal there are no spots at which generation can easily occur, and that generation can take place only at imperfections in the crystal.

The above discussions are important in the field of semiconductor photocells, since it appears that most photoconductive (resistance-type) cells are of the P-N junction type.

The dark current, for example, is thought to be made up of the thermally generated intrinsic conduction appropriate to the number of imperfections in the lattice and, of course, also appropriate to the natural intrinsic conduction of the material. In a photovoltaic cell, the action is probably also of the P-N junction type. Here the output voltage in the cell is dependent upon the intrinsic conduction, which in this case acts as a partial internal short circuit that reduces the output of the cell.

Thus we see that the P-N junction can act like a rectifier. When light shines on the barrier, it has the same effect as thermal agitation; that is, hole-electron pairs are created that immediately contribute to the back current of the rectifier. Again the problem is one of making the dark current small enough so that appreciable changes of back current are noticeable when light of the proper intensity is used.

Optical Properties of Germanium

Beyond the threshold of the absorption, germanium becomes quite transparent to infrared light beyond about 1.5 microns in wave length (Fig. 6). In the visible and the ultraviolet, germanium is highly absorbing, so that very little radiation can penetrate into the material more than a few angstroms. In the visible and the ultraviolet, the index of refraction has a value close to 1; but in the region where the absorption is decreasing rapidly, the index of refraction rises to value greater than 5 and settles to a nearly constant value of 4 for all infrared wave lengths—and indeed, for all wave lengths up to those corresponding to power-line frequencies.

This high value of the index of refraction makes germanium interesting as a possible lens or prism material, since the dispersion power for light is very large, and the bending power of a germanium lens for light of infrared wave lengths is also large.

Germanium is characterized in appearance by the brightly reflecting surfaces it shows when polished. The reflecting power of germanium for infrared light has been measured and found to be about 45 percent for a wide range of infrared wave lengths. The reflecting power for visible light has been measured and found to be about 50 percent. This high reflecting power presents a problem in the use of germanium photocells, since much light will be lost if the light is reflected from even one surface.

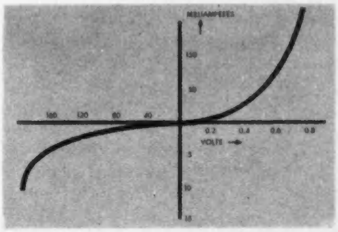


Fig. 5. RECTIFICATION CURVE of a P-N junction rectifier—"hole emission"

It is clear that germanium photocells can be sensitive only to infrared light if the radiation has to pass through an appreciable thickness of matter before reaching the sensitive area. On the other hand, if the sensitive area is very close to the surface, these cells may also be sensitive to visible and ultraviolet radiation. Photocells have been developed using thin surface barriers produced by the evaporation of metal layers, followed by heat treatment.

Photoelectric Properties of Germanium

It has been discovered that high-resistivity germanium of the type found to be good for high-voltage germanium diodes also shows photoelectric properties.

The photoelectric effects first studied were found in germanium diodes having a metal contact on N-type germanium. These diodes showed both the photovoltaic effect and the photoconductive effect for voltage applied in the "back" direction. The existence of these effects in a metal-germanium contact is best accounted for by the assumption of a surface P layer that is present either because of an oxide layer, or because of a "natural" P layer due to surface imperfections.

Photoelectric effects with diodes having the metal contact close to a known P-N junction have also been observed. The P-N junction may be one that shows up accidentally in an ingot, or it may be deliberately produced during the preparation of an ingot by addition of the proper impurities.

Other ways of producing P-N junctions include the addition of impurities by heating the germanium wafer in contact with the desired impurity, which may be in the form of solid, liquid, or vapor. The photoelectric effects of P-N junctions produced by bombarding the surface of a wafer of N-type germanium with alpha particles or deuterons have also been studied. Furthermore, it has been shown that photoelectric effects can be produced at the grain boundary between two sections of a wafer having different crystal orientations. The P-type section here is presumably the region of disorder at the grain boundary.

A formula has been developed for the output voltage of the germanium P-N junction cell, and it has been checked with results on junctions prepared by alpha particle bombardment. It is:

$$e^{V_p q/kT} - 1 = L/H = \alpha I$$

where the symbols are:

e = base of natural logarithms
V_p = output voltage of the cell
q = the charge on an electron (1.60×10^{-19} coulomb)
k = the Boltzmann constant
T = the absolute temperature
L = the rate of production of electron-hole pairs by the incident radiation
H = the rate of production of electron-hole pairs by thermal agitation (intrinsic conduction)
α = a proportionality constant
I = the intensity of the incident radiation

Germanium Photocells

Although the previous information has dealt with germanium photocells in principle, one cell with commercially interesting properties is the photoconductive germanium phototransistor.

The construction of the phototransistor is shown in Fig. 2. This is the same type cell as is illustrated in Fig. 1. A lens may be used at the opening of the housing to increase the effective area of the cell. As indicated in the diagram, the phototransistor is a point-contact device. In its construction a "coaxial transistor" is made. The unit shown in Fig. 2 is set up in a holder with an additional whisker that makes contact on the germanium wafer just opposite to the whisker shown. These two whiskers are used in an electrical power treatment called the "forming" process, that improves the characteristics. Then the additional whisker, used as the positive electrode or "emitter" during the forming process, is removed. During the application of the device, the remaining whisker is the collector and remains in use as the negative electrode, the housing being the positive electrode.

Characteristics of the phototransistor are shown in Fig. 7. There we see current-voltage curves for the unit "in the dark" and in the light of a tungsten lamp with and without infrared filter attached. The infrared data show that the cell is mainly responsive to the infrared wave lengths beyond 8000 angstroms (or 0.8 micron), since the infrared filter passes only 50 percent of the infrared wave lengths, and only a small percentage of the output of the lamp is in the sensitive portion of the infrared spectrum.

The sensitivity of the phototransistor is such that one lumen of luminous flux of color temperature 2850 K changes the current by about 0.1 ampere. The amount of power that can be transmitted to a power unit, such as a relay used for control operations, is in the order of 100 milliwatts. This is ample for the operation of moderately sensitive relays.

The sensitive area of the phototransistor is small. Its diameter is about 10 mils. Thus, for maximum sensitivity, it is desirable to use a small source and suitable lenses to reduce the image to a size approximating the sensitive area of the transistor. For some applications, the small sensitive area is a desirable characteristic. Such applications include the use of these cells in punch-card sorting machines.

One of the characteristics of the phototransistor is that of "current amplification." This means that more electrons pass through the photoconductive circuit than there are photons incident upon the sensitive area. This current amplification is usually in the range of two to five times. It has the same origin as the current amplification of the point-contact transistor.

Although the mechanism of current amplification is not completely clear, it appears that the holes that are released by light are trapped in the space-charge barrier surrounding the collector. There they modify the barrier sufficiently to allow many electrons to pass through or over the barrier under the influence of the negative potential applied to the collector electrode.

Available evidence to date indicates that a P-N junction, created by the forming process at the collector-germanium contact, is the source of the photoelectric properties. Thus, the phototransistor is a P-N junction device of the type previously described, even though the location and the origin of the P region are not, as yet, completely certain. One theory is that both an N and a P layer are formed beneath the point under conditions of high temperature and high electric field during forming. The N layer may be formed by diffusion, while heat-treatment may produce the P layer farther in. This configuration, which acts as a hole trap, is called a "P-N hook."

The response of these cells to handling and usage varies. Some cells have been left for periods of days with moderate currents passing through them and have shown no changes in characteristics. Other cells have been found to show a change by a factor two during the few minutes of a measurement.

Some cells change markedly in a few day's time while simply standing at room temperature. It is known that the contact area must be protected from moisture, and adequate moisture protection is difficult to achieve. Some cells have lost all their photosensitivity in a few week's time. These, however, can be restored to their original state in most cases by temporary attachment of the new emitter contact and by repetition of the power treatment.

As pointed out, broad-area P-N junction cells have been made by a variety of methods—growing the P-N junction in the original ingot, heat-treatment in contact with an impurity, as well as bombardment with nuclear particles. The characteristics of a small P-N junction cell are shown in Fig. 8. The P-N junction is perpendicular to the long dimension of a bar of germanium. The bar is about 0.4 cm in length and is 0.5 mm square in cross-section. The wave-length sensitivity is similar to that of other germanium cells.

The characteristics of point-contact phototransistors show that these cells are at present probably not suited to measurement work or to control work where a high degree of stability or discrimination is required. On the other hand, for many ON-OFF or switching applications where the characteristics need to be maintained over periods of time only to a moderate degree, their small size, reasonable power capacity, infrared sensitivity, and strength may make them useful.

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Figs. 6 and 8 reproduced courtesy *Physical Review*.

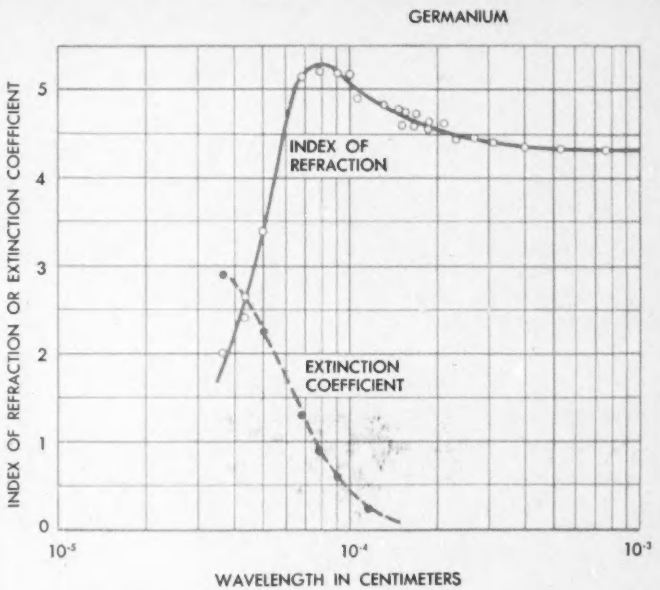


Fig. 6. OPTICAL PROPERTIES of germanium films. Region of greatest photoelectric sensitivity is between high absorption and low absorption (1.0 to 2.0 microns)

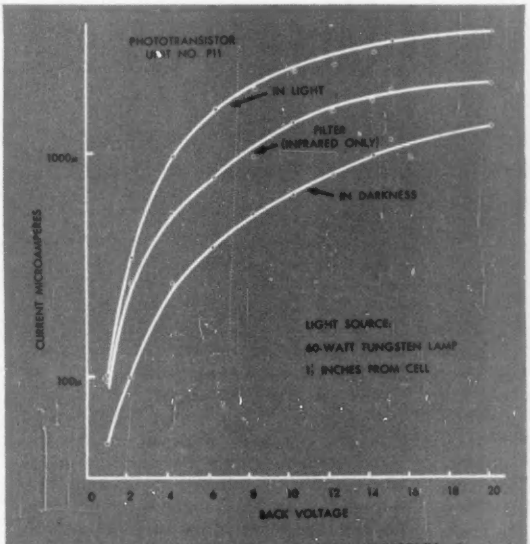


Fig. 7. PHOTOTRANSISTOR CHARACTERISTICS in response to light from a tungsten lamp

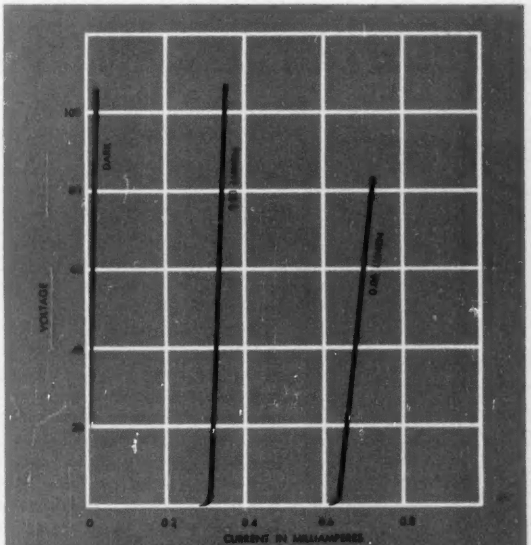


Fig. 8. P-N JUNCTION photocell characteristics for a small element of the filament type

NEW NORTH AMERICAN SABREJET, THE F-86D, IS POWERED BY A G-E JET ENGINE

GENERAL ELECTRIC ENGINEERING DEVELOPS POWERFUL PRIME MOVERS, UNAVAILABLE 10 YRS AGO

Builders of the first U. S. jet engine in 1942, G-E engineers have made tremendous progress towards solving difficult metallurgical problems caused by high temperatures and severe stresses

In March, 1942 the first U. S. turbojet engine, an aircraft gas turbine for jet propulsion, was built by General Electric. It propelled a P-59 Bell Airacomet at more than 400 miles per hour.

Today, improved G-E jet engines enable a pilot to fly at the speed of sound. Important? Yes—but so is the fact that the invaluable experience thus gained by G-E engineers—in overcoming tough metallurgical, electrical and mechanical design problems—has been put to work in many other fields.

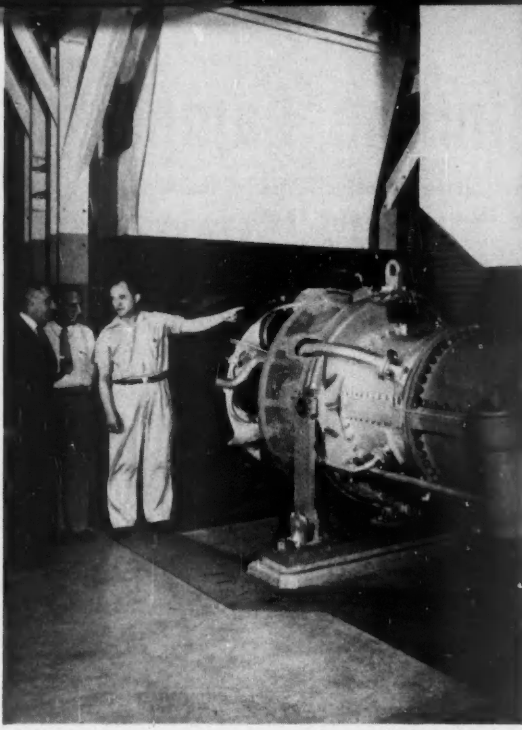
For example, in July, 1949 General Electric engineers installed the first gas turbine to be used by an electric utility. That same year, G.E. engineered the first gas turbine-electric locomotive in the U. S.

Another application of G-E gas turbine experience is in the diesel field. A high-pressure G-E turbosupercharger has reduced the weight per horsepower of the average locomotive and other diesel plants by almost half! The oil and gas industries will soon benefit from G-E engineering, too; a series of gas turbine pumping stations is now being built for a natural gas company.

You can take advantage of G-E engineering leadership. When you buy G-E industrial products, you benefit directly from this outstanding engineering experience. And on jobs where high-quality system engineering is required, G-E application engineers will draw on this experience in working closely with you and your consultants. Call the Apparatus Sales Division office nearest you. *General Electric Company, Schenectady 5, N. Y.*

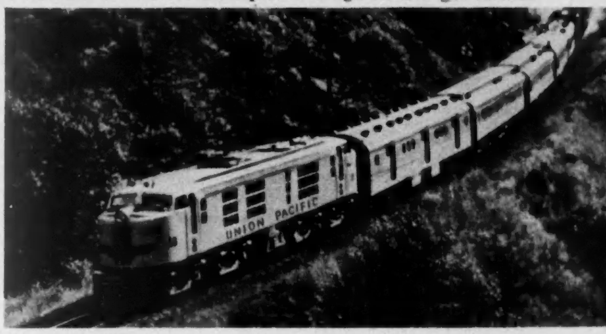
▲

PIONEER in developing first U. S. jet engine in 1942, G-E engineer D. F. Warner is shown with combustion chamber liner of a J-47 jet engine. Today, the record shows G-E-designed engines have powered more planes, flown more miles, broken more records than all other U. S. jets combined.

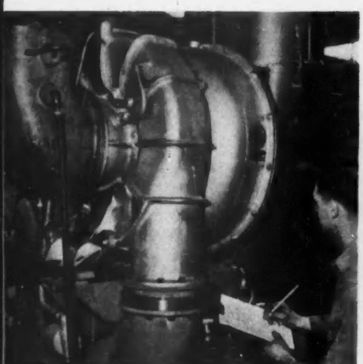


FIRST electric power-producing gas turbine in U. S. is this G-E 3500-kw unit built for Oklahoma Gas & Electric Co. After 18.500 hours of operation, the record shows no failure of any component.

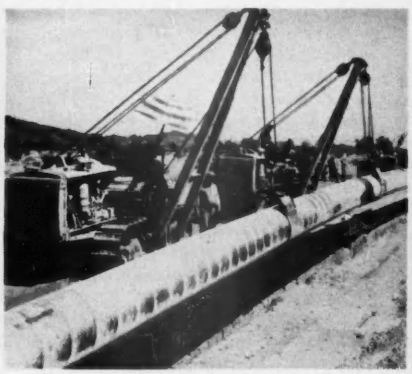
RESEARCH and creative engineering, plus 45 years of steam turbine experience, help G.E. keep gas turbine leadership. Here, lab technicians test advanced compressor design for new gas turbine.



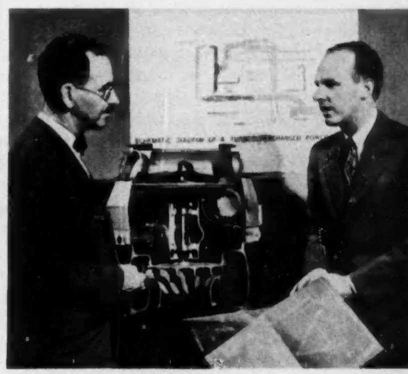
LOCOMOTIVE (like this unit shown on Union Pacific tracks) is powered by G-E gas turbine which is lighter and generates more hp than any other prime mover. U.P. has ordered ten of these units.



