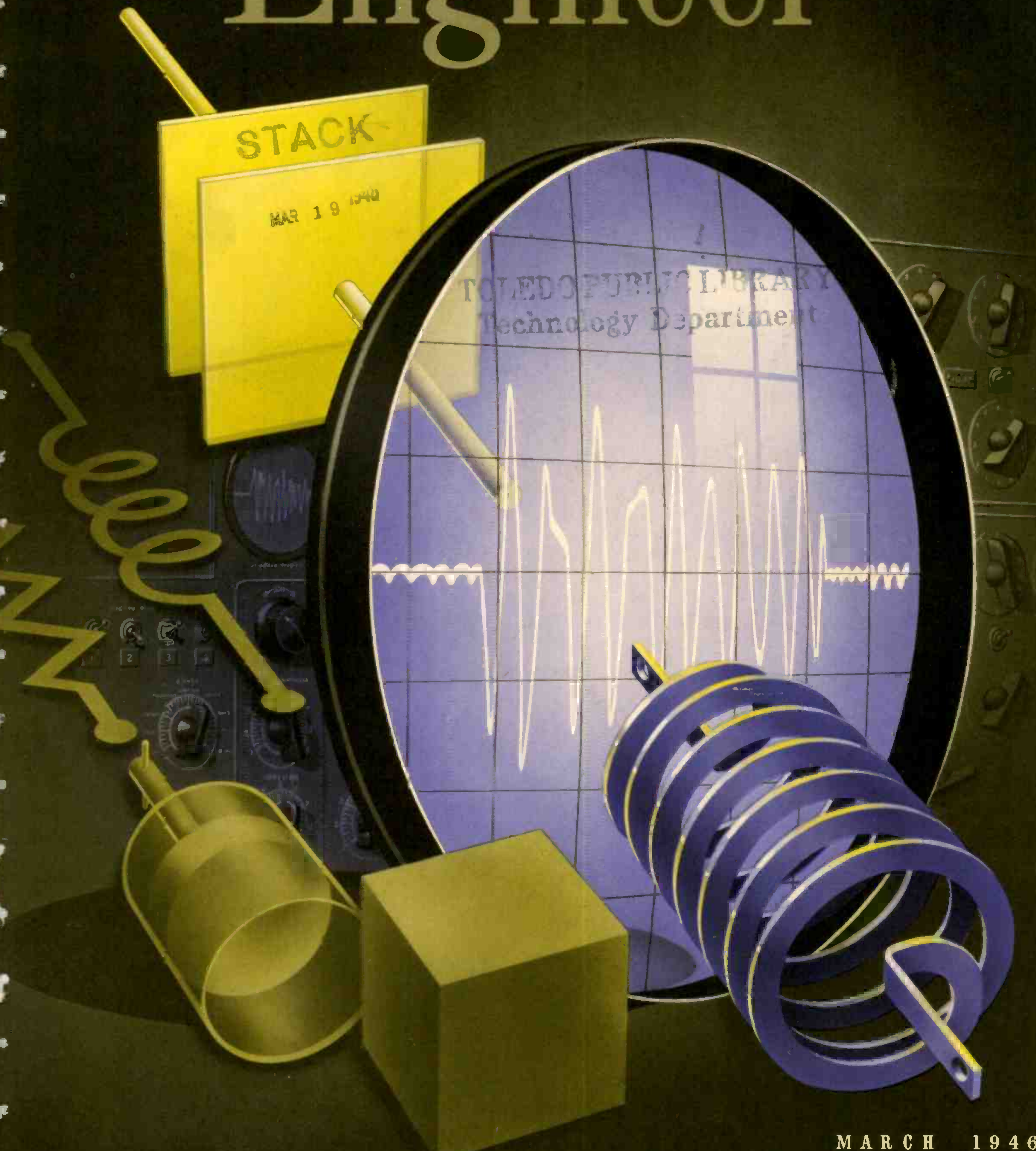
WESTINGHOUSE

Engineer



MARCH 1946

The ENERGY of MATTER

Now that nuclear reactions—as opposed to the milder chemical reactions—have burst into the engineer's world, even the technical man finds it difficult to grasp the new orders of magnitude. Nuclear reactions are from one million to several hundred million times more productive of heat than our accustomed fuel reactions. This is an increase of from six to seven magnitudes. A few comparisons in practical units help in this orientation:

One pound of U^{235} on disintegrating releases as much heat as is contained in 1500 tons of coal. Each pound of U^{235} split (not destroyed) releases nearly twelve million kilowatthours of heat energy.

Helium, if manufactured by nuclear reaction from hydrogen at the rate of one ounce per hour, would provide a continuous heat-energy output equivalent to more than seven million horsepower.

When one atom of U^{235} explodes, 200 million electron volts of energy appear. When one molecule of TNT explodes, the energy is equivalent to five electron volts.

One ounce of water made by the chemical burning of hydrogen and oxygen liberates about 200 000 Btu. In the nuclear reaction, by which lithium and hydrogen are combined to make helium, 5600 million Btu per ounce result.

The sun radiates energy continuously at the rate of 50 hp per square inch, but the weight loss per square inch of sun surface is only one twentieth ounce per century.

