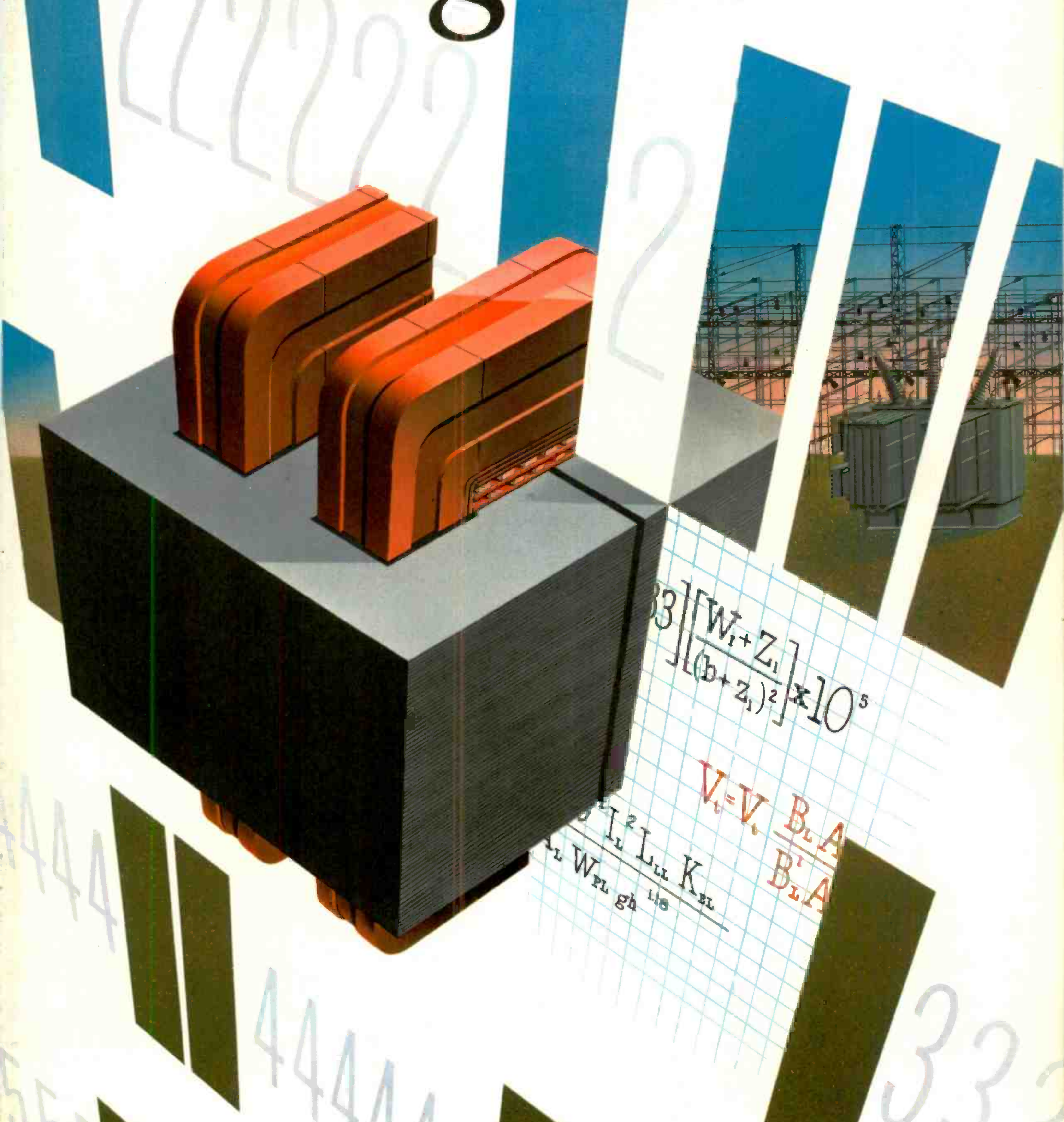
WESTINGHOUSE

Engineer



MARCH 1956

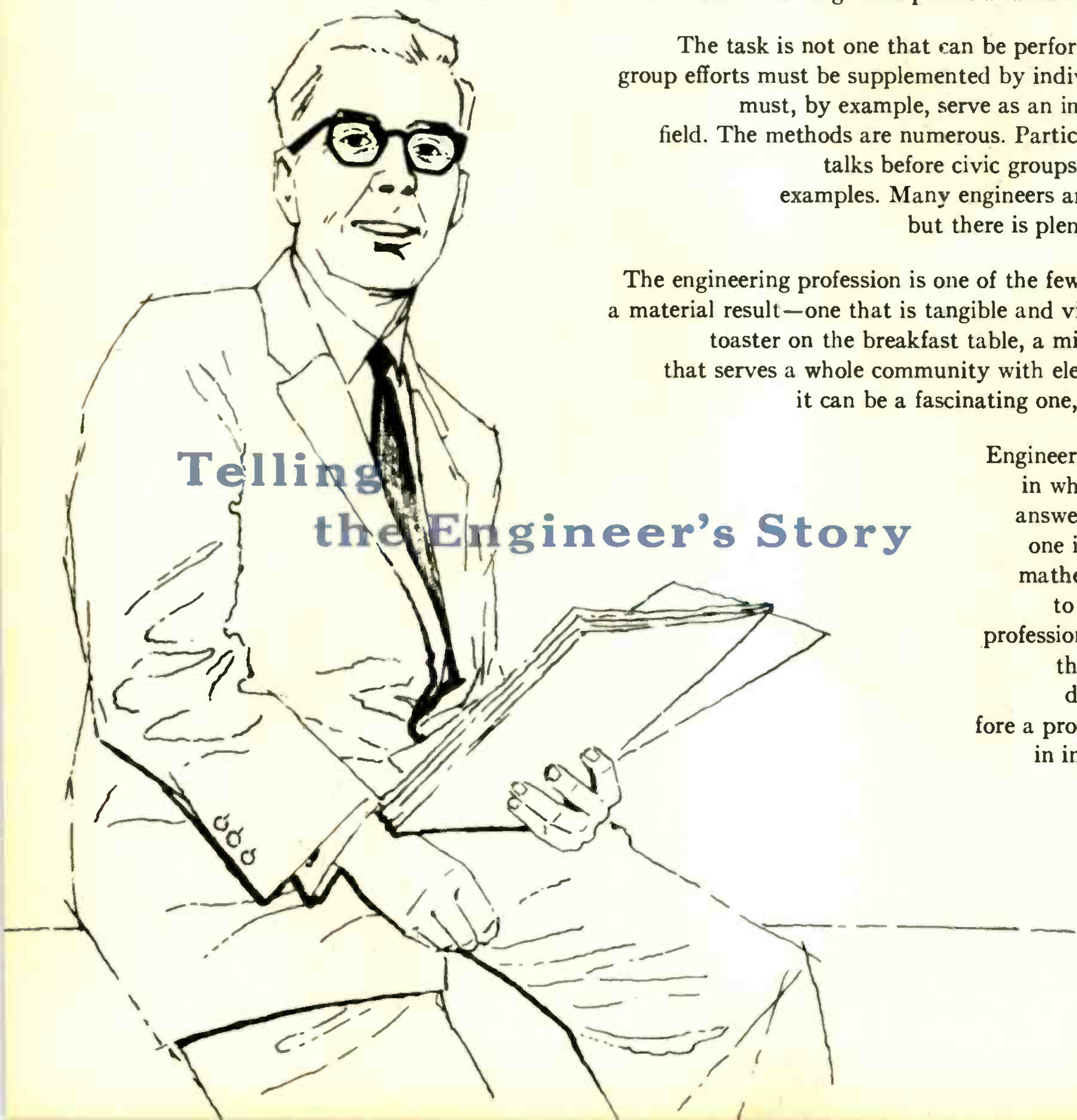
Telling the Engineer's Story

Engineers today constitute but a small fraction of one percent of our total population. Yet nearly everything we do or have is in some way affected or enhanced by engineering. Engineering builds our bridges, furnishes our water supply, controls rivers, furnishes our electric power—and the thousands of household and industrial devices that use it; it digs tunnels, produces airplanes that fly faster than sound, and nuclear submarines that can go vast distances non-stop and without surfacing; engineering helps grow better agricultural crops, and even figures in such common items as fountain pens and toys. You name it; the chances are that engineering is involved.

Yet despite the amazing role played by engineers in our modern civilization, engineering is probably not a well-understood profession. Well known, yes, but not well understood. In a sense, engineers have done their tasks too well and told about it too matter-of-factly. They have produced so many wonders that the general public accepts them with too little appreciation of the creativeness, not to mention the plain hard work, involved. The end results that engineers have produced have won them recognition; but for engineering to serve most effectively its obligation as a public service, there must be more awareness of the whys and hows of engineering. The story of *engineering* must be told, as well as the story of the devices and structures it builds.

One such effort to produce greater public awareness is the annual National Engineers' Week, held this year from February 19th through the 25th. Using all available communications media, a concerted effort was made to acquaint the public with many of the achievements of the engineering profession. This annual spotlight is a very worthwhile effort—but once a year is not enough. To any who can help tell the story of engineering, every week should be "engineers' week." The stories to be told are multitude.

The need for greater public awareness of engineering has many sides. But one, at the moment, seems extremely important to the welfare of the country. This concerns the task of attracting more young people to the engineering fields. Little needs to be said about our present shortage of engineers. Raising the general prestige of the engineering profession will help, in itself, provide more incentive. This is but one reason for the need for greater public awareness; others are equally obvious.



The task is not one that can be performed by any one group alone; group efforts must be supplemented by individual efforts. Every engineer must, by example, serve as an incentive to others to enter his field. The methods are numerous. Participation in community affairs, talks before civic groups, clubs, and schools are a few examples. Many engineers are already doing these things, but there is plenty of room for more activity.

The engineering profession is one of the few that nearly always produces a material result—one that is tangible and visible. Whether the result is a toaster on the breakfast table, a mile-long bridge, or a generator that serves a whole community with electric power, the story behind it can be a fascinating one, and one that should be told.

Engineering is not simply a profession in which facts are collected and an answer falls into place; neither is it one in which the solution of a few mathematical formulae is sufficient to produce a new device. It is a profession which has at its disposal all the scientific information so far discovered by man; it is therefore a profession requiring the ultimate in ingenuity, creative ability, and common sense, to put this information to the best use. *This story needs more telling.*

R. W. D.

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VOLUME SIXTEEN • NUMBER TWO • MARCH, 1956

In This Issue

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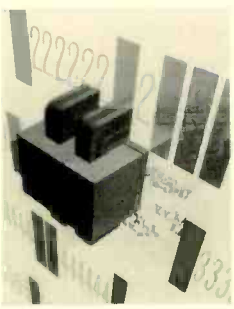
THE COVER



The digital computer, as outlined in this issue, now helps design equipment such as transformers. In our cover by Dick Marsh, this role of the computer is portrayed by a punched card, a transformer, and typical calculations.

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

Subscriptions: Annual subscription price in the United States and possessions is $2.50; in Canada, $3.00; other countries, $3.00. Single copy, 50¢. Address all communications to *Westinghouse* ENGINEER, P. O. Box 2278, 3 Gateway Center, Pittsburgh 30, Pa.

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

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

Low Temperature Research

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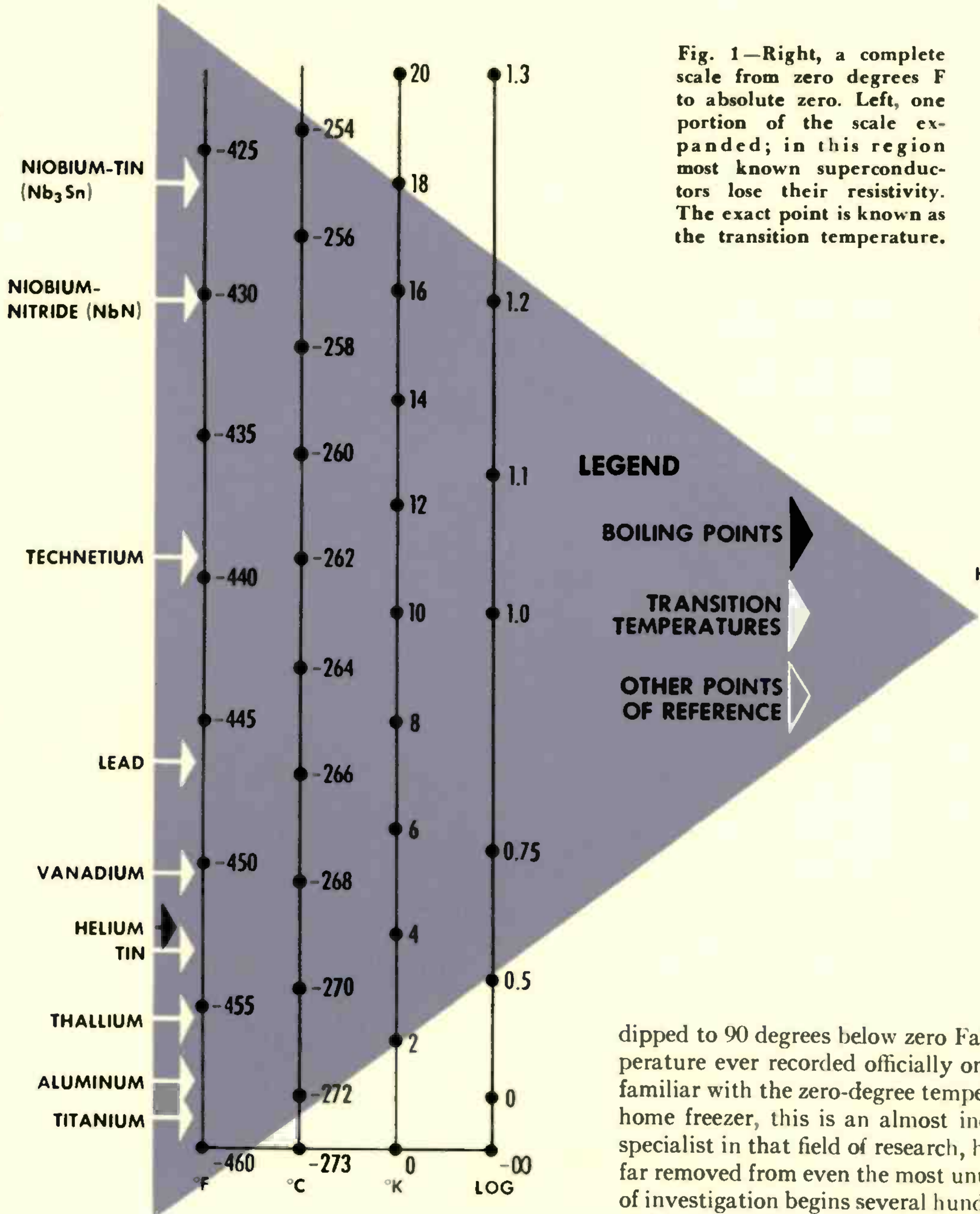
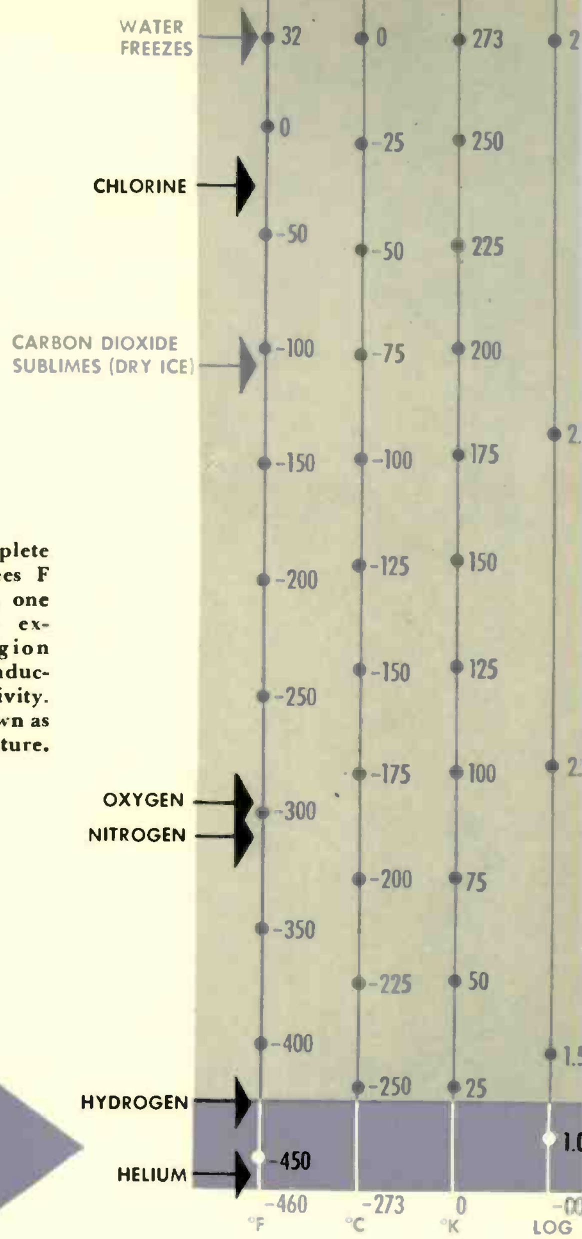


Fig. 1—Right, a complete scale from zero degrees F to absolute zero. Left, one portion of the scale expanded; in this region most known superconductors lose their resistivity. The exact point is known as the transition temperature.



In the frigid areas of northern Siberia, the temperature once dipped to 90 degrees below zero Fahrenheit, the lowest atmospheric temperature ever recorded officially on the earth's surface. To most people, familiar with the zero-degree temperature of a cold winter day, or of their home freezer, this is an almost inconceivably low temperature. To the specialist in that field of research, however, "low temperature" is a range far removed from even the most unusual atmospheric conditions. His area of investigation begins several hundred degrees lower, and ranges down to within a few tenths of a degree of −459 degrees F, or absolute zero.

Low-temperature research is a scientific and an engineering field of considerable and growing activity. Before the war this field was investigated intensively at perhaps a half-dozen laboratories, mostly in Europe; today the number of laboratories is of the order of 100, most of them in the United States.

Why has the low-temperature field continued to attract a growing number of scientists and engineers? Answers to this question involve the theoretical significance of low-temperature research as well as the discoveries that already have been made in this field.

In the first place, low-temperature research opens up for exploration, literally, a limitless temperature range. Experience has shown that in a given temperature range the abundance of new phenomena depends not on the number of degrees of temperature involved but rather on the ratio of the absolute temperatures covered. From this point of view, a more realistic picture of the importance of a given temperature interval is given by considering the logarithm of the absolute temperatures; the infinite extent of the low temperature field thus becomes apparent. More specifically, with simple liquid-helium techniques a temperature of 1 degree K can be reached quite readily, a temperature which is 1/300 of that of room temperature. To increase the absolute temperature by a factor of 300 upward from room temperature would involve a temperature of 90 000 degrees K.

In the second place, the power of low-temperature research lies in the effects of lowering the thermal energy of substances. Thermal energy is simply the energy a substance has by virtue of its temperature. In general, lowering the temperature greatly simplifies the physical processes that occur within a substance, and so low-temperature experimentation is a general tool for elucidating the electrical, magnetic, optical, thermal, and mechanical properties of substances.

One way by which this simplification occurs is through the reduction of the thermal agitation of the atoms comprising a substance; this often makes possible studies that at higher temperatures would be exceedingly difficult, if not impossible. For example, the role played by impurities in determining the electrical and thermal conductivities of metals is often masked at higher temperatures by the violently moving atoms, which, in colliding with the electrons, absorb most of the energy lost by them in passing through a metal. Lowering of the temperature brings this atomic dance to all but a halt, and the effects of the impurities as well as those of boundaries of the conductor can be observed.

Another example of great importance for the theory of metals is provided by a consideration of the specific heat of a metal, i.e. the ratio of heat energy absorbed to the change in temperature. For the understanding of the metallic state the contribution to the specific heat by the electrons must be known. Again, only in the liquid-helium range can the masking effects of the specific heat of the assembly of atoms be eliminated, and those of the electrons be made to stand out. To summarize, then, the obscuring effects of thermal agitation can be eliminated at low temperatures and individual fundamental processes, hidden at higher temperatures, can be sorted out and studied in relative isolation.

In the third place, the study of the temperature dependence of a property of matter over a temperature range involving a large ratio of absolute temperatures often provides an insight of the processes underlying the property. For example, the study of the magnetic susceptibility of phosphors from room temperature down to 1 degree K has shed considerable light on the nature of activators, i.e. the impurities present in minute amounts, on whose presence the effectiveness of the phosphor depends.

Thus, low-temperature techniques provide a unique and potent tool for fundamental explorations, a tool, which, like x-rays, has become essential for experimentation in diverse areas of physics, metallurgy, chemistry, and engineering.

There is yet another aspect of the lowering of thermal energy. Suppose that there exist in nature phenomena that are so delicate energy-wise that the thermal energy present in materials at ordinary temperatures prevents their appearance. On this basis entirely new properties might appear at very low temperatures. The most striking example of such a new phenomenon is superconductivity. A large number of metals and alloys, at temperatures below a certain transition temperature, characteristic of each substance, completely lose their electrical resistance, and, while in this superconducting state, are perfectly diamagnetic, i.e. have a magnetic permeability of less than unity. In sharp contrast to superconductivity is the rise in electrical resistance at low temperatures, another baffling low-temperature phenomenon exhibited by a number of slightly impure metals. At low temperatures liquid helium itself undergoes changes in properties that in many respects are as spectacular as those shown by superconductors. It becomes "superfluid," flows rapidly through the smallest openings, and its thermal conductivity increases enormously; it becomes, in fact, a better heat conductor than the purest metal.

In the world of low temperatures, one, like Alice in Wonderland, must be prepared for surprises and for the unfamiliar. At the temperatures of liquid helium all other substances are solid, and oxygen and nitrogen in appearance and mechanical behavior resemble white sand at ordinary temperatures. The strength of low-carbon steel increases by a factor of five over that at room temperature, but the steel becomes quite brittle. Certain dielectric materials—sapphire is an example—attain at these temperatures thermal conductivities as much as sixty times greater than that of copper at ordinary temperatures. The metal gadolinium, whose magnetic properties at ordinary temperatures are not unusual, is ferromagnetic at low temperatures, having, in fact, a saturation magnetization per unit mass 16 percent greater than that of iron.

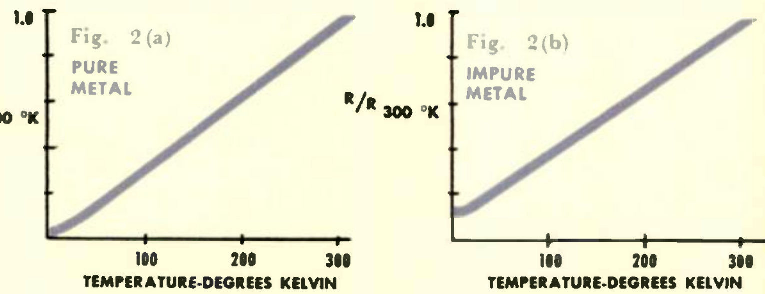


Fig. 2—Resistance-temperature curves of pure and impure metals.

Of the low-temperature phenomena mentioned, superconductivity is perhaps the most interesting both from a fundamental viewpoint and from the standpoint of possible usefulness to the electrical industry. In this field the Westinghouse Low-Temperature Laboratory is devoting most of its effort.

Superconductivity

When the temperature of a metal is decreased, its electrical resistance is lowered. Why this should happen is easy to see in a rough way. The carriers of electric current, the electrons, collide with the atoms comprising the metal and give up to the atomic lattice some of the energy acquired by the electrons from the electric field. This transferred energy is, of course, the Joule heat loss. According to theory, an electron passing through a perfect lattice would lose no energy. The thermal motion of the atoms destroys the perfection of the lattice, and an ideal metal would be expected to have a resistance-temperature characteristic as indicated in Fig. 2(a). In practice the electrical resistance of a metal does not go to zero as absolute zero is approached because there remain imperfections due to chemical impurities and to physical imperfections of the metal structure. As shown in Fig. 2(b), at low temperatures, where the scattering of electrons by the thermal motion of the atoms makes a negligible contribution to the resistance, the electrical resistance of a metal assumes a temperture independent value, called the residual resistance, which is a measure of the level of chemical and physical impurities.