DIESEL engine, with G-E turbosupercharger, weighs 18 lbs per horsepower as against 35 lbs without. On railroad locomotives, this diesel supercharger also improves operation at high altitudes.



PIPELINES carrying natural gas will benefit from booster pumps driven by General Electric gas turbines which burn gas "bled" directly off the main line. Because it needs no water, the G-E gas turbine is well suited for operation throughout desert areas.



HIGH-ALTITUDE flying was made possible by General Electric aircraft turbosuperchargers. W. O. Meckley (right) and M. G. Robinson, General Electric turbosupercharger engineers, discuss a model.

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Instant-start Slimline Lamps

Development Problems, Performance, and Application Characteristics of the Newest, Fastest-growing member of the Fluorescent Lamp Family

By R. N. THAYER and A. C. BARR

The fluorescent lamp found its first substantial commercial use at the New York World's Fair in 1939 and 1940. It has since become a popular light source because of its many basic advantages. The most important of these advantages are:

1. Higher luminous efficiency—about three times that of any other white-light source;
2. Lower surface brightness, which means less of the losses incident to the reduction of shielding of light-source brightness;
3. Less heating effect, because of higher efficiency and the small amounts of infrared radiation;
4. Architectural suitability, because the linear shape encourages use in lines and patterns.

In addition to these, slimline fluorescent lamps add special benefits of their own:

- Slimlines are instant-start. They require no starter switches and thus eliminate the cost and maintenance troubles those accessories involve.
- Stronger single-pin bases are used. This in turn leads to the use of stronger push-pull lampholders.
- Greater length—the 8-foot size is by far the most popular. This improves the appearance of installations by providing more nearly continuous lines of light. More important, it reduces the number of lamps required for a given lighting level.
- Each slimline size may be operated over a range of milliampere ratings, offering a two-to-one choice of brightness and light output. This gives maximum flexibility in meeting application requirements with a minimum number of sizes.
- The combination of greater length and instant starting greatly reduces the number of parts needed for a fluorescent lighting system (Fig. 1). Thus slimline systems bring great reduction in maintenance requirements.

These advantages of flexibility, maintenance, and appearance have led to increasing uses in many lighting fields.

Slimlines are available in a range of lengths and diameters (see Table). The 96- by 1½-inch size is by far the most widely used, because it offers best over-all economy. To add flexibility in fitting 1½-inch slimline installations into a variety of room sizes and lighting-fixture layouts, 72- and 48-inch lengths are also available.

The 1-inch diameter is available in 96- and 72-inch lengths. It finds use in applications where long lines of light are desired with less light output per foot than the 1½-inch diameter furnishes. Also, the higher-wattage loading which results when this size is operated at its maximum current rating (300 milliamperes) improves light output in cold weather by maintaining a higher bulb-wall temperature. So, the 1-inch diameter finds use not only for outdoor operation but also indoors, in refrigerated spaces.

Operated at 120 milliamperes, this diameter also finds use indoors in several ways. The reduced light output is desirable in some continuous-line applications, and the lower brightness is desirable where lamps are exposed to view or where reflected glare from louvered lamps may be a problem.

The ¾-inch diameter is particularly suitable for use in 4- and 6-foot showcases. There the small diameter allows their use in small reflectors. Like the 1-inch diameter, it may be operated over a range of currents and is well suited to low-temperature operation.

The successful development of a line of lamps with these favorable characteristics required the solution of many problems and involved a group of engineers for a period of several years. Important examples of these problems are discussed in the following paragraphs. Some answers were first worked out on the 40-watt instant-start bipin type, introduced in 1944. Its design requirements closely match those of the present 48- by 1½-inch slimline size.

Electrode Design

Electrode design and its manufacturing control are the chief factors determining lamp life and end discoloration. For instant-start lamps, design requirements are far more severe than for switch-start.

Since fluorescent lamps commonly operate on alternating current, each electrode takes turns many times each second in serving as either cathode or anode. When the electrode is positive, all exposed metal surfaces serve the relatively simple function of collecting current. When negative, the electron emission required for rated lamp current must be furnished by a coiled coil of tungsten wire (Fig. 2), coated with an emission mix of alkaline-earth oxides. This coil is called the cathode, and its design and quality are prime factors in producing satisfactory lamp life.

In switch-start lamps, the cathode is designed to heat to incandescence in the preheat current provided respectively by the starter-switch contact-time and the ballast (Fig. 3A). Although preheat delays lamp starting, it does prevent the severe sputtering of emission material that would otherwise occur

Mr. Thayer has been on the Technical Staff of the Lamp Development Laboratory at Nela Park, Cleveland, Ohio, since joining General Electric in 1928. He participated in the original development of fluorescent lamps.

Since coming to General Electric's Lamp Division at Cleveland, Ohio, 10 years ago, Mr. Barr has been actively engaged in the development of slimline lamps, cold cathode lamps, and the new deluxe fluorescent colors.

SLIMLINE LAMP DATA

Type	Length, Inches	Diameter, Inches	Ballast Open-circuit Volts	Nominal Lamp Current, Milliamperes	Lamp Volts	Lamp Watts	Brightness, Footlamberts*	Lumens at 100 hours*	Lumens per Watt*
T12	96	1½	625	425	192	74	1750	4800	65
T12	72	1½	525	425	145	55	1750	3400	62
T12	48	1½	430	425	97	38	1750	2200	58
T8	96	1	750	120	320	32	1200	2250	70
				200	285	49	1800	3300	67
				300	255	65	2350	4300	66
T8	72	1	600	120	240	24.5	1200	1590	65
				200	210	36.5	1800	2350	64
				300	190	48.5	2350	3050	63
T6	64	¾	600	120	265	25.5	1750	1510	59
				200	225	37	2500	2150	58
				300	195	48	3000	2600	54
T6	42	¾	430	120	168	17.5	1750	930	53
				200	145	25	2500	1320	53
				300	125	32.5	3000	1620	50

* Values are for standard cool white. White and standard warm-white colors run about 5 percent higher; daylight color, about 10 percent lower.

during starting. Without preheat, such sputtering blackens the lamp ends severely and reduces lamp life to one-third its normal value when tested at the normal starting frequency of one every 3 hours of operation.

To attain instant starting without starter switches it was necessary to design a cathode that would furnish normal lamp life and reasonably clean ends despite sputtering at every start. Numerous designs were life-tested in the search for a successful answer.

The successful design consists basically of a loose overwind of fine (0.7 mil) tungsten wire added to a coiled coil of modified dimensions (Fig. 2). The overwind performs a double function. First, it reduces sputtering time by rapidly reaching the emitting temperature when the arc first strikes; and, second, it acts as a "basket" to hold a large quantity of emission material tightly. Together, these provide satisfactory lamp life.

When 1- and ¾-inch-diameter slimlines were first marketed with these cathodes, it was found that marked end discoloration often developed during life, because sputtering cannot be completely avoided without preheat. Here again, extensive trials produced a remedy: the cathode shield.

In the conventional mount structure (Fig. 4), the cathode is mounted transversely to the lamp axis without shielding. Any material vaporized or sputtered from it deposits on the adjacent bulb wall in a variety of discoloration patterns. By shifting the cathode to an axial mounting and surrounding it with a close-fitting cylindrical shield of nickel or iron (Fig. 4), all material leaving the cathode is trapped by the shield, and end discoloration is consistently eliminated until the last few hours of lamp life.

The cathode shield has been standard on 1-inch diameters since 1947. It has not been used on the ¾-inch diameters because they are installed chiefly in concealed locations where the lamp is not seen directly. On the more recently introduced 1½-inch diameters, where the problem of end blackening is not as acute, its use to date has been limited by shortages.

Starting Reliability

Another development problem of slimline lamps was that of obtaining reliable instant starting on reasonably low open-circuit voltages. The nature of this problem can best be understood by first reviewing starting and open-circuit voltage requirements for switch-start lamps.

In this case (Fig. 3A), interrupting the flow of preheat current through the ballast windings by opening the starter-switch contacts produces a transient peak voltage ranging from several hundred to 2000 volts. This provides reliable starting over a wide variety of adverse lamp and service conditions.

From this, it might appear that ballast open-circuit voltage needs to exceed lamp operating voltage only slightly. This would minimize the ballast volts and watts, and consequently its size and cost. In practice, however, open-circuit voltage must be increased considerably, with further increase in all these items, to minimize variations in light output

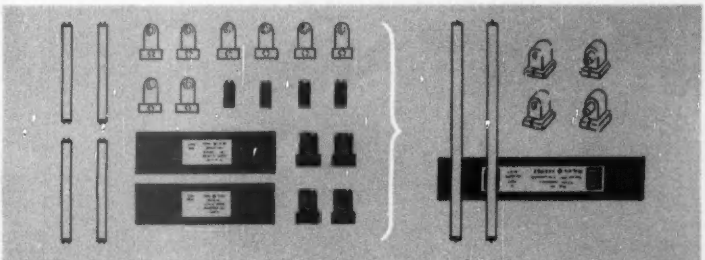

Fig. 1. ONLY SEVEN PARTS in a slimline system *(right)* produce 4 percent more light than do 22 parts in a 40-watt starter-operated system

for fluctuations commonly encountered in supply voltage.

These conflicting objectives have been compromised, in switch-start circuit designs, by using an open-circuit voltage about twice lamp-operating voltage. At this point, each 1 percent variation in supply voltage produces: (a) about 2 percent variation in lamp wattage and light output on reactively ballasted (lag) circuits; and (b) 1 percent on capacitively ballasted (lead) circuits.

The elimination of starter switches in slimline-lamp circuits also eliminated the starting transient which they provided. Thus all safety factors for reliable starting must instead be incorporated in the open-circuit ballast voltage. At the same time, practical values of ballast size, weight, cost, and wattage loss required that ratios of open circuit to operating voltage be kept as low as possible.

If a gradually increasing a-c voltage is impressed across the terminals of a 48- by 1½-inch lamp without cathode preheat, the instant-start voltages obtained will vary from a minimum of about 250 to a maximum of 750 volts, or even more. Use of the maximum figure to assure reliable starting of all lamps would result in an impractically large and expensive ballast, because the corresponding preheat type requires only 200 volts.

An investigation of this wide scatter, which often occurs on the same lamp tested at different intervals, disclosed that starting voltage increases with rising relative humidity (above 65 percent), and this in turn correlates with reduced resistance along the bulb-wall surface (Fig. 5). The apparent explanation is that low-voltage instant-starting of long arc gaps requires concentration of the impressed voltage near the cathodes. When the bulb surface is highly insulating, the lamp surroundings—such as a metallic fixture—serve this purpose. At relatively low bulb-surface resistances, leakage currents along the bulb perform the same function. But intermediate values of bulb resistance, often encountered at 65 to 100 percent relative humidity, make starting difficult.

Starting Aids

Several remedies for this difficulty were explored[1]. On slimline lamps, the first one to be used commercially was an unconnected, metallic, conducting stripe drawn most of the length of the bulb on its outside surface, and fired into it for permanence. This gives consistently low-voltage starting (250 to 350 volts on the 48- by 1½-inch size) and in addition is independent of the presence or absence of adjacent metal. This was important in some early applications where slimline lamps were directly mounted on ceilings or other nonmetallic backings.

Since the use of metallic louvers or reflectors has been almost universal in recent years, it has permitted shifting the starting aid to a nonwetting silicone coating, which is a simpler and more easily applied alternative. It keeps the bulb surface highly insulating at all values of relative humidity, and no current leakage path can form.

The use of starting aids then permitted, on slimline lamps of various dimensions, the determination of practical values of open-circuit voltage for reliable starting. Comparison of operating and open-circuit voltages for lamps of various dimensions showed that starting voltage does not increase, percentage-wise, as fast as operating voltage. The 20-watt switch-start size requires 5 times its operating voltage for reliable starting; the 40-watt and 48- by 1½-inch, 3.6 times; continuing on until the 96- by 1-inch size requires only 2.6 times. So, by choice of longer lengths and small diameters, the open-circuit to operating-voltage ratio can be reduced nearly to the 2:1 value required anyway for acceptable regulation.

Instant-starting has thus been achieved with but little percentage increase in ballast size, cost, weight, and loss over what would be required for corresponding switch-start designs. This is a design fundamental favoring the combination of instant starting with long lamps. Conversely, short lamps are least adaptable to high-voltage instant starting.

Even with the use of starting aids, several sources of variation in lamp starting voltage still remain. Individual lamps show considerable variation under identical test conditions because of random manufacturing differences. For ex-

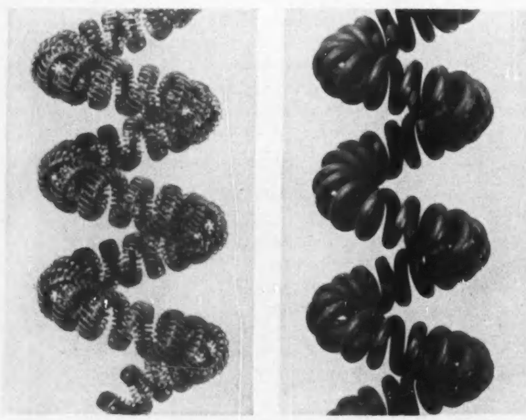

Fig. 2. CATHODE CONSTRUCTION—triple-coil design for instant-start slimline lamps *(left)*; and coiled-coil for switch-start

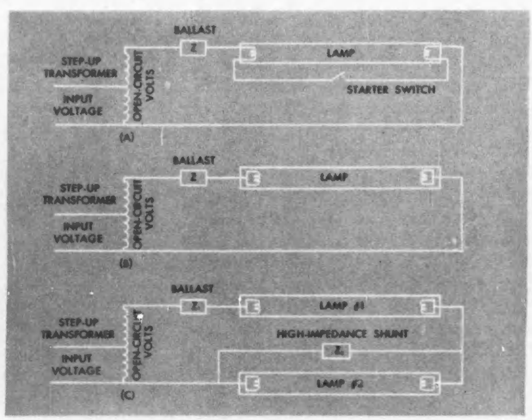

Fig. 3. BASIC CIRCUITS for switch-start lamps with preheat *(A)*; multiple slimline *(B)*; series slimline *(C)*

ample, starting voltages on a random selection of 96- by 1- and 1½-inch lamps show average values of 460 and 520, respectively, but 1 percent of each requires 560 volts or more. Also, starting voltage typically decreases from 20 to 30 percent after the first few hours of operation (it then remains relatively constant through lamp life). A third variation is the 5 percent average rise in starting voltage between the test point of 80 F and the usual minimum indoor ambient of 50 F. And finally, the recommended open-circuit voltage rating allows for a 10 percent fluctuation below rated supply voltage.

These various allowances result in recommended open-circuit voltages (see Table) well above median lamp values. Large numbers of lamps from different manufacturing lots, tested under varying service conditions, are required to determine a recommended value. Trial of only a few well-seasoned lamps can easily indicate an artificially low value for the size tested. Once burned a few hours, and especially with maintenance of full-rated line voltage, many slimline lamps will start reliably at ambient temperatures well below 50 F.

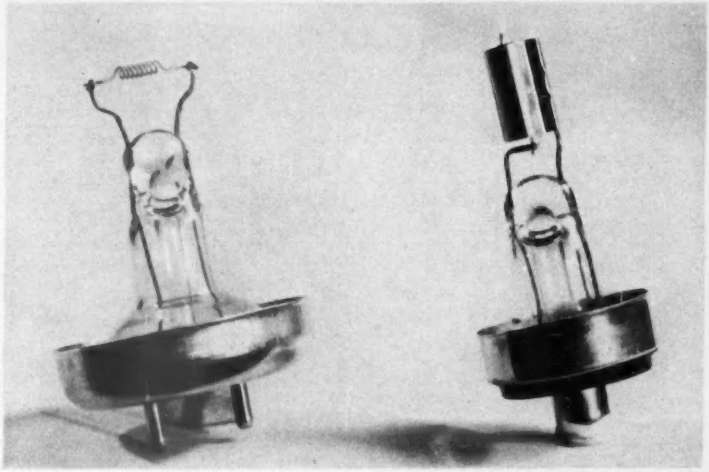

Fig. 4. ELECTRODE COMPARISON: Conventional design used chiefly in switch-start lamps *(left)*; and shielded-cathode design, developed for use in slimline lamps

Ballast-circuit Requirements

Open-circuit voltage and electrical operating values for fluorescent lamps are the basic specifications for ballast circuits. Most slimline lamps to date have operated from the familiar twin-lamp variant of the fundamental circuit (Fig. 3B). From the step-up winding, a reactor ballasts one lamp (lag), and a reactor-capacitor series combination the other (lead). The combination provides 90 to 100 percent power factor on the input side and reduces cyclic flicker—"strobe"—in the combined light from the lamps. Flicker is reduced, however, by less than on switch-start circuits to the extent that increases above the 2:1 open-circuit to operating-voltage ratio have an adverse effect on phase angle. But in practice, these differences have not been significant.

Development aimed at reduced size, weight, and cost of ballast has been active for years. One circuit long studied operates two lamps in series, with a high-impedance shunt across one of them (Fig. 3C). The shunt first permits one lamp to start, then the other, on an open-circuit voltage only slightly higher than the value required for one lamp.

Early development designs of this type, and some similar ones recently marketed, reduced lamp life by one-third or more. This was apparently because starting current through the series shunt was too low for rapid cathode heating, resulting in excessive sputtering. But there was, nevertheless, a reduction in size and other items which is attractive, and a study of the cause and cure of short lamp life was undertaken.[2]

Tests showed good correlation between lamp life and the starting current furnished to resistors, substituting for lamp load (Fig. 6). A minimum requirement of 100 milliamperes starting current has been adopted by the industry, and ballasts meeting this requirement are commercially available. They deliver rated lamp life where ambient temperature exceeds 50 F, while maintaining advantages in size, weight, wattage loss, and cost.