In 1903 an undistinguished young mathematician went to work in the Swiss patent office in Berne. His tasks, which included the investigation of perpetual-motion schemes, left him ample leisure time. Then in one year—1905—this obscure patent investigator sent to the editor of a journal of physics three papers. Each—on a different subject—was of astounding scientific significance, quickly recognized. Any one of these was of sufficient importance to secure this young man a place in the all-time hall of scientific fame and mark him as a genius. The young mathematical physicist, then only 26 years old—was Albert Einstein.

The most famous of that trio of Einstein papers, which fell like bombs into the scientific world, was his Special Theory of Relativity. The other two also were momentous. One of these explained the Brownian movement, which had baffled scientists for 80 years, as the thermal-energy fluctuations of the molecules. The other paper promulgated the theory of the photoelectric effect and reduced Planck's work on radiation to mathematical expression for the first time. In short Einstein established the quantum theory which states that the energy of one photon divided by the frequency of the electromagnetic radiation is a constant, known as Planck's constant.

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The equivalence of mass and energy—i.e., energy is equal to mass multiplied by an extremely large constant, the square of the velocity of light—as set forth by Einstein was only one aspect of this theory of relativity. For a long time it remained as an abstract concept. Even Einstein at first expressed doubt that it would ever be given practical application. He is reported to have expressed great gratification in 1932 when, after he had become a professor at Princeton, he learned of its verification by Cockcroft and Walton in Rutherford's Laboratory in England when they bombarded lithium with protons and obtained helium.

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The obvious significance of Einstein's statement that energy is equivalent to mass multiplied by the square of the speed of light, is that one gram of matter if converted to energy becomes the staggering total of 900 billion billion ergs, or, in more common units, one ounce of matter is equal to 707 million kilowatthours. This has given rise to the many statements seen in the popular press that the energy in a small amount of matter—a tea cup of water or a lump of what-have-you the size of an egg—is sufficient to drive a ship, etc., etc. This is, of course, true. But it should always be remembered that this statement is based on 100-percent conversion of mass to energy, something distinctly different from all nuclear reactions now known.

All present successful nuclear heat reactions—the atomic bomb, the uranium piles, the sun—are based on a reshuffling of the basic nuclear constituents of one substance into other substances of slightly less total mass. That mass difference multiplied by the velocity of light squared is the heat gain. The mass changes are small, generally under one percent. But, of course, even one percent of 707 million kilowatthours is an enormous total. As matters stand now there is no prospect of turning a cup of water into energy—which is perhaps just as well.

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Comprehension of nuclear reactions makes the energy release from our sun understandable. Furthermore it is comforting as it makes plain we will not run short of sun heat soon. The total amount of energy contained in the world deposits of coal equals the energy radiation by the sun for only one second. This represents a continual loss of sun mass of about five million tons per second by the "burning" of hydrogen to helium. (See article by Dr. Seitz in this issue.) But its mass is so enormous that the sun will last for at least another 15 million million years.

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Engineer

VOLUME SIX MARCH, 1946 NUMBER TWO

On the Side

The Cover—The striking correspondence between mechanical and electrical relations is just one example of the essential simplicity of the universe. The analogy between mechanical and electrical reactions, in which mass, spring action, and damping have their counterparts in resistance, capacitance and inductance, is depicted by the artist on the cover and discussed by Dr. McCann in connection with the device for solving complicated mechanical problems electrically.

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Science Reporting—What scientist, what engineer has not longed for a more adequate, accurate job of reporting events of science and technology! The requirements of combining interest, clarity, and accuracy all too often bedevil the scientific reporter. It is admittedly a difficult task. An important step in fostering better reporting is the George Westinghouse Science Writing Award Fund recently announced by the American Association for the Advancement of Science. The purpose of this Fund, supported by Westinghouse Electric Corporation, in commemoration of the 100th anniversary of the birth of George Westinghouse, is to give national recognition to newspaper writers and newspapers contributing most to better popular understanding of the achievements of science and technology. The Fund provides two annual rewards: An award of $1000 to a newspaper writer for outstanding science reporting of the year and a citation to the newspaper with the most complete, authoritative and interesting science news coverage. In addition, other citations may be given for distinguished service in science journalism. The first annual awards, covering the year 1946, will be announced by the A.A.A.S. in March, 1947.