This was the state of knowledge when in 1911, three years after he had succeeded in liquefying helium, the Dutch physi-

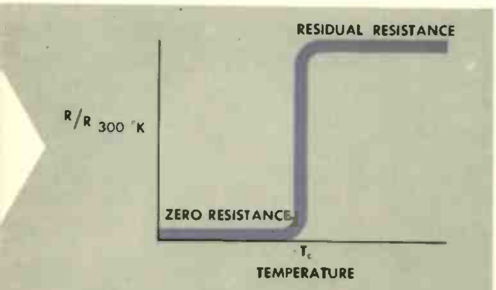


Fig. 3—The onset of superconductivity in mercury, i.e. the complete disappearance of electrical resistance. This phenomenon was first discovered by the Dutch physicist Kamerlingh Onnes in 1911.

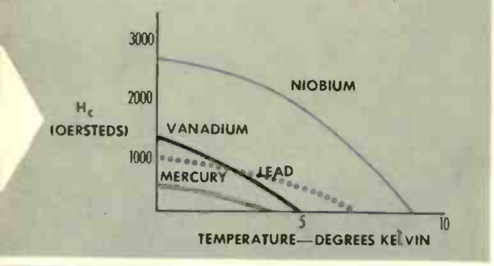


Fig. 4—Magnetic fields of certain magnitudes destroy superconductivity. These curves illustrate the relation between temperature and critical field for different metals.

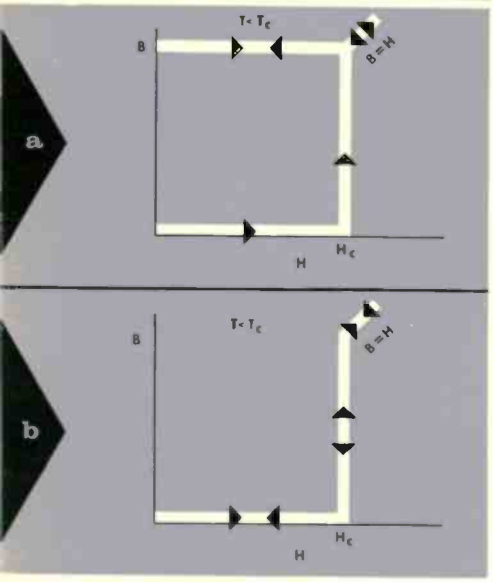


Fig. 5—At left, the predicted magnetic properties of a superconductor, and at bottom, the observed properties. This illustrates that the magnetic induction (B) of a superconductor is zero and is independent of magnetic history.

cist, Kamerlingh Onnes, discovered in mercury the first example of the complete disappearance of electrical resistance in a metal. His completely unexpected discovery is illustrated in Fig. 3. What was observed was that the resistance suddenly became immeasurably small as the temperature was lowered below a characteristic transition temperature, 4.15 degrees K.

After more than forty years of experimental and theoretical study, a great deal is known about the properties of superconductors, and to the large list of known superconductors new ones are continually being added. Yet the phenomenon has eluded an explanation based on first principles; it ranks with the nature of nuclear forces as one of the major problems facing the theoretical physicist.

Production of Liquid Helium for Low-Temperature Research

Basically, the problem of obtaining ultra-low temperatures is no different than that of producing ordinary refrigerator temperatures, i.e., heat must be pumped from the region to be cooled and "dumped" in a region of higher temperature. However, because the temperature sought is at the extreme end of the scale, the techniques and equipment employed are somewhat more complex.

Most low-temperature experiments are conducted in either liquid nitrogen, which liquefies at about —321 degrees F, or in liquid helium, which liquefies at about —452 degrees F; both are liquefied by essentially the same processes. The low liquefaction temperature of helium makes it most suitable for experiments conducted within a few degrees of absolute zero.

One common method of liquefying helium is shown schematically in the diagram at right. Fundamentally the process consists of compressing pure helium gas to a pressure of about 200 psig, precooling it by means of a heat exchanger, and then allowing the gas to expand. The expansion cools the gas to the point where it liquefies.

Helium is first passed through a purifier, and then to a reservoir. The gas is then compressed in four stages to a little over 200 psig, and is fed—at room temperature—into the heat exchanger. Here it is first precooled by gas already processed or by liquid nitrogen.

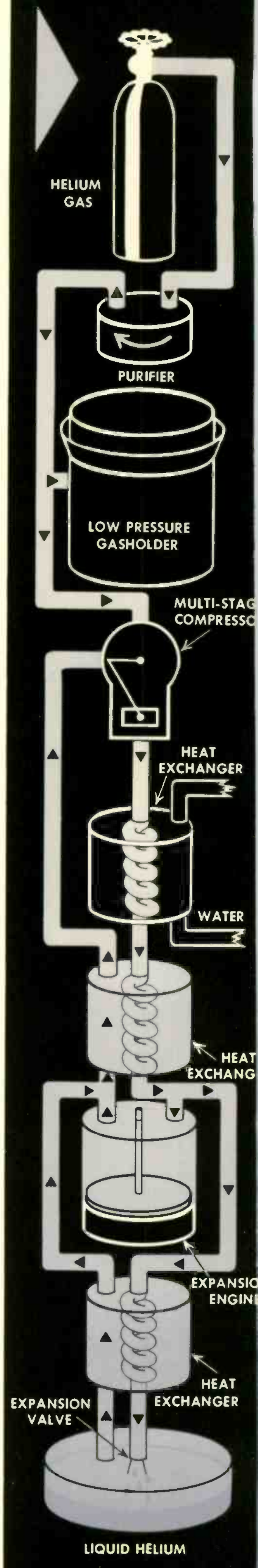
Part of the gas is fed to an expansion engine where it is allowed to expand, and thus cool further. This portion is fed back to the precooler to cool incoming gas.

The remainder of the gas goes to a second heat exchanger, where it is further cooled; it is then allowed to expand through a special valve, which cools it to the point where it liquefies (—452 degrees F). Gas that does not liquefy is drawn off and fed back through both heat exchangers to remove heat from incoming gas. It then returns to the compressor and starts the cycle again. Frequently more than one expansion engine and heat exchanger are used to cool the gas in several stages.

The temperature of the liquid helium can be further reduced by pumping a vacuum above it and by special magnetic means, to obtain temperatures within a few tenths of a degree of absolute zero.

Helium can be maintained in a liquid form for long periods in a special container developed at the Westinghouse Research Laboratories; the container of liquid helium is surrounded by a second container filled with liquid nitrogen.

This produces, in effect, a large thermos bottle. Liquid helium can be stored in this manner for several months; a 12-gallon container will hold helium as a liquid for almost a year.



What are the important properties of superconductors? It has been found experimentally that to every temperature below the transition temperature there corresponds a value of the magnetic field that destroys superconductivity, i.e., causes restoration of the normal resistance. In Fig. 4 is sketched the critical field, temperature relation for a number of superconductors.

From the standpoint of certain possible applications, for example, as resistance-less winding in transformers, it is unfortunate that nature has imposed these limitations of magnetic field. From Fig. 4 it is seen that, as far as is now known, the maximum field in which superconductivity can be maintained in a pure metal is 2600 oersteds in the case of niobium.

The magnetic properties of a superconductor, like the electrical ones, are unique. From electromagnetic theory one would predict that once a material is in the superconducting state, a magnetic field could not enter the bulk of the material, for in a thin layer at the surface of the perfect conductor would be induced shielding currents by any applied external field. What would be predicted is shown in Fig. 5a.

As long as the critical field, H_c, is not exceeded, the magnetic induction within the material would be expected to remain zero. If, however, H_c is exceeded and the field is then reduced below H_c, it would be expected that the induction $B = H_c$, obtaining in the material when it again becomes superconducting, would remain "frozen" in. Experimentally, in fact, an entirely new phenomenon is observed; namely, the magnetic induction of a superconductor is zero and is independent of its magnetic history. This perfect diamagnetism is a totally unexpected property, and, like the absence of electrical resistance, remains unexplained to this day.

Of course, an immediate question arises, "Do we really mean that a superconductor has zero resistance?" Experimentally such resistance as may remain can be shown to be no greater than a certain amount, that is, only an upper limit to the resistance can be established. But the upper limit that has been established is very low; below the transition temperature the resistance of a superconductor is no more than 1×10^{-15} of its value at room temperature.

A very low upper limit can be demonstrated quite easily. A ring is made of the material and cooled below the transition temperature. Physically, the ring may be very similar to a wedding ring. The ring is exposed to a magnetic field in excess of the critical field at that temperature, and then the field is reduced to zero. As a result, thousands of amperes may be caused to flow in the ring, and, judged from its magnetic effects, this huge current continues to flow for days with no measurable diminution.

How prevalent is this property, which, if it could be applied commercially, would revolutionize the electrical industry? More than twenty elements and a large number of intermetallic compounds become superconductors. Curiously enough, the best conductors, copper and silver, are not among them. In fact, a useful trick employed by low-temperature physicists is to copper-plate superconductors when one turn of superconducting wire must be insulated electrically from another! At temperatures near absolute zero, copper of the best purity available has a resistance only one thousandth of its room temperature value. Thus, its efficacy as an electrically insulating coating is based not on its absolute resistance, which is quite low, but rather on its resistance relative to that of the superconductor it insulates.

The element with the highest transition temperature (about 11 degrees K) is technetium; another element with a high transition temperature is lead (7.2 degrees K). Other metals, such as cadmium, ruthenium, and titanium, have transition temperatures within one degree of absolute zero. Incidentally, during the last decade extensive studies have been pursued in a temperature range within a few thousandths of a degree of absolute zero, a range of temperature in which man has surpassed nature by a handsome margin. The highest transition temperature (close to 18 degrees K) for superconductivity so far observed is for the intermetallic compound Nb_3Sn. The search for high transition temperatures, which could provide important clues to the understanding of superconductivity as well as bring practical application closer to realization, is continuing apace.

Thus far, only certain highlights of the properties of superconductors have been touched upon. To elaborate somewhat, consider the low-temperature research being done at the Research Laboratories on superconductivity and other low-temperature phenomena.

Low-Temperature Research Projects

Specific Heats of Normal and Superconducting Metals—The temperature dependence of the specific heat of a class of substances provides an important clue to their fundamental nature. Thus, metals are thought to take up thermal energy by exciting to higher energy states two physically different systems, the system of atomic ions or crystal lattice and the system of electrons. According to the theory of metals, at low temperatures—temperatures below, say, 4 degrees K—the lattice specific heat should vary as the cube of the temperature (T^3) while that of the electrons should vary linearly with T. The most convincing experimental demonstration of these temperature dependencies was provided by the work of a group in the Research Laboratories on the noble metals, copper, silver, and gold. Thus, for normal metals, experiments support the theoretical conceptions of the nature of metals.

In the case of superconductors, the theoretical picture is very unsatisfactory and so the experimental establishment of the temperature dependence of the specific heat of the electrons, for example, is of the greatest importance in suggesting the direction in which further theoretical study might proceed. Up to very recently, available experimental evidence indicated a T^3 dependence for the electronic specific heat of a superconductor as well as for the lattice. During the last year experiments on vanadium, tin, and aluminum led to the discovery at the Research Laboratories that the electronic specific heat of a superconductor varies exponentially with temperature (i.e., $C_{es} = ae^{-b/T}$, where a and b are constants). The result has revived theoretical interest in the idea that in the electron energy spectrum of a superconductor there is a forbidden gap between the ground state electrons and those in excited states.

This work has established new standards of precision in liquid-helium temperature calorimetry resulting from refined experimental techniques. Some idea of the difficulty of the experiments can be gained by noting that it was necessary to reduce extraneous heat inflow to the sample under study to less than five hundredths of a microwatt. Many times this rate of energy input could be introduced by stray electromagnetic fields or by eddy currents induced in the sample by its vibration in the earth's magnetic field. Suitable precautions were taken to eliminate these disturbances. In an actual measurement, heat equivalent to 150 microjoules was introduced into the sample, an amount which raised its temperature about five hundredths of a degree. Studies on aluminum involved further elaborations of technique since it was necessary to work at temperatures within 0.2 degrees of absolute zero and with energy inputs only 1/15 of that mentioned above.

The methods developed already undoubtedly will continue to supply important contributions to our understanding of the nature of normal conductors and of superconductors.

Superconducting Materials—During the last year a program was established to determine the conditions that must be fulfilled if a substance—element, compound, or alloy—is to become superconducting. This study involves (a) surveys of metallic compounds and alloys in order to evaluate the full range of crystal structures and types of material that become superconducting and (b) more detailed work on normal electronic properties such as electrical resistivity, specific heats, magnetic susceptibility, etc. of known superconductors in an effort to establish correlations between these properties and the occurrence of superconductivity. The first part of the program has resulted in the discovery of a number of new superconducting elements and compounds.

Here Dr. John Hulm of the low-temperature laboratory prepares a demonstration of superconductivity. The container is double-walled; the inner portion contains liquid helium, the outer, liquid nitrogen. For the demonstration a ring of superconducting material is immersed in the helium, and power applied. After removal of the power source, current continues.

High-Pressure Physics at Low Temperatures—Experiments are in progress on the effect of pressure on the properties of normal conductors and of superconductors. Pressures up to 30 000 pounds per square inch are applied at helium temperatures to change the distances between atoms. This provides an opportunity to investigate experimentally the way in which various properties of metals depend on interatomic distance, which is a crucial test of any theory.

Electrical Conductivity of Metals as a Function of Frequency—Experimental and theoretical studies have been underway on the conductivity of copper and other metals at low temperatures over a wide range of frequencies, 10 to 10^7 cycles per second at one end of the spectrum and optical and infrared frequencies at the other end. These experiments allow tests of the microscopic behavior of electrons under varying conditions of free paths and of spatial variation of the electromagnetic field in the metal.

Magnetic Susceptibilities of Solids—From studies of the temperature dependence of the magnetic susceptibility of activators in phosphors, it has been possible to explain why one activator in a crystal can produce so many different colors depending upon the method of preparation. This has been done by deducing from the magnetic measurements the several ways in which the activator can reside in the crystal and identifying a particular color with each form. Studies of this type may eventually make it possible to predict the properties of a phosphor before making it. These studies of feeble magnetic properties have been extended to metals to test further our understanding of the electronic properties of metals.

Other Experiments Involving Low-Temperature Techniques—Low-temperature techniques have proved valuable in the Research Laboratories to various groups whose interests are not primarily in the low-temperature field. These techniques have made possible a number of experimental programs designed to elucidate important semiconductor properties. In the field of metallurgy, investigations of the strength of metals and the nature of fracture at low temperatures are adding to our fundamental knowledge of the properties of metals. Low-temperature techniques have also proved useful in the preparation of extremely pure helium gas required for studies in gaseous electronics, as well as in the production of silicon crystals having a minimum of structural defects.

Conclusion

Up to the present time the rich store of low-temperature phenomena has been virtually untapped with respect to commercial applications. While it is not impossible that low-temperature techniques will one day be applied to heavy electrical equipment, the first applications will probably come in specialized fields of instrumentation, such as in automation and in computers. Here is the promise of greatly decreasing the size of complicated equipment by the use of new types of tiny computer elements.

One example of the use of low-temperature phenomena in special areas of instrumenation is the superconducting bolometer. The superconducting bolometer is a device used as a detector of radiant energy. A typical bolometer has a minimum detectable energy in a single flash of 2×10^{-6} erg or, in units more familiar to the electrical industry, 6×10^{-20} kilowatt hour! The superconducting bolometer can be used as an alpha-particle detector that not only counts the particles, but gives an indication of their energy as well.

Another example of instrumentation using low-temperature techniques is to be found in liquid-helium and liquid-hydrogen bubble chambers. Superheated liquid helium and liquid hydrogen have been found to be very sensitive bubble chambers, giving tracks when exposed to ionizing radiation in a manner analogous to that of the more familiar cloud chambers.

The possibility of useful applications of low-temperature phenomena is among the less subtle reasons for the interest of the electrical industry in this field. By now the unity and interdependence of various fields of the physical sciences are well appreciated. Research in a pioneer field like low-temperature physics necessarily is of value not only to the specialist in this field but also to those working in related fields. The interactions of scientists, both within a given laboratory and through normal channels of exchange of scientific information, are essential to rapid and continuing progress of science.

In the manner of the science-fiction writer, predictions could be made here of the marvelous innovations that will result from research in a field which already has revealed such startling electrical and magnetic phenomena. This will be left to the imagination of the reader; the history of science indicates that the actual developments coming from research in pioneer fields generally dwarf the predictions made by the most futuristic crystal-ball gazers.

The era of large-scale use of low temperatures in industry has already arrived. In specialized fields, as in gas separation and liquefaction, the applications have been in effect for many years. Large-scale low-temperature techniques have played an essential role in thermo-nuclear developments. Special containers whose temperature can be maintained within a few degrees of absolute zero for hundreds of days have been developed at the Westinghouse Research Laboratories and are universally used. Just when low-temperature techniques will be used on a commercial scale by the electrical industry is in the hands of its scientists and engineers.

Product Design by Digital Computers

Marshall Middleton, Jr.
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Man has yet to devise a machine that can do creative thinking. But almost as helpful are the modern automatons that can be instructed to do an ordered arrangement of simple problems in arithmetic and make decisions of logic, at many times the speed of the human brain. These modern, high-speed computers are increasing the "thinking capacity" of today's design engineer manyfold.

Industrial and consumer product designs that require days, weeks, or even months to complete may soon be designed in a matter of minutes. At the same time, tremendous improvements will be made in the quality of the product. The savings in engineering man-hours and the quality improvements will be made possible by the introduction of modern high-speed digital computers into the design work. These computers have proved themselves invaluable in every design problem to which they have been applied, and show promise of completely face-lifting many future design operations. Their application, however, requires laying a great deal of groundwork before designs can be attempted.

Although small- and medium-powered digital computers have been used for years in product design, they did not greatly affect established procedures. Engineers still used manual methods. Digital computers were used only to calculate physical characteristics of certain parts of a complete design. For instance, in the design of a motor or generator, the computer was used only to calculate the critical speed of the rotating system. The engineer used this result as a criterion for modifying his design. Because of the limited storage capacity of the early computers and their inability to make logical decisions, components of a particular design could only be analyzed one at a time. While this computer-manual design produced a better-engineered product, the basic design methods were not appreciably affected.

The modern high-powered digital computer, by virtue of its extremely high speed and practically unlimited storage capacity, is causing a major change in the present design methods. The complete design of a product, from customer specifications to shop manufacturing information could be performed by computers. The computer would calculate many variations of the same design, and select the best from the standpoint of performance, cost, etc. Alternate proposals for customer quotations could be obtained quickly. All of these would result in a shorter delivery time for a better-engineered product, at a lower cost.

Programming

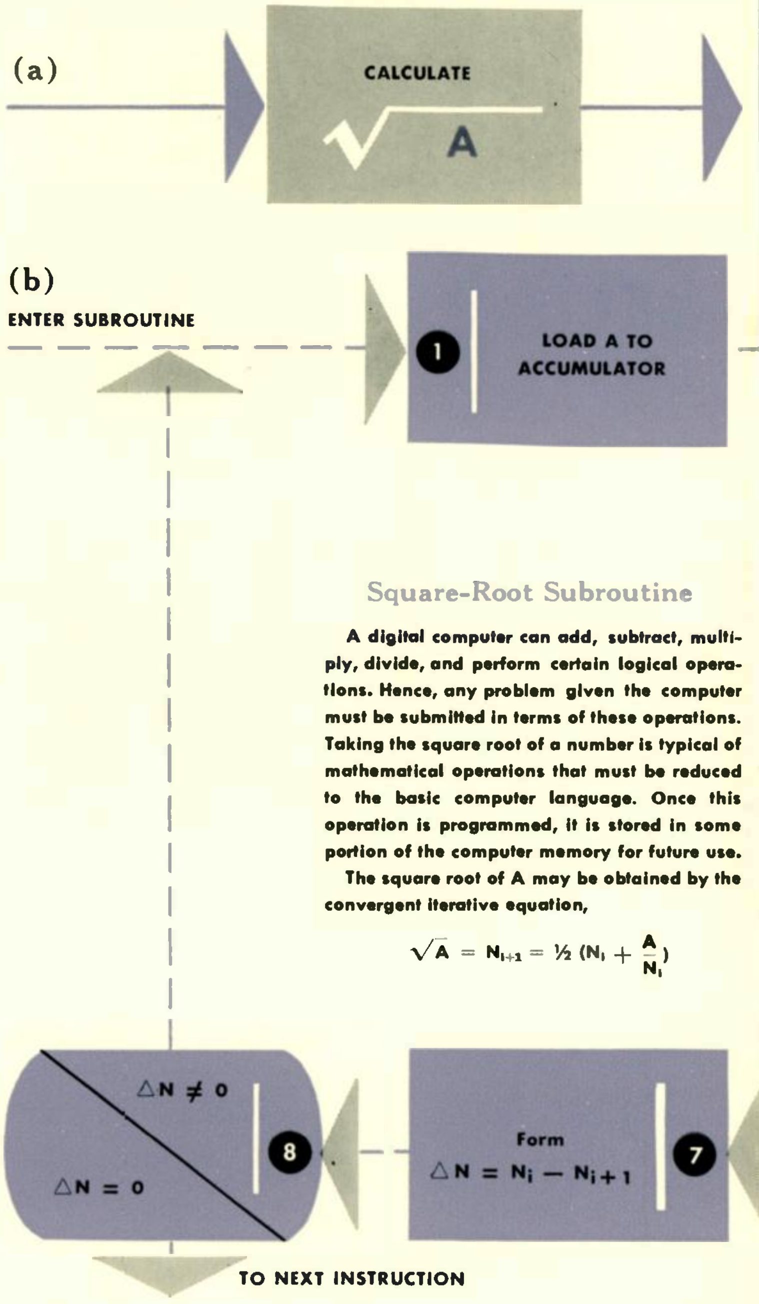
Before a digital computer is capable of designing equipment, the design engineer and a computer consultant must convert the design methods and associated data to a form that the machine can accept. This conversion process is called *programming*. In general, a digital computer designs equipment using the same design philosophy as that followed by an experienced engineer. Starting with the customer's specifications, a set of initial input parameters are calculated by means of empirical formulas based on previous models. These parameters are used in the design method to determine a set of performance characteristics. The calculated characteristics are compared with performance characteristics specified by the customer and manufacturing codes. If the calculated characteristics fail to meet the guarantees, the input parameters are modified and the process repeated.

In organizing the design method and associated data for the computer, the design engineer and programmer must develop a flow chart and a complete step-by-step mathematical outline of the method. The flow chart is a graphical representation in block form of the design procedure. First, a general block flow chart is constructed that illustrates the major accomplishments of the computer program and any iterative loops; then a block flow chart for each major accomplishment is constructed that graphically represents every operation and logical decision described in the mathematical outline. The step-by-step mathematical outline must contain the mathematical relationships of all equations, curves, etc. to be used in the design method. Also, the designer must record in logical sequence all the decisions made during the course of a design. Fulfilling this last requirement is no simple matter. The design engineer must rely on all his ingenuity and design intuition to develop a set of rules for modifying the input parameters whenever certain calculated performance characteristics fail to meet the guarantees. Based on a specific performance-guarantee disagreement pattern, the designer must determine which input parameter to change and in which direction. This requires an extensive study of the design process, but is essential if the computer is to design a product over the entire range of possible product ratings.

The programmer uses the flow chart and mathematical outline to convert the mathematical relationships and logical decisions of the design method into the basic machine operations. Actually, a high-powered digital computer is only capable of performing simple logical and arithmetical operations. Its tremendous advantage stems from its ability to perform these simple operations at incredible speeds. Hence complex lengthy mathematical equations that are expressible in terms of the basic arithmetical operations—addition, subtraction, multiplication, and division—can be solved in a reasonable length of time.

After the program has been written for all the design equations and their associated logical decisions, this information is read into the computer.

Basically, any high-powered computer consists of four main components: input, output, storage, and arithmetic units. Information can be read into the computer on paper tapes, punched cards, or magnetic tapes. Results of a computation can be obtained from the computer on paper tapes, punched cards, magnetic tapes, a cathode ray tube screen, or printed on paper. Data and instructions can be stored in the computer in magnetic cores, on magnetic drums, or magnetic tapes. Because of the high speed with which information can be read to and from the magnetic-core storage, it is used in conjunction with the arithmetic unit. Programs are stored in block form on the magnetic drums and tapes and are read



Square-Root Subroutine

A digital computer can add, subtract, multiply, divide, and perform certain logical operations. Hence, any problem given the computer must be submitted in terms of these operations. Taking the square root of a number is typical of mathematical operations that must be reduced to the basic computer language. Once this operation is programmed, it is stored in some portion of the computer memory for future use.