Base and Lampholder Designs

In developing the 1- and 1½-inch switch-start base and lampholder designs introduced in 1938, length tolerances were tightly set to minimize the dark space between lamps mounted in continuous rows. Lamp length must be held within $\pm\frac{3}{64}$ inch, and lampholders must be mounted in good alignment with a length tolerance of $\pm\frac{1}{32}$ inch. In practice, these limits have handicapped economical lamp manufacture, and in many instances lamps have not fitted properly into fixtures. The insertion and turning of lamps for good electrical contact has also been troublesome on occasion.

These experiences were valuable in the development of new designs of base and lampholder for single-end contacts and the new lengths of the slimline-lamp sizes. The base has a sturdy single pin $\frac{5}{16}$ inch long (Fig. 4 right). Lampholders are also larger and stronger. Lamp-length tolerance has been increased to $\pm\frac{1}{8}$ inch. This is still an accuracy of ± 0.1 percent, a small tolerance for a glass bulb with a melted seal and cemented base on each end. Lampholder spacing tolerance has been increased to $\pm\frac{1}{16}$ inch.

Lamps are easily inserted (Fig. 7) by grasping them anywhere along their length, inserting one end into the spring-backed high-voltage lampholder, pushing to depress the spring, and then seating the other end in the low-voltage lampholder. The primary circuit of the ballast is not completed until this last step. With this design, insertion and removal of lamps is simple, lamps are securely held, electrical contact is firm, and tolerances are more practical.

Luminous Efficiency

Slimline lamps show the highest lumens-per-watt efficiency ever obtained in a commercially available white-light source (see Table). In the standard cool-white color, the popular 96-inch sizes yield 65 to 70 initial lumens per watt. (This compares with 59 for the

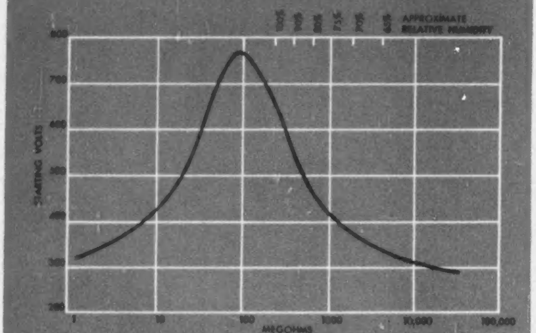

Fig. 5. INSTANT STARTING voltage of untreated 48- by 1½-inch slimline lamps vs bulb surface resistance and approximate relative humidity

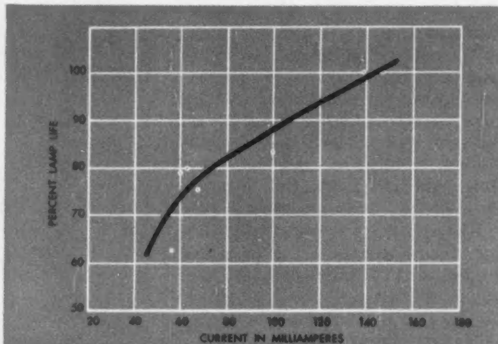

Fig. 6. RELATIVE LIFE of 48- by 1½-inch and 96- by 1½-inch lamps vs current supplied by the ballast under test to resistor loads of 2750 and 4000 ohms, respectively

40-watt preheat size, and 10 to 15 for filament lamps of comparable wattage.) White and warm-white colors run several percent higher, and peak efficiencies up to 120 lumens per watt have been achieved with laboratory lamps of slimline dimensions in green fluorescent color. On the other hand, with deluxe warm-white and cool-white colors, developed particularly for applications where excellent color rendition is more important than maximum luminous efficiency, lumen-per-watt values are about 25 percent lower than for standard cool white (see Table).

Slimline high efficiencies result from minimizing unavoidable end losses, for all fluorescent lamp designs suffer fixed losses of light and wattage at the ends. The loss of light occurs because some of the light generated by the fluorescent coating is directed internally and is partially absorbed by striking the electrode structure and base of the lamp.

The loss of wattage represents the sum of cathode and anode voltage drops. In hot-cathode slimline and switch-start fluorescent lamps, this drop is 15 to 20 volts. This energy is required for current emission and collection, but it does not result directly in light output.

As lamp length and operating voltage increase, luminous efficiency progressively increases (Fig. 8), because these fixed losses become a decreasing percentage of the total. As Fig. 8 shows, the efficiencies of the 96-inch lengths are within 7 percent of the theoretical maximum for a lamp of infinite length and voltage.

For slimline lamps with a range of operating currents (see Table), luminous efficiency increases slightly at lower currents, and vice versa.

Life and Lumen Maintenance

The value of long lamp life is often overemphasized, while other performance factors—notably lumen-maintenance and color-rendition properties are overlooked. Nevertheless, lamp life is important and should be evaluated in its proper relationship. Slimline lamps now have a rated life of 6000 hours at the standard test cycle of one start every 3 hours, and a 7500-hour rating may be anticipated with further refinements and controls in lamp manufacture. Thus, the instant-start cathode development has produced a life rating substantially equal to that of switch-start lamps.

Lamp life appears reasonably constant throughout the 120- to 300-milliampere range for lamps so rated. This is probably also true for the 1½-inch diameters, despite their single rating of 425 milliamperes, for all slimline sizes use the same basic cathode design with only minor changes.

If the 1½-inch diameters are operated above 425 milliamperes, however, life is reduced. At 600 milliamperes, a point of commercial interest, tests to date indicate a 20 percent reduction in life.

The percent maintenance of initial light output through life closely parallels the values found for switch-start lamps of the same diameter and current rating. Typical values are 83 percent of 100-hour lumen ratings at 3000 hours, and 77 percent at 6000 hours. The average light output throughout rated life is 85 percent of the initial rating.

Slimline instant-start lamps end their useful life in a different manner than do switch-start types. The life of any fluorescent lamp normally ends when one cathode has used up all of its coating of emission material; it is "deactivated." The voltage drop near the cathode then rises, from the 12- to 15-volt value typical of normally active cathodes, to a value of 100 to 150 volts, which is typical of bare tungsten at the temperatures produced.

In switch-start circuits, this increase produces a total lamp voltage in excess of the restriking voltage of the glow-switch starter. Continuous recycling and flashing occur unless a starter incorporating a time-delay lockout, such as the "Watch Dog"* type, is used to open the circuit after a few trials.

In slimline circuits, no starter is present to restrike. Open-circuit voltages are enough higher than operating voltages to maintain the arc even after the voltage rise caused by deactivation.

So, on lag circuits, the lamp continues to operate with partial rectification, because of the differing voltage drops in the two directions. Light output is reduced to about half, flicker is increased, and the deactivated lamp end is blackened rapidly by the sputtering of metal from all parts of the electrode structure.

On lead circuits, rectification is prevented because of the series capacitor. There, equal current is forced through in both directions, and the deactivated end again produces rapid sputtering and end discoloration. Various kinds of

*Reg. trade-mark of G.E. Co.

Fig. 7. RELAMPING is easy with the slimline base and socket combination

flicker and spiraling of the discharge may also occur. The added wattage dissipation at the deactivated end raises the temperature of the bulb wall opposite that electrode from a normal value of about 60 C to about 150 C, and fixture parts close to the bulb end should be chosen and spaced to withstand this temperature.

To reduce annoyance, and to avoid the overloading of the ballast produced by these irregular arcs, deactivated lamps should be removed as soon as they are noticed. A reliable indication is complete blackening at one end of the bulb. Ideally, lamps should fail to operate at all at the end of their useful life but in actuality this remains a development problem for future solution.

Lighting Costs

In both initial cost and cost of operation, lighting systems using the 96- by 1½-inch slimline lamp compare very favorably with those using the most popular of the earlier fluorescent lamp types, the 40-watt 1½-inch preheat. Using a suggested standard cost-analysis method[3], which compares on the basis of equal maintained illumination, recent studies indicate almost identical costs for the two systems. A study based on industrial lighting installations showed the relative initial cost of the 96- by 1½-inch size to be 2 percent higher than that of equivalent 40-watt preheat systems. On the other hand, operating cost of this size is from 2 percent to 6 percent lower, depending on energy rate and burning hours per year.

In an over-all cost comparison, where operating cost is weighted with a portion of initial cost, the 96- by 1½-inch size is 1 to 5 percent lower. Cost studies made in the office-lighting and store-lighting fields show similar results.

To summarize, lighting costs with 96- by 1½-inch slimlines are no higher than they are with 40-watt starter-operated systems. Yet slimline has the advantages of instant starting, better appearance and, most important, less maintenance.

Lamp Manufacture and Use

Setting up facilities to obtain the many design advantages of slimline lamps by mass production at high quality and low cost was itself a development problem matching the design work in scope.

Most of the existing fluorescent-lamp manufacturing equipment would not accommodate lengths exceeding 64 inches. Also, longer lamps have required much stricter control of manufacturing variables to maintain end-to-end uniformity in coating appearance, color, and brightness. Further, new or additional equipment was required for the special cathodes, shields, and starting aids necessary for use in slimline lamps.

All this development was completed in 1948, when General Electric's newest and largest fluorescent lamp factory was opened at Circleville, Ohio. This modern single-purpose plant is devoted exclusively to slimline-lamp manufacture.

The sales of slimline lamps have approximately doubled each year since their introduction in 1945, until now the amount of lighting being installed with slimline and 40-watt fluorescent lamps is substantially equal. There is every indication that the careful research and development work invested in slimline fluorescent lamps has already proven of great benefit to users, and is bringing about an increasing demand for the accessory equipment as well.

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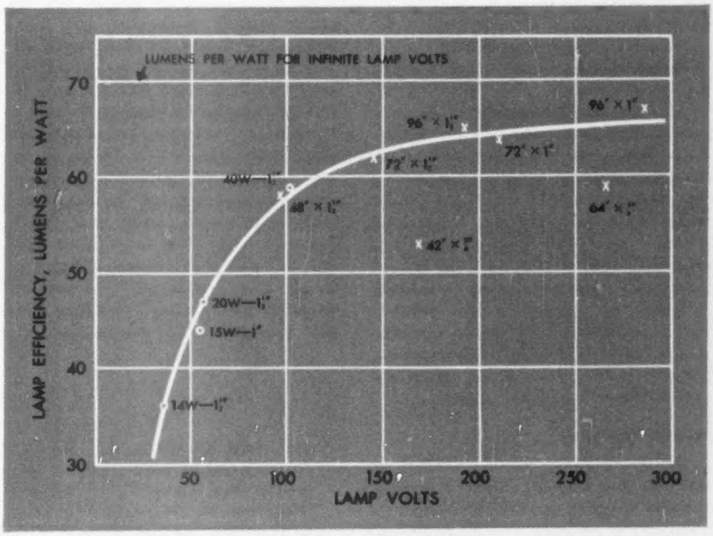


Fig. 8. LAMP OPERATING VOLTAGE vs lamp efficiency, in lumens per watt at 100 hours for standard white. For multiple-current lamps, values of ¾-inch diameters are 120 milliamperes and, 1-inch diameters, 200 milliamperes, for current density and brightness approximately equal to 1½-inch diameters at 425 milliamperes

Savings by the Barrel

By CHARLES O. FURBISH

Such rapid strides have been made in the field of barrel-working—the process commonly known as "tumbling"—that its extensive use now rates serious consideration in any industry producing parts that require hand deburring, smoothing, shaping, or other surface finishing.

No other method producing comparable results in quantity operates so economically and requires such moderate skill.

Extensive development programs that result in improved equipment and materials make it possible to barrel-work many parts previously considered impractical. Parts of all description can be barrel-worked at production volumes of almost any level and with uniformity of finish and low micro-inch surfaces where required. Besides the well-known deburring operation, you can barrel-work parts to cut down, to form uniform and precise radii, to reduce surface porosity, to finish threaded and intricate parts, to remove paint scale and heat-treatment oxides, and to produce many other results related to your particular manufacturing needs.

Barrel-working is no longer a crude and rough process.

All barrel-finishing operations are related. Results from the various operations differ only in the amount of material removed from the part and the type of finish obtained, the results being determined by the barrel and "media" used. Media is the term that describes the material in the barrel other than the parts being processed.

Since the operations are related, they can be generally classified under rough tumbling, rolling, or burnishing. Illustrations of these three operations are shown on the adjacent page.

Rough Tumbling

Rough tumbling, mainly limited to castings and foundry work, is comparable to snagging or rough grinding.

In this process the work is packed in a nearly filled barrel so that the parts do not shift appreciably. The barrel rotates horizontally and causes the media to roll over and around the load. This chips off the scale, sprues, and fins, and smooths the protrusions. The media and abrasives are in the dry form, although wet tumbling is not uncommon.

Rolling

Rolling, which is comparable to the more finished forms of grinding and polishing, is the most widely applied. The parts, media, and compounds are in continuous motion, shifting with the mass.

The barrel is generally half filled. The action takes place when the revolving barrel lifts the mass to a point where the mass slides in the direction in which the barrel is turning, thus creating the working action in the load.

Results depend a great deal on the shape and size of the barrel, its speed, and its angle. These factors are selected according to the shape, size, material, and the quantity of parts being worked. Disregard of these factors is many times the cause of improper barrel loads where the parts, separating from the mass, pound around on each other and cause nicking, impinging, and other deformities. Improper barrel loads also require longer barrel cycles and, in some instances, will not produce the results under any circumstances.

Suitable parts can be rolled upon themselves either wet or dry or, as may be required, with an abrasive or cleaning compound, available in varieties to meet most requirements. More often, however, because of shape, size, quantity, or delicacy of the part, a filler must be added to form the load mass essential to proper barrel action. This filler keeps the parts spaced and carries the action into crevices and interstices when parts with irregular surfaces are being worked.

For wet loads fillers may be shaped pieces or punchings of either steel or mineral. Wood blocks, sawdust, leather, and various forms of vegetable concoctions are used for dry loads. In both cases fillers are selected to perform their function without damage to the work and in sizes that will not lodge in blind holes and cutouts.

Abrasives, both natural and tailored, as well as cleaning, descaling, coloring, and lubricating compounds, are available in a wide variety ranging from alkaline through acid. When used in strict accordance with the manufacturers' recommendations, they speed the process for which they were compounded.

Burnishing

The third process is barrel-burnishing, which is capable of producing luster and finishes most nearly comparable to cloth-wheel grinding and buffing.

In this process the parts are rolled in a solution of water and burnishing compound, one function of which is to lubricate and reduce the erosive action on the surfaces of the parts. This results in lustrous finishes and reduced micro-inch readings.

Adding hardened steel to this mixture increases the weight factor, making possible a degree of surface hardness that is desirable for durability and antifriction. The weight also tends to close pores, resulting in tighter surfaces for plating and in some instances eliminating the need for plating.

Cleanliness and careful preparation are of paramount importance if the results are to be satisfactory. You must eliminate burrs, sharp edges, abrasives, oils, and other foreign matter that could cause scratching and contamination, and the entire process must be one of absolute cleanliness. Work to be burnished is usually prepared by the rolling process, then thoroughly cleaned before burnishing.

Improved Techniques

During the past few years the science of barrel-finishing has advanced rapidly.

Mr. Furbish received General Electric's Charles A. Coffin Award (1950) for his work in the development of tumbling as "an economical and scientifically controlled manufacturing process." He is a specialist in that field for the Meter and Instrument Department.

Manufacturers of barrel-finishing equipment and distributors of barreling supplies are constantly enlarging the field and improving the techniques.

Results of this research are reflected in the advanced procedures where manufactured abrasives, crushed and sized, serve as both the mass and the abrasive. The barrels, ranging from 30 to 60 inches in circumference, and 32 inches to 8 feet in length, supply volume for the "boxing" of more and larger parts.

Greater diameter and length of slide gets results faster. And the selective speed at which the drum revolves allows for innumerable combinations where finish may be sacrificed for faster and heavier cutting—or perhaps the cut reduced and the finish made the primary objective.

Submerged Barrel-finishing

Possibly the newest adaptation of one of the fundamentals of barrel-finishing is now being applied in the process known as submerged barrel-finishing. The work and filler are contained in a perforated cylinder that revolves in an open tank of liquid containing abrasive, cleaning, or burnishing compounds. This technique is proving useful in the processing of heavy parts and large soft-metal parts. The cushioning effect, resulting from the complete submersion of the cylinder, lessens the impact to such an extent that nicking and scratching are minimum.

Various combinations can be used and in-line installations made. With the open tanks in multiple, the loaded cylinder is moved from one tank to the next until the process is completed. Without removal from the cylinder the work is ground, polished, cleaned, descaled, burnished, or rust-proofed.

In the Meter and Instrument Department at the General Electric Company's West Lynn Works, barrel-working of many small parts for precision products is a major operation. In these operations, we have no definite formula whereby it is possible to predetermine the factors that make up the original process of tumbling for a particular part. Each new assignment is considered in the light of past experience, and trial runs are made to determine the proper procedure.

For this reason, our setup includes a Tumbling Methods Section. All new work and changes are routed through this section, where the process is developed and recorded.

To develop a process intelligently, certain preliminary information is essential. To aid this procedure, planning, engineering, and manufacturing sections are furnished "request-for-tumbling" cards, on which this information is recorded when the request is submitted. A problem number is assigned each card, and the number becomes the permanent reference and identification for that particular part.

Once the process is developed, "tumbling-process" cards are prepared and distributed. They contain the problem number and the information necessary to set up and process successive lots of parts.

Reports are compiled and forwarded to the interested parties. One report lists the reasons for barrel-working and results of the development work, type of barrel to be used, and an estimate of the barrel-hours and direct labor that will be required to meet production needs. The latter information is essential for accurate records in the planning and wage-rate divisions.