In This Issue

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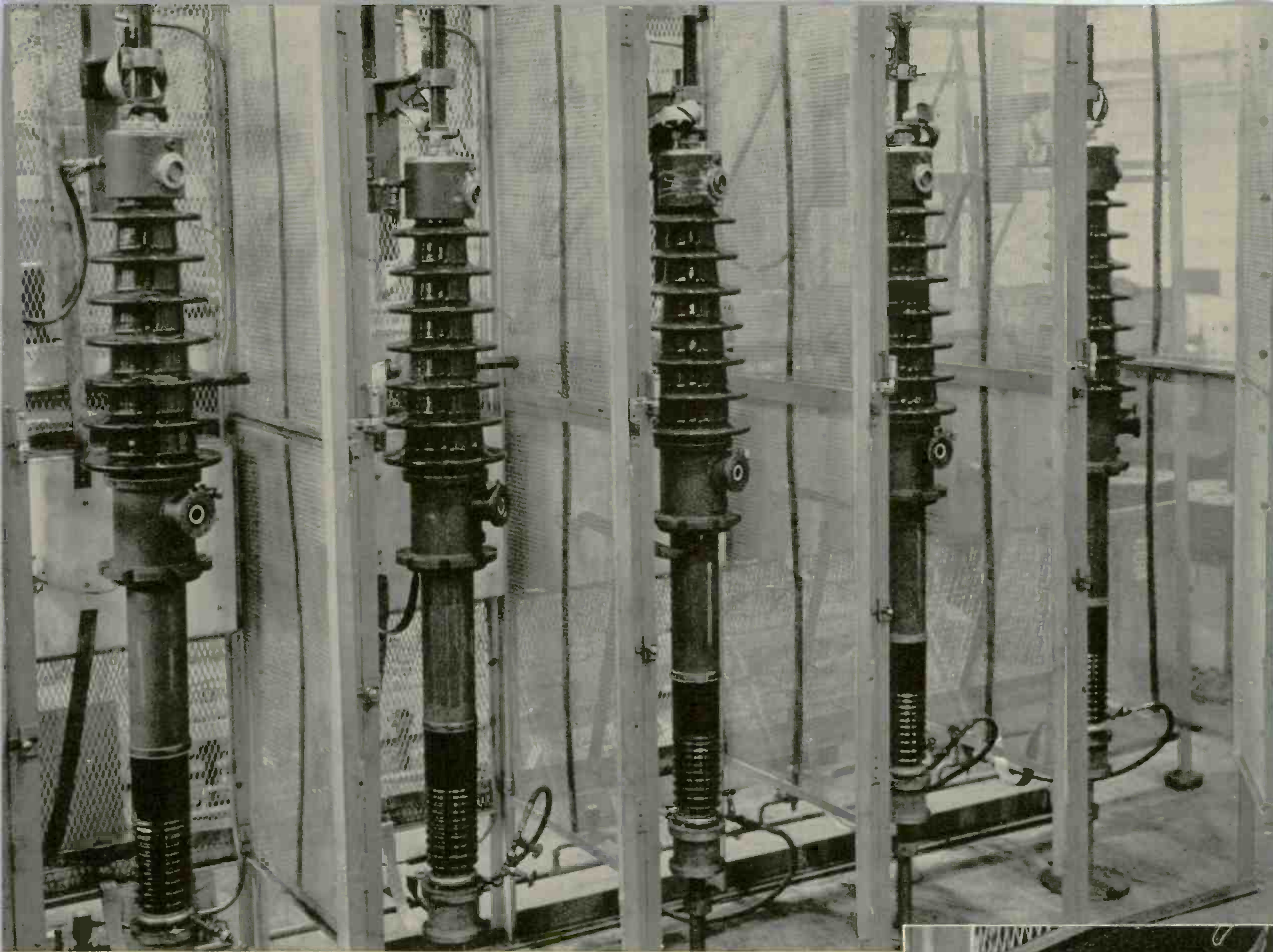
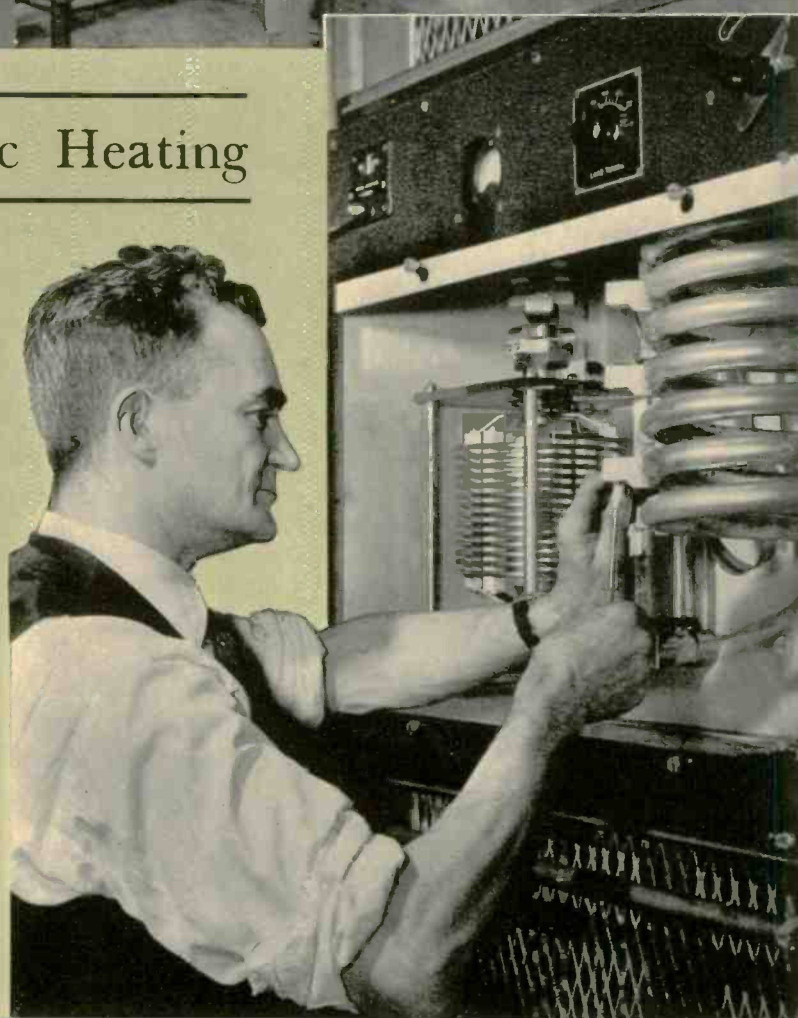