The square root of A may be obtained by the convergent iterative equation,

$$\sqrt{A} = N_{i+1} = \tfrac{1}{2}\left(N_i + \frac{A}{N_i}\right)$$

in this form into the magnetic-core storages whenever the computer is required to execute that particular program. High-speed storage registers, instruction register, multiplier-quotient register, and the accumulator combine to form the arithmetic unit. The high-speed storage registers hold the information involved in the current calculations. The multiplier-quotient register contains the multiplier in any multiplication operation and is the register in which the quotient is developed during a division. The instruction register contains directions for the computer operation. The instructions are stored in sequential storage locations and are executed in the same fashion. The accumulator is an adding register in which the sum or difference of any two numbers can be obtained. It is also used to hold the dividend in division.

A modern high-powered digital computer is capable of performing over eighty simple arithmetic and logical operations. Each mathematical expression in every design equation must be reduced to these simple operations. If the mathematical expression involved is not included in the existing computer operations, it too must be further reduced. Certain mathematical expressions that fall into this category can be expressed in relationships involving only basic machine operations. For example, the design equation might require the square root of some number, say A. This expression is not included in the basic machine operations. However, it can alternately be expressed by the convergent iterative equation,

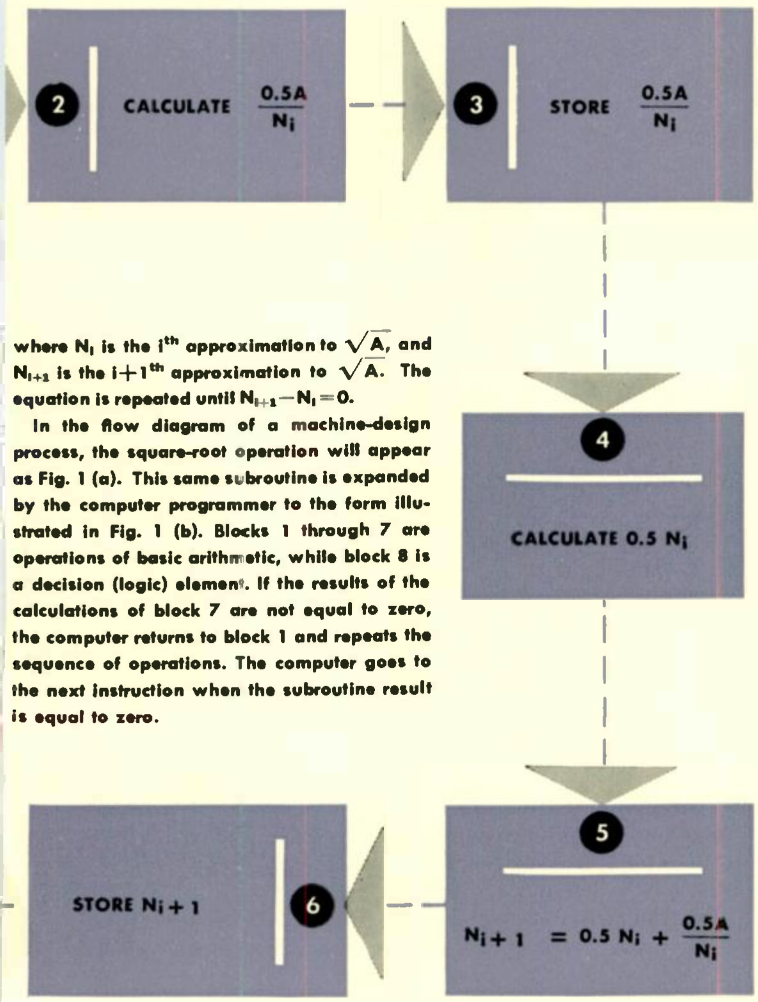
$$\sqrt{A} \longrightarrow N_{i+1} = \tfrac{1}{2}(N_i + A/N_i)$$

in which every operation in the equation is included in the machine operations. When this set of operations has been programmed, it is usually stored in some portion of the computer memory. Henceforth, whenever this same expression is required, use may be made of the existing program. Such a program is called a *subroutine*.

The square-root subroutine (see box at left) will clarify the meaning of the flow chart and the functions a programmer must perform to reduce a mathematical operation to the basic machine operations.

While digital computers can execute a program in a matter of minutes, programming is sometimes a tremendous task. Once written, however, programs can be used for years with occasional revision.

Fig. 1—Subroutine for calculating $\sqrt{A}$ on a digital computer.



where N_i is the i[th] approximation to $\sqrt{A}$, and N_{i+1} is the i+1[th] approximation to $\sqrt{A}$. The equation is repeated until $N_{i+1} - N_i = 0$.

In the flow diagram of a machine-design process, the square-root operation will appear as Fig. 1 (a). This same subroutine is expanded by the computer programmer to the form illustrated in Fig. 1 (b). Blocks 1 through 7 are operations of basic arithmetic, while block 8 is a decision (logic) element. If the results of the calculations of block 7 are not equal to zero, the computer returns to block 1 and repeats the sequence of operations. The computer goes to the next instruction when the subroutine result is equal to zero.

Digital-Computer Design of Transformers and Motors

Large standard-line core-form transformers and induction motors are currently designed by digital computers. Transformers have been designed over a range of 750 to 20 000 kva, with basic impulse levels up to 350 kv. Induction motors have been designed with ratings from 200 to 2000 hp, at line voltages up to 6900 volts.

Transformer Design—The digital computer designs transformers using the same philosophy as that followed by an experienced engineer. Once the input information, such as kva rating, basic impulse level, temperature rise, etc., has been entered into the machine, the computer initially selects or assumes certain design parameters necessary to calculate performance characteristics. These characteristics are then compared with the specified guarantees. If calculated values exceed those guaranteed, the initial assumptions are revised and the process repeated until a favorable design is produced.

A total of 16 subroutines are used by the computer to design a transformer. Their relative operational position in the computer program is illustrated by the transformer flow diagram (Fig. 2). The first subroutine includes all items generally specified by the customer, such as maximum temperature rise, winding connections, impulse levels, etc. Subroutines two through ten deal with design parameters, which are the quantities to be varied in order to produce an acceptable design. Subroutines 11 through 14 represent the test criterions based on the specified guarantees. Subroutine 15 calculates the type and amount of external cooling equipment required to maintain the operating temperature of the transformer below the allowable maximum. Subroutine 16 calculates the weight and cost of the transformer.

The computer begins a transformer design by first selecting a core size by means of empirical formulae based on kva ratings and the basic impulse level. High- and low-voltage windings are selected to complete the initial transformer design (subroutines 1 through 10, Fig. 2). The design is next checked for impulse strength (step 11 in Fig. 2). If the initial design fails to meet the impulse-strength criterion, corrective changes are made in the proper design parameter and the test applied again. The operation is repeated until the impulse-strength criterion is satisfied. The iron and copper losses are

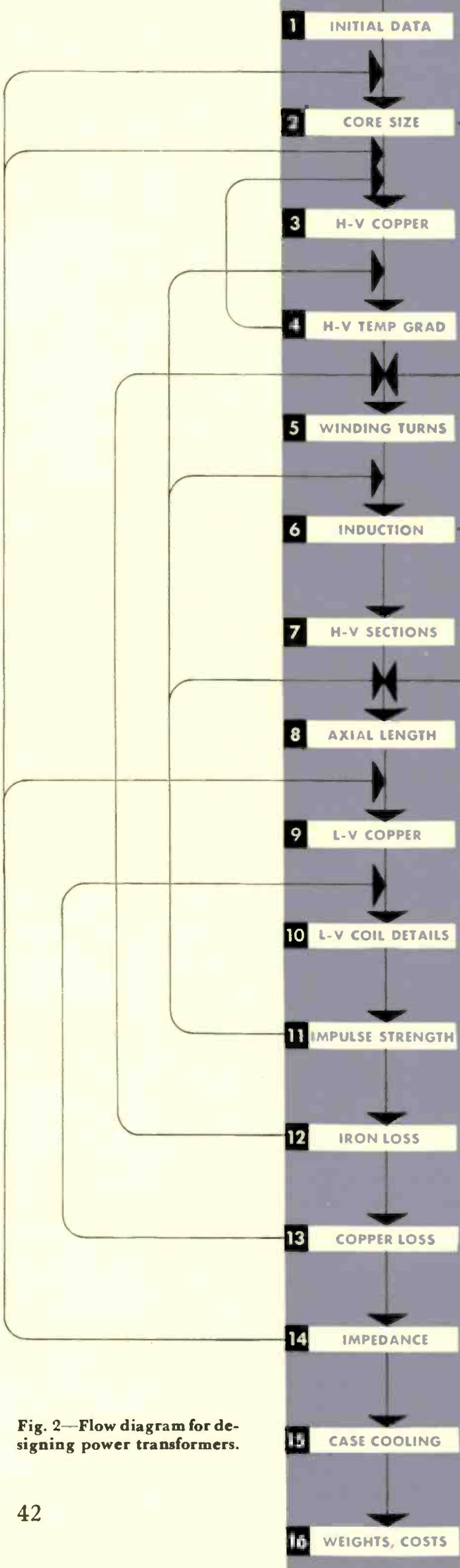
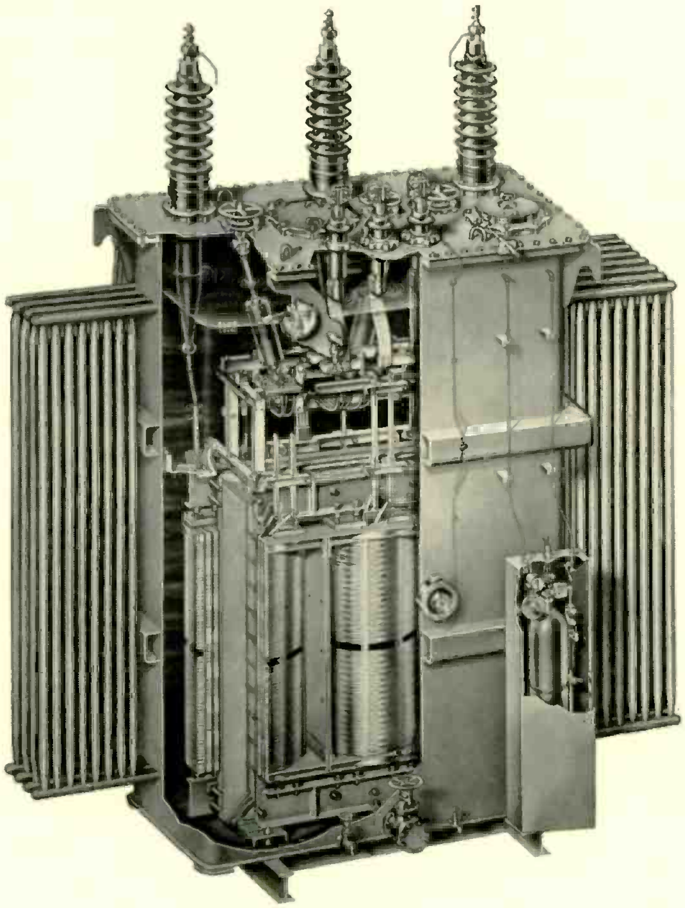


Fig. 2—Flow diagram for designing power transformers.

then calculated. The maximum allowable iron loss for a given core size can be obtained by programming to obtain the maximum allowable induction. The copper loss is varied by increasing or decreasing the size of the wire in the proper winding. When these two results satisfy the guarantees, the impedance is calculated (subroutine 14). If the calculated impedance does not correspond to the guarantee, the physical proportions of the existing design may be changed or a new core size selected. The latter alternative means that an en-



Typical power transformer that has been programmed for automatic design by digital computers.

tirely new design must be made. After the proper impedance has been obtained, cooling, weight, and cost are calculated to complete the transformer design.

Induction-Motor Design—Thus far, only large standard-line induction motors are being designed by computers. This line consists of a discrete number of frame sizes that have definite stator and rotor diameters, slot dimensions, air gaps, etc. Again the trial-and-error process is employed. The computer first determines an initial D^2L value from an empirical equation based on horsepower and pull-out torque. (Diameter squared times length is an arbitrary design parameter used to obtain a first approximation of machine size.) The computer assumes a diameter starting with the smallest frame size, and obtains a length based on the calculated D^2L. If the determined length lies outside the range or lengths specified on that particular frame size, the next frame diameter is selected and the process repeated. When an acceptable rotor length is obtained, the temperature rise of the rotor during starting is calculated. This determines if sufficient slot volume exists to prevent the damper bars from overheating during starting. The length is increased by small increments until sufficient volume is obtained. With a suitable diameter and length established, the associated machine constants (such as the iron depth below rotor and stator slots, the iron area between adjacent rotor and stator teeth, etc.) are calculated for use in the various performance equations. At this point, a flux density is calculated by equating one of the performance equations to its guarantee. This density is then substituted into the remaining performance equations to determine the remaining characteristic of the particular motor. If the calculated density when substituted into the remaining equations fails to produce a result that meets the required guarantees, a new flux density is obtained and the calculation repeated. If there exists any one density or set of densities that satisfies all the performance guarantees, an acceptable design results. If no density satisfies all the performance criterion, the length is increased and the process repeated. When a suitable density is established, a winding is selected that will produce the required density at the proper line voltage.

This card-program-calculator installation is typical of the increasing use of computers in engineering departments. This computer is directed by information from punched cards as they are read into the machine.

The data processing machine is another computer now employed for engineering design work. This machine has a "memory" for 2000 ten-digit words.

Digital Computers and the Future

The number of digital computer applications and their ensuing advantages are almost infinite. Present computer auxiliary equipment now in use or being planned supplies a hint of the future potential of these devices.

The first step toward remote control of computers has already been taken. By means of a transceiver and existing telephone circuits, information from cards located at one location can be punched onto duplicate cards at the computer site. These duplicate cards supply the computer with information, and the results are punched on another set of cards. Information is in turn relayed back to the originating station. Even the card handling involved in the computer area may soon be eliminated by switching control of the computer to the distant transceiver station.

Through standardization of computer components, one computer may soon be able to control the operations of several other computers. For example, output data from one computer could be supplied as input data to a second computer through interconnecting circuits. The first computer may instruct the second to perform a certain operation on the received data and return its calculated output to the first. This particular feature would create tremendous possibilities for integrated computer systems.

Consider the possibility, remote as it may seem now, of digital computers for controlling the daily flow of production in many industrial plants throughout the nation. The production schedule of every item to be manufactured and assembled in any plant could be calculated and stored in the memory of the computer. When the time arrives to begin the manufacturing cycle of any particular item, the computer automatically issues purchase orders for the required raw material. When the material is delivered, the computer could issue the necessary work slips to the section or sections involved in the manufacture of the item. If, for any reason, a work stoppage occurs in the system, this information is communicated to the computer and a new schedule obtained in a matter of minutes. Loading of the various shops for any period of time would be readily available from the computer.

Conclusion

In product design, digital computers will save engineering time and manufacturing costs. By the use of digital computers, extensive studies can be made of product performance characteristics, under the variation of one or more design parameters, in a reasonable length of time. Test data obtained on a new line of products can be quickly analyzed by digital computers to determine the best values of the design-formula parameters to be used.

Besides creating savings in time and costs, digital computers are producing a marked effect on the engineering profession. By removing burdensome routine computations from the design engineer, considerably more engineering time is being spent developing new methods and products, and engineers are able to do more creative work. Likewise, digital computers are helping to alleviate the shortage of engineers by relieving the existing engineers of their routine calculations. In the near future, a thorough knowledge of computer capabilities will be mandatory of every design engineer.

Application of Testing Transformers

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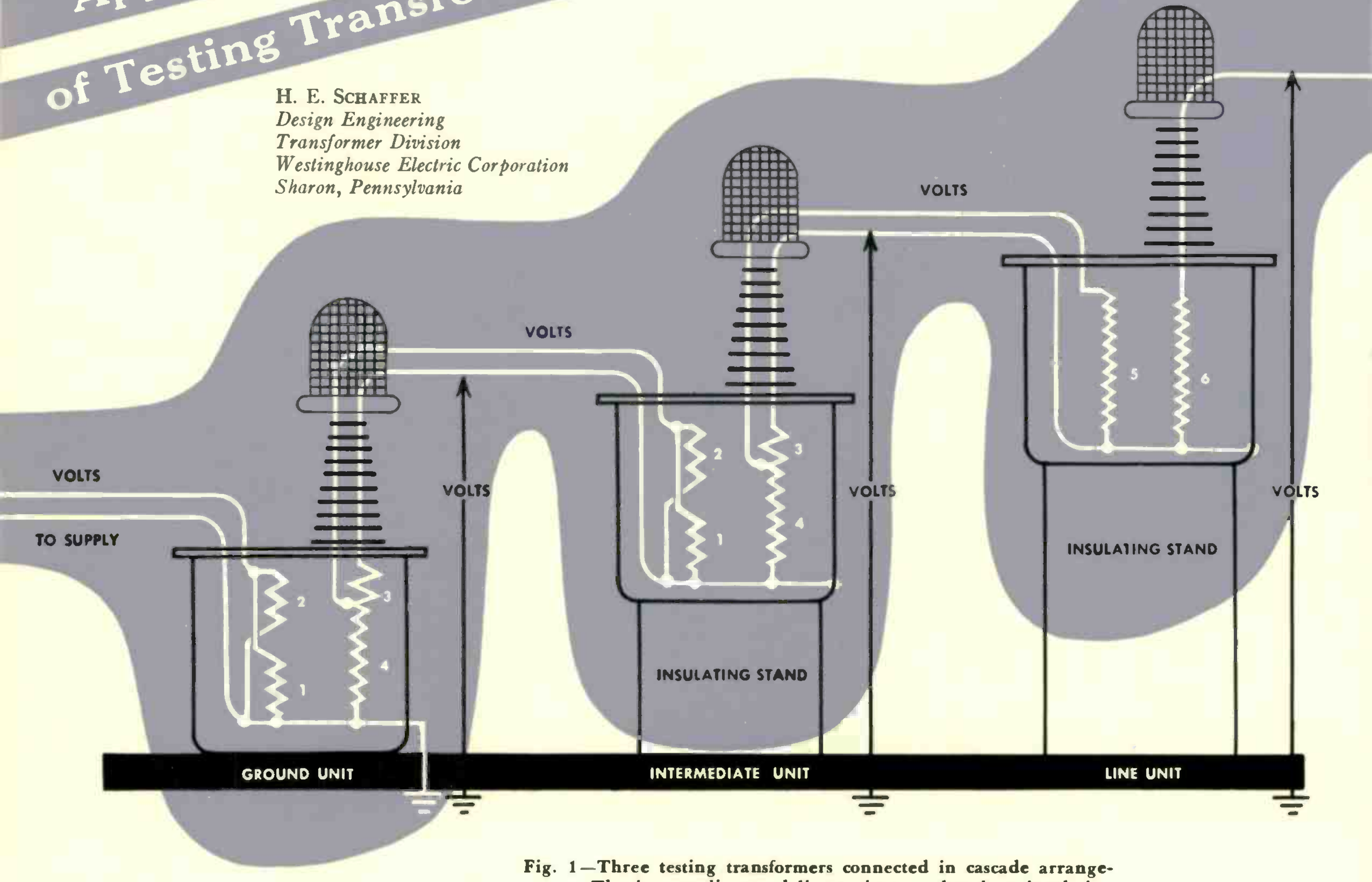


Fig. 1—Three testing transformers connected in cascade arrangement. The intermediate and line units are placed on insulating stands to provide the necessary insulation from case to ground.

High-voltage testing is an essential ingredient of the electrical industry. Both college and industrial laboratories require low-frequency, high voltage for research in dielectric materials, and for insulation testing of electrical components. Also, nearly every type of electrical equipment, from the smallest relay to the largest transformer, as well as components such as bushings and insulated cables, must be tested at high potential by the manufacturer to assure satisfactory operation. The stationary testing transformer, which produces voltages ranging from 50 kv to 1000 kv or more, plays a key role in all of these tests.

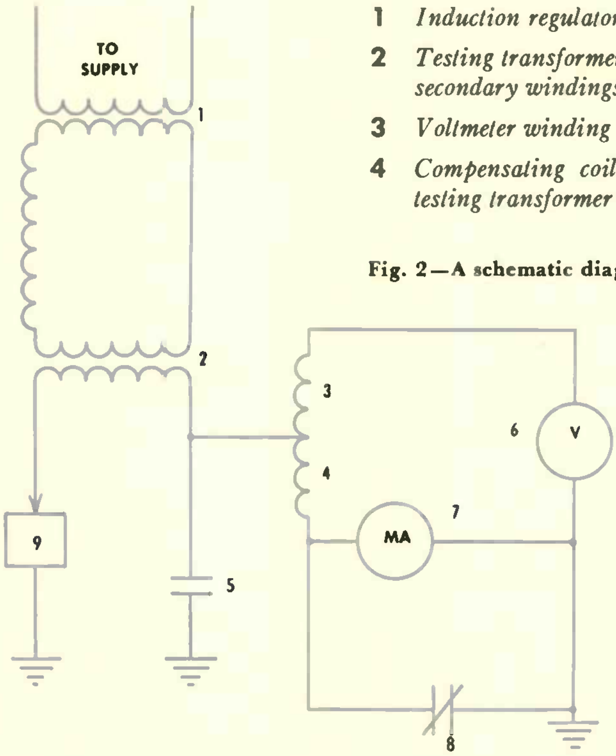
As the kva output and voltage class of electrical apparatus increases, so must the voltage output and current capacity of testing-transformer facilities. Careful attention should be given to many factors in establishing new facilities or increasing the capabilities of existing equipment.

General Considerations

The dielectric strength of insulating materials varies greatly with the rate of application of the voltage; that is, the more rapid the increase in voltage, the higher the breakdown voltage. The a-c testing transformer is primarily a device for applying voltage at a uniform specified rate; it permits the voltage to be held at any point for as long a period of time as required, or until failure of the specimen occurs. Thus the various tests for assembled apparatus, devised by the American Standards Association, can be readily performed, as can the tests for dielectric strength of materials established by the American Society for Testing Materials. These tests range in scope from short-duration tests, in which the voltage is increased rapidly at a specified rate, and one-minute tests at specified voltages, to endurance tests in which a given voltage is often held for hours.

One important advantage of low-frequency testing is that in many cases the behavior of the specimen under stress can be observed. This is in contrast to the rapidly applied voltage from a surge-voltage generator, which has a very rapid rate of voltage rise and a somewhat less rapid rate of decay, and does not permit much observation. Each, however, has a particular function in both research and commercial testing.

The stationary testing transformer set for a particular application consists of a single transformer, or two or more connected in cascade. If the required voltage is in excess of 350 kv, several units are usually connected in a manner similar to Fig. 1, which shows three units in cascade arrangement. The ground and intermediate units are each essentially



1 *Induction regulator*

2 *Testing transformer, primary and secondary windings*

3 *Voltmeter winding on testing transformer core*

4 *Compensating coil mounted inside case of testing transformer*

5 *Film cutout mounted in testing transformer*

6 *Voltmeter*

7 *Milliammeter*

8 *Switch*

9 *Test specimen*

Fig. 2—A schematic diagram of a typical single-unit test set. An induction regulator is used for control.

two transformers on the same core, consisting of a parallel supply winding (1–2), an exciting winding (3), and a main high-voltage winding (4). The electrical centers of windings (2–3) and (1–4) are balanced so that power transfer between these windings is accomplished without axial unbalance.

Since each unit is grounded to its own case, the intermediate and line units are placed on insulating stands of the required height to provide the necessary insulation from their respective cases to ground.

When the voltage output must be increased in an installation consisting, say, of a single transformer, one or more cascaded transformers with exciting windings can be added, using the existing unit, on an insulating stand, as the line unit. The kva rating of the control circuit must at the same time be increased in proportion to the amount of added transformer capacity. This scheme provides a flexible means of increasing the voltage output, utilizing much present equipment, as the need for higher voltages occurs.

The diagram for a typical single-unit test set using an induction regulator for control is shown in Fig. 2. Note that the compensating coil (4) is placed in series with both the secondary winding and the voltmeter winding so that the current will be the same through each. In this manner, the compensating coil maintains a fairly accurate and constant ratio between the voltmeter winding and transformer secondary winding at all load values, regardless of whether the current is leading or lagging the output voltage. The film cutout (5) has a two-fold function. First, it protects the operator in case the ground on the metering circuit is lost, and second, it permits an ammeter to be placed in the ground end for spot checks on the magnitude of the load current. The switch (8) is normally closed except when current readings are required.

Many variations or modifications of this basic circuit can be used depending on the nature of the tests. For example, a crest voltmeter can be added for measuring the crest or maximum of the output voltage wave, where this data is needed. Also, the induction regulator can be replaced by a motor-generator set or a step-type regulator. The relative merits of each type of control are discussed later.