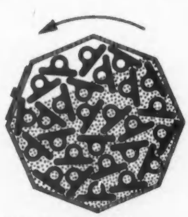
When direct savings have been realized, a cost-reduction or salvage report is also compiled and distributed. Copies of cards and reports are retained in the development-section master file with the complete history of the problem.

Savings realized at West Lynn from the barrel-working of parts for the past several years would be almost impossible to calculate, since much of the work

THREE BASIC BARREL OPERATIONS

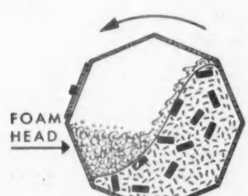
Barrel-working encompasses such a wide field and consists of so many variables that it is difficult to illustrate clearly the differences between rough tumbling, rolling, and barrel burnishing. Various types, shapes, and sizes of barrels are operated at speeds ranging from slow to fast, while loaded with nearly unlimited combinations of parts, media, liquids, and compounds.

A barrel type can in many instances be used to obtain either or all of three results, depending on the load combination available and the quality specification for the finished part. In other instances the requirements are such that the barrel and media must be carefully selected to suit the part and the results required. The sketches show one type of barrel and the three basic loadings.



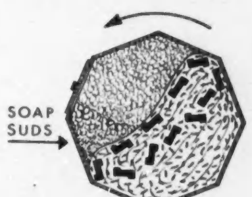
ROUGH TUMBLING

Wet or dry—mostly dry. Parts stacked in for little shifting or moving of load. Media rolls over, through, and around parts to chip off fins, sprues, and scale



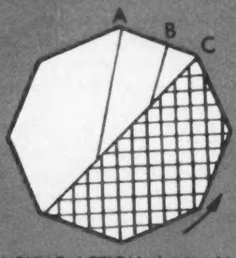
ROLLING

Wet or dry—mostly wet. Barrel usually half full of media and parts plus liquid, abrasives and/or compounds. Parts, in motion, should retain relative position in mass



BURNISHING

Wet only. Same as rolling, but barrel and load must be clean. Soaps are added to lubricate and reduce erosive action, to cushion load, and to form heavy suds that fill voids



TUMBLING ACTION obtained in an octagonal barrel, with points designated to illustrate lift and slide at various operating speeds.

A: Turn-over point at 40 rpm
B: Turn-over point at 30 rpm
C: Turn-over point at 20 rpm

has never been done by other methods, but the total savings would easily exceed hundreds of thousands of dollars when compared with more costly hand methods of grinding and polishing.

By developing a unit for barrel-working small parts we are precision-working innumerable parts of varying size and texture. If the same results were to be obtained by hand-working methods, the cost would be prohibitive. A balanced assortment of larger-size units makes this tumbling department a flexible and practical instrument for "savings by the barrel."

Case No. 1

On June 6, 1950, a request card was submitted to our development section with a detailed explanation outlining the method then used for producing a certain part. Stickiness and erratic operation in the apparatus made this vital part unsatisfactory as produced. The development section recommended that hand filing be eliminated and a tumbled radius be substituted. We did this on the theory that there would be a higher degree of uniformity and, when ball-burnished, a lower coefficient of friction.

To prove our theory, sample parts were barrel-rolled to form the radius, cleaned, and then ball-burnished to a smoothness and luster suitable for plating. After plating, the parts were again ball-burnished. This operation restored the luster, smoothed the plating slick, and closed the pores, thus increasing life qualities. Parts are now barrel-processed with 100 percent acceptance. Cost is approximately 68 percent less than the previous method, and there is no more stickiness and erratic operation of the instrument.

Case No. 2

A second example is well illustrated by the accompanying unretouched photograph of the parts of a viscosimeter. Hand-polishing and chemical methods for finishing the stainless steel proved so unsatisfactory that a request was issued to the development section to try to obtain a final finish that was comparable to the plated finish.

Here are the progressive steps in the stainless-steel process: (1) draw, anneal, then apply a fused salt treatment to remove scale; (2) draw, anneal, and salt-process; (3) deep-draw, anneal, and salt-process; and (4) barrel-work for final finish. Since production did not justify setting up a descaling treatment in the plant, the parts were shipped outside for descaling, which led to delay, confusion, and high unit cost.

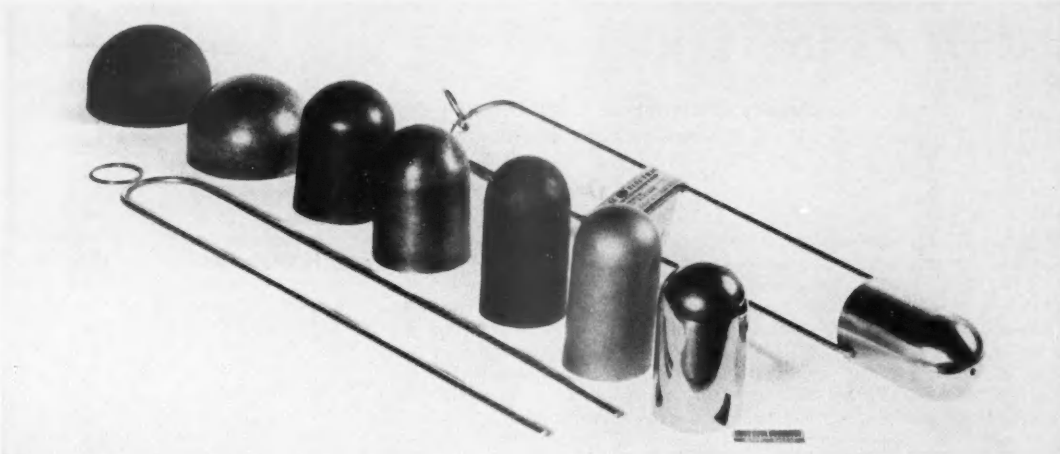
While barrel-working for finish, we discovered that the transportation problem could be eliminated. Scale could be removed and a surface finish produced that would be more favorable to die life than that produced by the fused salt process. Cost also would be reduced and the three stages of barrel-working would progressively improve the metal surface and contribute to a better final finish.

Parts are now barrel-worked with excellent results and cost reduction. The ring of the viscosimeter is also barrel-polished, and we have done the same to the bail when required.

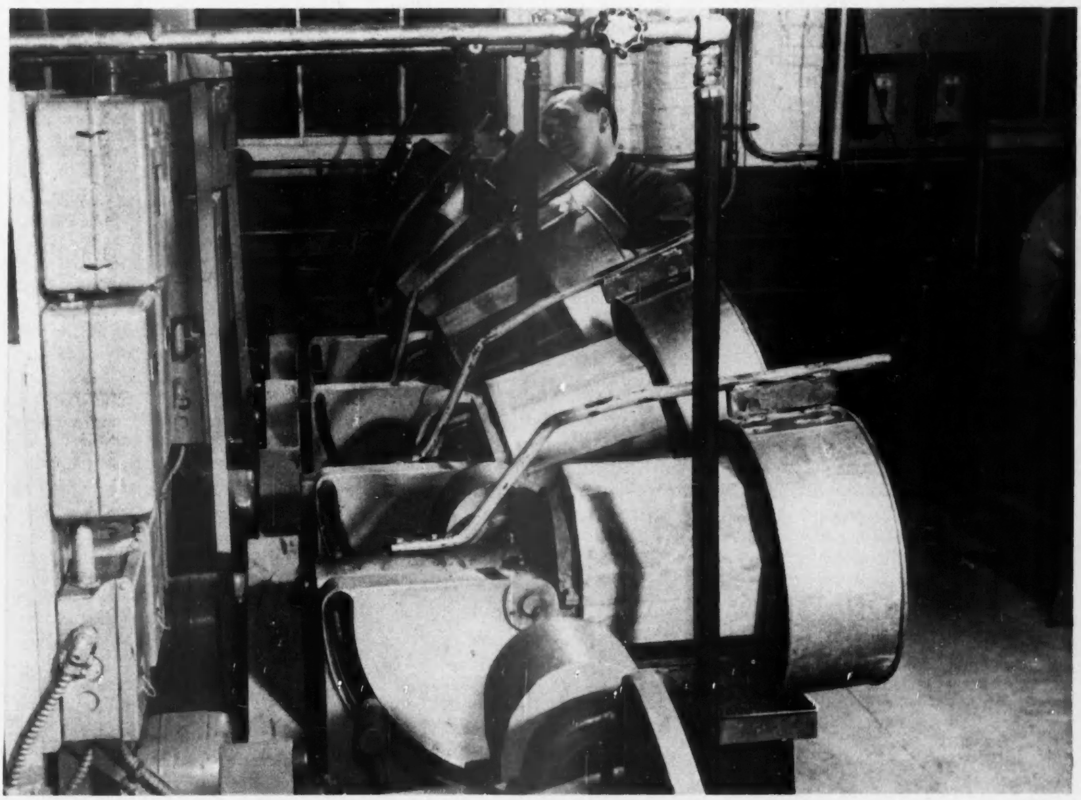
The one important fact to be stressed is that tumbling today is a logical, controllable process, capable of producing consistent results of excellent quality at low costs.

At West Lynn, where more than 900 variable parts are now being barrel-processed, and the requests far exceed the development capacity, tumbling means—"savings by the barrel."

EXPERIMENTAL TUMBLING equipment showing some of the barrels used while determining processes in the tumbling development laboratory



VISCOSIMETER CUPS are tumbled to remove scale after three stages of drawing and anneal and are finished by tumble burnishing; stainless steel bail and ring are also finished and burnished by tumbling



SMALL BARRELS designed for flexibility in tumbling activity permit variation in mechanical conditions because they can be positioned to obtain most efficient deburring and polishing actions

A New Transformer for an Old Application

A fundamentally different type of construction makes small three-phase distribution transformers more efficient

By N. M. CASE and J. P. MAY

There is a steadily increasing demand on utilities to serve more and more three-phase loads, such as small air-conditioning units in restaurants and neighborhood theaters, commercial refrigeration in supermarkets and large apartment buildings, small industrial loads, and the like. This in turn has materially increased the demand on manufacturers for small three-phase distribution transformers. Also influencing this second trend is the increased labor cost of installing equipment. For the cost of mounting one three-phase transformer is substantially less than the cost of installing three single-phase transformers.

Because three-phase distribution transformers are almost invariably pole-mounted, there is constant pressure from users to keep weights and dimensions down to a minimum.

In the past, the requirements for small three-phase transformers for such purposes, rated 150 kva or 15,000 volts and less, have been met by supplying either of two types of unit:

1. The horizontal or conventional core construction. This has been the more popular design; it represents about 70 percent of the business today.
2. The vertical or stacker design, introduced by General Electric in 1927. It consists of three single-phase core-and-coil units stacked one above the other in a single tank. The idea has been adopted in modified form by other manufacturers.

Of these two forms of construction, the conventional three-phase single-unit core is the better adapted to the system conditions usually encountered. For this reason it has been the more suitable for the majority of three-phase connections. And General Electric engineers have therefore concentrated their efforts on a study of methods for reducing weights, dimensions, and materials involved in this design.

The basic core construction of most small three-phase transformers has remained relatively unchanged for many years. Yet it is true that perhaps the most promising opportunities for effecting economies in transformer manufacture lie in the quality of the core steel.

Spirakore in 1937

A good example of what can be done through improvement in core design is found in the Spirakore*, or wound-core, transformer which General Electric introduced in 1937. This was a single-phase transformer using cold-rolled oriented steel in the core, as contrasted to the hot-rolled sheet steel formerly used. The significant orientation was effected primarily by the introduction of the cold-rolling technique. The core, made up of this cold-rolled steel, was so constructed that the flux path was parallel with the grain and the direction of rolling. As a result, losses and exciting current were reduced. This made it possible to reduce the size and weight of the transformer. And that meant less cost to the user.

*Reg. trade-mark of G.E. Co.

It was obvious that, if this wound-core design could be applied to three-phase transformers, it would produce similar economies. And it would meet the demand from users for smaller sizes and weights. The problem lay in finding a way to use cold-rolled silicon strip steel effectively.

Now there are many ways in which cold-rolled strip can be applied to three-phase core construction with varying degrees of success. The most obvious is to substitute flat rectangular punchings of the cold-rolled strip in place of the hot-rolled sheet in the conventional three-phase core. But this is only partially effective, since the flux path in such a core is at an angle with the orientation of the steel over a relatively large portion of the magnetic circuit.

New Spirakore

The best over-all construction for small three-phase transformers of the type in question was found to be a new Spirakore design, known among our designing engineers as the wound-delta-yoke construction. This new design is now standard for all General Electric three-phase transformers rated 150 kva or 15,000 volts, and less.

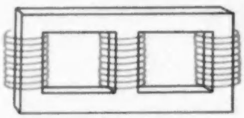
In the wound-delta-yoke construction, both top and bottom yokes are wound in the form of a spiral from preannealed cold-rolled strip. They are wound on a six-sided mandrel, after which they are given a strain-relief anneal. The final form approximates a triangle or delta.

The top and bottom yokes, as assembled, have half as many turns as there are punchings in the legs. Alternate leg punchings butt against, or are lapped by, the turns of the yoke. Therefore, the turns in the yoke, except in the joints, are separated by a space approximately equal to the thickness of a leg punching.

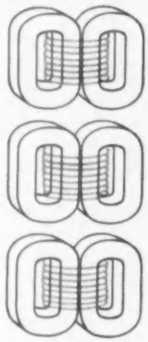
Each of the three vertical legs consists of a number of flat cold-rolled steel punchings. These vertical leg pieces are first assembled in the bottom yoke. For example, the first piece will butt the

Mr. Case, Section Engineer, General Electric pole-type distribution transformers, has for 20 years been engaged in design and development work, being responsible for transformers 6000 volts and less. He has made important contributions to the new three-phase Spirakore transformer design.

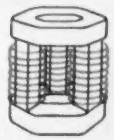
Mr. May's experience in transformer sales and application extends over 20 years, 12 of which were spent in the field. Until recently Assistant Manager of General Electric's Distribution Transformer Sales, he is now Manager—Marketing, Capacitor Department of the Transformer and Allied Products Division.



Core for conventional three-phase transformer

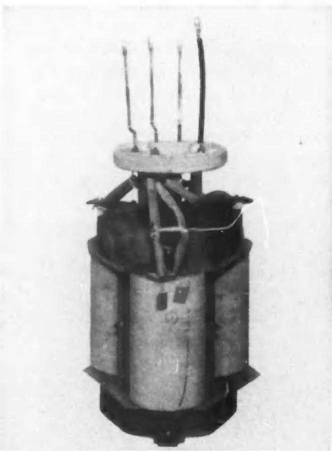


Core for vertical or stacked-type three-phase unit



New three-phase Spirakore construction

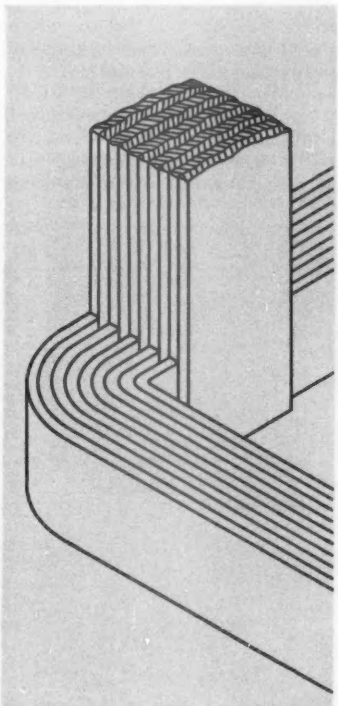
RELATIVE PROPORTIONS are indicated by these elementary sketches showing a comparison of Spirakore transformer structure with that used in the conventional three-phase transformer and with that used in the vertical or stacker type



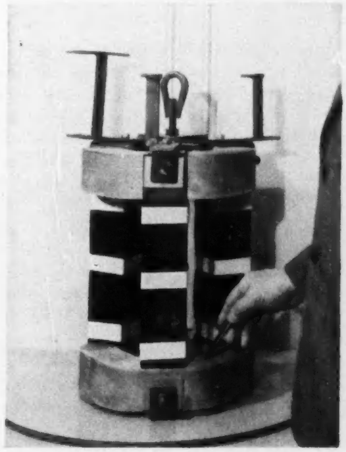
INTERNAL STRUCTURE of 15-kva 2400-volt oil-immersed wound-delta-yoke transformer characterized by compactness and symmetrical flux distribution

first turn of the yoke, the second piece will be inserted between the first and second turns of the yoke, the third piece will butt the second turn of the yoke, and so on until the leg is completed.

The coils are then assembled on the legs, and the top yoke, after suitable preparation, is laced into position. The positioning of leg punchings and top-yoke windings is the same as in the bottom yoke.



DESIGN DETAIL—A simplified sketch illustrating the arrangement of layers in the junction of core materials in yoke to the vertical punchings in the core legs



CORE AND CLAMP assembly of a 15-kva 3-phase Spirakore transformer; this improved wound-core structure utilizes cold-rolled oriented steel

A less apparent result of this construction is a symmetrical flux distribution, in contrast with the unbalanced arrangement in the conventional three-phase core. The exciting current is appreciably reduced because of the large gap area and fewer effective gaps.