Better Bushings Via Dielectric Heating

High-frequency heating is an ideal method of drying out condenser bushings during production. The bushing core is a series of equal capacitors, and the volume of paper insulation in each layer is about the same. High-frequency energy applied across the condenser layer produces almost uniform heating throughout. The high frequencies available from electronic generators now make this desirable scheme applicable to the production line. In addition to being a superior method of drying out bushing insulation, high-frequency heating reduces the time required by eight to ten hours. The above five bushings are being dried out electronically while to the right is a part of the high-frequency apparatus.



The Relation between Energy and Mass

DR. FREDERICK SEITZ, JR., *Head, Department of Physics, Carnegie Institute of Technology*

ONE of the extremely important corollaries of the theory of relativity promulgated by Einstein in 1905 is the principle that all forms of energy possess inertia, which is most commonly associated with matter. Thus a body that contains heat energy should have somewhat more mass than an otherwise identical but colder body. Similarly a hollow box with perfectly reflecting internal walls has more mass if radiant energy is streaming back and forth within these walls than if the radiation is absent. According to the theory, the relationship between the components of mass M and the energy E is

$$M = \frac{E}{c^2}, \text{ or } E = Mc^2 \qquad (1)$$

in which c is the velocity of light, or 3×10^{10} cm per second in the centimeter-gram-second (cgs) system of units. In this system, M is in grams and E in ergs.

The atomic bomb, among other things, catapulted Einstein's mass-energy relationship into the engineer's world. All of our accustomed heat reactions are of the chemical type in which only the outer electrons of atoms participate and the nuclei and inner electrons remain aloof. Now we have a vastly different sort of reaction, with a million times greater heat release. In this the atom nucleus is involved—and with it all phases of engineering.

One may reasonably ask why the velocity of light should enter into this fundamental equation. The simplest answer to this question is that the velocity of light is a very basic quantity in the theory of relativity and hence enters into many of the equations derived from it. It is notable, for example, that the velocity of light is the same for all observers, regardless of how fast they are moving relative to one another, i.e., it is a basic constant. Moreover, this velocity is the fastest that any form of energy can be propagated.

When Einstein gave the world this mass-energy formula, it seemed likely that the relation was only of philosophical interest and might always remain so. This was because the mass represented by all ordinary amounts of energy conversions is so infinitesimally small compared to the mass of the materials involved in the generation or storing of this energy. This expectation has been altered, however, by the advent of laboratory-controlled nuclear reactions in which elements are transmuted, for the changes in mass that occur in these reactions turn out to be comparable to the masses of the elements involved. More specifically, the atomic bomb abruptly changed engineers' view of the Einstein relation.

The Mass Changes in Ordinary Chemical and Physical Processes

Consider the changes in mass that occur in the course of ordinary chemical reactions. A typical reaction of common interest is that between hydrogen and oxygen to produce water. When 18 grams of water (i.e., two-thirds ounce; an amount equal to the molecular weight of water and referred to as one mol) are produced by the reaction of hydrogen and oxygen, 2.4×10^{12} ergs (67 watthours) of heat energy appear. Although this is an appreciable amount of heat, it represents the disappearance of an almost undetectable but calculable amount of mass.[1] The loss of mass associated with the formation of each gram of water is one and a half millionths of a millionth of a gram. That much has been converted to energy—an exceedingly small proportion!

The more common heat-producing reaction is the burning of coal. One ton of carbon (to be more precise) combined with oxygen produces 28 million Btu or 8200 kilowatthours of energy. Here, too, the mass disappearance is infinitesimal, twelve millionths of an ounce or one ten billionth of the total.

Before comparing this change in mass with measurable changes, we may consider another typical problem. When one mol of graphite (12 grams or nearly one half ounce) is heated from room temperature to 7500 degrees F, approximately 100 Btu are absorbed in the form of heat. The absorption of this energy results in a fractional increase in the mass of the graphite that is closely comparable to that lost by hydrogen and oxygen in the reaction just discussed.

These mass changes and all others in the familiar heat reactions are so insignificant that, although predicted by Einstein, they have been considered of no engineering importance. They are indeed beyond measurement.

The most sensitive instrument for measuring changes in mass by direct means is the mass spectrograph,* which is used to determine the weights of both atoms and molecules. Although the most highly refined mass spectrographs have made it possible to determine differences in the mass of the lightest elements to several parts in one million, even this sensitivity is, unfortunately, about one million times too coarse to detect the changes in mass that occur when hydrogen and oxygen combine to form water. Similarly we must conclude that the changes in mass that occur when ordinary bodies are heated to temperatures attainable even in the laboratory at present are at least a million times too small to detect by any means now available.