Since the power supply for testing transformers is practically never obtained directly from exposed circuits, the problem of applying insulating materials based on standardized impulse levels does not exist to the same extent as for power-transformer design. The proper quantity, type, and location of the dielectric material between windings and between windings and ground is based primarily on the crest value of the low-frequency power voltage, bearing in mind that during normal use the transformer may be subjected to an almost unlimited number of flashovers to ground at values up to full rated voltage. All dielectric material must also be stressed well below corona levels, so that radio interference is kept to a minimum.

A fact not generally realized is that a testing transformer rated 350 kv to ground is comparable to a three-phase, wye-connected, grounded-neutral system of 606 kv line to line, insofar as voltage above ground is concerned (see Fig. 3). This is far in excess of the voltage of any transmission system currently in operation. However, both the impulse voltage and the dynamic transient voltages are smaller than those on a 606-kv exposed system. The power voltage level then is the principal consideration in applying internal insulation and the condenser bushings.

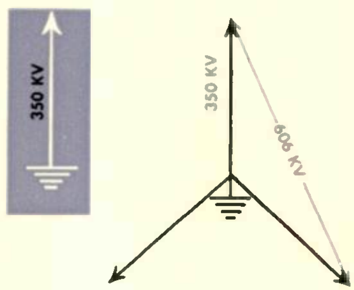


Fig. 3—A testing transformer rated 350 kv to ground is comparable to a three-phase wye-connected grounded neutral system of 606 kv line to line, as far as voltage above ground is concerned.

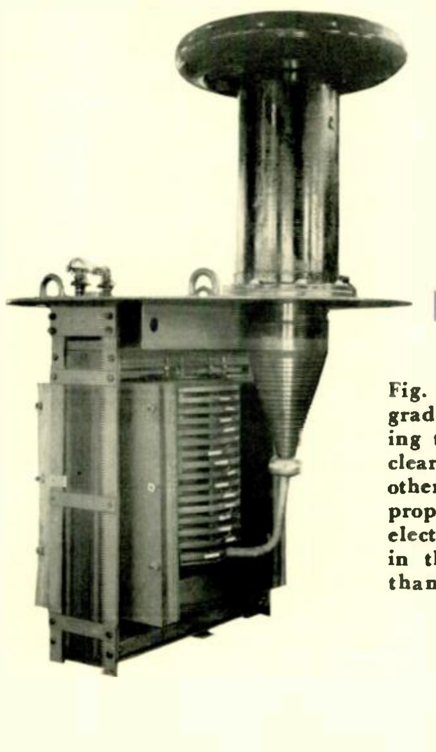


Fig. 4—This illustrates graded insulation on a testing transformer. Insulation clearances to ground and to other windings must be in proportion so that the dielectric strength at any point in the winding is greater than the dielectric stress.

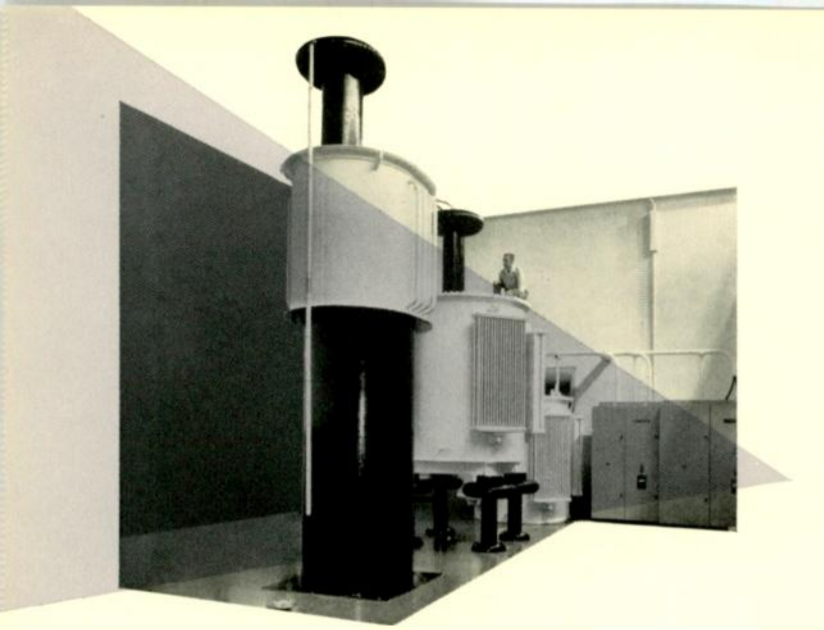


Fig. 5—An installation of three cascaded testing transformers.

Since one end of the secondary winding, as shown in Fig. 2, is always grounded through a film cutout or other protective device, no insulation problem exists at this point; but from here, through the winding, toward the other end connected to the test specimen, the voltage above ground increases at a fairly constant rate, reaching a maximum at the extreme end of the winding. Likewise, the insulation clearances to ground and to other windings must be in proportion, so that the dielectric strength at any point in the winding is greater than the dielectric stress at that point. This method of insulation application is commonly called graded insulation, and is illustrated in Fig. 4.

Application Considerations

Many factors are involved in planning the installation of a new high-voltage test set. These include: (1) present and future voltage and current-capacity requirements; (2) voltage supply; (3) type of control; (4) space available and accessibility to available space; (5) flexibility desired; and (6) initial installation costs. All these factors must be evaluated.

Voltage and Current-Capacity Requirements—The rapidity with which electrical progress moves should be carefully considered in planning the present and future voltage and current requirements. Higher application voltages, for example, mean higher voltage testing facilities, for such things as cable, as well as for assembled apparatus such as transformers.

Much the same consideration must be given current capacity, except that here it is the maximum charging current of the test apparatus for present and future needs that is concerned. Actually, current capacity is of more importance than maximum secondary voltage, since it is more expensive to increase. All component parts have a specific rated current capacity, which usually necessitates complete replacement to gain increased capacity.

Voltage Supply—This factor must be considered simultaneously with present or future capacity requirements. First, so that the interrupting capacity of the circuit breaker can be kept to an economical minimum, and second so that the current in the exciting windings of the ground and intermediate units, if a cascade set is planned (Fig. 1), is small enough to insure minimum dielectric heating in the condenser bushing. This usually can be accomplished if the current through the bushing is kept to about 200 amperes as a maximum value.

Type of Control—Three different types of control are now used in most applications: (1) motor-generator sets; (2) induction regulators; and (3) step-type induction regulators.

If the set is to be used primarily for research testing, or if the output voltage must approach a pure sine wave, a motor-generator set should be the source of supply voltage. However, an m-g set in most all cases has a higher initial cost than the other two forms of control.

If, however, a small distortion in the output voltage wave shape is permissible and a supply voltage having little deviation from a sine wave is available, an induction regulator provides adequate and satisfactory control for output voltages through 250 kv.

For voltage ratings beyond 250 kv, either a step-type induction regulator or a motor-generator set should be used. The step-type induction regulator is a tap-changing-underload device, with a small induction regulator bridging each step to insure a smooth response from 0 to 100 percent.

Availability and Accessibility of Space—Limited space often is a real handicap in selecting the proper set, since high-voltage testing transformers require large air clearances to existing structural parts of the building. If floor space is limited and headroom ample, a single unit of the required voltage is most suitable. If, on the other hand, headroom is limited and floor space ample, two or more units cascade connected for the required output voltage are more suitable. This is especially true if accessibility to the desired location is limited in respect to hallways, existing doors, or maximum weight that can be handled with existing equipment.

Flexibility—Cascading of two or more units may also have an advantage if the upper voltage range of the set is used at infrequent intervals. The top unit or units can be disconnected at the terminals of the ground unit, and the ground unit operated as a single transformer, thereby effecting a saving in losses of the units disconnected. This is especially useful if power is purchased from an outside source.

In addition, one unit can sometimes be removed for servicing or repairs while still maintaining limited testing facilities with the remaining units.

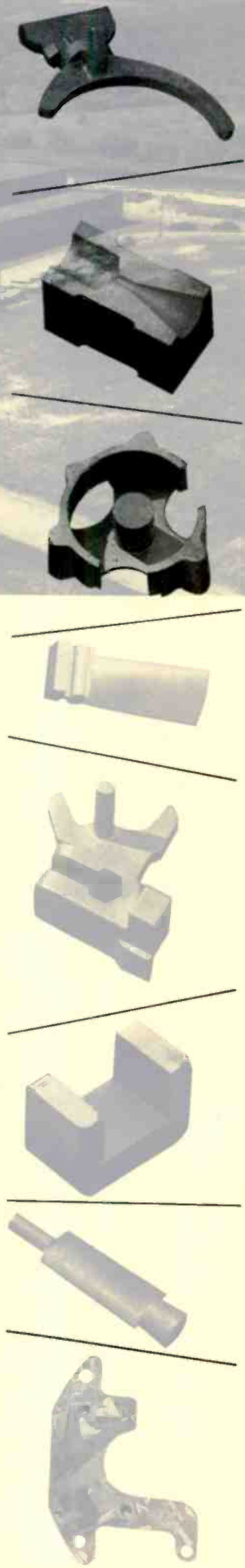
Initial Installation Costs—Many factors enter into the initial installation cost of a high-voltage test set since it consists of many component parts. The equipment in Fig. 2 represents the minimum for either commercial or laboratory testing. In addition, especially for laboratory testing, a sphere gap and a crest voltmeter are almost essential.

Here again, the multi-unit set connected in cascade has decided advantages. For example, two 250-kv units with an output voltage of 500 kv can be purchased for less than half the price of a single unit with the same output voltage. In addition, the headroom required is considerably less than for the single unit. These two advantages alone are sufficient, in most cases, to justify the use of multi-units in cascade for all output voltages in excess of 250 kv.

Conclusion

For every installation all factors, such as present and future voltage and current-capacity requirements, voltage supply, type of control, space available and accessibility to available space, flexibility desired, and initial installation costs, should be carefully considered. For instance, it is essential that the type of control selected meets present requirements as well as those in the foreseeable future. Also, in planning initial installations for voltages in excess of 250 kv, the economic aspects and the flexible features of multi-unit cascade connected sets should not be overlooked. If these factors are properly evaluated in the beginning, all existing test apparatus can be fully integrated into a future expansion program.

Pilot Plant for Metals



Versatility is a key feature of this new metals pilot plant. It is equipped for nearly every type of operation, including development and production.

When you try to "scale up" the ingredients and processes used in making a laboratory sample of a metal alloy, you frequently run into trouble. For one reason or many, the large batch often doesn't have the same characteristics as the small sample. So you backtrack trying to find the reason. You change the processes slightly, juggle the ingredients a little, and after a number of attempts, come up with a close approximation of the original material. So now you have an ingot. But how will it react to forging and rolling? What heat treatments does it need, and what characteristics does the heat treatment produce? These and many other questions often must be answered before you are ready to use the new metal in the application for which it was designed.

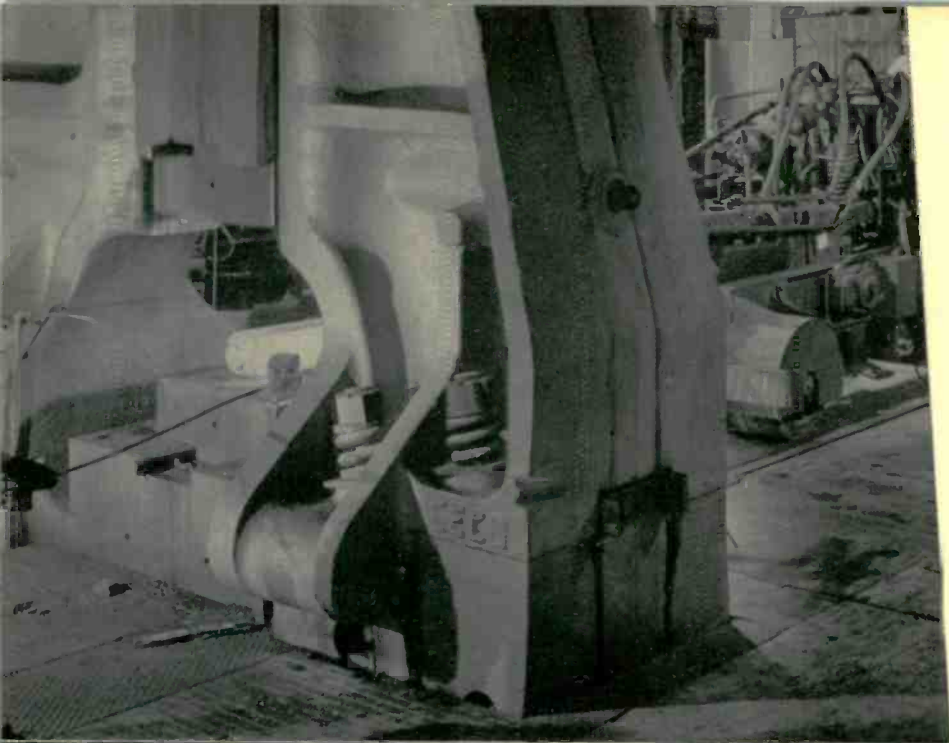
Gaining the answers to questions like these is one aim of a new Westinghouse metallurgical pilot plant recently opened near Blairsville, Pa. One function of the new plant is to take metallurgical developments produced by the Research Laboratories and find out how to produce them on a large scale. This, however is not the only purpose of the new facility.

The new plant will also investigate and develop new processing methods. Because this kind of development requires full-scale equipment and production processes, another function of the new plant is to produce metal parts in quantity for Westinghouse divisions and for other companies.

The new plant is fully equipped for the development and production of many special wrought alloys and castings. For example, melting equipment can handle heats from 10 pounds to 5000. For precision casting, there are automatic rocking electric furnaces; for shell molding, induction-heating equipment is available. For air melting of magnetic alloys, non-magnetic high-strength alloys, and high-temperature alloys, a 700-kw unit accommodates heats from 2000 to 5000 pounds; this unit produces ingots from 500 to 5000 pounds.

To fully explore the possibilities of vacuum melting, a large furnace capable of handling 300-pound to 2000-pound heats is available; a smaller 50- to 200-pound vacuum furnace will be used for process development. Versatile cold-hearth arc-melting facilities for producing high-purity alloys for jet engines and nuclear-power generating equipment are also available.

Forging equipment includes steam hammers ranging from 800 to 18 000 pounds capacity, a 300- and a 1000-ton forging press, and auxiliary equipment such as furnaces and grinding equipment. Also available are power hacksaws, automatic billet cut-off machines, lathes, and a vertical boring mill.

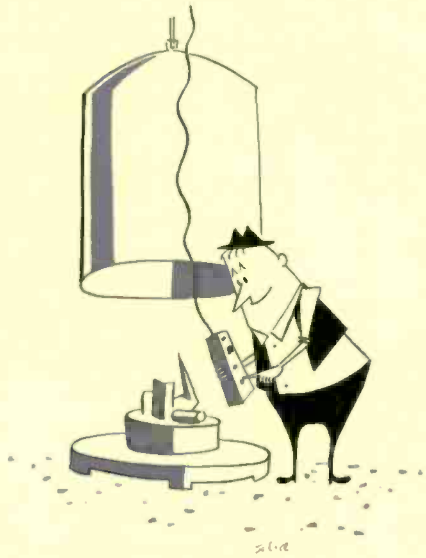


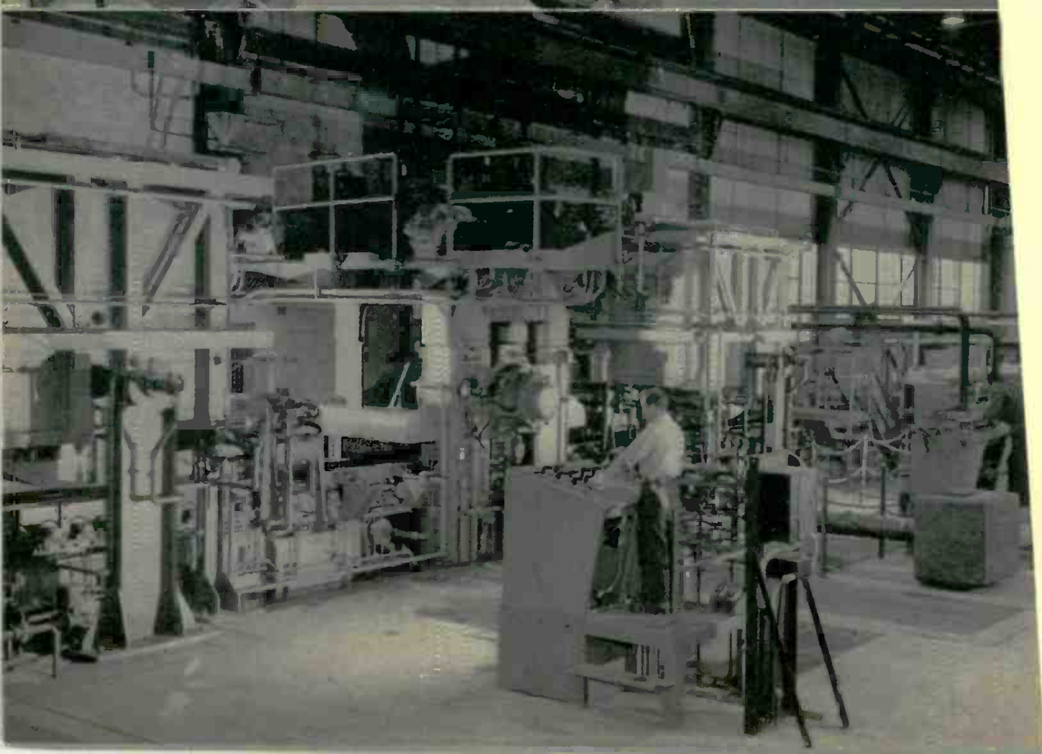
Forge Hammer

This 18 000-pound forge hammer drops onto an ingot that is held in place by the manipulator (right).

Heat Treating

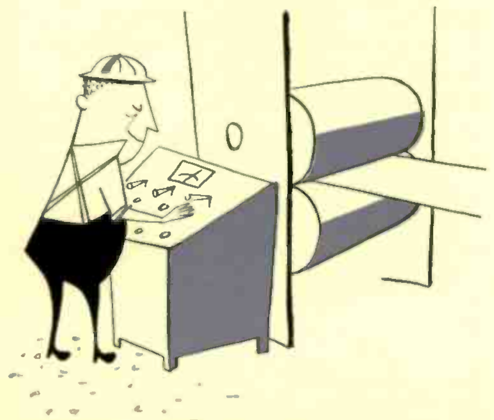
Left, in the foreground a pusher-type heat-treating furnace. Special smaller furnaces are in the background.





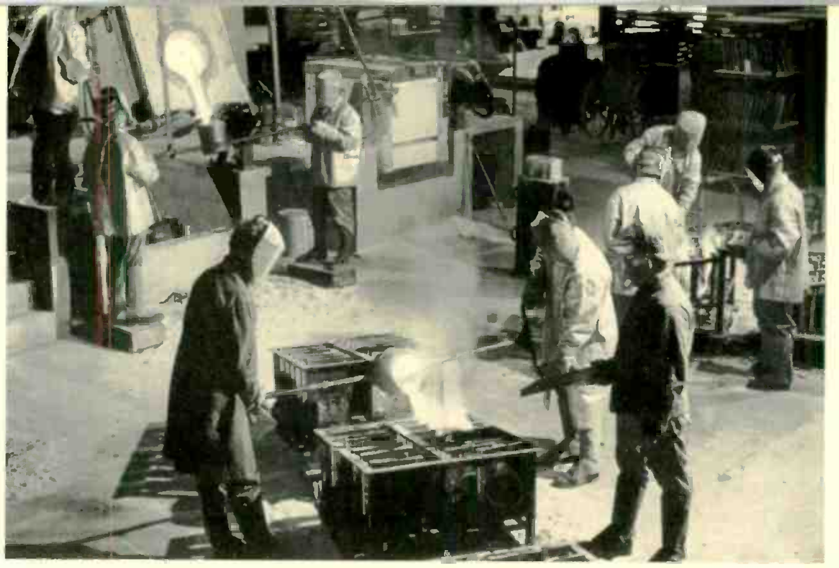
Strip Mill

A 1000-hp, 350/700-rpm, 600-volt d-c motor drives this four-high hot strip mill; the mill has a top speed of 400 fpm.



Shell Molding

Steps in the shell-molding process. Metal from the furnace in the background is being poured in the molds assembled in pouring racks.



Complete facilities for hot rolling of sheet, strip, bar, and rod are also available. A 2000-hp hot mill will handle anything from soft magnetic alloys to high-temperature metals, and will roll an 8-inch billet to as low as 0.05 inches and widths up to 20 inches. This is a four-high reversing mill, with coiler furnaces for continuous heating of strip during rolling. A high-speed four-high bar-rolling mill will also be installed.

A 1200-hp cold-rolling mill reduces strip from 0.20 inches to 0.010 inches; it handles 3000-pound coils of strip 20 inches wide. For thinner materials, a Steckel and a Sendzimir mill can produce foils of about 0.0005 inch thick. Shears, edgers, upcoilers, descalers, slitting lines, and other auxiliary equipment is provided.

The new pilot plant has complete heat-treating facilities, including bell-type electric furnaces for annealing in hydrogen at temperatures up to 2000 degrees F, and several different types of gas-fired furnaces.

Both investment (lost wax) and shell-mold casting can be thoroughly explored in the new facility. Investment casting is primarily used to produce intricate and complicated parts. Shell molding, a newer technique, produces parts with better surface finishes and dimensional tolerances than can be accomplished by sand casting. In addition to casting, considerable effort will be devoted to improving the technology of powder metallurgy.

The new metals plant is already in action, both in development and production of a wide variety of metal products. The assortment includes such things as rolled magnetic-steel strip, jet-engine blades, cast components for several electric appliances, and many others.

This versatile new plant, which houses nearly every type of metal-processing equipment, will help to assure that metals are not a "design block" in the development of any device. By helping to develop processing techniques to "scale-up" laboratory developments, it will help convert research knowledge to practical application in the shortest possible time.

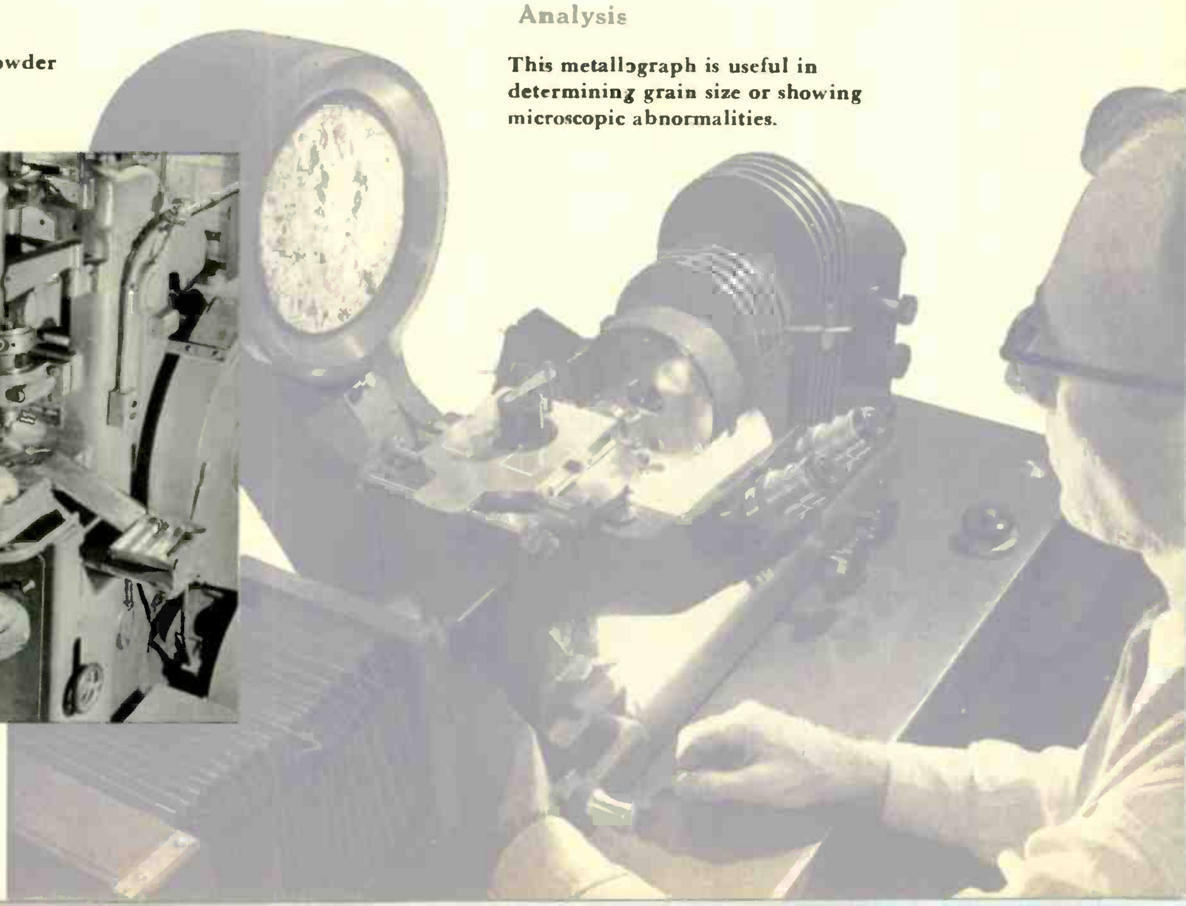
On these pages, some of the facilities of the new laboratory and pilot plant are shown.