Some Comparisons

The table on page 46 gives comparative figures on weight, dimensions, and

COMPARISON OF THREE-PHASE TRANSFORMERS
(UNITS OF 0-150 KVA, 5000 VOLTS AND BELOW)

		9 Kva	15 Kva	30 Kva	45 Kva	75 Kva	112.5 Kva	150 Kva
Net Wt. incl.	Stacker	450	562	920	1100	1575	2210	2650
Insulating	Conventional	500	800	1150	1400	2100	2500	2900
Liquid	Delta Yoke	390	510	900	1000	1400	2100	2450
Height	Stacker	46	47	61	64	69	78	84
(Inches)	Conventional	29½	37	46	46	58	58	58
	Delta Yoke	29	39	47	47	57	63	70
Floor	Stacker	21x20.5	23.5x22.5	26x26	28x26	30.5x26.5	33x29	33x30
Space	Conventional	30x28	36x20	39x21	43x23	48x25	50x28	53x29
(Inches)	Delta Yoke	24x23	24x23	28x26	30x26	33x29	36x34	36x34
Insulating	Stacker	19	25	50	50	57	86	87
Liquid	Conventional	22	28	43	47	80	78	85
(gallons)	Delta Yoke	16.5	20	39	37	62	87	92

insulating liquid for the wound-delta-yoke design, the vertical or stacker design, and the horizontal or conventional core construction for a group of 5000-volt units. From this it is obvious that weight has been reduced, with the new construction, approximately 25 percent on the average over the conventional design and 10 percent over the stacker design. Spirakore height is considerably less than that of the stacker in all cases; except for the largest two sizes, it is approximately equal to the height of the conventional design. The projected floor area of the new design approximates that of the stackers and is considerably less than that of the conventional units.

These comparisons indicate a number of advantages to the user. Decreased height, for example, is a major factor when joint pole use with communication systems is required. When compared to the conventional or horizontal unit, there is a definite saving in floor space for platform mounting—or in cross-arm space for pole mounting. Weight reduction is a definite advantage, also, for obvious reasons.

Except for very special applications of Y-Y operation, where the new delta-yoke design has the same limitation as any unit of three-legged core construction, the new construction can replace both the stacker and the conventional three-legged transformer core designs, thus contributing to smaller user inventories.

Its dimensions are better than a good compromise. A transformer of this type is suitable for either pole or floor mounting, and it is superior both in appearance as well as handling.

A reduction in the number of types required, plus savings in critical materials, will ultimately result in lower costs to the user. And reduced weights will permit less costly pole-line construction.

EXTERIOR COMPARISON of two 30-kw three-phase transformers: the horizontal or conventional construction *(left)*; and the delta-yoke construction *(right)*; the latter unit incorporates noteworthy improvements in design and construction

We're Training Men to Be Leaders

By F. T. LEWIS

Half a century or so ago, in the early days of General Electric, manufacturing leadership meant simply putting one skilled workman in charge of other skilled workmen. The demand for supervisors was comparatively light. Skilled leaders could be obtained by letting capable men simmer in experience, and they'd come to the top as fast as their ability could bring them.

Manufacturing leadership cannot be defined as simply as that today, nor can supervisory requirements be met in so passive a manner. True, technical skill is still of great importance, but a manufacturing leader must know not only his own particular operation but also its relation to the over-all pattern.

Every day brings new problems involving human relations, technical decisions, and administrative procedures. And because of the scope of General Electric activities—with more than a hundred thousand people engaged in direct manufacturing activities, with factories in over a hundred cities, with complex products, many of which were unknown 10 years ago, now being produced by mass production—because of all this, such leaders must be specialists.

We must recognize, too, that we need hundreds of such men right now. And we will continue to need them from now on, to meet the needs of our expanding business. There just isn't time for them to gain experience and rise in the former way. They must be chosen and specially trained to fill those jobs.

The need for leaders extends over the entire range of manufacturing operations, from group leaders and foremen right on up to top management positions. Also, in addition to direct supervision and management, leaders are needed for such specialized fields as improvement, modernization, and mechanization of shop layouts; the use of better machinery and mechanical methods; the development of better production procedures, including the control and flow of material, scheduling, and inventory control; procurement; quality control; the improvement of labor efficiency; and many more.

Manufacturing training programs are by no means new to General Electric. As sponsored in various forms and in various fields, they have been important sources of leaders in the manufacturing field for a half century. But the current manufacturing training program is our first co-ordinated activity on a Company-wide basis designed to train leaders for all fields of manufacturing.

The program has three main parts.

The first step, of course, is critical selection of candidates. These may be college graduates, or they may be outstanding young men already employed by the Company.

The number of candidates to be recruited will be substantial, and it will be determined exactly by periodic "personnel audits" of manpower requirements. In making selections, educational or work background will be an important factor. But the prime consideration will be whether the candidate has qualities which show promise for development in the supervisory, creative, or analytical aspects of manufacturing.

Part two in the program is a series of carefully planned on-the-job assignments, scheduled to cover about three years. Through these the trainee learns by actual guided experience the main operations in a manufacturing organization. He gets a detailed picture of the supervisory, creative-engineering, and analytical aspects of the business.

The emphasis on creative engineering in manufacturing is particularly important. It is a recognition of: (1) the high degree of technical competence required in some manufacturing activities; (2) the necessity of specialized training for these activities; and (3) the influence such activities have on the over-all field.

Mr. Lewis has had wide manufacturing experience. He has served as assistant works manager at General Electric's Schenectady Works, as manager of manufacturing of the Company's Aeronautics and Ordnance Systems Department, and of the Small Apparatus Division. He is now manager of the Manufacturing Personnel Development Services Department.

The third part of the program consists of carefully planned classroom sessions. In these, actual manufacturing problems are considered, and management theories can be explained. The instructors are experienced manufacturing supervisors with years of successful factory operation behind them.

Manufacturing is a technical field, and experience has shown that the men most readily adaptable to it are those with technical or engineering educations, or with definite technical inclinations. Definite and serious consideration is given to science major, business administration, and liberal arts graduates if they have this technical inclination toward manufacturing and can meet the standards of the course.

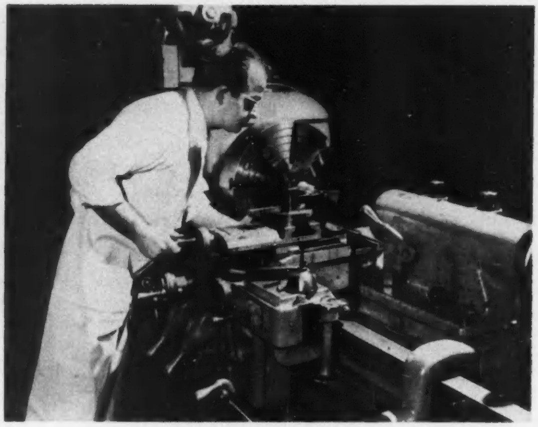
These standards are high. They *must* be high in order to get men who can stand the pace required to meet our objectives. A sound background must be combined not only with a personality that adapts well to leadership and responsibility but also with the mental capacity for sound thinking in any or all of the three fields of supervision, creative manufacturing, or analysis.

These men must be able to do more than train for an immediate job. They must be able to apply parts of that training to their second and third promotion. In other words, they must train not only for one job but also for the job beyond.

Each new man is assigned to one of the training centers established at major General Electric plants throughout the country, such as those at Schenectady, Bridgeport, Syracuse, and Fort Wayne. Each center is under the direction of a full-time area training supervisor, who will have charge of administering and co-ordinating manufacturing training in that area. Each center has complete training and classroom facilities.

At one of these training centers the trainee will begin his intensive program of rotating assignments and classroom activity. These assignments are planned carefully for each trainee, and each assignment has four basic characteristics:

PRELIMINARY INTERVIEW is an important step in determining background and aptitude of candidates, as in this chat with the author *(right)*



ON-THE-JOB ASSIGNMENTS give trainees actual manufacturing experience and opportunities to relate it to creative engineering work

1. **Actual job responsibility.** Assignments are real jobs. Each man will have well-defined responsibilities for which he will be held accountable.

2. **Definite objectives.** Goals are set for each assignment. Each one is planned to add a specific type of manufacturing experience to the trainee's background.

3. **Performance standards.** Definite measuring sticks, against which a man's performance will be judged, are established for each job.

4. **Personal counseling and evaluation.** The progress of men on assignment will be followed closely, and their performance will be reviewed regularly with them.

Assignments fall into three general categories: shop, functional, and general. The shop assignments will usually be among the first a trainee has; he will spend about six months in them, learning about machine tools and factory equipment in the same way an apprentice does—by actually working with machine tools under trained instructors. Then the trainee will move to a real factory job, where he will either run a lathe, a screw machine, or a punchpress on a production basis as though it were his actual job, or he will serve in a semi-supervisory capacity, as an assistant to a factory leader. General Electric has found that the importance of early training in the cutting and forming of metal products into parts and assemblies cannot be overemphasized.

The functional type of assignment introduces the men on the program to the various specialized operations which are so vital in manufacturing today. One, for example, will take him to a methods and planning group, where he will become acquainted with the techniques involved in planning the actual manufacture of a product. He will also learn at first hand the importance of such highly specialized fields as materials handling and quality control.

Then, perhaps, he will move on to an assignment in production or purchasing, to learn the significance of good scheduling and inventory control in efficient manufacturing, as well as some of the problems involved in the efficient procurement of materials.

Cost and expense control are vital to any organization. The trainee will spend several months in a group devoted to those activities. This will be followed by several more months in a wage-rate and time-standards organization.

Finally come the assignments in the "general" classification. These take him into such fields as personnel and labor relations, general administration, or the business end of an operation with emphasis upon such things as profit and loss statements, operating reports, etc. He will even dip into engineering and sales, to bring home the importance of these subjects and their relationship to manufacturing problems. For an appreciation of these relationships is probably the most important single factor in successful manufacturing leadership today.

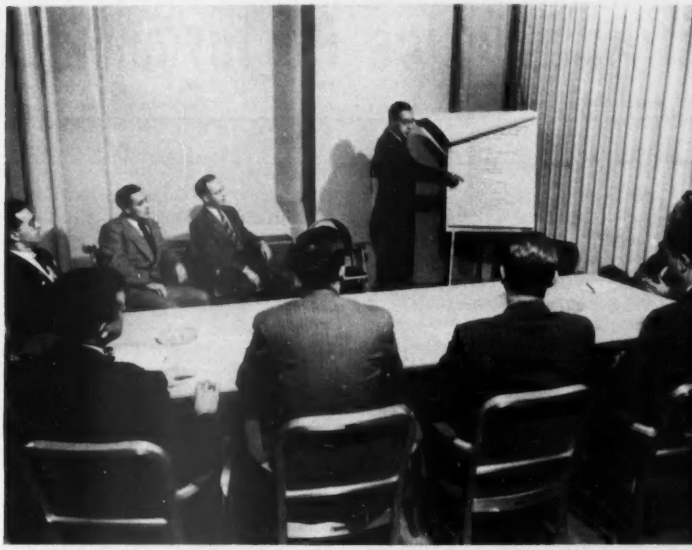
This rotation among such a series of operations not only provides a well-rounded knowledge of the interrelation of manufacturing activities but does it by the best possible method—first-hand contact. Specialization is avoided during the early part of the rotation period, not because specialization is antagonistic to sound training, but rather because the development of a wide horizon for the whole field of manufacture is so important to men who are being trained for greater responsibility. Only after this broad pattern has been established does the program begin to specialize in its development of the trainee.

Because the rotating assignments are of the actual job variety, where he rises or falls by his own efforts or lack of them, the trainee soon comes to appreciate the great number of imponderables and uncertainties that enter into business decisions and thus can affect the result of a particular operation. A trainee working in a production section soon learns how a wage-rate problem in another group can affect his inventory —or how scheduling can be only as good as the material flow behind it.

The classroom sessions, too, are an important buttress to these assignments in achieving the ultimate goal—trained men with a well-rounded background. Members of the training program attend classroom sessions for about 36 weeks a year. Two 2-hour sessions are held each week. The classes are led by men who hold responsible positions in various fields of manufacturing.

Classes are informal; discussion and participation are encouraged by all. The latest motion pictures, slide films, and visual aids in the manufacturing field are used. In addition, there is homework.

In all cases, the classes closely parallel the assignments, both in treatment and in subject matter. In the first portion of the program, when the trainee is on his horizon-broadening assignments, the classroom sessions are broad in scope. Then, when the assignments become specialized, so do the classes. And operating experts in special phases of each problem act as instructors.



CLASSROOM SESSIONS, directed by experienced manufacturing personnel, complete a three-part program of training for leadership in supervisory, creative, and analytical fields. Training centers are in major General Electric plants

The effectiveness of this combination of job experience and classroom training as a key for personnel development has been proved many times. The trainee's growth is encouraged by the variety and increasing complexity of the assignments. It is further augmented through the personality development that is nurtured by the classes, and through their exchange of ideas. But most of all, perhaps, the trainee's development is encouraged by the counseling of the experienced supervisors whom he meets every day. Thus, daily experience is tied to theory, and the whole thing is related to the man in training on a personal basis.

Three years is a short enough time to learn even the basic skeleton of manufacturing. For a training program to be successful in that time requires close following by the training staff, careful evaluation of the trainees' progress, and development of the best personal program for each of them. Therefore, the trainees are rated periodically, just as they would be on a regular job. These ratings have a profound effect upon the man's career, since to a very large extent his assignments will be based upon his aptitudes as indicated by these reports.

Upon completion of his assignment schedule, a man's record will be evaluated carefully and in detail. If his ratings and the reports of his supervisors indicate that he is especially competent in a special factory technique, his final placement may be in that field. If over-all administration has proved to be his strong point, his assignment will be in a job that will encourage this tendency. Outstanding competence in either techniques or administration may result in his being retained for further training on an advanced program.

The requirements of the program are high—but so are the rewards. The job opportunities are numbered literally in the thousands. Two years ago 10 branches of the General Electric Company, forming only a fraction of its manufacturing facilities, made a survey of their manpower requirements for the next five years. They found that more than 2000 supervisory positions, from foreman to top management, would be open. Since then, plant expansion programs have increased the total.

Furthermore, other responsible positions are constantly opening—or being created—in which a knowledge of manufacturing is not merely desirable, but absolutely necessary. Examples abound in the field of labor relations and employee relations and benefits. Jobs that once were routine parts of other jobs are now becoming specialists' assignments in their own right—with commensurate opportunities.

One of these is materials handling. Last year one of the General Electric organizations set up a committee of materials handling representatives to see how much could really be saved by concentrating attention upon this activity. A young manufacturing supervisor was placed in charge. At the end of the year the group's savings totalled more than a million dollars, and plans have been made for a second million-dollar year.

In another organization, a three-pronged attack was made on the eternal manufacturing bogeys of faster production and reduced costs. Attention was focussed on method improvement, waste elimination, and replacement of old machines. Typical of the results obtained was the development of a new forging method that saved more than a hundred thousand dollars, improved inspection procedures that eliminated a serious production bottleneck, and the application of quality-control methods to precision manufacturing that previously had been inspected 100 percent. The latter not only saved $39,000 but eliminated 13 stages of time-consuming inspections.

Supervisors and manufacturing specialists like those involved in the above examples are the vital substance of growth in any organization. And the finding of men with such potentials, and the development of such men so that they can use their potentials to the greatest advantage, is the over-all goal of the General Electric manufacturing training program.

Antibiotics Perform Modern Miracles

By JOHN L. DAVENPORT

A number of miracles of industrial expansion have been wrought on the American scene in our time. The newest expansion has come about in the chemical industry, through an ever-accelerating stream of new discovery and accomplishment. New ideas have tumbled forth at a rate never before seen in recorded history. The chemical industry has outstripped all others in volume and new growth. New products have completely transformed our daily life in a single generation.

A close scrutiny of natural phenomena by trained researchers has been responsible for new ideas and concepts which have left in their trail great industries. As an example, it is most interesting to trace the way by which a single observation, followed by the concept which it produced, has created a baby giant in the pharmaceutical industry and in animal husbandry. I refer, of course, to antibiotics.

It was in 1928 that Sir Alexander Fleming made his historic observation on the effect of a stray mold which had settled out of the laboratory air upon a plate containing pathogenic organisms. The manner in which this stray Penicillium mold cleared an area where the pathogenic organisms would not flourish was carefully recorded and published, with speculations as to what the product of metabolism of this mold could do against disease germs. The idea and the speculations lay fallow for several years —until a realization of their importance was grasped by scientific workers who had seen the remarkable chemotherapeutic effect of sulfonamides.

The work of Sir Howard Florey on Fleming's Penicillium culture brought to fruition a product which in minute quantities would annihilate the fearful gram-positive bacteria that have plagued the human race for hundreds of centuries with boils, sore throats, scarlet fever, rheumatic fever, anthrax, and many more ailments of varying severity. This work was done in England and was caught up by research workers in this country. It was not long before the British research workers urged the American chemical industry to undertake the production of large quantities in a stable form.

America's successful answer to this plea is now a well-known story. New screening techniques were developed, and soon other antibiotics were discovered. Streptomycin, found by Dr. Selman A. Waksman, has proved invaluable in tuberculosis. Aureomycin and Chloromycetin* were made available. Terramycin, newest of the broad-range antibiotics, was introduced in 1950.

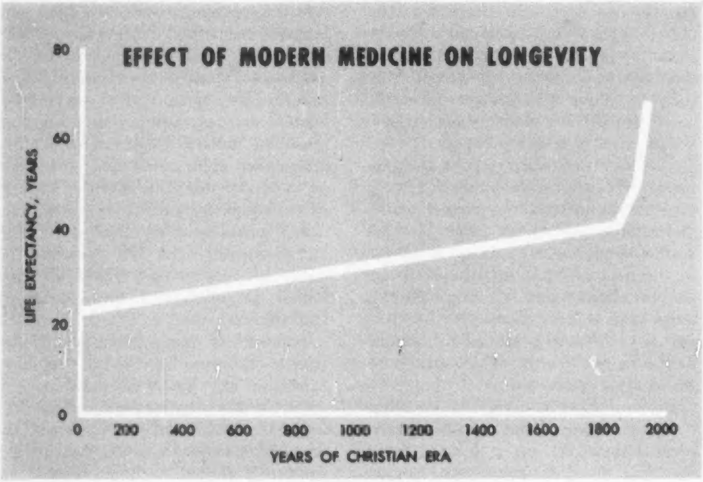
These three drugs have made it possible to control twice as many diseases as with Penicillin. Other antibiotics of more limited use, such as Bacitracin, Polymyxin B, Neomycin, and many others not yet clinically evaluated, are adding to this array of weapons for medical science.