The Energy Associated with Ordinary Masses

The fact that the changes in mass associated with ordinary reactions are so exceedingly small compared with the masses

[1]See appendix for numbered references.
*See "The Mass Spectrometer." J. A. Hipple, *Westinghouse* ENGINEER, Nov. 1943, p. 127.

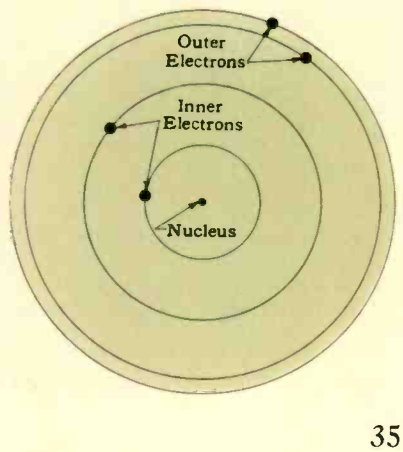


Fig. 1—A schematic representation of the atom. The electrons move in orbits about the positively charged central nucleus. Only the outermost electrons are appreciably influenced by chemical binding. The diameter of the orbits of these electrons is of the order of 5×10^{-8} cm in most atoms. The nucleus is about 100 000 times smaller, but contains almost all of the mass of the atom.

used to release the energy shows that the latent energies associated with ordinary masses are enormous. It follows at once from the fundamental mass-energy equation[2] that the energy associated with one ounce of matter—any matter—is about 707 million kilowatthours, or equivalent to the yearly output of an 80 000-kw power station at 100 percent load factor. This is equal to the energy released in the chemical formation of about 211 000 tons of water from hydrogen and oxygen.

Although this observation is astonishing, it is, unfortunately, not very useful unless we have at hand a mechanism whereby the energy resident in matter may be released, either in part or in full. This, in a sense, is the real problem of modern physics, and is one on which substantial progress has been made in the last 15 years, dramatically demonstrated in New Mexico and in Japan.

Nuclear Reactions and Mass Changes

All atoms are composed of negatively charged electrons revolving, in more or less planetary fashion at various radii, about a central positively charged nucleus which contains almost all of the mass of the atom, Fig. 1. The coulomb field of the nucleus prescribes the nature of the electronic orbits. The charge on the nucleus is always an integer multiple of the charge of the electron, with reversed sign. This integer, called the *atomic number* (designated by P), is the number of planetary electrons in the atom when it is in its normal, uncharged state. Likewise it is the number of protons in the normal nucleus. Thus the atomic number for hydrogen is 1, for carbon 16, and for uranium, the most massive of nature's elements, the atomic number is 92.

The chemical properties of atoms are determined by the properties of the outermost planetary electrons. When atoms are combined in ordinary chemical reactions, it is the motion of these electrons that is altered; the nuclei and the innermost orbital electrons are not affected appreciably.

All power derived from the combustion of fuels, ordinary explosions and other chemical processes—even muscle power—utilizes the energy liberated when atoms exchange or share between themselves the electrons that form the outer portion of an atom's structure. Indeed, only those electrons farthest away from the nucleus of an atom are involved in ordinary chemical reactions, and even in the most energetic of them, the nucleus is not disturbed. Thus, a carbon atom retains its identity when it is taken through a complicated series of organic reactions, or when it is converted to carbon dioxide in the combustion of a fuel.

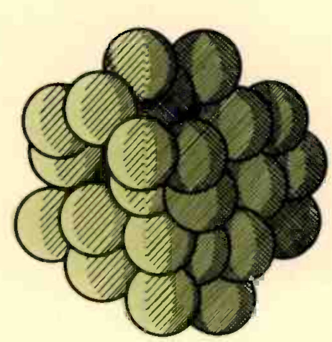


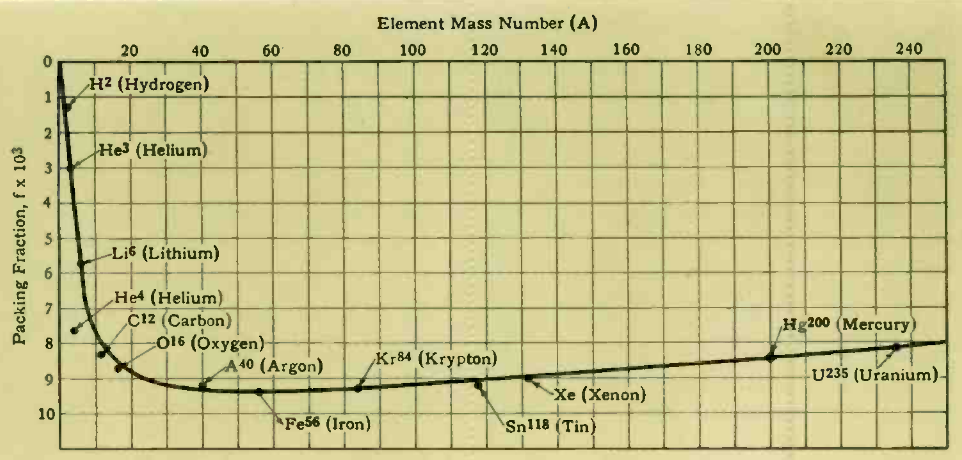
Fig. 2—Schematic representation of a typical nucleus. It is a tightly packed cluster of neutrons and protons, which are constantly moving relative to one another. The diameter of the nucleus is of the order of 5×10^{-13} cm in typical cases.