Powder Metallurgy

This is a view of the 40-ton powder metal compacting press.

Analysis

This metallograph is useful in determining grain size or showing microscopic abnormalities.



Remotely Operated Pipeline Pumping Stations

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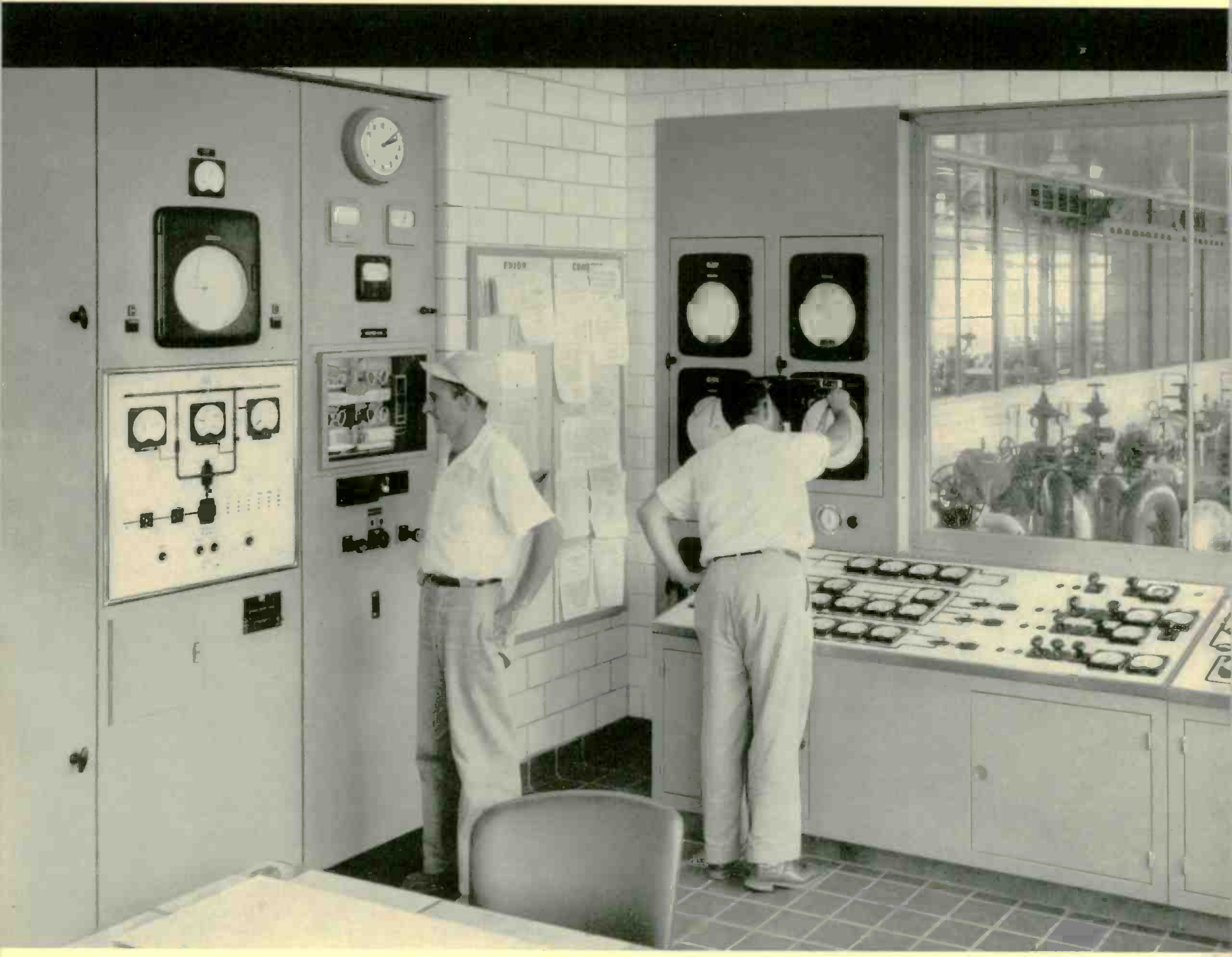
A booster station operated by supervisory control over microwave. From left to right are the outdoor substation, control building, microwave building and tower, and pump building.

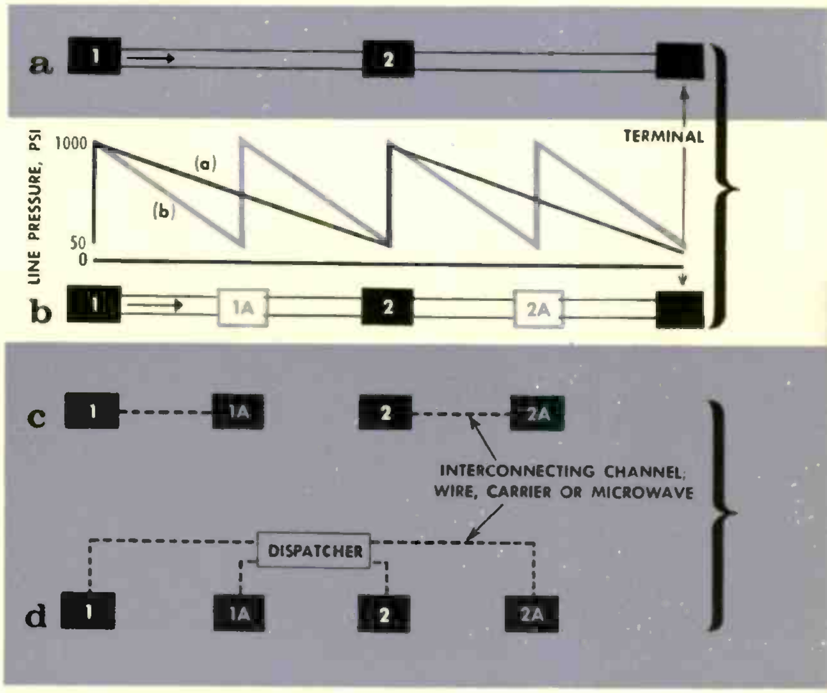


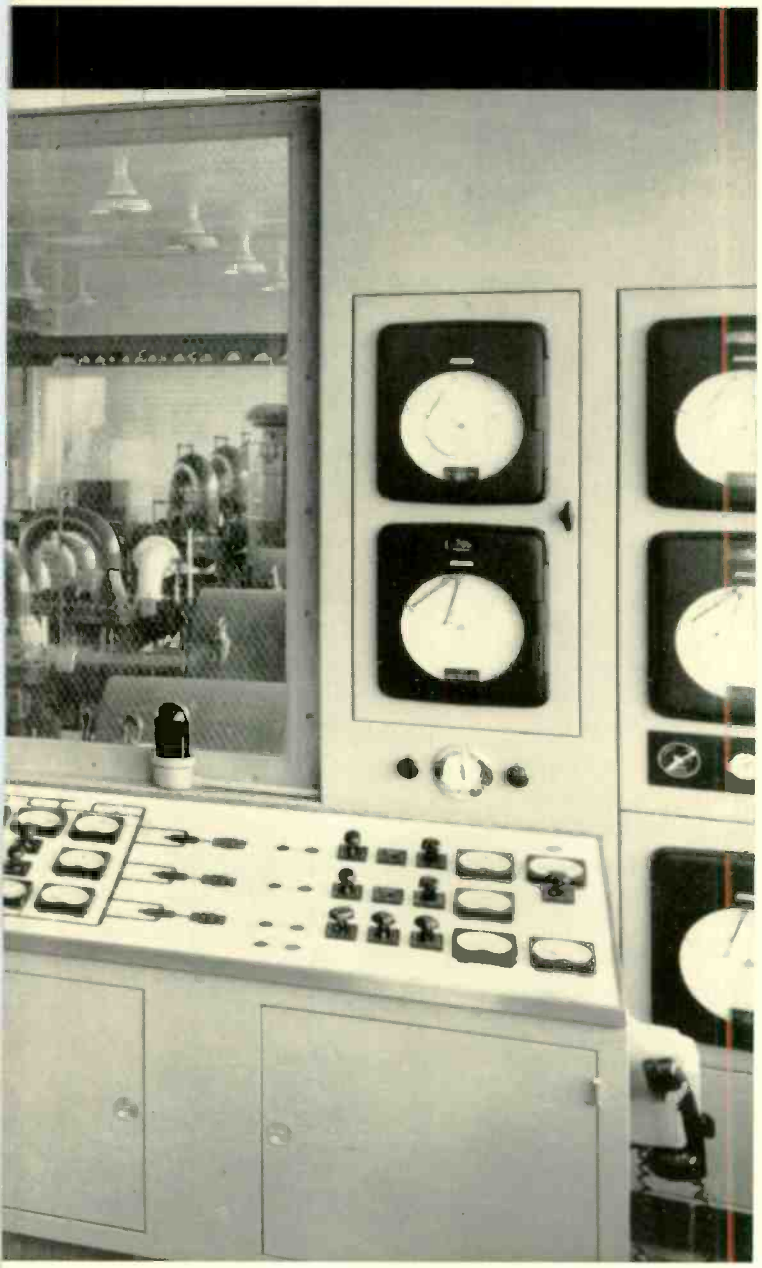
ALTHOUGH the initial application of supervisory control to pipeline pumping was made 25 years ago, only recently have the costs of station attendance risen to a level where pipeliners have taken a lively interest in its possibilities. Installations have been made or equipment put into manufacture the past four years for remote operation of at least 60 electrically powered pumping stations on pipelines transporting crude oil or refined petroleum products. An unprecedented number of future projects are under active study. Because of the relatively long distances between pipeline pumping stations, economics dictate the use of supervisory control for remote operation to minimize channel requirements.

Fundamentals of a Pipeline System

A pipeline, in its simplest form, is a conduit with a means for causing flow of fluid from the initial to the terminal end; flow results from pressure developed by a pump at the initial end. In a crude-oil or product line each flow rate (for a given liquid and pipe size) requires application of a certain pressure per mile of pipe. The total pressure that must be developed by the pump is the pressure drop per mile multiplied by the length of pipe in miles, plus the positive or negative static pressure corresponding to the difference in elevation of the two ends of the line. Thus the length of line that can be served by one pumping station is determined by the desired flow rate, the difference in elevation of the ends, and the limiting working pressure for the pipe.

Fig. 1—If discharge pressure of a simple system (a) with one downstream station is limited to 1000 psi, booster stations (b) will double total impelling pressure. Remote stations can be operated by two-station links (c) or from a centralized dispatching office (d).





To accomplish long-distance transportation, several pipeline sections are installed in series, each section with a pumping station at its initial end. In the past, oil was delivered from the terminal end of each section into a tank, from which it was pumped into the next section of line. Modern practice is to operate the sections end-to-end without tankage, as illustrated diagrammatically in Fig. 1.

The throughput of a line can be increased by employing greater total impelling pressure. However, since the discharge pressure at a pumping station is limited by allowable pipe stress, additional throughput is obtained by inserting pumping stations at intermediate points between terminal stations. Such booster stations may develop any pressure up to the allowable pipe pressure. Booster stations at midpoints which develop the same pressure as the original stations, are shown in Fig. 1b. The total impelling pressure is doubled, and the increased flow is the same as would result if this pressure were all applied at the initial station, the new pressure gradient having a steeper slope (greater psi drop per mile).

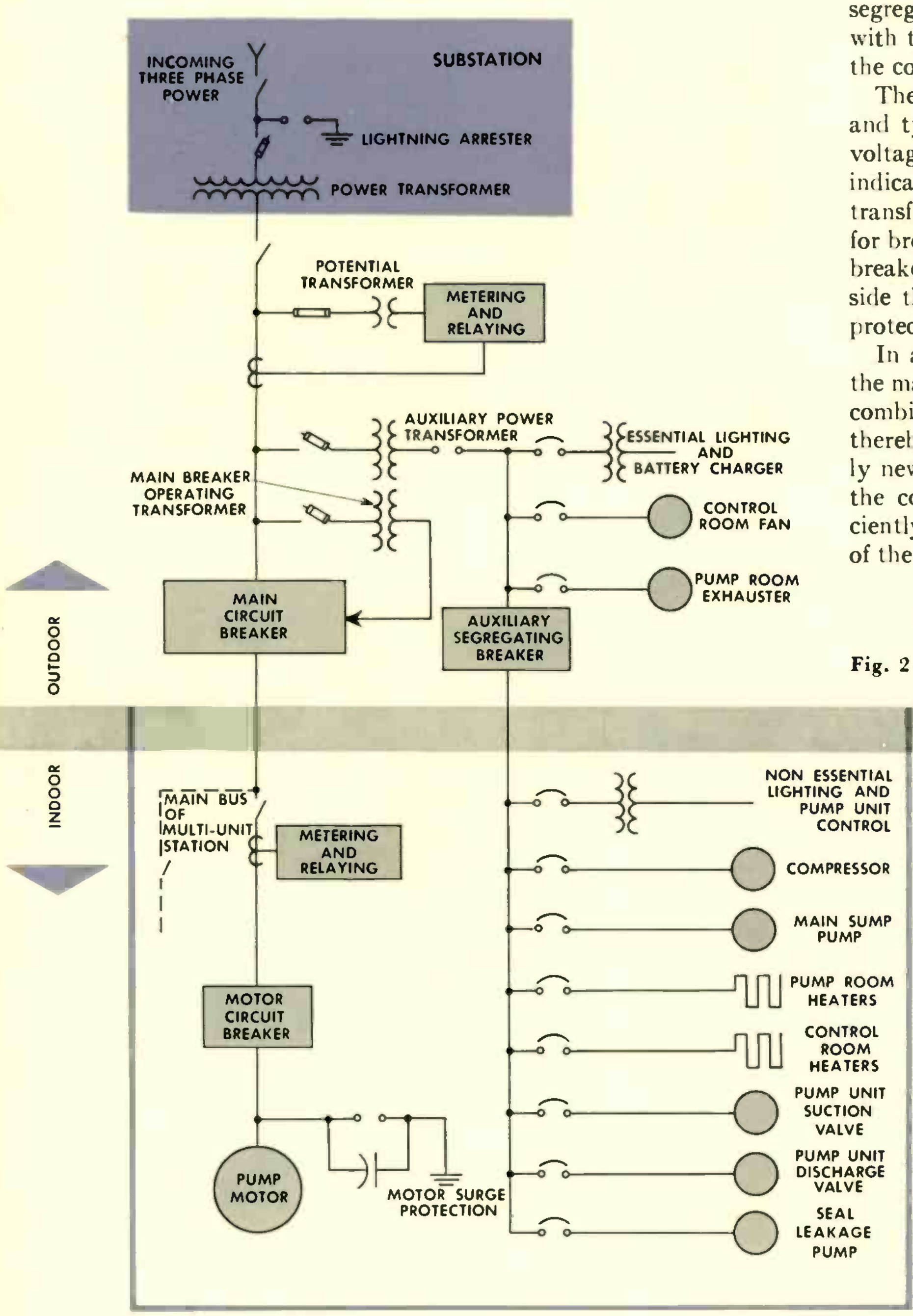
Remote Operation

Two-Station Link—Most frequent type of remote operation is the two-station link shown in Fig. 1c, where booster sta-

At left, control room of a large multiunit pump station. Pushbutton sequence control for seven local units is provided on the central control console. The diagram panel (at left) controls a booster station that is located 56 miles downstream by supervisory control.

tions 1A and 2A are remotely operated, each from a neighboring attended station. Usually the controlling station is upstream, because from changes in his local operation the attendant can readily anticipate the conditions that will follow at the next station downstream. This arrangement is particularly applicable where electric booster stations are inserted between existing stations for increased line capacity. In a series of pumping stations over level terrain, a throughput increase of about 50 percent is attained by doubling the number of stations, with no increase in station operators.

Centralized Remote Control—In this arrangement, the control for a complete series of stations is carried out from a single location, as shown in Fig. 1d. The controlling location can be the initial or terminal station, but if the system is to be centrally controlled it is logical to place this responsibility directly under the dispatching personnel. This location is normally at the administrative headquarters, which is likely to be near the center of the line.



Equipment Arrangement of Remotely Controlled Station

A typical single-line electrical diagram for a simple single-unit pumping station is shown in Fig. 2; the piping and valve arrangement for the same station is shown in Fig. 3.

The scheme shown employs a main circuit breaker located outside of the station building and the hazardous area. Principal control equipment is installed in a pressurized room of the station. For safety, station ventilation is operable even when the main breaker is open. By connecting the auxiliary-power transformer on the supply side of the main breaker, this breaker can be opened without interrupting service to the control-room and pump-room fans, battery charger, and necessary lighting. Station isolating valves and local residential load may be likewise served. All equipment supplied from this so-called "essential" auxiliary bus and located within the station building is explosion-proof.

The remaining auxiliaries are supplied through a segregating breaker. Their control equipment is installed in the pressurized control room along with the main-pump control. The segregating breaker is arranged for tripping simultaneously with the main breaker in an emergency such as might cause the control-room atmosphere to become hazardous.

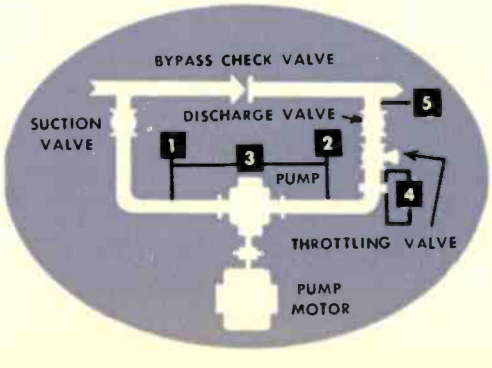
The main breaker feeds the pump unit (or pump-unit bus) and typically is equipped with relaying for phase reversal, voltage failure, and overcurrent. A voltmeter and wattmeter indicate power supply and load conditions. An operating transformer on the supply side of the breaker furnishes power for breaker closing, and a battery furnishes direct current for breaker tripping. The main breaker has connected to its load side the main pump-motor starting equipment, with surge-protection capacitor and arrester.

In a single-unit station employing full-voltage starting of the main unit, the layout shown in Fig. 2 can be modified by combining the main-breaker function with the motor breaker, thereby eliminating a breaker. Some installations, particularly new stations designed for unattended operation, have all the control equipment installed in a single location, sufficiently separated from the pumping equipment to be outside of the hazardous area. No hazard is introduced in the control

Fig. 2—Single-line diagram for a single-unit pump station.

Fig. 3—Piping and valve arrangement for single-unit pump station is shown below.

1. Pump Suction Pressure Tap
2. Pump Case Pressure Tap
3. Pump Differential Pressure Taps
4. Pump Flow Taps to Orifice
5. Station Discharge Pressure Taps



room when its ventilation is interrupted, and the segregating breaker is omitted.

The main circuit breaker can be manually controlled either locally or remotely. If the breaker is tripped by a protective relay, it must be manually reclosed. A condition for closing the breaker is that power supply voltage and phase sequence be normal. As an alternative, the breaker can be arranged for automatic reclosing for conditions other than those resulting in lockout.

Sequence Control of Pump Units

When a pipeline pumping station is remotely operated, an automatic-sequence control system for the pump units must be established. That is, operating procedures for starting or stopping a unit should be carried out in a prescribed order.

A typical automatic starting sequence for a simple single-unit pump station as shown in Fig. 2 is: (1) suction valve and pump-venting valve opened, and necessary ventilation equipment started; (2) pump motor energized; and (3) discharge valve opened and pump venting valve closed.

For stopping: (1) pump motor and its associated ventilation equipment de-energized; (2) discharge valve closed; and (3) suction valve closed.

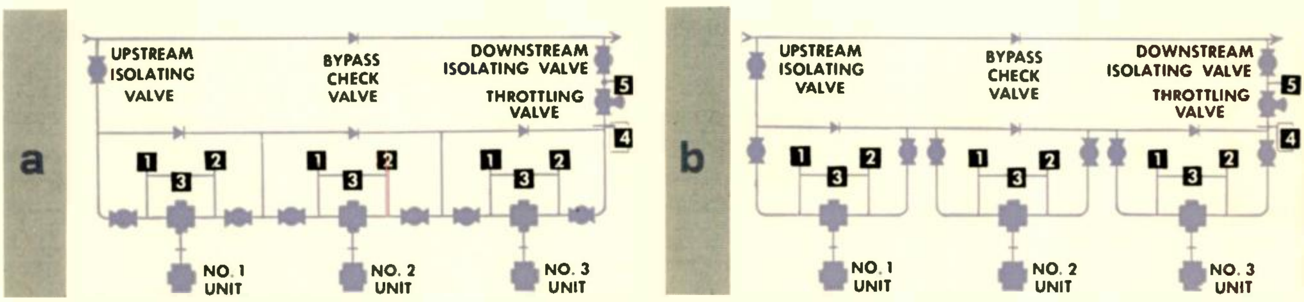
There are individual variations from these procedures, since many installations do not require venting, and others close the suction and discharge valves simultaneously when stopping the unit. In a remotely controlled station, the starting sequence can be initiated by a start pushbutton at the remotely located controlling station or at the local station start. The stopping sequence can be initiated by remote and local stop pushbuttons, or by operation of protective devices.

Coordination with Hydraulic Control

With constant-speed motors, which are ordinarily employed for reasons of simplicity and adaptability to hazardous atmosphere, regulation of the station incremental pressure to suit line requirements is usually accomplished by some form of throttling valve in the station discharge, as shown in Fig. 3. This throttling valve is under pneumatic control by pressure-regulating elements responsive to station suction and discharge pressures, and arranged to keep these pressures within prescribed limits under varying line conditions.

Stations having more than one unit usually employ pumps connected in series with a single throttling valve on the downstream side of the final pump, as shown in Fig. 4. Shutdown in response to abnormal pressure is desirably sequential; this will minimize hydraulic shock and keep as much of the station in operation as practical when shutdown of some of the units would correct the abnormal pressure. Shutdown due to low suction or high case pressure in the individual pump is accomplished in the same manner as for a single-unit station, by pressure switches installed on each side of each unit, at tap points 1 and 2 shown in Fig. 4. Since low station suction pressure is reflected on the suction side of the upstream operating unit, this arrangement provides inherently sequential shutdown in the event of low station suction pressure. High case pressure is sensed initially on the downstream unit, and results in sequential shutdown in the reverse order to that for low station suction pressure. Shutdown due to station high discharge pressure must be actuated by a single pressure switch tapped to the downstream side of the station throttling valve (tap point 5 of Fig. 4). In many stations this switch shuts down all units simultaneously. Sequential shutdown on high station discharge pressure can be accomplished.

Fig. 4—Typical piping diagrams for multiunit stations: minimized station piping and pressure drop (a) is commonly used for crude-oil lines; arrangement for product lines (b) maintains a minimum of contamination.



Pump-Station Protection

In all electric-equipment installations, protection against abnormal operation or equipment failure is important, but in no type of installation is an adequate protective system more important than in a pipeline pump station, because of the nature of the medium transported. This is particularly true for remotely operated stations.

Protection for individual stations varies according to the basic arrangement. In existing installations, the selection of protective functions has been based on individual analysis. Based on experience, protective functions can be assigned to four basic categories, which are believed to be best for the typical unattended station.

Station shutdown should result only from phase reversal or a-c undervoltage. The main circuit breaker is opened. When voltage conditions are restored to normal, the breaker is reclosed either manually or automatically, depending on the method of operation employed, and the individual pump units can then be restarted after their suction and discharge valves have closed.

Station lockout should result from a-c overcurrent, battery undervoltage, low instrument air pressure, high level in main sump, or unsafe atmospheric condition in control room. The main breaker is opened and locked out; it can be reclosed only when the lockout device is manually reset.

Unit shutdown consists of stopping a pump and closing its suction and discharge valves in the normal manner. Conditions for pump unit shutdown are low suction pressure, high pump-case pressure, high discharge pressure, motor overtemperature, pump-case overtemperature, or motor phase-current unbalance. The pump can be restarted when the condition corrects itself.