These antibiotics have, in a sense, fulfilled the alchemist's dream of an elixir which would prolong human life indefinitely. A brief glance backward shows us that human life expectance was only 22 years in the time of Caesar, 33 years in the Middle Ages, and 41 years by 1840. By 1900 the expected span of life had nearly reached the half-century mark. Today it is 67 years, and the final story of the effect of antibiotics has yet to be told.

The purpose of medical science, however, reaches beyond the mere preservation and extension of life. It is concerned as well with the health, happiness, and capacity of people to work and enjoy the fruits of their labor.

An outline of all the boons which antibiotics have conferred upon man reads like a tale of magic from a fairy

*Reg. trade-mark of Parke, Davis & Co.



LONGEVITY took a sharp rise with the advent of modern medicine. This curve shows the increase in human life-span over the period of the Christian era

Development of new antibiotics through research, production, and distribution has played an increasingly prominent part in Mr. Davenport's work. He has spent his entire career as a chemical engineer with Chas. Pfizer & Co., where he is now Executive Vice President.

TERRAMYCIN hydrochloride. One-third ounce is used in one ton of feed

book. It has been estimated that up to 50 percent of the patients requiring a doctor's attention can be treated with antibiotics.

For example, the average pneumonia case a few years ago was hospitalized for 19 days. Today many pneumonia cases treated with antibiotics respond in a week or less. In a number of cases, patients with severe contagious diseases have become rare enough to force the closing of contagious-disease wards in hospitals. Mastoiditis has become so rare that doctors who formerly specialized in this type of operation have been able to use their talents in other directions. Blood infections, carbuncles, boils, and acne, which have long afflicted the human race, can now be treated successfully. Today it is possible to wipe out the scourge of venereal disease and typhus. The perilous diseases of childhood such as scarlet fever, whooping cough, and diphtheria are now under control.

Conquering Trachoma

Every day new conquests of disease are reported. One of the most far-reaching has just been revealed. In the Far East the age-old disease of trachoma has doomed hundreds of thousands to a life of blindness. Trachoma is an infectious disease of the eye involving inflammation and scarring of the conjunctiva and cornea. It is caused by a virus agent, *Chlamydozoon trachomatis*, and is widely prevalent especially in Asia. As high as 30 percent of the population of China is said to suffer from trachoma. In India and Pakistan the figure runs perhaps as high as 75 percent; in Indonesia, 30 percent; and in some countries of the Middle East, 90 percent of the people are infected by the disease.

The World Health Organization, which tried to assemble the figures, made this final statement in its report: "In the present state of our knowledge, it would be hopeless to try to estimate the total number of trachoma sufferers throughout the world. Some authorities speak of millions, others of tens or hundreds of millions. Perhaps the most pessimistic figures are those nearest the truth." Of those who contract the disease, 1 percent to 5 percent are faced with blindness.

Dr. Yukinido Mitsui, working in the medical clincs of Kumamoto University, Japan, has found that Terramycin, Aureomycin, and Chloromycetin are effective in treating the acute stage of this dread ailment. Over 1000 controlled clinical cases have indicated that Terramycin ointment can cure the disease in three weeks. Doctor Mitsui has concluded that Terramycin is the drug of choice for this disease. At this stage it appears that a few tubes of ointment, costing less than $1, will accomplish this cure.

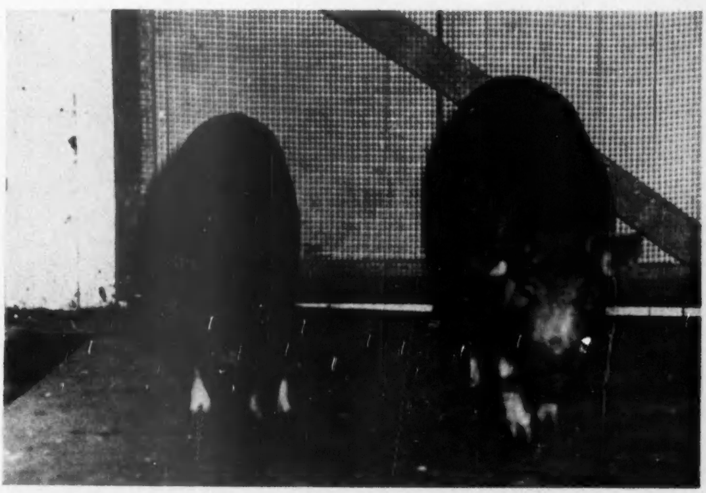
What this means in the relief of human misery is another facet to the fabulous antibiotic story. Doctor Mitsui is about to commence a lecture demonstration throughout the trachomatous regions of the earth in an effort to bring this discovery before the local medical professions and public health officials so that early remedial and prophylactic action can be started where it will do the most good.

Feeding Animals

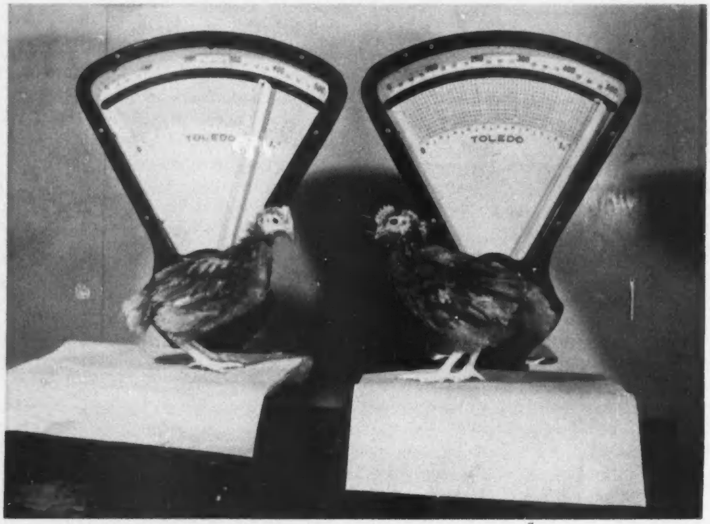
We come now to a new tangent thrown off by the original Fleming observation. The impact of antibiotics soon hit agriculture. Since animals are a prey to many of the same sort of diseases as plague the human race, it was natural to begin testing antibiotic applications in that field.

The research workers were astonished to find that antibiotics possessed great nutritional merit in addition to their curative properties, and this has led into fields which will have a profound effect on the meat supply of the nation. It was found that when antibiotics were added in very small amounts to the rations of poultry, swine, and young calves, some of them promoted growth not observed to occur with any other chemical substances. The growth-promoting level of antibiotics is far below that used in treating disease. It is of the order of 5 to 10 grams (1/6 to 1/3 ounc.) per ton of feed.

The story of the growth-promoting effect of Terramycin used to supplement hog feeding can be told most simply by an account of the controlled experiments run at the Arenel Farms near Shoemakersville, Pa. At this farm, which is one of the largest and most scientific hog farms in the United States, 600 weaned pigs averaging 34.5 to 34.8 pounds at the age of 8 to 9 weeks were



TERRALAC FEEDING brought the pig on the right to 111 pounds after 104 days, while the sow-fed pig on the left reached 84 pounds in the same period



TYPICAL CHICKENS fed with and without Terramycin, at four weeks of age. The one on the right received Terramycin and will be marketed two weeks earlier

divided into two equal sections. The first 300 pigs were fed a good standard ration. The other 300 were fed a good standard ration plus a Terramycin supplement.

The control group without Terramycin reached 200 pounds in 155 additional days. The group of 300 pigs which received Terramycin supplement reached 200 pounds in 115 additional days. Not only was the time shortened, but the cost was cut in a remarkable manner. The quickened growth does not run to fat. The Terramycin-fed hogs all drew premium prices.

Controlled experiments on hog farms have determined that using Terramycin feed supplement results in a saving of about 50 pounds of corn per hog marketed. If all hogs were so managed on a broad national scale, there would be a reduction in corn requirements for hog feeding by 100 million bushels. Assuming an average yield of 50 bushels of corn per acre, the savings due to antibiotic feeds could thus reduce the planting average by 2 million acres. The antibiotic supplement feeding of poultry, which is now on a large scale, would, if extended to a wholly national basis, have a similar marked effect on the arable land required for the production of feed grains.

For similar results are obtained with poultry. Penicillin or Terramycin provides the same measure of growth stimulation in turkeys and chickens. Poultry raisers are enthusiastic over the savings which these antibiotics produce by reducing the period necessary to obtain birds of marketable weight and by reducing mortality. Birds are ready for market two weeks earlier than heretofore, in 10 weeks rather than 12 in the case of broilers, which makes a significant saving in feed costs. In the Pfizer laboratory a special type of Penicillin was evolved to give the stability required for a successful feed supplement.

Raising Piglets

There has been a further marked advance in the animal-husbandry field. It concerns the artificial rearing of suckling pigs, which may revolutionize swine production in this country.

There are a number of serious problems in raising piglets. Among these is the fact that most sows give birth to more piglets than they can properly care for, which results in runts who have an extremely high mortality. Indeed, it is estimated that the average death rate of piglets is about 18 to 35 percent.

In addition to the lack of the sow's feeding facilities, many piglets are faced with sanitary hazards and crushing by the sow, for, in spite of the beneficence of nature, sows are not necessarily the best mothers. For many years, the researchers in this field have sought supplementary feeding methods or methods for outright artificial feeding so that the young pigs could be separated from the ungainly sows soon after birth. University of Illinois workers have shown that pigs so raised could weigh 50 percent more at weaning time than when raised naturally.

Dr. J. L. Krider of McMillen Feed Mills interpreted this success as being due to getting more nutrients into the piglets and reducing hazards and discomforts. He predicted that, by removing the drain of a long lactation period of the sow, she could bear three litters instead of the customary two a year, and that advantage could be taken of advances in genetics to breed larger litters. Previous large litters had led to more runts or higher mortality, because of the natural limitations of the mother.

At this point, a nutritional team at Pfizer set to work on a solution to the problem of large-scale artificial feeding of newborn piglets. From an analysis of actual sow's milk, a duplicate formulation was devised containing Terramycin and all the required elements of proteins, fats, carbohydrates, and vitamins. The resulting formulation was named Terralac.* The wide-range antibiotic serves two functions in the ration: first, it stimulates the rate of growth, and, second, it gives invaluable protection against disease.

Under the regimen worked out by this research group, thousands of pigs have been taken from 24 to 48 hours after birth and fed on Terralac until weaned, with excellent results. In sharp contrast to the mortality rate mentioned above, more than 3000 Terralac-fed orphan pigs averaged only about 5 percent mortality. Separation of mother from young has been a tremendous aid in maintaining more sanitary conditions and removing possible sources of infection.

In developing the regimen mentioned earlier, an auxiliary device called the "pig symphony" has been created. Undisturbed piglets sleep many hours without eating, especially at night. The sow's grunting response to hungry nuzzling serves to wake her piglets to eat once every few hours. If piglets were to be reared away from the sow, some means was needed of awakening them at mealtime.

In order to solve this problem, the pig symphony, which consists of a

*Reg. trade-mark of Chas. Pfizer & Co., Inc.

sequence of squeals and grunts, backgrounded by Brahms lullaby, is played automatically every hour. Wakened by it, the piglets rush to their trough and hungrily drink their Terralac.

In practical use on the farm, Terralac has been fed to infant pigs in two ways: in troughs on the floor, with 20 to 25 piglets occupying the space usually required for a sow and litter of eight; and in a nursery such as was contrived in the Pfizer laboratory.

Piglets which were started in the nursery, then moved to specially insulated and sanitized quarters for an additional 10 days to two weeks, and then to a less carefully controlled environment in a larger barn, have done best. Watchful, clean management practices pay off. Many piglets handled in this fashion have been brought to "weaning" status in five weeks and have thereafter gone into the feeder lots on a par with eight-week weanlings from sows.

Terralac opens the way for rapid development of a fledgling pig-hatchery industry which could provide farmers with a thrifty, dependable supply of weanling pigs. By purchasing his feeders from a hatchery, the smaller farmer would be avoiding most of the headaches and risks of pig raising. The bane of existing hatcheries has been periodic waves of disease which ravished their herds. It is felt that separation of the piglets from the sow and then the feeding of Terralac can break this cycle. Current experiments indicate that Terralac may prove of similar nutritional and economic significance in other areas of animal husbandry.

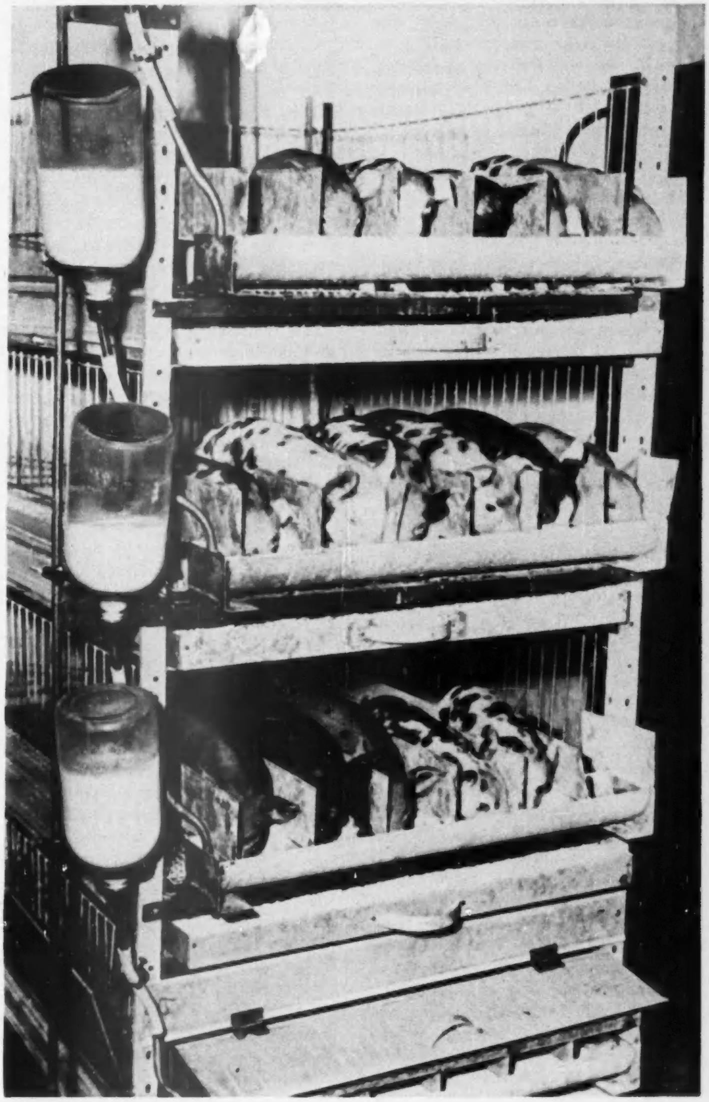
The Future

There is a strong feeling that the antibiotic field has only been scratched. Some diseases are still untouched by modern drugs. We do not have cures for cancer, poliomyelitis, or the common cold. A vast effort is being expended each year to bring these under control. Cancer, in particular, is being attacked on an unprecedented scale. No one today can predict the solution of this formidable problem, but there is a firm conviction that it will be found.

With our aging population, degenerative diseases become increasingly important. Here again the role of antibiotics is difficult to predict, except to say that they will play an important part in preventing disease in human tissues which do not have the resistance of youth. A new science, geriatrics, has been developed to seek techniques for assuring older people good health. And, as geriatrics grows and assumes an increasing importance, the social sciences, as well, must play their own role to integrate older people into our society.

Antibiotic research in the next decade may well lead down diverse and unexpected paths alien to these fields but having comparable advantages in the betterment of life. As each new product emerges, hope runs high for further advances in health and happiness.

PIGLETS ON TEST in the laboratory of Charles Pfizer & Co. drink Terralac from troughs built in poultry batteries. These piglets are one week old



Silicone Rubber Can Now Be Bonded

By ROBERT SMITH-JOHANNSEN

The new family of chemical compounds known as silicones has many very desirable characteristics. But it has one outstanding quality which is a mixed blessing: silicones are incompatible with an unusually large number of other materials. In other words, they don't stick well to very many things.

It's all very well from one standpoint. It provides certain silicones with the ability to serve as mold-release agents for rubber and plastics, and even as lubricants on certain textile fibers to prevent them from sticking together. And it makes it possible to design a relief valve that will not stick shut when the time comes for it to let go.

But, on the other hand, this native insolubility in other substances makes it difficult to put silicones in many places where we want them to stay put. That is, it did make things difficult until a new primer, recently announced by General Electric, made its appearance. With this new primer it is now possible to mold or bond silicone rubbers to metals, glass, ceramics, and some plastics, as well as to themselves.

To understand the nature and behavior of this new bonding technique, it will be necessary to know something about the fundamental nature of adhesion—what makes things stick together.

What Is Adhesion?

Adhesion is a subject which can be considered from many viewpoints. And it's a pet topic of discussion among people who are interested in bonding and bonding agents. When these people get together to talk about the nature of adhesion, such terms as adsorption, secondary forces, and chemical bonding are often used indiscriminately to describe a specific bond.

It seems probable that there are no clear-cut cases of adhesion due to any single cause. Since a variety of phenomena are responsible for the cohesion *within* a material, the adhesion between two different materials is likely to involve at least that many factors—and probably more, in the bargain.

It isn't so bad in the case of crystalline materials. Their structure involves a maximum of structural order and simplicity. But when you consider a solid which is a mixture of different materials, either in solution or suspension—or both—the internal cohesion is caused by many things at once. And when such a material is bonded to the surface of still another one, it's just about impossible to form a simple picture of what happens.