Since 1932, when the neutron was discovered, all nuclei are known to be composed of protons and neutrons, which are bound together by forces of mutual attraction, Fig. 2. The proton, which appears in isolated form in the nucleus of ordinary hydrogen, has a positive charge equal to the negative charge of the electron, but is 1840 times heavier. The absolute mass of the proton is 1.673×10^{-24} gram; its mass is 1.0076 on the relative scale for which the mass of oxygen is arbitrarily set at 16.000. The neutron, which is not found free in nature and which can be made free only for short periods of time, has no charge and possesses a mass slightly larger than that of the proton. This mass is 1.0089. The integer that gives the number of neutrons in a given nucleus is commonly designated by N. Similarly the sum of the neutrons and protons, $N + P$, gives the total number of particles in the nucleus and is commonly called the *mass number*, A.

Inasmuch as the charge on the nucleus is determined by the number of protons and because this charge determines the number and behavior of the orbital electrons, all atoms having the same number of protons belong to the same chemical species, regardless of the number of neutrons the nucleus may contain. In fact, many elements possess mixtures of atoms, or *isotopes*, in which the number of neutrons in the nuclei differ. All isotopes of an element are chemically identical (hence inseparable by ordinary chemical means) and differ in mass number only by the differences in the neutrons in their nuclei. For example, two types of hydrogen atoms are stable. In one of these the nucleus is composed of a single proton; in the other it is composed of a proton and a neutron in combination. The latter type of hydrogen atom (heavy hydrogen) is relatively rare, being present to only about one part in 5000 in natural hydrogen.

It is customary to designate the element of given P and A with the symbol $_PCh^A$, where Ch is the chemical symbol. For example, ordinary hydrogen is designated as $_1H^1$, whereas

Fig. 3—The variation of the packing fraction with mass number. The values are plotted in a negative direction for clarity. The units used in the vertical axis are 10^{-3} relative mass units in the scale for which the mass of oxygen is 16. It will be seen that maximum stability occurs in the vicinity of iron, and that both the very light and the very heavy elements are less stable than those of intermediate mass. He^4 lies appreciably below the curve, showing that helium is unusually stable for a light atom.



the hydrogen containing a neutron is designated $_1H^2$ because $A = 2$ for it. Similarly, the most abundant isotopes of helium and oxygen are designated by the symbols $_2He^4$ and $_8O^{16}$, respectively. In this terminology the neutron receives the symbol $_0n^1$ because its charge is 0 and its mass number is 1.

If the forces between neutrons and protons when combined to form a nucleus were very small, in the sense that the energies of combination were comparable to those of the atoms in ordinary chemical reactions, the mass of a nucleus containing P protons and N neutrons would, for all practical purposes, be equal to the total mass of the constituent particles. We might then write

$$M\ (P, N) = 1.0076P + 1.0089N \quad (2)$$

This rule would be the counterpart of the rule of ordinary chemistry that states that the mass of a compound is equal to the mass of its constituent atoms, and which, as discussed, is valid only as an approximation. The mass deficit or excess in an equation of a chemical heat reaction is neglected because it is insignificant. For a nuclear equation to balance, one side must contain, in addition to the masses, one factor significant of the energy involved. Thus equation 2 must be written

$$M\ (P, N) = 1.0076P + 1.0089N - E \quad (3)$$

where E is the binding energy in mass units.

Actually the energies of interaction of the nuclear particles are so great that the changes in mass that occur are well within the accuracy of observation of good mass spectrometers. Consider, for example the reaction between two neutrons and two protons to form helium. The mass of the two neutrons is 2.0178 and of the protons, 2.0152, or 4.0330 total. When combined to form a helium nucleus, however, their mass is 4.0028. Hence there is a decrease of 0.0302 unit of mass when helium is formed of the elementary particles. This represents nearly one percent of the mass of the helium atom. In more commonplace terminology, it represents an energy release of nearly five million kilowatthours per ounce (seventeen billion Btu) of helium produced. This energy evolved could appear in many forms, for example, as x-rays or in the form of kinetic energy.

Clearly then the masses of nuclei differ appreciably from the aggregate mass of the free constituent particles. Mass can be said to be conserved in such reactions, even in a practical sense, only if the mass associated with the energy evolved is taken into account.

For example, in the nuclear reaction by which helium is formed from hydrogen

$$2N + 2P = {}_2H^4 - 0.0302$$

The fact that nuclear reactions involve appreciable changes in mass suggests that changes in mass are a convenient way of determining the energy of these reactions. For example, the difference between the mass of an atom and the mass of its components separately provides a measure of the energy of cohesion of a given nucleus, i.e., the energy required to break the nucleus into isolated component particles. This difference is commonly called the *mass defect*, or *binding energy*.

The physicist has found it appropriate to employ as a unit of energy the *electron volt*. When a particle having the charge of one electron falls through an electric potential of one volt, it gains a kinetic energy of one electron volt (1 *ev*). This unit of energy is widely used as a measure of the energy of individual atoms or molecules. Thus most chemical reactions involve an energy change that is of the order of one electron volt per molecule.