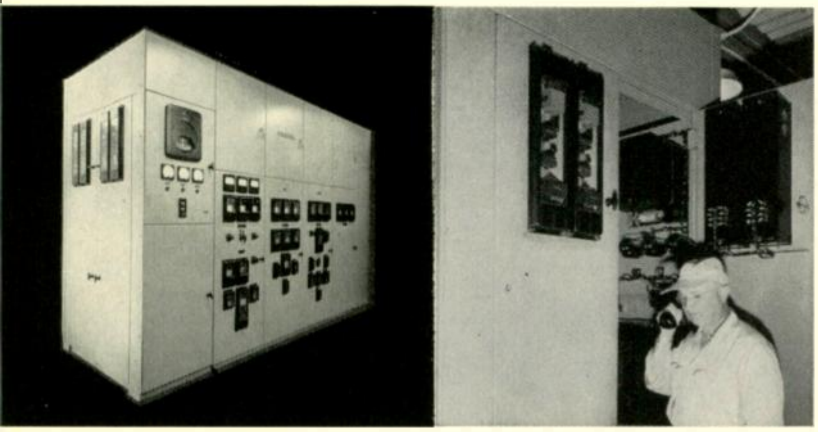
Unit lockout should result for motor overcurrent, incomplete starting sequence, seal failure, motor-bearing overtemperature, or pump-bearing overtemperature. The pump is stopped, and suction and discharge valves closed. The unit can be restarted only by manual reset of the lockout device.

All protective functions should be individually annunciated locally. At a remotely controlled station the most satisfactory form of annunciator is the drop type.

Supervisory Control

Supervisory control operating over a single telegraphic-type channel performs the necessary operations, providing information on the position of apparatus, and indications and alarms for trouble conditions.

Remote operation must be effective over relatively long distances ranging from approximately 20 miles to hundreds of miles. The necessary channels for operation of pipe-line pumping stations can be provided by telegraphic-type tones operating over privately owned microwave or telephone-line carrier links. In addition, individual telegraphic-type channels can be leased, or a voice channel can be leased and the necessary number of telegraphic-type channels obtained by use of audio-tone generating and receiving equipment.



Supervisory-control equipment is generally installed with the motor-control equipment, and in new stations, is often made an integral part of the switch gear assembly, as shown here for a single-unit unattended pump station. The supervisory-control equipment is mounted on the rear panel of the left-hand unit.

The equipment in a pumping station remotely operated by supervisory control must be arranged to provide the following minimum control functions and indications of device positions: (1) start-stop sequence control of each pump unit; (2) indication of stopped or running condition of pump motors; and (3) indication of open, closed, and intermediate positions of the suction and discharge valves of all pump units.

In addition, an indication of the position of the main breaker is desirable (also control of main breaker unless it is completely automatic), as well as indications of station lockout and individual pump unit lockout. A supervisory control cutoff or transfer switch is desirable at the controlled station, and the position of this switch is usually indicated at the controlling location. In some installations, control of the main sump pump is desirable. Unless completely automatic means are provided, provision for remote adjustment of the control-point setting of the station discharge-pressure controller may be necessary. Where electrically operated isolating valves are employed, remote operation may be desirable.

Rather than have the starting and stopping of pump units directly under the control of a remote operator, a combined remote manual and automatic arrangement is sometimes preferable. With this type of control the operator can stop a pump unit at any time, but he can only prepare it for starting; actual starting and subsequent stopping is then dependent on line hydraulic conditions as sensed by pressure or flow switches.

Economic considerations may prohibit individual indications over supervisory control for all of the protective-device operations. However, protective devices can be grouped in various combinations to provide a relatively small number of indications that will assist in determining the type of personnel to be dispatched to the controlled station when a lockout is reported. A typical grouping of functions for common indications for a single-unit station could fall in the following categories: (1) power failure; (2) electric equipment failure; (3) mechanical equipment failure; and (4) abnormal hydraulic conditions.

Supervisory control for pipeline pumping is usually arranged to provide the same type of operating procedures as required for local sequence control. The equipment is usually arranged so that the starting or stopping sequence for a pump unit can be initiated with a pushbutton. Likewise, alarm lamps for protective-device operation are usually arranged to remain lighted until the trouble contact has opened and a reset pushbutton operated. The lamp indications for the pump motors and suction and discharge valves are often located in a diagram of the main station piping.

Telemetering

Regardless of the number of pump units in a remotely operated station, telemetered indications to the controlling location of the several hydraulic quantities is essential: (1) initial pump suction pressure; (2) final pump discharge pressure; and (3) outbound line pressure if a throttling valve is employed.

Telemetering of flow may be desirable where flow conditions are not uniform throughout the line, as may result from deliveries at intermediate points. While not essential for remote operation of a pump station, telemetering electrical quantities such as watts and amperes for the pump motors and volts for the station may be desirable.

Telemetering can be continuous with a separate channel for each indication, or the telemetered quantities can be indicated in consecutive order through some type of time-division multiplexing. Or, they can be selectively obtained at the will of the dispatcher through the supervisory control equipment. Economics usually favor one of the latter arrangements, although many compromises, with some continuous and some selective or multiplexed telemetering, are both possible and practical.

Pulse-duration or frequency-type telemetering systems are usually employed. Pulse-duration-type telemetering transmitters can be directly actuated by the hydraulic quantity or by the electric output of a transducer. The frequency-type telemetering transmitters can only be employed for hydraulic quantities through the use of transducers. The frequency-type telemetering system provides faster rate of response but requires channels capable of handling higher keying speeds.

Reliability cannot be overemphasized in the design of remotely operated stations. A full complement of devices to detect all hydraulic and electrical trouble conditions is all-important. Locally actuated shutdown of the unit or station in trouble should result after a condition of trouble has been detected by one of these protective devices. Remote operation should only be employed when its functioning is coordinated to an adequate protective system.

Network Calculators aid the Utility Engineer

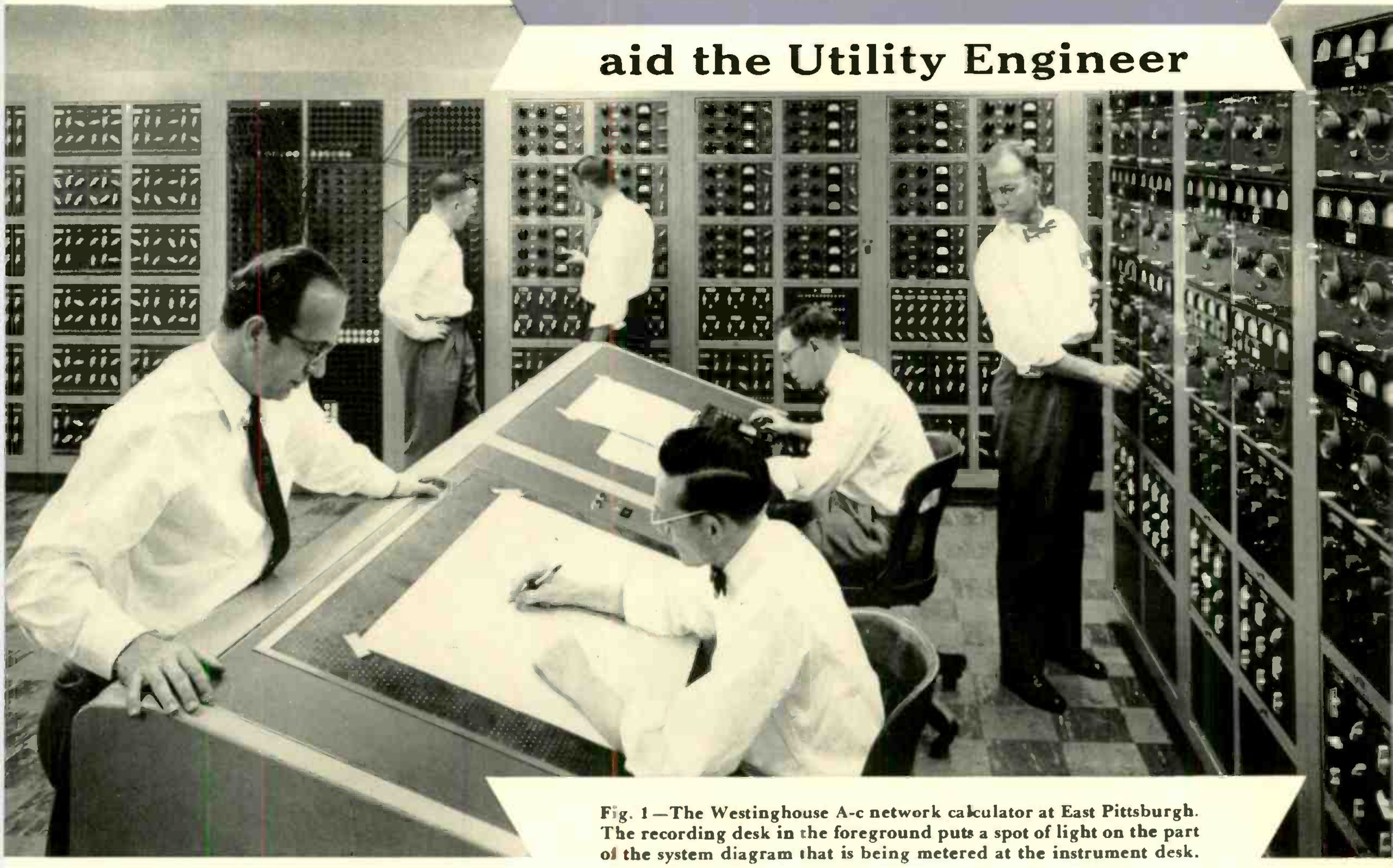


Fig. 1—The Westinghouse A-c network calculator at East Pittsburgh. The recording desk in the foreground puts a spot of light on the part of the system diagram that is being metered at the instrument desk.

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IN THIS AGE of computers, of "giant brains" with thousands of electron tubes, the a-c network calculator continues to dominate its field of use, giving utility engineers the answers to many of their problems concerning present-day power systems. Since its beginning twenty-six years ago, this device has been constantly improved to match the increasing complexity of the modern power system, and the ever-present demands to increase efficiency, reliability, and service. First used by only the largest companies for their most pressing problems, this versatile aid to the power system engineer has increased in versatility and availability until it is now useful to all utilities and to some industrial power systems.

The Network Calculator

The a-c network calculator, also called a network analyzer or calculating board, is basically an electrical model of the power system. Voltages, currents, and powers of the power system to be studied are scaled down proportionally so that a few volts, amperes, and watts represent the electrical conditions on the most extensive utility system. Percent or per unit quantities on a common kva base are used for power, voltage, current, and impedance. For example, a common arrangement employs 100 volts as 100-percent voltage, 100 ohms as 100-percent impedance, 100 watts as 100-percent power and 1 ampere as 100-percent current. The operating frequency, independent of the power-system frequency, is most often 440 cycles, but ranges from 60 to 10 000 cycles in different calculator designs. All of the elements of a power system—generators, transformers, transmission lines, and capacitors—are represented on the network calculator by sources of power and combinations of resistors, reactors, and capacitors. These various elements are mounted in removable drawers with the controls and calibrations on front panels. The generator units include four instruments to show simultaneously volts, vars, watts, and amperes and facilitate generator adjustment.

The two terminals of each circuit component are connected to cords and plugs, which are brought out near plug boards where the power system being represented is connected.

The instrument and recording desks are the heart of the network calculator, where circuit measurements are read and recorded. The instrument desk has three master instruments—voltmeter, ammeter, and watt-varmeter—which can be connected to any circuit on the calculator by means of metering relays. A selector system controlled by 30 pushbuttons operates any one of the hundreds of metering relays and brings the network conditions of the associated circuit to the master instruments. These are driven by stabilized electronic amplifiers to eliminate the loading effect on the network. The instruments have five voltage ranges and five current ranges to measure all network conditions accurately. Both scalar magnitudes and vector quantities (phase angle or in-phase and quadrature components) can be measured. The instrument accuracy is 0.5 percent of full scale and the overall accuracy of the calculator is one to three percent.

The top of the recording desk provides a surface for placing a single-line diagram of the power system. Whenever a circuit is connected to the master instruments, a spot of light appears on the diagram at the location of this circuit so that the recorder will know immediately where measurements are being made. The light is produced by one of the many lamps installed below the transparent top of the recording desk.

Automatic Scale Selector—The operator no longer has to worry about which ammeter range of the five available must be selected; this operation is now performed by an automatic scale selector. When the circuit to be metered is selected, the highest current range is used momentarily. If the range is incorrect, automatic equipment selects the next lower until a range is found that gives a deflection on the ammeter between $\frac{1}{3}$ and full scale. If the current either increases or decreases afterwards, the equipment will move immediately to a higher or lower current range. Lighted instrument scale numbers and decimal multiplier lights permit direct reading in system quantities on a wide range of bases.

Automatic Reversing Switch—The reversing switch used with the watt-varmeter is one of the most frequently operated switches on the instrument desk. Although use of a zero-center instrument would eliminate the switch, this would cut the effective scale length in half and make reading more difficult and less accurate. A better method has been found that eliminates need for the switch in over 90 percent of the operations. An automatic reversing device compares outputs of the current and voltage amplifiers to determine when the watt-

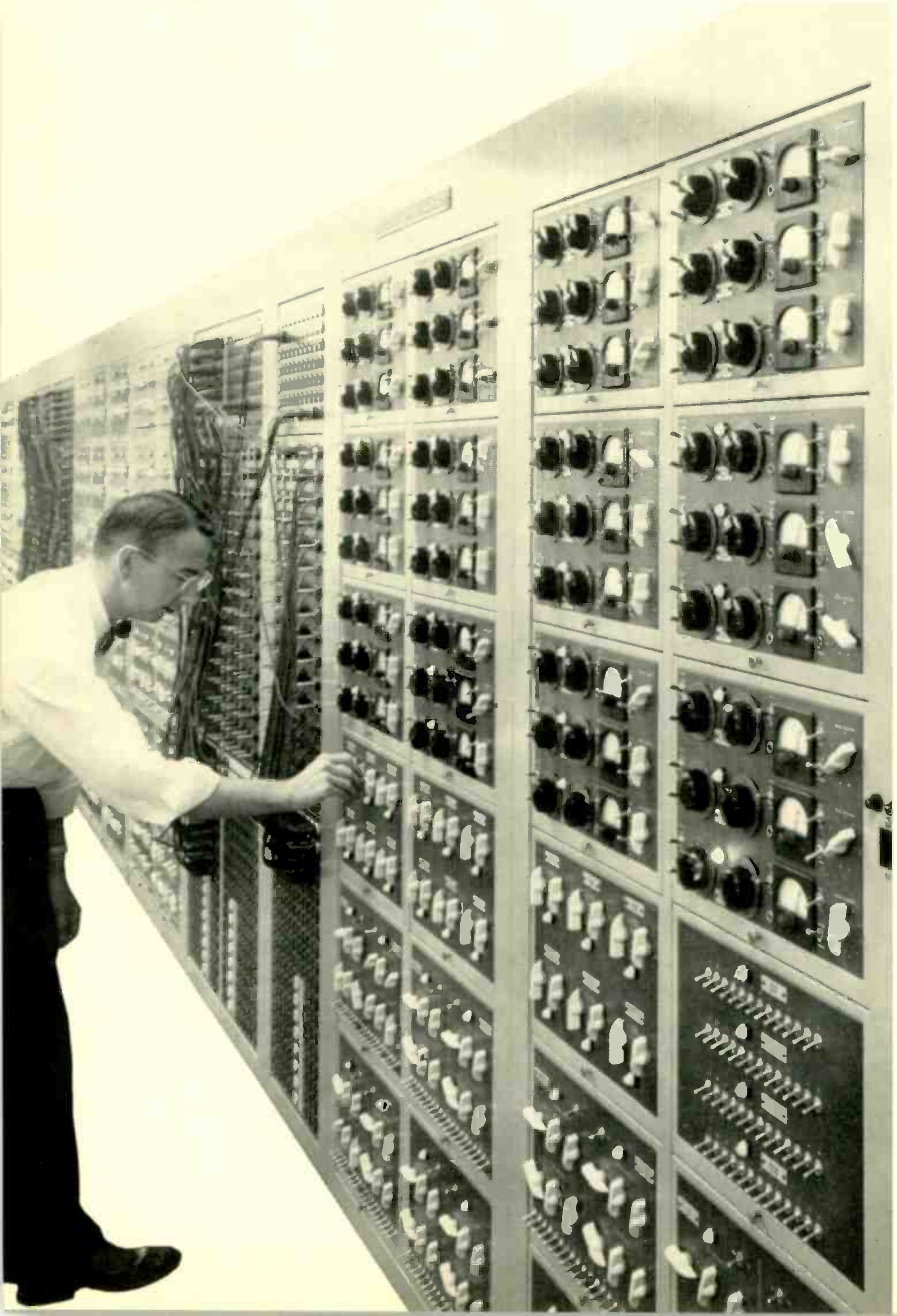


Fig. 2—The network calculator at East Pittsburgh is designed to accommodate the largest interconnected systems and power pools. There are a total of 668 circuit components for representing generators, transformers, transmission lines, and system loads.

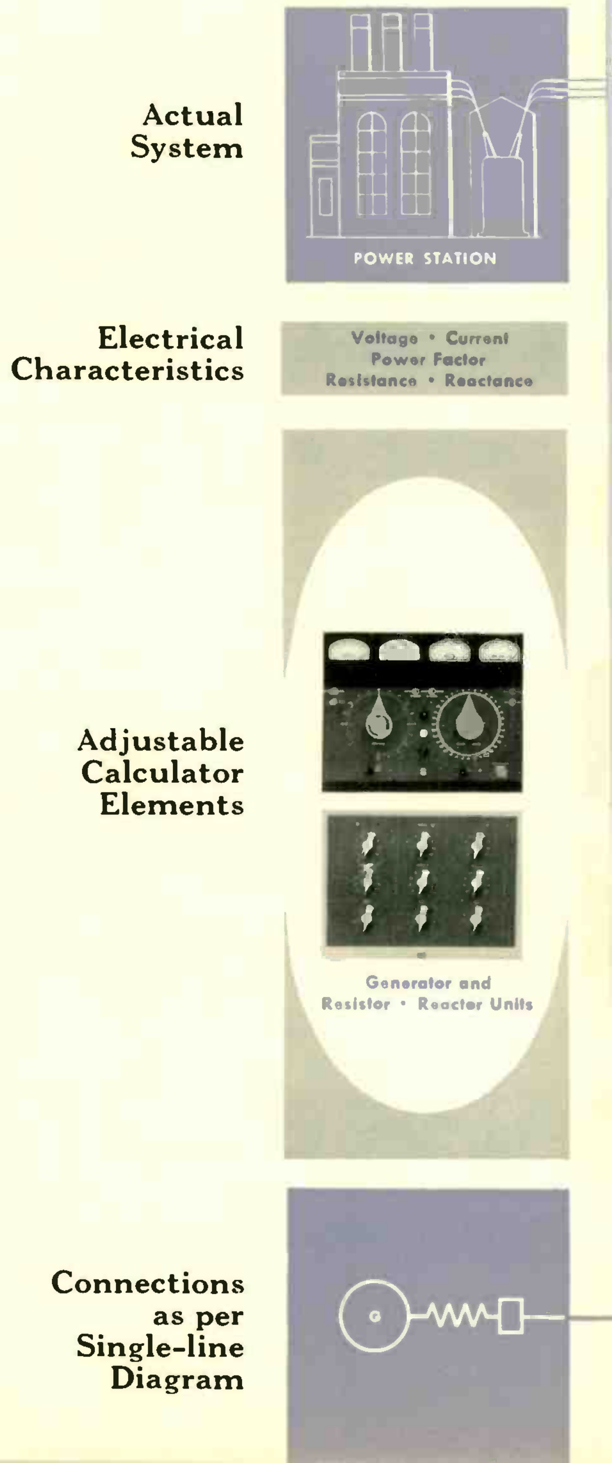


Fig. 3—All the characteristics of each element of a power system are reproduced in miniature by the corresponding a-c calculator element.

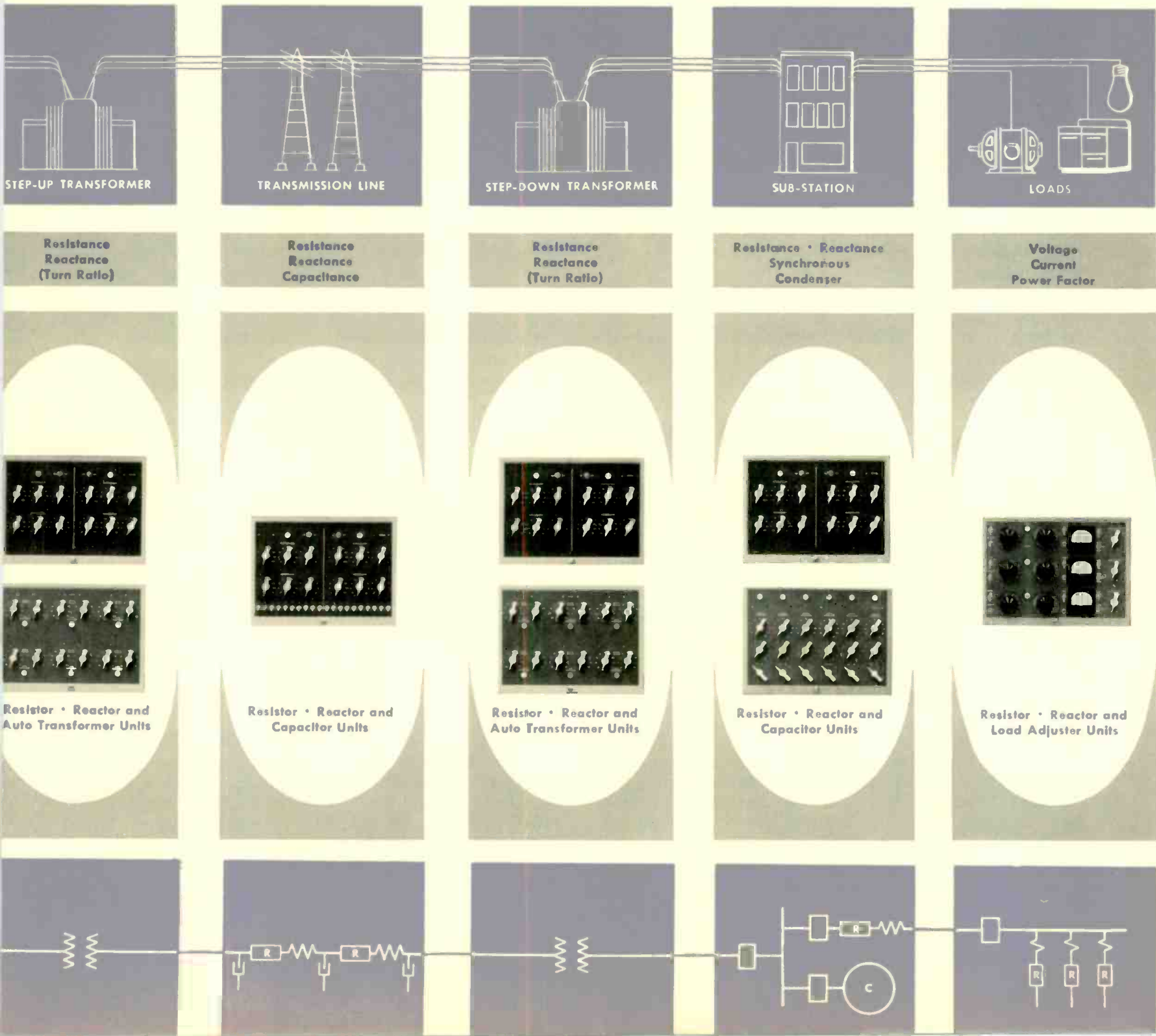
varmeter has an upscale deflection. Should the deflection not be upscale, a simple electronic circuit operates a relay to reverse the instrument. The sensitivity of this device is sufficient to operate for all watt-varmeter deflections greater than approximately ¼ inch. For those readings falling close to zero, a manual reversing switch can still be used.

Watt-Regulators—One of the major differences between the operation of a power system and its equivalent system on the network calculator has been in the generator units. Most generators on a power system are held by governor action or by operators to a constant power output at any given time. On the other hand, the network-calculator generators have held constant phase angle and, of course, have had to be readjusted to divide the total generation in the correct manner after every change in load. This discrepancy has been removed by adding watt-regulators to the generator units. The generator-unit wattmeter is used to sense when the output of a particular generator differs from the desired value; the difference between the desired and actual watt output appears as a voltage, which is amplified by an electronic power amplifier and used to drive one phase of a small two-phase gearmotor. The gearmotor turns the rotor of the generator phase shifter until the generator power output is again equal to the desired output.