There is, however, another way of looking at adhesion which isn't quite so confusing. This idea is based on the continuity of structure. With this in mind, a perfect bond would be one in which no discontinuity could be distinguished anywhere between the two materials bonded together. A perfect example of such a continuous bond would be the union of two pieces of ice which started out with moist surfaces and then were frozen together.

A practical example of the principle of continuity of structure in the formation of a bond can be found by using ice and silver iodide. The crystals which make up both of these substances are remarkably alike in structural form, and their dimensions (lattice constants) are but slightly different. For this reason, silver iodide can be made to act as a nucleus for the formation of ice. When water is frozen by cooling in contact with a silver-iodide surface, the resulting bond is very strong. Any failure as a result of impact testing occurs not in the bond but in the ice or in the metal—or both.

This experiment is especially interesting because the two materials in question have no similarity other than a structural one. And yet that structural similarity is sufficient to bring about a good bond.

Mr. Smith-Johannsen's interest in why things stick has been life-long. While at college he formulated his own wax to combat ice on his skis. Eventually this led to several interesting silicone adhesion developments in G.E.'s Chemical Division.

Fig. 1 illustrates the structural similarity between ice and silver iodide. The crystals of silver iodide have exactly the same hexagonal structure, and almost the same dimensions, as the crystals in a simple ice structure. That being the case, a silver-iodide crystal could replace any of the ice crystals without destroying the continuity of the structure or the adhesion between itself and neighboring ice crystals. In effect, its presence would cause but a very slight change from the surrounding ice structure. And the adhesion between silver iodide and ice is accordingly very great.

But what causes the adhesion between materials which do not have this similarity of crystal structure? To find the answer to that question, we must consider some fundamentals.

A Good Fit

It is usually considered a chemical axiom that "like likes like." This is especially true of chemical groups on molecules. The nature of these groups is shown in Fig. 2.

Fig. 1. HEXAGONAL CRYSTAL group found in simple ice structure; silver-iodide crystals look the same

Now chemical similarities in molecules at the surfaces of materials to be bonded together *are* effective in promoting adhesion—but only in so far as they can come into proximity with one another by virtue of a "good fit." In other words, the active groups "reaching out" from the surfaces of each of the two substances must have a chemical attraction for each other.

But the presence of adhesion-inducing groups in molecules of the kind described is not alone sufficient. These groups must be properly spaced (Fig. 3).

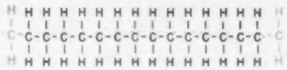


Fig. 2. CHEMIST'S PICTURE of a stearic-acid molecule. At the left end is an inert methyl group (CH_3); at the right end, an active acid group (COOH); between them, a number of CH_2 groups form a typical hydrocarbon chain. These might be schematically represented by a straight line with a bump on the right end to indicate the active group, as shown below:

From this figure it will be seen that chemically active groups wouldn't be likely to be effective unless they were so arranged that they would come close enough to other suitably reactive groups to permit the chemical union and the resulting so-called "chemical bond."

Another interesting form of adhesion may be observed in the wetting or non-wetting of a solid by a liquid. This compatibility, or incompatibility, as the case may be, is what causes high or low adhesion.

For example, a clean glass surface can be "wet" by both water and hydrocarbon oils. If the surface is then coated with a film formed from molten stearic acid, oil will continue to wet it, but the "contact angle" with water (Fig. 4) will be raised somewhat—in other words, the water tends to form droplets and not spread out. If the stearic acid is in the form of an oriented monomolecular film, the surface will repel oil, and it becomes even more resistant to wetting

Fig. 3. GROUP SPACING is a condition that influences bonding
A: The matching faces of two molecules whose active groups are spaced
B: Matching faces of two molecules whose active groups are not properly spaced for a good fit

with water, with a contact angle close to 90 degrees.

Now, if we proceed a step further and form an oriented monomolecular film of ferric stearate, the stearic acid molecules are not only uniformly oriented but also *very closely packed*. This results in a surface consisting essentially of methyl groups, from a chemical standpoint. It still further resists wetting either by oil or water. The hydrocarbon oil won't wet it because the oil surface consists mostly of CH_2 groups, which are chemically incompatible with the CH_3 groups predominating in the surface film of ferric stearate. The same is true of water, whose active groups are hydroxyl groups (OH), which are even more incompatible with the CH_3 groups predominating in the ferric stearate surface film.

Finally, if a film of paraffin wax is placed on the glass surface, it will repel water just as strongly as the ferric stearate did, because its molecules have no active groups to attract the water groups. But hydrocarbon oil will wet this surface readily. In the latter case, both the oil and wax surfaces consist principally of the same kind of group (CH_2).

From these examples, it will be seen that the same molecules at a surface can cause a variety of adhesion effects, even when oriented. The variety results from the extent of the orientation and "packing" of the surface groups. This again emphasizes the importance of structural continuity, or fit.

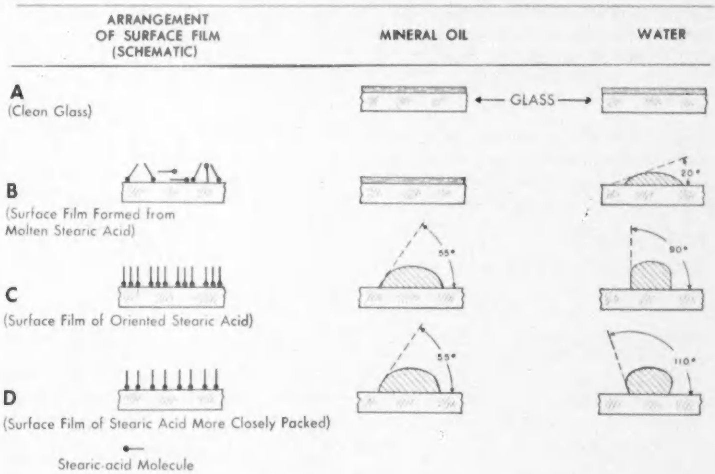


Fig. 4. PROGRESSIVE STEPS in wetting caused by changes in structure of surface film. The greater the contact angle, the less the adhesion. Also, the more perfectly oriented and closely packed the surface film, the greater the contact angle

Mechanical Adhesion

The foregoing may seem like a pretty complicated picture of adhesion, and in truth it isn't always necessary for it to be so complicated. After all, we can consider a bond as a satisfactory one if it is stronger than the materials being bonded and physical failure doesn't occur in the bond itself. This may result from any of the causes already discussed—but simple mechanical adhesion may be equally strong. The reason for that is quite simple.

We can find a good example of strong mechanical adhesion to a low-adhesion surface in the case of a good bond between ice and Teflon foil. Normally, when water freezes to a Teflon surface, the adhesion is very poor. But, when supercooled water droplets impinge on a Teflon surface at high velocity, a bond is formed which is stronger than the cohesion of the ice.

The explanation lies in the fact that the Teflon foil surface contains irregularities, presumably with re-entrant angles (Fig. 5). Water normally has a high contact angle with Teflon; it tends to form droplets on that surface rather than enter the tiny cavities in question. But, when particles of supercooled water strike the Teflon surface at high speed, the water is forced into the cavities, where it freezes instantly. Thus many ice footholds are formed. And the resulting bond is mostly due to the mechanical clinging of the ice to the surface irregularities.

Now that we have a picture of some of the fundamentals involved in ad-

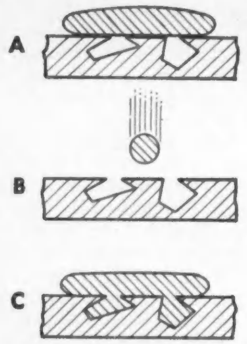


Fig. 5. MECHANICAL ADHESION between ice and Teflon foil. (A) A water droplet rests and freezes on the Teflon surface without penetrating the surface irregularities; (B) a droplet strikes the surface at high speed; and (C) is forced into the irregularities, where it freezes

hesion or bonding, we can turn once more to the consideration of bonding silicone elastomers, or rubbers, with the aid of the new General Electric primer.

Silicone Bonding

The reason that silicones don't normally bond well with other substances lies in the fact that silicones present a surface of inert methyl groups, closely packed together. In some silicones, this surface may be changed, and other more active chemical groups partly substituted for the methyl groups. Thus the degree of incompatibility may be altered.

At any rate, this native insolubility of silicones with other substances, coupled with the fact that silicones usually have low surface tension, makes bonding difficult. But a new primer is designed to take advantage of the principle of a mating or "good fit" of the kind previously described, when applied to a silicone rubber. In other words, it has the same kind of chemical groups as the silicone rubber, and these groups are properly spaced to promote bonding when heated under pressure in contact with the raw silicone rubber. The fact that it works, and works well, suggests the possibility that the primer-to-silicone-rubber bond is largely chemical in nature.

On the other hand, the bond between the primer and the metal—if it is metal to which we want to bond our silicone rubber—may or may not be of a chemical nature.

For example, although such bonds are always stronger than the silicone rubber itself, they don't always stand up similarly under test. When exposed to boiling water or strongly swelling solvents, on some surfaces the bond is affected as the rubber itself is deteriorated, while on other surfaces there is no measurable effect on the bond. In the latter case, the bond is possibly as close to a chemical bond as can be obtained between two unlike materials.

This new bonding technique for silicones incorporates some advantages not yet obtained with the methods used for other types of rubbers. Where standard practice now involves the use of one, two, or even three coats of rubber cement, involving varying degrees of baking, the silicone-rubber primer requires merely a surface contamination with the primer, followed by a few minutes of air drying.

The usual rubber bonding technique makes use of layers of rubber of varying composition. The result is a bond zone consisting of a gradation in chemical makeup between the rubber and the surface to which it is bonded.

On the other hand, the silicone bonding technique needs but a simple surface treatment of the substance to which the silicone-rubber compound is going to be bonded.

Some metal surfaces have a distinctly detrimental effect on the curing of the silicone rubber at the junction face, when bonding is attempted with the new technique, and this prevents adhesion. But the difficulty can be eliminated by the correct choice of silicone-rubber stock.

Silicone rubbers may be used as adhesives between combinations of many materials, when used with the new primer. Such bonds are heat resistant, flexible at low temperatures, and resistant to many aging or deteriorating influences. These qualities depend on the properties of the silicone-rubber stock chosen—although bonding performance cannot always be predicted from the silicone-rubber properties.

Another peculiarity of silicone bonding is the fact that the thickness of the bond is often dictated by the curing characteristics of the silicone rubber in contact with the surfaces to be joined. It is a general rule that the thinner a bond is, the stronger it is. But this principle sometimes has to be sacrificed in order to assure a good cure, for without a good cure there is no bond.

As already mentioned, some surfaces have a considerable inhibiting effect on the curing catalyst; to counteract this, a greater volume of bonding compound is required.

Silicone Bonding Applications

With suitable primer, silicone-rubber paste, and silicone-rubber compounds as tools, almost any bonding job may be carried out (see Table). We may mold any of the silicone-rubber compounds to metal, glass, ceramic, or plastic surfaces. We may also bond together any combination of these materials—or even bond-cured sheets of any silicone rubber can be bonded to themselves or to any of these surfaces.

Among the metals that may be bonded are aluminum, anodized aluminum, brass, copper, nickel, steel, phosphor bronze, tantalum, tin, magnesium, and stainless steel. Plastic surfaces which may thus be bonded include silicone, melamine, polyester, and phenolic resins. Some of these cases, however, require special techniques which are at the present time in the laboratory stage.

One such special technique has been worked out in the laboratory for bonding cured silicone-rubber parts to metal inserts without the necessity of using uncured silicone-rubber compound or paste. Where a large volume of silicone rubber is to be bonded in a largely enclosed space, great savings in cure time may be made by the use of this technique.

A variety of shock or instrument mounts is now being made using silicone rubber, with silicone-rubber compound molded directly to metal inserts. In some cases, anodizing of exposed parts of the aluminum inserts is done after the molding.

As a matter of fact, almost any organic rubber article made by molding to metal inserts can now be duplicated with silicone rubber, and this can be done with all the advantages resulting from the use of that material.

Silicone-rubber pastes may be coated on glass cloth and then, by mandrel-wrapping and proper curing, formed into tough heat-resistant heater ducts. Good bonding is necessary to prevent delamination in the glass-cloth structure when it is flexed.

Silicone rubber cannot currently be bonded directly to other types of rubber. But, where resiliency is desired and stretch is not necessary, as in a gasket, it may be indirectly bonded to butyl, neoprene, or any other rubber by bonding first to a barrier, such as aluminum foil. This makes it possible to cold-bond silicone gaskets to metal surfaces by following the standard rubber-cement bonding technique.

Primerless Paste

In addition to the adhesive combination of silicone-rubber compound and primer, General Electric has a primerless adhesive paste.

Although it is not strong enough to be considered a real adhesive, this paste forms a very lasting bond to most surfaces, and it therefore fills the requirements of a sealer. It has already been used successfully in two General Electric products, one an industrial device and the other a household appliance. In each case, the use of a small amount of the new paste brought spectacular savings, together with improved performance as a by-product.

In some cases, better performance can be obtained with a thin adhesive sealer layer, cured in position, than could be obtained with a gasket and any amount of pressure on it. In fact, since leakage is usually *past* the surface of a gasket rather than *through* it, the bonding sealer must do a better job than a conventional gasket. Compression set, a vital property of any gasket, is of no importance where a bond is formed, and thus compensates for a fundamental gasket weakness. Such bonded gaskets resist high pressures and blowout, since they are held in position by a bond over a large surface. A seal bonded in this manner was found to stand up very well against oil in a General Electric product that is used in the medical profession.

To demonstrate the permanence of a bond with this primerless paste, copper foil was bonded to porcelain enamel. The bond resisted all deterioration after exposure to water and a quarter million cycles of alternate freezing and thawing. A film of this paste, when it is properly applied, is not affected by continuous soaking in water.

To summarize, silicone rubbers, although having pronounced release properties, are also excellent bonding agents when properly used. But of course it must be remembered that they are not in competition with other more conventional, and certainly less expensive, adhesives.

Furthermore, silicone adhesives and bonded silicones can accomplish new things—things not previously attempted by other adhesives. For this reason, any study of present adhesive uses sheds very little light on the future of silicone adhesives.

The biggest uses for these new adhesives are likely to be still unimagined, and it may possibly be a long time before their usefulness will be fully appreciated.

WHAT SILICONE TO USE FOR ADHESIVE PURPOSES

	Glass	Ceramic	Aluminum	Tin	Low C Steel	High C Steel	Stainless	Copper	Brass	Magnesium	Silver	Tantalum	X, Cured	Y, Cured	X, Uncured	Y, Uncured
Glass	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2	1&2	1&2,5	1&2,5	1&2	1&2	1	
Ceramic	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2	1&2	1&2,5	1&2,5	1&2	1&2	1	
Aluminum	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2	1&2	1&2,5	1&2,5	1&2	1&2	1	
Tin	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2	1&2	1&2,5	1&2,5	1&2	1&2	1	
Low C Steel	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2	1&2	1&2,5	1&2,5	1&2	1&2	1	
High C Steel	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2	1&2	1&2,5	1&2,5	1&2	1&2	1	
Stainless	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2	1&2	1&2,5	1&2,5	1&2	1&2	1	
Copper	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2	1&2	1&2,5	1&2,5	1&2	1&2	1	
Brass	1&2	1&2	1&2	1&2	1&2	1&2	1&2	1&2	1&2	1&2	1&2	1&2	1&2	1&2	1&2	1&2
Magnesium	1&2	1&2	1&2	1&2	1&2	1&2	1&2	1&2	1&2	1&2	1&2	1&2	1&2	1&2	1&2	1&2
Silver	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2	1&2	1&2,5	1&2,5	1&2	1&2	1	
Tantalum	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2,5	1&2	1&2	1&2,5	1&2,5	1&2	1&2	1	
X, Cured	1&2	1&2	1&2	1&2	1&2	1&2	1&2	1&2	1&2	1&2	1&2	1&2	2	2		
Y, Cured	1&2	1&2	1&2	1&2	1&2	1&2	1&2	1&2	1&2	1&2	1&2	1&2	2	2		
X, Uncured	1	1	1	1	1	1	1	1	1&2	1&2	1	1				
Y, Uncured									1&2	1&2						

LEGEND

1. **General Electric primer SS-67.**
2. **General Electric elastomer SS-15.**

5: General Electric elastomeric primerless sealer SS-64.
X: General Electric silicone elastomers SE-450, SE-460, SE-461.
Y: General Electric silicone elastomers SE-980, SE-971, SE-960.

Dollar-sign Engineering

By L. D. MILES

Four years ago the General Electric Purchasing Department undertook a new project that sent us on a widespread search for value—the basic value of every part, every item, of a piece of apparatus. What does the item do? How important is it in relation to the other parts? Can we eliminate it or simplify it? Can we replace it with a standard? Can it be combined with another part? Can it be made from some other material at a lower cost—and better value? This project intensely focused our entire efforts on each individual part to obtain one thing—the same performance at lower cost. What we did was to make a "value analysis."

The results over the four years have been impressive not only in dollar savings but in better products. The first project helped save 30 cents per unit on a control device. This figure was small in itself but, with an output of one million units a year, it added up to a tidy $300,000. In value analysis we don't overlook pennies—or even mils; one cent on one million items means $10,000. Value analysis has paid its price of admission—it has proved its ability to eliminate nonfunctional costs. It is established and operating in many General Electric plants.

A value-analysis program shows keen insight on the part of industrial management; it makes purchasing a full-time partner in cost reduction.

Why did we in the Purchasing Department organize this project? For one thing, we can bring a terrific potential of knowledge to bear on a particular problem. Besides checking into our own purchasing arrangements, we can supply specialized information on markets, materials, standard parts, and processes, and we can apply to the problem the engineering skill and ingenuity of specialized suppliers.