A list of the mass defects of common elements is given in table I. It should be reiterated that these are the energies released when nuclei are formed from free neutrons and protons. It is readily seen that the numbers are about a million times larger than the heats of reaction of chemical systems.

It is interesting to consider another quantity that is closely related to the mass defect. This quantity, which is called the *packing fraction*, f, is equal to the mass defect, D, divided by the number of particles in the nucleus, A. The packing fraction provides a measure of the binding energy of a nucleus *per particle involved*. The larger the packing fraction, the greater the stability of the average particle in the nucleus. Table I contains values of the packing fraction for the elements listed, whereas Fig. 3 shows the packing fraction in graphical form. For purposes of visualization, the values of the packing fraction are plotted in the figure in the negative direction. Thus the most stable elements appear near a minimum of the curve, instead of near a maximum. The packing fraction curve discloses interesting facts:

1—The stability increases very rapidly in going from the lightest element (hydrogen) to approximately the middle weight elements, just beyond iron, and then gradually decreases again. It follows that the light elements and the heavy elements are less stable than those of intermediate mass, such as zinc and copper.

2—Some of the lighter elements, most notably helium and oxygen, are much more stable than their neighbors. As a result, the values of their packing fractions do not lie exactly on the smooth curve, but below it.

The explanation of these two facts is not in the province of the present article, although they present some of the most basic problems of nuclear structure. We shall be content with accepting the empirical observation and drawing the important conclusion that energy would be released if the very light nuclei could be combined to form heavier ones and if the heaviest nuclei could be split into lighter ones.

The first of these two exothermic processes is believed to take place in the hot interior of stars. In particular, the interior of the sun is thought to be at a temperature of about 20 million degrees and that at this temperature the following sequence of reactions is taking place spontaneously:

$$\begin{aligned} {}_6C^{12} &+ {}_1H^1 \rightarrow {}_6C^{13} + e^+ \\ {}_6C^{13} &+ {}_1H^1 \rightarrow {}_7N^{14} \\ {}_7N^{14} &+ {}_1H^1 \rightarrow {}_7N^{15} + e^+ \\ {}_7N^{15} &+ {}_1H^1 \rightarrow {}_6C^{12} + {}_2He^4 \end{aligned} \quad (4)$$

TABLE I—THE MASS DEFECTS AND THE PACKING FRACTIONS OF IMPORTANT ELEMENTS

	Mass Defects			Packing Fraction
	Mass Units X 10^{-3}	kgcal/mol X 10^7	Electron Volts Per Atom X 10^6	Mass Units X 10^{-3}
$_1H^2$ (Hydrogen)	2.35	5.05	2.19	1.17
$_2He^4$ (Helium)	30.29	65.00	28.20	7.57
$_3Li^6$ (Lithium)	34.31	71.31	31.94	5.72
$_3Li^7$ (Lithium)	42.01	90.14	39.11	6.00
$_4Be^9$ (Beryllium)	62.3	133.7	58.0	6.92
$_5B^{10}$ (Boron)	69.2	148.4	64.4	6.92
$_5B^{11}$ (Boron)	81.4	174.7	75.8	7.40
$_6C^{12}$ (Carbon)	98.6	211.6	91.8	8.22
$_6C^{13}$ (Carbon)	103.8	222.9	96.7	7.98
$_7N^{14}$ (Nitrogen)	112.0	240.4	104.3	8.01
$_7N^{15}$ (Nitrogen)	123.5	265.1	115.0	8.20
$_8O^{16}$ (Oxygen)	136.6	293.2	127.2	8.53
$_8O^{17}$ (Oxygen)	141.1	302.6	131.3	8.30
$_{18}A^{40}$ (Argon)	368	788	342	9.20
$_{22}Ti^{46}$ (Titanium)	446	957	415	9.30
$_{26}Fe^{56}$ (Iron)	523	1123	487	9.35
$_{36}Kr^{84}$ (Krypton)	783	1680	729	9.30
$_{50}Sn^{116}$ (Tin)	1080	2330	1011	9.15
$_{54}Xe^{132}$ (Xenon)	1190	2559	1110	9.00
$_{64}Gd^{158}$ (Gadolinium)	1390	2745	1290	8.80
$_{82}Pb^{204}$ (Lead)	1700	3641	1580	8.35
$_{92}U^{238}$ (Uranium)	1900	4103	1780	8.00

TABLE II—CONVERSION TABLE FOR ENERGY UNITS

Multiply	By	To Obtain
Mev..........	1.07×10^{-3}	mass units
	1.60×10^{-6}	ergs
	3.83×10^{-14}	gram cal.
	4.45×10^{-20}	kw. hrs.
Mass units	9.31×10^{2}	Mev
	1.49×10^{-3}	ergs
	3.56×10^{-11}	gram cal.
	4.15×10^{-17}	kw. hrs.
Ergs..........	6.71×10^{2}	mass units
	6.24×10^{5}	Mev
	2.39×10^{-8}	gram cal.
	2.78×10^{-14}	kw. hrs.
Gram cal......	2.81×10^{10}	mass units
	2.62×10^{13}	Mev
	4.18×10^{7}	ergs
	1.16×10^{-6}	kw. hrs.
Kw. hrs.......	2.41×10^{16}	mass units
	2.25×10^{19}	Mev
	3.60×10^{13}	ergs
	8.60×10^{5}	gram cal.