Watt regulators can be applied to all generating units except one and will therefore operate simultaneously on all machines to hold power constant. The "swing" machine carries the load variations. The use of watt regulators is particularly helpful on large network calculators, reducing considerably the amount of time necessary for balancing generator units. The regulators will hold the watt output of the generator units to approximately one percent full scale on the wattmeter. The output of each generator can be "touched up" before readings if closer measurements are necessary.

What an A-C Network Calculator Can Do

The calculator is an invaluable tool to system-planning engineers in the design of power systems. The elements can be connected to represent any of the equipment of the actual system, and can be operated electrically in the same manner



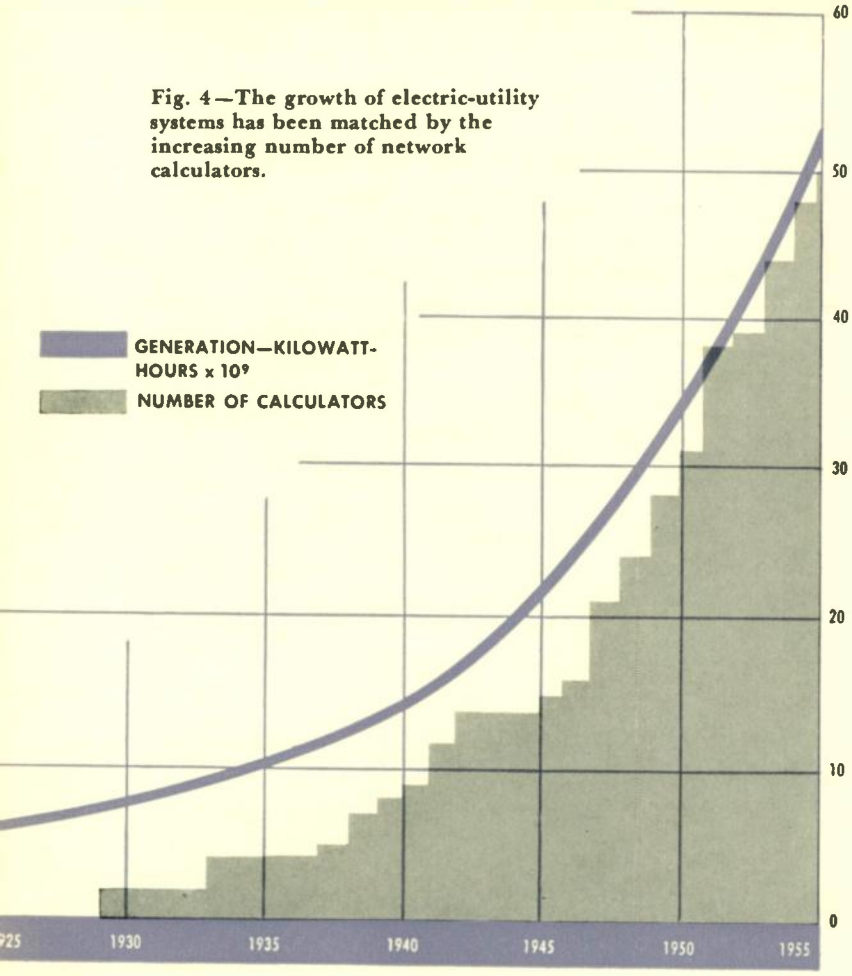


Fig. 4—The growth of electric-utility systems has been matched by the increasing number of network calculators.

as the actual system. The calculator eliminates many man-hours of calculations and is capable of solving problems that would be nearly impossible to do by other means. The calculator is used to study four general power-system conditions—load flow, loss evaluation, stability, and short circuits. Experience on the Westinghouse calculator in East Pittsburgh over the past year has shown that 51 percent of the time was used for load-flow studies, 20 percent was used for loss-evaluation studies, 17 percent was used for stability studies, and 12 percent was used for short-circuit studies.

Load-Flow Studies—Load-flow and voltage-regulation studies represent the day-to-day and month-to-month planning of the electric utilities to determine such things as voltage levels, circuit loadings, best location of new equipment, and detail changes in system design. A mistake in locating a new power station, building a new line or substation could cost thousands of dollars; these studies allow engineers to plan the system before any construction is started, leaving little chance for mistakes to occur. Planned and unplanned outages can be investigated and operating procedures developed to give the minimum of service interruption.

Loss-Evaluation Studies—During the past ten years, the cost of electrical energy has gone up very little. This is no accident, but due in part to better planning and to the manufacture of more efficient equipment. Another factor has been the development of new operating techniques. Until several years ago, generation was dispatched considering only production costs at the stations, with little or no consideration given to power lost in transmission lines. The a-c network calculator, teamed with high-speed digital computers, has made possible the development of techniques to take these losses into account. The original data for a loss-evaluation study is obtained on the a-c network calculator. The results of the calculator study are processed with a digital computer to develop loss formulas, which can be used in an economic dispatch computer, or for developing curves for economic dispatching.[1]

Stability Studies—Transient-stability studies on the a-c network calculator will determine if system generators will stay in synchronism after a disturbance, such as a three-phase fault. The swing of the machines is calculated by means of a step-by-step procedure. The accelerating power is determined from the calculator and the change in angle over a short interval is computed for each machine. The new angles are set on the calculator, new power readings made and new angles calculated. This procedure is continued until the system is proved to be stable or unstable. Stability studies take longer than other types; however, they usually are necessary at relatively infrequent intervals, such as when a major expansion in system capacity is contemplated.

Short-Circuit Studies—Short-circuit studies of all types can be made on the a-c network calculator for determining circuit breaker sizes and relay settings. The short-circuit studies made on the a-c board are usually limited to the zero-sequence network with substantial mutual coupling between lines. The d-c board is usually considered sufficient for other fault studies.

Availability of Calculators

The number of calculators in the United States has increased tremendously since 1929, when the first calculator was put in service. In fact, the increase in the number of calculators has followed very closely the growth of the electric utility industry; this is illustrated in Fig. 4.

The curves in Fig. 4 do not show two things: first, that as the generation has increased, the complexity of the power systems has increased even more—more ties between systems, reduction of reserves through interconnections, and even greater emphasis upon economy in operation; secondly, the usefulness and output per man-hour of the later network calculators have increased several times over earlier units. Hence the increased demands upon the system designer have been alleviated by the increased productivity of the network calculator.

The time required to study a particular problem on a power system varies with the type of problem and the complexity of the system. Experience on the calculator at East Pittsburgh has shown that the average time for a study is two weeks. For example, a 24-generator problem can be set up on the calculator in a half day and the first study completed by the end of the first day. Approximately 25 to 30 load-flow studies a week can be made on a system of this size, depending somewhat upon the extent of the changes for each study. Stability studies take longer and an average time would be two stability studies per day. Short-circuit studies rarely require more than a week, even though they involve many conditions of circuit arrangement and generation.

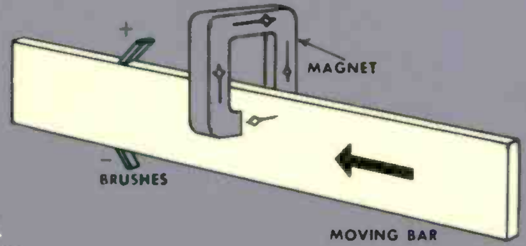
The increased availability of network calculators is making easier for electric utility engineers the solution of problems involving loading, minimum losses, stability, or short circuits on their power systems. Because the network calculator is a specialized tool, both the increasing number of engineers who have a chance to use it and the consulting engineers who often guide engineering activities should be familiar with the capabilities of the network calculator, and the personnel, cost, and time required for its use.

[1] "Economic Load Dispatching," by E. L. Harder, *Westinghouse* ENGINEER, November, 1954, p. 194.

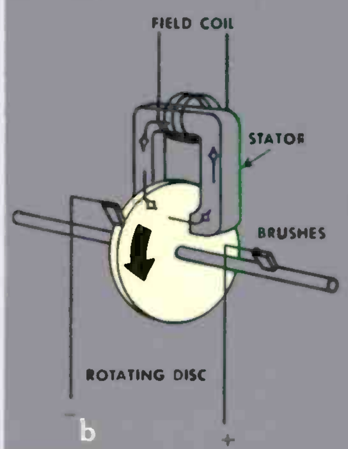
LOOKING FOR A JOB . . . . .

The Unipolar Generator

E. H. Myers,
Manager, Standard Machine Section
Transportation and Generator Division
Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania



a



b

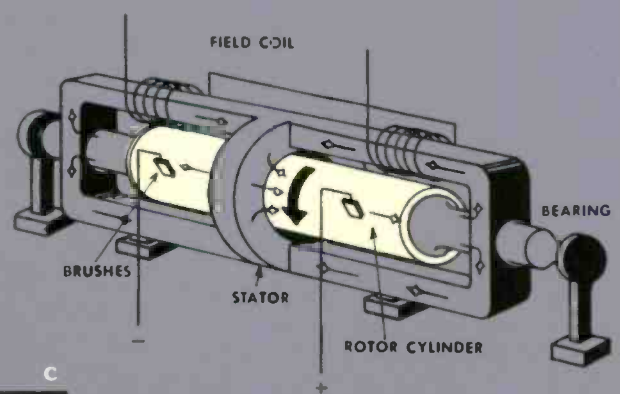
The operation of a unipolar generator is demonstrated by these simplified three-dimensional sketches, which illustrate four phases in the evolution of the modern unipolar machine:

(a) Faraday's original concept

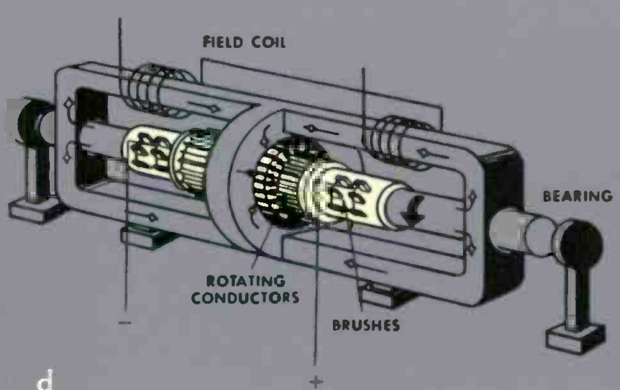
(b) Radial-disc machine

(c) Cylindrical type

(d) Modern cylindrical type using conductors Compensating windings, flux-bucking coils, and other refinements have been omitted.



c



d

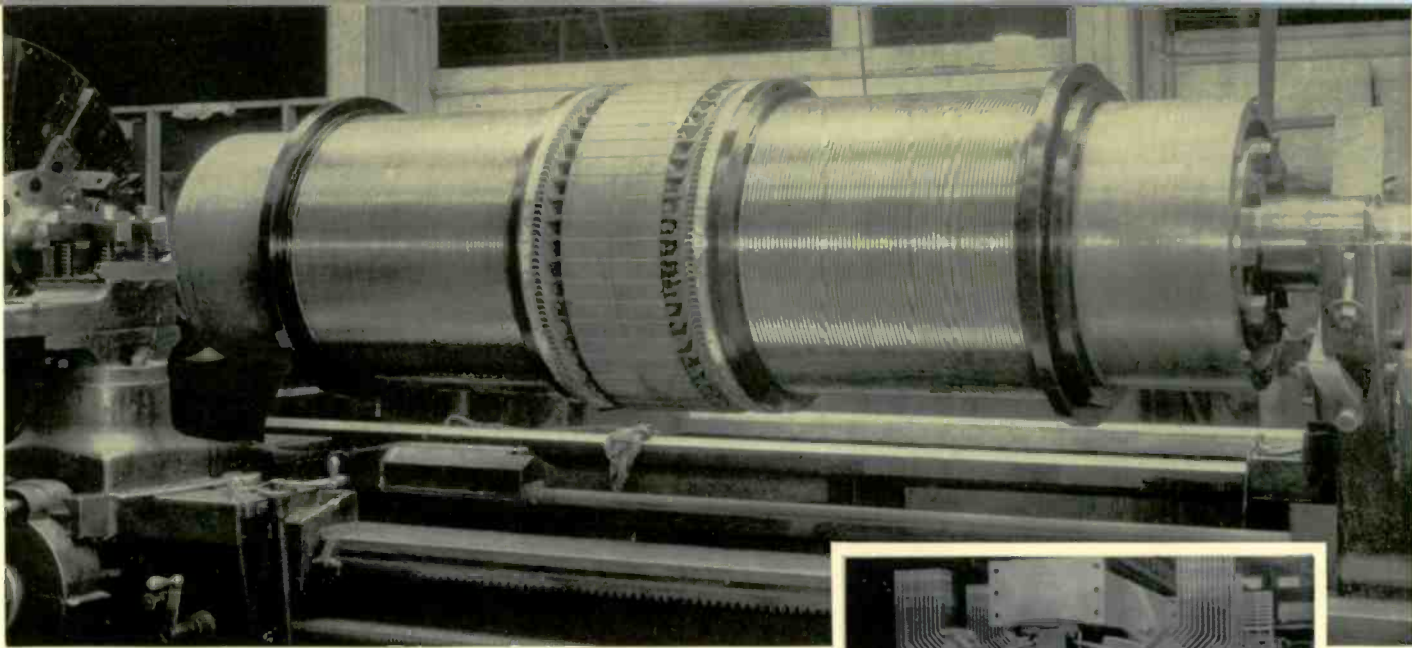
Although electrically the unipolar generator is probably the simplest of all electrical generators and certainly one of the first to be conceived, its use has been rather limited. With very high direct currents at low voltages its forte, the unipolar showed promise of finally coming into its own in the new atomic age. It just couldn't be beaten in providing the type of power required to pump electromagnetically the liquid metals used in atomic-power processes. But before it was hardly proven successful for these processes, the "canned" motor-pump was perfected, and the unipolar is still looking for a process that needs hundreds of thousands of amperes at ten volts or less—there is yet no better way of generating currents of this magnitude.

Michael Faraday devised the first unipolar generator in 1821 when he moved a metal strip between the faces of a magnet and established a voltage between the two ends of the strip. Since that time, this "single-pole" d-c generator has fascinated engineers. Most unusual is the young d-c machine designer who has not schemed to turn the unipolar "inside out" so the voltage-generating, current-carrying parts could be on the stator. This would avoid all the brush and collector problems. However, to date, all attempts have failed. As Mr. B. G. Lamme once said, "You can't fool the flux."

Since Faraday's first model, however, there have been several successful forms of the unipolar (or homopolar) generator. First were the early disc types, which used a thin plate rotating between the poles of a horseshoe magnet and later between the faces of circular magnetic poles. Copper-leaf brushes collected current from the shaft and from the outer circumference of the disc. Designers then found they could double the output voltage by making a "two-conductor" generator, using two discs on the shaft and collecting the current at the outer edges of the discs. Unfortunately, the required high peripheral speeds made brush wear (and disc wear) prohibitive. Also, the small space for brushes around the periphery of the disc limited the current so drastically that the disc type was replaced by the "axial" machine.

Originally, the axial unipolar generator used a simple copper cylinder on a large shaft. The flux path was from the encircling main pole through the cylinder to the shaft, then out the shaft and returned to the main pole through steel arms beyond the cylinder. Brushes rode the ends of the cylinder.

The next step was a design that used more conventional armature conductors located in slots, thereby avoiding the large main air gaps required by the cylindrical type of rotor conductor. This construction also used separate collector rings that could be located more advantageously, and replaced after wear without replacement of the conductors. The use of many collector rings also permitted connection to different armature coils. Outputs from the collectors could then be connected in series to obtain high voltages of conventional d-c machines. This generator was built by Westinghouse in 1906, and rated 2000 kw, 260 volts, 7700 amperes, and 1200 rpm. The unit operated commercially in a cement plant under



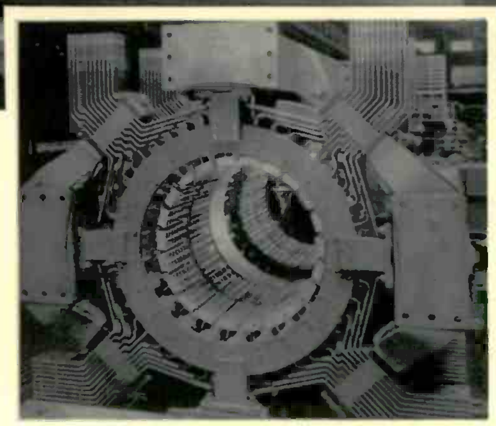


Fig. 2—Rotor and stator of the 150 000-ampere unipolar generator.

trying atmospheric conditions, and was used until 1925 when the plant changed over to purchased power.

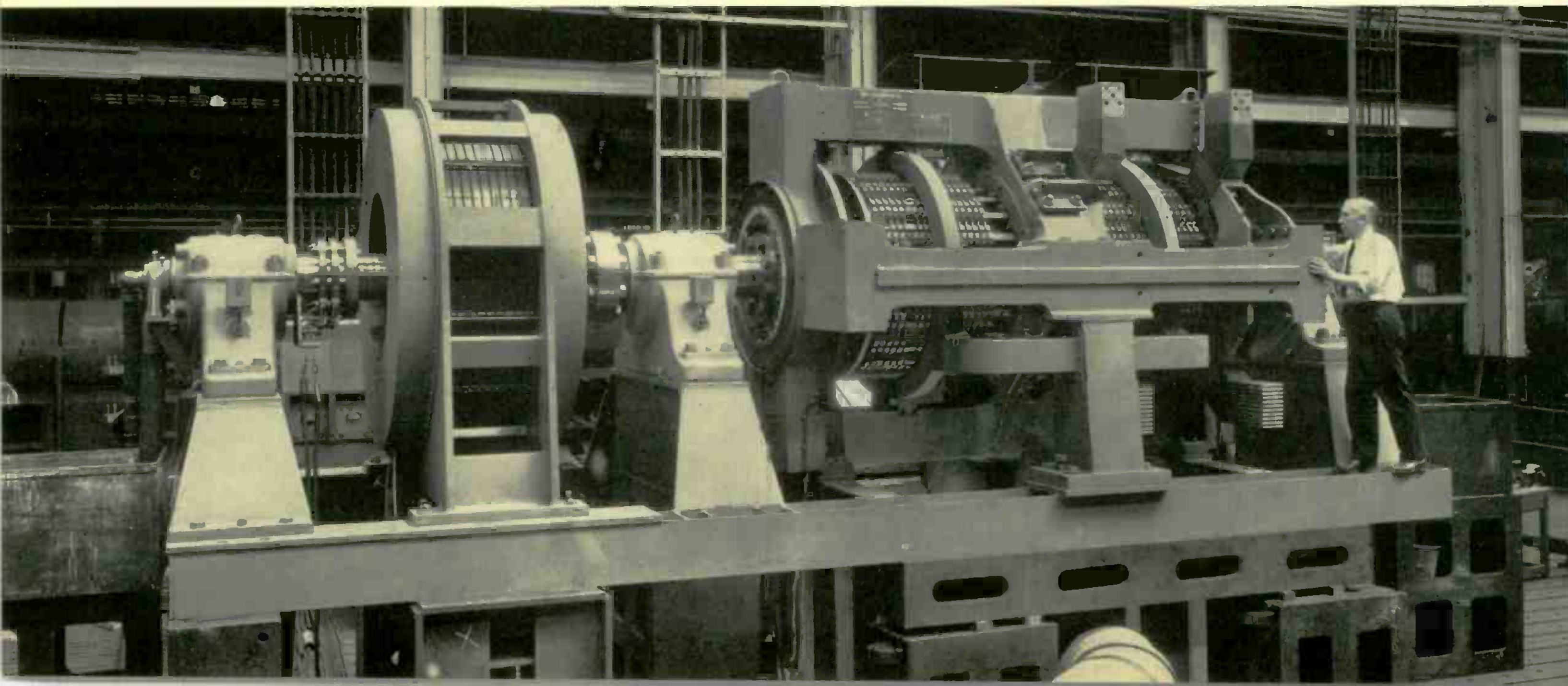
Backed by early developments Westinghouse designers literally jumped at the chance to build a 150 000-ampere, 7½-volt unipolar generator in 1934 when the Youngstown Sheet and Tube Company needed this rating to manufacture large-diameter steel pipe. Foreseeing the great expansion of oil, gasoline, and natural-gas pipelines across our country, the Youngstown Sheet and Tube Company wanted to form pipe from long sheets of hot-rolled skelp, and join the edges by direct-current resistance welding. This method would produce a high-quality pipe with a weld free from the "stitch" effect that occurs with a-c welding.

The design problems for a 150 000-ampere generator were considerably different from those tackled in 1906. Before any drawings were made, research projects and investigations were set up to tackle the problems of obtaining fundamental information and to obtain needed new materials.

The most formidable problems were the collectors that had to handle the huge currents. A suitable and stable oxide film was required to help insure uniform current distribution among the many brushes covering some 11 square feet on each collector. A material of high conductivity was needed to keep heating and voltage drops as low as possible. The material would have to be hard to prevent objectionable wear, and would have to retain that hardness even at elevated temperatures. Few materials met even some of these requirements and none would meet them all. The answer to the problem was the development of a new material, now called Cupaloy, by the Westinghouse Research Laboratories.

Laboratory testing verified Lamme's original findings that the negative collector wear could be expected to be 10 to 20 times the positive ring wear, and showed the necessity of reversing the generator polarity every eight-hour shift. The following interesting and vital facts were also discovered: (1) The ambient air should have not less than 1.5 grains of water per cubic foot or extreme brush wear results. Three

Fig. 3—The 150 000-ampere unipolar generator during construction at the East Pittsburgh plant.



grains were chosen as a reasonable figure and an air humidifier was furnished with the generator to insure that minimum amount. (2) A brush size of 1.5- by 1.5-inch cross section was selected to give the best stability of contact. Smaller brushes proved to be less stable and larger brushes indicated too few electrical points of contact were maintained. A metal graphite brush was selected to give the low contact drop for reduced heating but still sufficient to help proper division of current. (3) Spiral grooving was found desirable not only to increase the cooling of the collector but also to force any local concentration spot of current collection to be swept across the brush face and thus tend to prevent selective action by overheating at a spot on one brush. This was particularly important because of the negative coefficient of resistance of carbon.

Other preliminary studies indicated that the collectors would have to be water cooled as well as cooled by air blast. The air-blast nozzles were located between the brushholders and not only cooled the collector and brushes, but also removed carbon and copper dust as it was worn off the brushes.

Water cooling of the collectors was accomplished by forming labyrinths under them and using special rubber inserts in grooves machined in the shaft. Cool water was brought in from a hole in the center of the shaft at three points on each collector and the heated water taken out at three points, each parallel circuit cooling one third of the collector. The heated water was then taken out through the shaft.

Special brushholders were developed to permit maximum coverage of the collector surface by the brushes and over 60 percent was covered, which was four to six times the normal coverage for collectors. The holders, springs, and fingers had to be designed to permit brush maintenance and replacement with minimum difficulty. The brushholders used the compensating bars extended from the stator slots as brackets, a logical development based on Lamme's 1906 design.

It was recognized that all rotating parts of the generator would become separate little unipolars unless all stray fluxes were prevented from cutting them. This posed a real problem in the case of the collectors because the large steel arms that carried the useful flux from the end yokes back to the center pole had to be located around the collectors. These arms would be at considerable magnetic potential difference from the shaft under the collectors and leakage flux would cut the collectors as a result. If the pancake field coils were located at outer ends of the collectors, the voltage induced in the collectors would tend to cause circulating currents, which would add to the load currents in the brushes at the outer end of the collector and subtract from the load currents in the brushes at the inboard end. This at first appeared beneficial as it tended to compensate for IR drop in the collector itself. However, the results were far too powerful and even with special bucking coils located on the yoke arms, the leakage flux from above the coils was sufficient to cause the outboard brushes to have current densities of over 1000 amperes per square inch while those on the other end had none or negative current densities. The problem was solved by placing pancake field coils at both ends of the collectors so that the ampere turns could be provided at the position where they were used, that is, at the center main-pole air gap and at the return-flux air gap at the outer yokes. By varying the proportions of these properly located fields, the current distribution along the collector could be changed to obtain almost perfect distribution.

Bucking coils provided on the outside of the end yokes successfully prevented stray flux from reaching bearings and shaft journals.

Years of successful and profitable operation have proven the unipolar generator and resulted in thousands of miles of the highest quality "big-inch" pipelines. After the welder was put into service, operations were found to need up to 270 000 amperes—180 percent of the original rating. The unipolar has complied without complaint. However, there is no doubt that its useful field is limited to applications requiring low voltage and high currents beyond conventional d-c machine ratings. Several possible applications for currents many times that of the 1934 machine have been considered. When one comes along that must have currents of hundreds of thousands of amperes at ten volts or less, the unipolar can do the job.

what's NEW!