By reason of our value analysts' specialized abilities and training, we lengthen the arm of the engineer, the manufacturing man, and the buyer. To the engineer, value analysis offers a new outlook to component-part design. It puts a dollar sign on his ideas and so intensifies the cost-consciousness of every engineer that he makes certain the new designs include the latest ideas in low-cost production techniques. It aids the methods man by providing him with new tools and processes. Draftsmen are part of the team because every one of their decisions—selection of tolerances, bushings, fasteners, as well as many other details—has an effect on cost.

In value analysis, teamwork is not a catch-word but a vital working plan of operation. It uses highly trained specialists in the large operations, and it trains the buyers in the small units to get the same results. Value analysis ties in with, and supplements, the value-improvement activities in both engineering and manufacturing groups. Conferences or committees play very little part in the value-analysis picture; it is a highly individualized responsibility.

In beginning a value-analysis study, it has been found that a basic deficiency in value can usually be determined after a complete cost breakdown of the part under consideration has been examined. This cost breakdown should show the cost of material, labor and overhead, and all other essentials. Each of these costs is then related to the function it buys. Costs that are badly out of line stand out; thus they serve as a starting point.

By reason of his knowledge of purchasing and of what outside vendors can do, the value analyst can bring to bear upon the problem an important store of information. He knows dependable vendors and specialty suppliers who over the years have developed a high degree of ingenuity and technique, each in his own restricted field. These vendors are brought in, presented with the problem, and are requested to suggest how their particular facilities can be used to help solve the problem. Thus the best specialty suppliers become members of the value-analysis team.

With a small group of engineers in the Purchasing Department, Mr. Miles has developed methods and techniques that have resulted in eliminating millions of dollars of "wasted" cost from General Electric products. In recognition of this achievement, the Company in 1950 presented him with its highest award, the Charles A. Coffin Award.

We have developed what we call The Ten Tests for Value, the main purpose of which is to indicate the absence of value. Every material, every part, every operation must answer these questions:

1. Does its use contribute value?
2. Is its cost proportionate to its usefulness?
3. Does it need all of its features?
4. Is there anything better for the intended use?
5. Can a usable part be made by a lower-cost method?
6. Can a standard product be found which will be usable?
7. Is it made on proper tooling—considering quantities used?
8. Do material, reasonable labor, overhead, and profit total its cost?
9. Will another dependable supplier provide it for less?
10. Is anyone buying it for less?

After the study has been made, suggestions are reported to the proper person for action. The value analyst does not make decisions, nor can he await decisions—he is the prosecuting attorney, indicating the lack of value. When he has set forth the best evidence as he sees it, his job is finished, and he undertakes the study of some other device. Always the decisions are made by men responsible—the engineer, the manufacturing man, the buyer, the stylist, the commercial man—usually after they have completed sufficient tests to evaluate the evidence that has been presented.

It is basic that no reports or claims of dollars saved are issued by the value analyst himself. Savings are reported by the men who make the decisions and have the responsibility.

There are many things, as I have outlined, that value analysis is, and there are many things that it is not.

Value analysis is by no means just a search for new materials and processes, because the laboratories and engineering and manufacturing organizations are constantly doing just that.

Nor is it a substitute for the effective cost-reduction committees that daily are increasing the value of our product.

Yet it does embody all of these.

Value analysis does not involve any magic—although the results may sometimes look like it. Rather, it is hard intensive work that continues, even though the first answer to a problem may be "No." It continues until the roadblock has been removed.

Over the course of the years we have added many techniques to our lore; for instance, we have found that the success of an analysis depends to a large extent upon its intensity. Intense concentration and interest cannot be continued for any length of time. We therefore make our examinations short and concentrated.

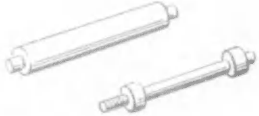
Value analysis is a new tool. Placed in the hands of the engineer, the buyer, and the methods man, it removes nonfunctioning costs from any product anywhere.

In a forthcoming issue of the GENERAL ELECTRIC REVIEW we will take you step by step through a typical value-analysis project.

THE AUTHOR, L. D. Miles *(right)*, and R. E. Fountain together attack a value-analysis engineering problem, with the subject matter under consideration between them

THREE CASE HISTORIES

Actual value-analysis studies which showed where savings could be made



Standoff Stud

The stud shown at the left above is part of a motor assembly. The annual requirement is 100,000.

Since a double-upset cold-headed part providing identical support and fastening could be obtained, saving much material between the shoulders, cost could be reduced. The original stud had a shop cost of about ten dollars per thousand. The cold-headed part could be made at a cost of $4 per thousand. This would mean a saving of more than 50 percent.

Pinion Gear

This gear is part of the assembly of a timing motor. The annual requirement is 100,000.

It could be a miniature zinc casting, or could be made of nylon, or of powdered iron or powdered bronze, or cut from pinion stock—all at substantial savings.

The current gear has a shop cost of about $50 per thousand. Made by some of the new methods it would cost between eight and ten dollars per thousand, saving annually about $4000.

Spring

This spring was used in quantities of 100,000 per year.

A specified tolerance of 0.01 inch in length was found to make no contribution to performance, and could be increased to 0.02. Also another specification, "no initial tension" made no contribution in present use.

The original cost was $18 per thousand; the cost now is under $12 per thousand, saving about one-third in production costs.

Ultrasonic Cleaning of Small Parts

By GEORGE E. HENRY

Scientific interest in the varied and startling phenomena of ultrasonics inevitably leads to the question, "What are the applications?"

Ultrasonic cleaning is one of the best answers yet given to that question. Here is a method of removing oil, grease, chips, dirt, lapping compound, and many other contaminants from the surfaces of small precision work pieces at a rate hitherto unattainable, and to a degree of cleanliness that usually surpasses the most stringent industrial standard.

This is accomplished by beaming a high-frequency sound wave through the cleaning solvent or detergent solution, as the case may be, to the surface of the submerged work piece. The sound wave, usually, but not always, in the 300- to 1000-kilocycle-per-second range, is set up directly in the liquid cleaning bath by means of a vibrating quartz crystal. The crystal, in turn, is driven by an electronic oscillator.

Pioneer Installation at Schick

Among the first industrial installations is the unit, of the type shown in the accompanying pictures, built by the General Engineering Laboratory of the General Electric Company for use in the factory of Schick Inc., of Stamford, Conn., noted manufacturers of electric shavers.

This cleaning machine is basically a General Electric ultrasonic generator with the addition of suitable conveyor equipment. The lower cabinet contains a 750-kilocycle-per-second electronic generator. The cleaning process takes place within the upper cabinet, which houses the conveyor chain and drive motor, the treating tank, and the electroacoustic transducer.

A cylindrical stainless-steel housing for the crystal is used in preference to the plastics housing of the usual ultrasonic generator because of the incompatibility of plastics and the common chlorinated hydrocarbon solvents. The upper surface of the crystal is covered by water or a weak salt solution, supplied from a small cylindrical reservoir in front of the housing. This liquid provides the ground-side electrode, being, as it were, one plate of a capacitor, the dielectric of which is the crystal.

The motion of the crystal sets up the sound wave in the salt solution; the wave passes upward through an acoustic window into the trichlorethylene flowing in the treating tank, where the cleansing action takes place. The conveyor chain moves uniformly at a rate of approximately one foot per minute.

Cleaning Operation at Schick

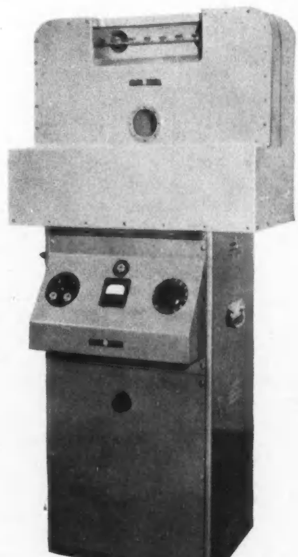
This specialized device serves a specialized purpose; it is used solely for cleaning shaver heads. These heads consist of a thin steel wrapper, slotted and crimped to shape, and tack-welded to the baseblock. A series of grinding and lapping operations leads to the plating process, after which a finish lap is applied. It is following the finish lap that a most careful cleaning operation is required, and it was here that ultrasonics offered the promise of eliminating the expensive hand brushing which for many years had been the only sure way of cleaning the heads.

Results more than justified expectations. Over-all cost of the final cleaning was cut some 50 percent. Floor space was saved. Most important, the cleaning is more effective. Slits, holes, and crevices are *clean*. There is even some evidence that oil film is being dissolved in an unbelievably inaccessible location —the space between the baseblock and the inner surface of the wrapper.

Ultrasonic Cleaning at Fairchild

Such results were interesting to other manufacturers, among them the Fairchild Camera and Instrument Corporation of Jamaica, Long Island. Here the work piece in question is a small precision-wound rotary slidewire potentiometer, manufactured to extremely tight standards for mechanical and electrical tolerance. Low electrical noise, in particular, is an essential requirement. This can be met only when windings and wiper arms are completely free of extraneous matter.

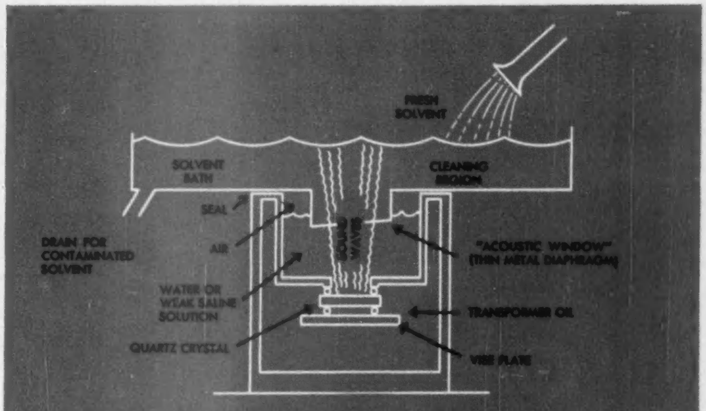
Conventional cleaning methods that are entirely adequate for most purposes would on occasion pass over the minute particles of dust or dirt left clinging to these critical parts. Ultrasonics provided the answer to the difficult problem of making the cleaning complete. It is used both on the windings and on the housings, before final assembly. The result is a finished product of superior functional accuracy and increased service life.



ULTRASONIC DEGREASER built for Schick Inc. with conveyor equipment and tank for cleaning solution surmounting the generator

At General Electric's General Engineering Laboratory, Mr. Henry is in charge of industrial applications of ultrasonics. A former physics lecturer at the University of North Carolina, he is still a frequent speaker at engineering meetings.

CLEANING at Fairchild utilizes generator, cleaning region without conveyor



SIMPLIFIED VIEW schematically showing components of acoustic portion of the ultrasonic cleaning machine for Schick

The situation at Fairchild, unlike that at Schick, has not required any modification of the ultrasonic generator. No conveyor equipment is needed, nor is there a solvent capable of damaging the plastics housing normally furnished in the transducer assembly. Soapy water has proved to be a satisfactory detergent medium in which the high-frequency sound can operate.

Multiple-crystal Installation

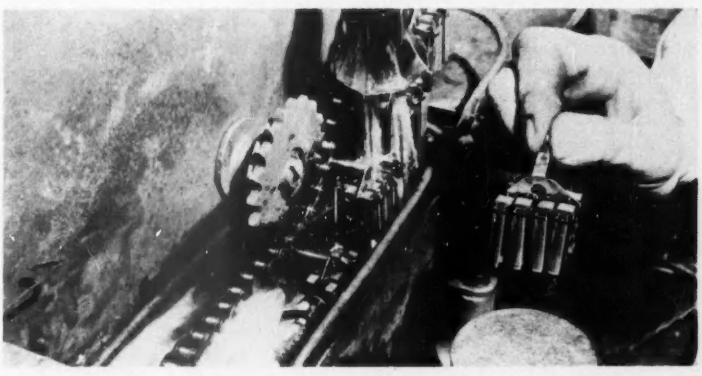
Both Schick and Fairchild units are rated 500 watts gross power input. Application of a production-line cleaner of higher power rating was made at Erie, Pa., for the Refrigerator Unit Manufacturing Division of General Electric.

The four quartz vibrators, each driven by its own r-f power supply, are lined up 12 inches apart in the floor of the cleaning tank. Work pieces are suspended from a conveyor chain in such a manner that the critical surfaces and tapped holes face downward toward the crystals. The conveyor chain is driven by a Geneva-type indexing arrangement, so that each work piece is positioned over the center of each crystal for the maximum portion of the cycle time.

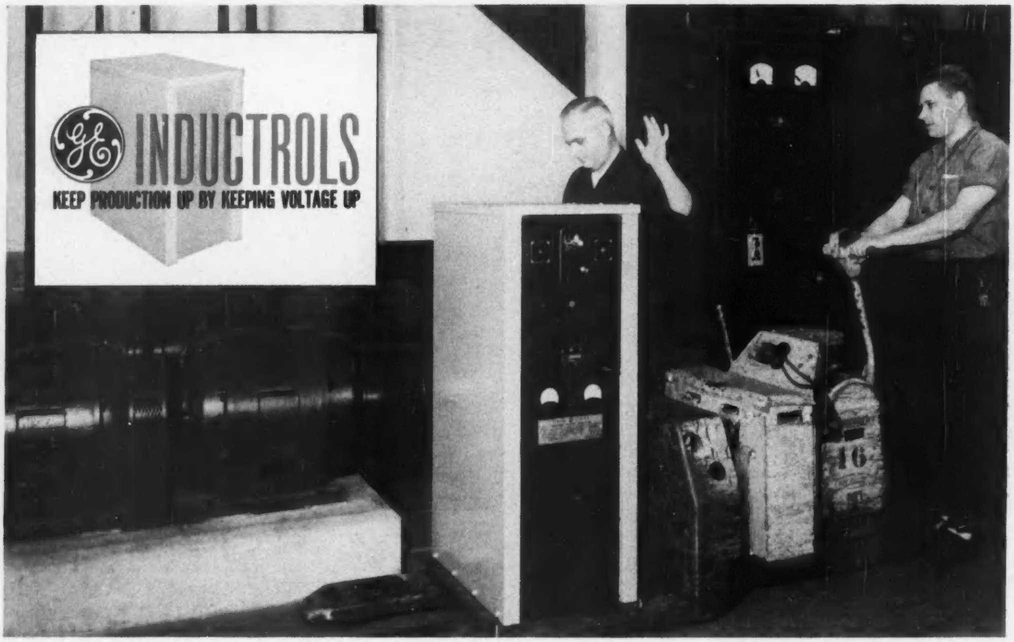
Conclusion

Natural quartz crystals are limited to dimensions of a few inches. Ultrasonic generators of kilowatts rating must therefore utilize an array of crystals, or else a ceramic or magnetostrictive transducer. This limitation suggests that for some time to come ultrasonic cleaning will find its greatest field of usefulness in small-parts manufacture. The relatively high installed cost of generating r-f power, on the order of a dollar a watt or more, suggests further that ultrasonic cleaning will be justified mainly in the case of precision-built work pieces having a high intrinsic value per cubic inch and requiring a really thorough cleaning.

But within these limitations we can make superlative claims for this method. It is applicable to pieces of almost any material—to metals, glass, textiles, or molded products—and to pieces of practically any conceivable shape. We may even say that the more irregular the shape the better; ultrasonics is particularly good for getting at blind holes and capillary cavities. Great variety is possible in the choice of solvent, solutions, or detergents. The liquid medium must of course be compatible with the material of the work piece, and will usually be one which would accomplish a partial cleaning without ultrasonics. We confidently predict that the present decade will see many more installations like the foregoing, saving untold thousands of manufacturing dollars.

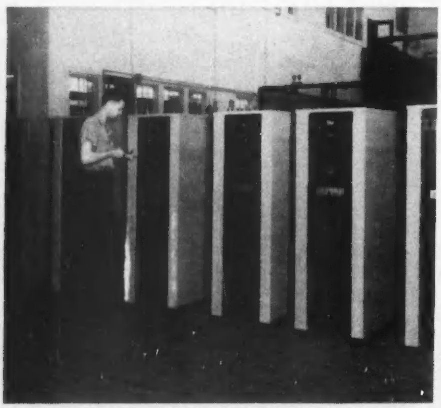


SPECIALIZED DEVICE for cleaning operation (shown in the accompanying diagram) includes handling equipment for the shaver heads and the means of providing freshly distilled cleaning solution



GENERAL ELECTRIC INDUCTROLS maintain correct voltage on electrical equipment, guard against the bad effects of poor voltage. Here a new three-phase Inductrol is being installed in a large industrial plant.

Is Poor Voltage Slowing Your Production?



INDUCTROLS ARE AVAILABLE for both manual and automatic operation, and both single- and three-phase circuits. Single-phase units are being prepared here for final test prior to shipment. Standard automatic regulators range in size from 3 kva, 120 volts up to 500 kva, 600 volts.

When voltage sags, motor performance and lamp brilliance suffer. Efficiency and output drop sharply. That's why it pays to keep voltage up with G-E Inductrols. These new dry-type regulators *automatically* maintain correct voltage on your electrical equipment—assure peak operating efficiency.

Inductrols do not require expensive fireproof vaults. All-steel cabinets, attractively styled, protect personnel by completely enclosing all live parts.

For more information on Inductrols, contact your G-E sales representative or authorized agent. Write for bulletins GEC-712, GEC-795, and GER-341. *General Electric Company, Schenectady 5, New York.*

HOW POOR VOLTAGE LIMITS YOUR PLANT EFFICIENCY

UNITS	10% Undervoltage	10% Overvoltage
Incandescent Lamps	Light output cut 30%	Life reduced 70%
A-C Motors	Overheats, ups maintenance	Power factor decreases
Resistance Heaters	Heat output cut 19%	Injurious overheating
Electronic Tubes	May destroy gas tubes	Life cut 75%

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GENERAL ELECTRIC