Magnetic Amplifiers Capture More Business

The magnetic amplifier is rapidly "horning in" on the vacuum tube. Although there are numerous applications where vacuum tubes still hold a "closed-shop" status, magnetic amplifiers are finding increasing use in control systems where their simplicity and reliability, long life, and maintenance-free operation in all types of surroundings are a definite advantage.

A magnetic-amplifier control panel has become the "middle man" in a control system for temperature control of electric-furnaces. The Magamp unit amplifies the signal from a proportional controller and provides d-c excitation for a 37½-kva saturable reactor, which in turn controls the voltage to the furnace heater units. The unit gives a two-to-one reduction in size over the previous control system, combined with longer operating life, more reliable service, and lower cost.

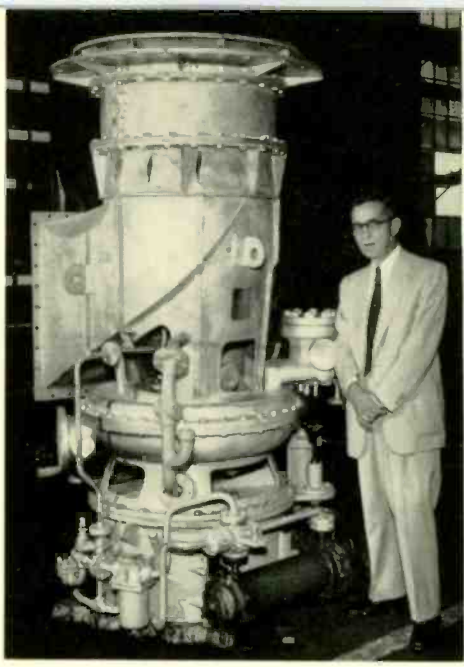
Another new device is a Magamp servo drive, which accurately positions the cutting tool in a newly developed spark machining process. The drive consists of a sensing circuit, a magnetic amplifier, and a drive motor. The sensing circuit detects voltage and current conditions at the spark and furnishes this information to the Magamp unit, which amplifies the signal and drives the motor to position the tool for optimum cutting conditions. The pilot model of the servo drive system reduced machining time over previously used methods of control The Magamp drive requires only a three-phase power source for operation, with no additional special power supplies necessary. The spark machining process was developed by the Method X Company, a division of Firth-Sterling. Commercial units are being manufactured by Ex-Cell-O Corporation, Detroit, Michigan.

Frequency-Shift Relaying over Microwave

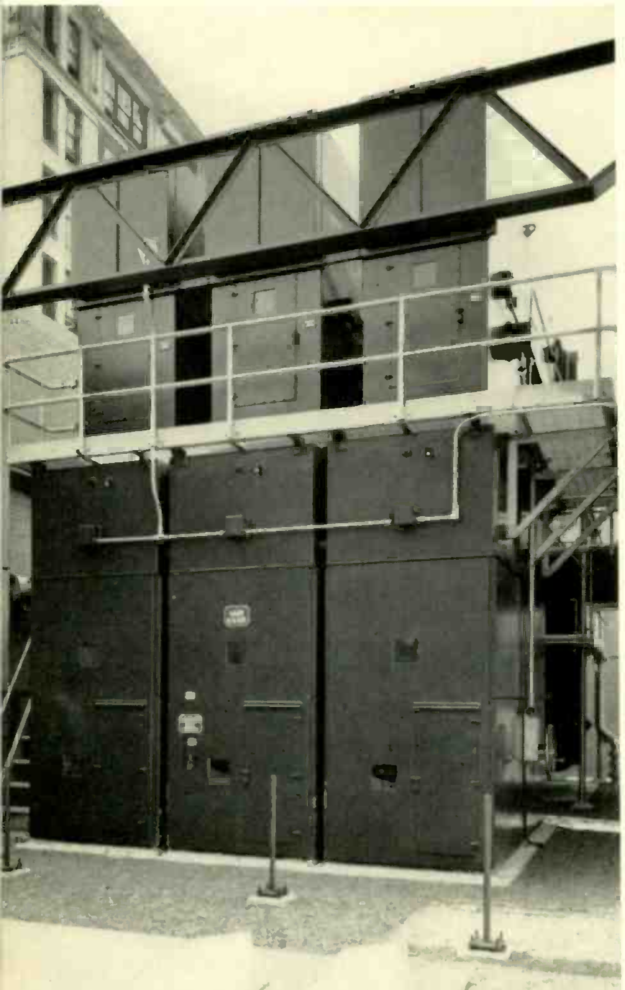
A NEW HIGHWAY is being readied to carry the relaying signals that protect heavy distribution equipment—a microwave avenue. These signals have been traveling power-line carrier or pilot-wire routes.

A big advantage of microwave is that trip signals can travel independently of the power lines they are protecting. This makes it possible to apply new techniques. To be fail safe, previous schemes had to rely on blocking signals, i.e., continuous signals that prevented breaker operation by their presence. The new scheme makes it possible to trip breakers by sending a signal. A special design prevents false operation under any circumstance. Failure of any element will not cause false tripping. A continuous monitor sounds an alarm the moment anything goes wrong. The new device cannot be fooled by the presence of noise, such as might be generated by storms or other electrical disturbances on the power lines. This is accomplished by using a new frequency-shift technique, which is insensitive to static.

And it's a high-speed highway; warning signals can travel it in six milliseconds. This high speed, combined with fail-safe, monitored operation should make this a well-traveled highway in the future.



Twenty years ago a typical axial-flow, forced-draft blower for naval vessels operated against a pressure of eight inches of water and required a turbine of about 150 hp to drive it. Today the back pressure is 130 inches and the turbine power is close to 1000 hp. Such is a result of greater crowding of boilers and auxiliaries. But—and this is significant of progress in direct turbine-driven axial blowers—the machines are no larger physically and weigh no more than their predecessors of 1934. A sizable number of these 130-inch forced-draft blowers with three high-efficiency stages are being built for the large new aircraft carriers and destroyers.



The first 69-kv substation with phase-isolated leads having the full impulse rating—350 kv—for this voltage class has been put into service by Philadelphia Electric. The substation contains pothead compartments and disconnecting switches for connecting incoming lines to transformers.

Several thousand magnetic cores such as these may be used in a single computer or data-processing machine. These cores are wound on ceramic spools that range in size down to 1/32 inch in diameter and 1/16 inch high. The strip with which these cores are wound—a nickel-iron alloy—is rolled as thin as one eight-thousandth of an inch thick. Normally a core consists of only 6 to 15 wraps of the magnetic material on the spool. These Hiperthin cores have higher permeability and are more temperature stable than ferrite cores. These cores are also applicable to high-frequency magnetic-amplifier circuits, where high gain is needed.

Longer Life for Thyratrons

AN ELIXIR for longer life has been found for the xenon-filled thyratron. By adding mercury vapor to the xenon gas, the thyratron maintains the favorable low- and high-temperature range of operation characteristic of the xenon thyratron, but also has the inherent long life of a mercury-filled tube. This is possible because the ionization potential of xenon gas is higher than that of mercury vapor and therefore, when the temperature of the tube is sufficient to provide sufficient mercury vapor, the voltage across the tube will not rise high enough to ionize an appreciable number of xenon molecules. Under practically all conditions of operation in commercial service, the tube will therefore be operating on mercury vapor. Xenon will be ionized only when the tube is starting after a period of nonoperation at low ambient temperatures. Since xenon is relatively close to mercury in atomic weight, the current-carrying capabilities and other characteristics of the tube remain practically constant whether it is working on mercury or xenon.

"Push-Pull" Aids Tin Reflow

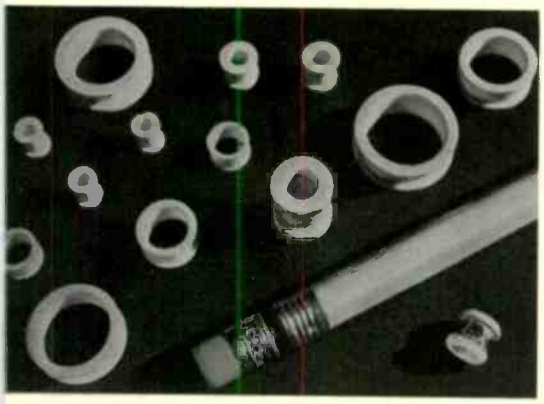
A NEW 2400-kw tin-reflow line, one of the largest single-package installations to date, will process tin-plated steel strip at 2000 feet per minute. The steel strip will pass progressively through induction-heating coils rated at 400, 600, and 800 kw. The tinplate is brought up to melting temperature and flowed. Up to 500 kw can be applied per foot of strip length, this high density making possible a sharp flow line or melted zone.

An automatic temperature-control system uses photoelectric cells to pick up light reflected from the bright flow line, which is held in position within ± one inch, regardless of speed, width, or thickness of the strip.

A special feature of the installation is a newly designed oscillator unit. The basic oscillator cubicle units are rated at 150 and 200 kw. Formerly, each unit consisted of two oscillator tubes connected in push-pull.

To get improved versatility in combining cubicles, the new units have parallel oscillator tubes, making in effect, a single oscillator tube per cubicle. Two cubicles can be easily combined to operate push-pull, or groups of paralleled cubicles can be operated push-pull. This allows a versatile grouping of the units in multiples of two, so that complete oscillators can be easily assembled in ratings from 150 to 800 kw with no special hook-ups required.

The multiple-break interrupter design, so successful in the 330-kv breaker, has been scaled down for the 161-kv oil circuit breaker. As a result, 161-kv breakers can now be built with an interrupting rating of 15-million kva. The previous maximum for this voltage was 10-million kva. Similar to the 330-kv interrupter, the new interrupter has multiple breaks (two instead of four), finger contacts, and provides ease of maintenance and examination, with time-savings in adjustment and reassembly. The interrupter can be adapted to some of the older breakers.

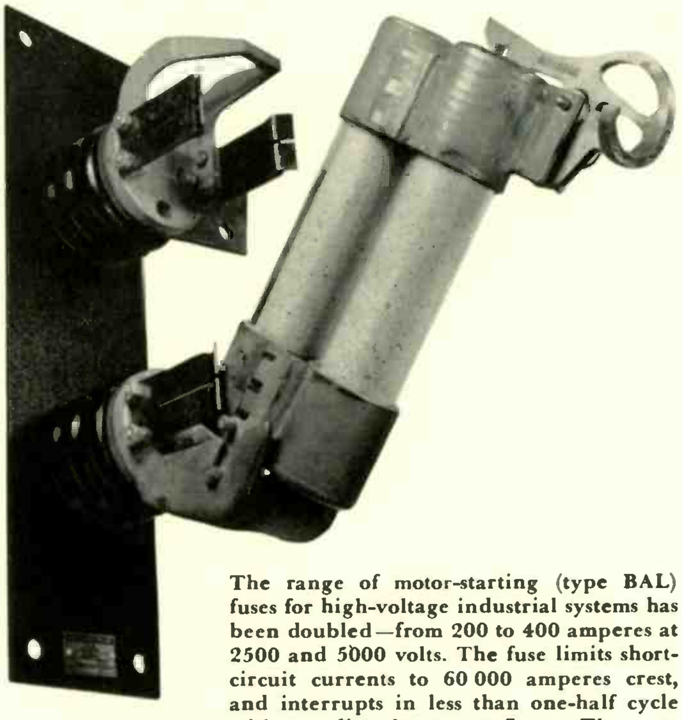


This form-fitting plastic container for the image orthicon is not gift wrapping. The protective case fits closely over the bulb to protect it during shipment, and is intended to remain on the tube while in storage. The transparent plastic permits inspection of the tube and its parts without breaking the package seal. It has also been designed so that when the tube is laid down, the case keeps the tube in a favorable position so that any loose particles within the tube will not fall onto the sensitive target.

Solving Motor-stability Problems

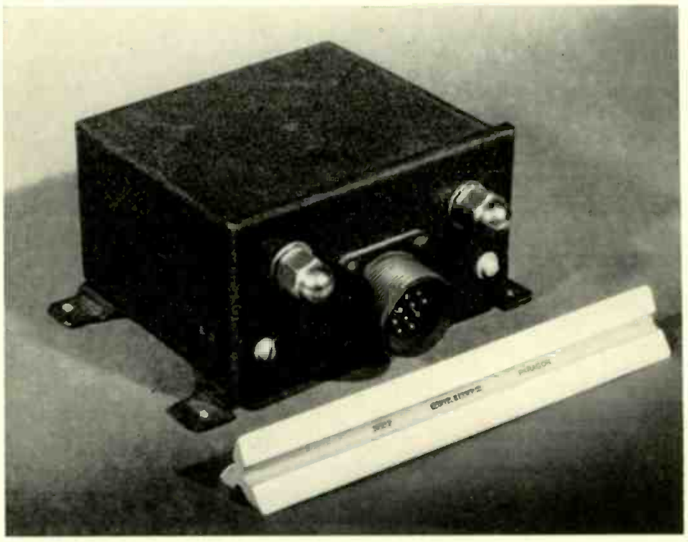
INCREASING use of large blocks of induction motors has introduced the problem of motor stability—both transient and steady state. To solve such problems, engineers have developed a method of handling them on the a-c network calculator and digital computer. As a result of such studies, utility and industrial companies can determine maximum loads that can be carried, critical switching times for faults, relay performance and settings, and the requirements on the power system to supply loads reliably.

These methods may also be used for studying large individual motor loads, such as wind-tunnel drives, pumping loads, or automatic-transfer performance of powerhouse auxiliary motors. The digital-computer technique promises to save engineering manpower in solving such problems, particularly when a large number of studies are involved.

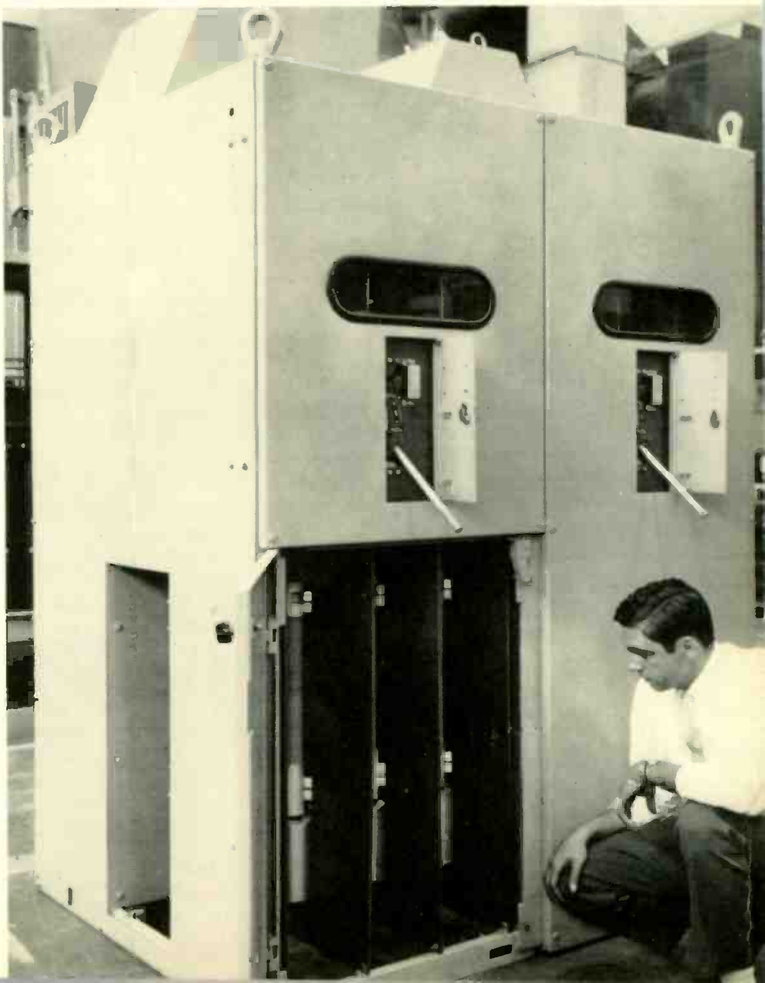


The range of motor-starting (type BAL) fuses for high-voltage industrial systems has been doubled—from 200 to 400 amperes at 2500 and 5000 volts. The fuse limits short-circuit currents to 60 000 amperes crest, and interrupts in less than one-half cycle with no disturbance or flame. The new 400-ampere design is completely inorganic and sealed.

The fuse consists of two barrels or units brazed together by a bridging member, which acts as a contact surface and a support for the pivot pins. There are no bolted connections between the parallel units to cause possible unequal current distribution. Wrap-around fuse fittings have been eliminated and no tools are required to change a fuse. The fuse can be disconnected, removed and replaced with a standard hookstick. The fuse and mounting requires only slightly more space in the starter than the present 200-ampere rating.



Heat is applied to aircraft windows to defrost or de-ice the glass, to insure clear vision for the pilot under all environmental conditions. This small black "box" contains the complete control for regulating the power applied to aircraft window heaters. This is an all-Magamp control, and replaces two electronic types. It operates from a 115-volt, single-phase, 380/1000 cycle supply. The device can also be adapted to regulate the heat supplied for de-icing aircraft surfaces, or to control the ambient temperature in personnel compartment in aircraft.

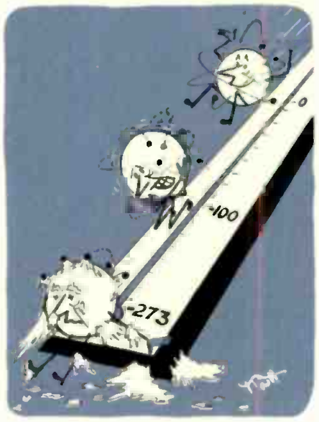


This air-insulated load-break switch has a rating of 500 operations interrupting 100 amperes at 15 kv and a continuous current rating of 600 amperes. It also meets the NEMA standard of 40 000 amperes momentary and 25 000 amperes for four seconds. The new switch is intended for use on 15-kv circuits with a basic insulation level of 95 kv. Design emphasis was also placed on minimum space requirements. The case matches the appearance and height of standard switchgear and dry-type power-center transformer cases, and is 34 inches wide, 48 inches deep, and a little over 90 inches high. Provision is made for connection to customer's lines either at the top or through the bottom. The new switch is available only as an integral part of a transformer.

personality profiles

Dr. A. Wexler • *H. E. Schaffer* • *W. A. Derr and M. A. Hyde* • *R. B. Squires and R. H. Swanberg* • *E. H. Myers* • *M. Middleton*

• Like so many of our articles, written by busy scientists and engineers, the article by *Dr. Aaron Wexler*, is "well traveled." It was started in the old Research Laboratory in East Pittsburgh, written on a trip to Europe, and completed in the brand new Research Laboratory. The occasion for Wexler's trip was to present a paper on low-temperature research at the International Conference on Low Temperature Physics at the University of Paris.



Wexler joined the Westinghouse research staff in 1947 and established the low-temperature laboratory. Under his direction, low-temperature techniques and apparatus have been developed and important scientific contributions made to this field. In 1952, Wexler was appointed an advisory physicist, and in 1953 the manager of the magnetics and solid-state physics department. Last year he became an associate director of the Laboratories.

Upon graduation from Brooklyn Polytechnic Institute, Wexler was awarded a National Fellowship at Johns Hopkins. There he received his PhD in 1944, and remained as a research associate until he came to Westinghouse three years later.

• *H. E. Schaffer* came to Westinghouse in 1922 after gaining his BSEE from Bucknell University After a short stint as a tester in the transformer section, he transferred to transformer engineering in 1923. In 1925 he moved with the Transformer Division from East Pittsburgh to Sharon, Pa; since that time he has been a design engineer in the section concerned with network and power transformers. For the past 12 years he has specialized in the design of the stationary-type high-voltage testing transformers, of which he writes in this issue.

In his spare time, Schaffer combines his two hobbies, travel and photography. In his travels through 44 states and 4 provinces of Canada, he has amassed a large collection of color slides of the scenery enroute.

• The combined talents of *W. A. Derr* and *M. A. Hyde* produced the article on remote operation of pipeline pumping stations—and few teams would be as well qualified. Derr's specialty has been supervisory control since he first joined Westinghouse in 1936. Hyde is a widely recognized authority on pipeline electrification.

Derr's first assignment after finishing the Graduate Student Course was to help test the supervisory control equipment for the Hoover Dam to Los Angeles line. In the ensuing years he has worked on many phases of supervisory control, including its adaptation to microwave, and the application of this combination to pipelines. He is now in charge of the supervisory control activity.

Hyde has been largely engaged in pipeline and other petroleum and chemical activities since 1935. Before this he had worked on general mill activities, particularly cement mills. Hyde has played a part in most of the pipelines electrified during the past fifteen years in the United States.

Derr is a graduate of Penn State, with a BSEE in 1935 and an MS the following year. Hyde majored in physics at Marietta College, and also graduated from Case, where he earned his EE degree. He also holds an ScD from Marietta. Both Hyde and Derr have appeared as authors in the ENGINEER several times.

• *R. B. Squires* and *R. H. Swanberg* are well qualified to speak of network calculators. Both have played a major role in the present Westinghouse network calculator installation in East Pittsburgh, largest in the world.

Squires is a graduate of Purdue University, from which he received his BS in EE in 1940. He entered Westinghouse on the Graduate Student Course the same year, and subsequently was assigned to the Central Station Section in 1941. The following year he transferred to the Technical Section of Switchboard Engineering, where he first came in contact with network calculators. Except for two of the war years that he spent working on special government projects, he has worked on calculators and computers ever since—first as an operator, later as a development engineer helping to design new and better equipment for calculators, and finally as manager of the Technical Section (1954). The field is broad, since Squires' section, in addition to developing calculators and computers, also works on a wide variety of switchgear application problems and system studies.

To supplement his actual experience, Squires has also devoted time to further academic work; in 1946 he obtained his MS in EE from the University of Pittsburgh, and is now doing advanced study at the same institution.

Swanberg came to Westinghouse from Iowa State College in 1951 with a BS in EE. After the Graduate Student Course, he joined the Switchgear Division in East Pittsburgh in early 1952. Shortly thereafter, he was assigned to the network calculator.

When the calculator was transferred to the Analytical Section of the Engineering and Service Department on January 1, 1954, Swanberg went along as chief operator. It was in this position that he captained the new 36-generator calculating board through its initial shakedown cruise in late 1954.

• *E. H. Myers* has been designing d-c machines for Westinghouse for 17 of his 18 years with the company. The other year was spent on the Graduate Student Course, and with the Motor Division.

Myers came directly to Westinghouse after receiving his BS in EE from Kansas State college in 1937. After the Student Course and a two-month stay with the Motor Division, he joined what was then called d-c generator engineering. He became the section manager, his present position, in 1952.

The unipolar machine has always been of special interest to Myers. Shortly after coming with the d-c design section, he inherited some problems of the machine that he describes in this issue. As a result, he holds several patents on field-coil arrangements for unipolar machines.

Myers has passed some of his knowledge along to other potential designers, as an instructor in the Westinghouse Design School from 1948 to 1952. He has also found time to attend school himself, receiving his MS from the University of Pittsburgh in 1944.

• *Marshall Middleton*, who plays soothsayer to the future via engineering design by computers, graduated from the University of Pittsburgh in 1943 with a BS in EE. From college, he went directly into the U.S. Army Signal Corps, and served in the South Pacific, installing high-powered radio transmitting and communications equipment. He entered a private, and left a Lieutenant.

Middleton came with Westinghouse on the Graduate Student Course in 1946, and from there went to the Rectifier Section of A-C Engineering in the Transportation and Generator Division in East Pittsburgh.

In 1951 he transferred to the group that has now become the Analytical Department. He is the charter member of the rapidly developing digital-computer section, which has dealt with such subjects as turbine-blade design, critical speeds for rotating equipment, and transformer and motor design, which he discusses in this issue.

His major hobby since joining Westinghouse has been attending night school at the University of Pittsburgh. This is evidenced by a masters degree in 1950, and his present candidacy for a doctors degree in mathematics from the University of Pittsburgh.

Middleton is a member of the Electronic Computer Committee of the IRE, and a member of the AIEE.

Transonic Tunnel

Above, the compressor rotor of the transonic portion of the Propulsion Wind Tunnel being lowered into place. This tunnel is part of the Air Force's new facilities at the Arnold Engineering Development Center. Smaller photo shows the four motors—totalling 216 000 hp—that will power both the transonic and supersonic tunnels. Motors on either end are 83 000 hp each; the two in the center are 25 000 hp each.