in which e^+ is a positive electron or positron. Each reaction in this series has been studied under laboratory conditions with the use of protons accelerated to high rates of speed with man-made devices. Each reaction is known to be exothermic. In the first and third reactions positive electrons, to be discussed later, are emitted. The sum total of the four reactions is equivalent to the single reaction

$$4\,{}_1H^1 \rightarrow {}_2He^4 + 2e^+$$

as simple addition of both sides of the four equations shows. Thus, carbon merely plays the role of a catalyst and the basic reaction is that of forming helium from hydrogen. Other reactions releasing enormous quantities of heat are likely.

The release of energy by the degradation of the heavier elements into lighter ones is accomplished in the fission of uranium (${}_{92}U^{235}$) and plutonium (${}_{94}Pu^{239}$). Both of these isotopes are made unstable when a neutron is added to their structure; as a result they proceed to split into two nearly equal fragments. The energy released in this splitting process is 200 million ev per atom, or 650 000 kwhr per ounce.

The Complete Conversion of Matter into Energy

In all reactions mentioned only a fraction of the matter present is transformed into available energy. In the case of the transformation of hydrogen into helium this is nearly one percent, but the conversion is still not complete. In fact, both in this reaction and in the fission of uranium and plutonium the total number of protons and neutrons is not altered so that the number of material particles is not changed. They are simply rearranged into a more stable form. The bonus derived as heat is related to the difference in stability between the original and the end substances. Or looking at the problem in a different way, the mass of the final substances is slightly less than that of the original substances.

Can we expect to convert material particles completely into energy? In the first and third of the hydrogen-to-helium reactions an electron having a positive charge is produced. These positive electrons, which have the same mass as an ordinary negative electron, exist only briefly. As soon as they have an opportunity to collide with a negative electron they combine with it and produce x-rays, which are just light waves having a very short wavelength. In this process, two material particles—a positron and an electron—combine to produce radiant energy. Their mass disappears entirely. It can be said without ambiguity that in this case the conversion of ponderable matter to energy is complete.

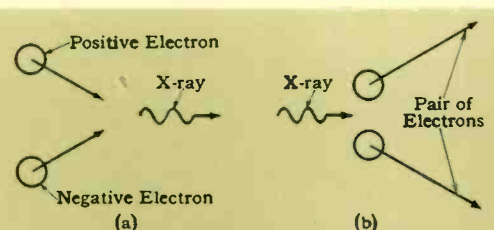


Fig. 4—The annihilation and generation of pairs of electrons of opposite charge. In (a) a positive and negative electron combine to form an x-ray. All of the "ponderable mass" of the charged particles is converted into electromagnetic radiation. In (b) is shown the reverse process, in which x-rays are converted into matter consisting of positive electrons (i.e. positrons) and negative electrons.

The reverse process has also been observed. In fact, positive electrons were first discovered in this way. The hardest x-rays (i.e., shortest wavelength) produced in an x-ray tube operating at more than one million volts produce pairs of electrons of opposite sign when they pass close to nuclei.* The threshold energy of the x-rays is just the value needed to generate the mass of the two electrons, one positive and the other negative. Any energy the x-rays possess above this threshold value is converted into the kinetic energy of motion of the electrons. The positive and negative electrons thus formed are, as pointed out, shortlived. They recombine, their mass disappearing in favor of radiant energy, this time of longer wavelength than initiated the process.

It is not too much to expect that other material particles can be generated and annihilated in a similar fashion and that these processes will be observed in the near future. From the standpoint of the fundamental mass-energy relation we can state with assurance that protons and neutrons, the fundamental bricks of ordinary matter, will not be generated until units of energy of the order of one billion electron volts are available for the conversion, because this is the energy associated with the mass of either of these particles. Thus before x-rays could be used to generate neutrons or protons, it would be necessary to obtain rays of the hardness that would be produced in a tube that operates at one billion volts or more, which is only ten times larger than the highest voltages attained thus far. Some cosmic rays have more than this amount of energy available for inducing reactions. Possibly the first generation of protons and neutrons will be observed by studying the reactions induced by cosmic rays.

Man-made transformations of this type will occur in laboratories only when machines have been devised that can supply charged particles with kinetic energies of the order of one billion electron volts. This probably will come within the next decade. Einstein's astounding prediction 40 years ago of the interchangeability of mass and energy has assumed engineering significance. The principles of nuclear physics must be added to the engineer's handbook of fundamentals.

APPENDIX

1—The mass lost when hydrogen and oxygen are combined to form one mol (18 grams) of steam is

$$M = \frac{E}{c^2} = \frac{2.4 \times 10^{10}}{9 \times 10^{20}} = 2.7 \times 10^{-11} \text{ grams}$$

The mass per gram of steam is

$$M = \frac{2.7 \times 10^{-11}}{18} = 1.5 \times 10^{-12}$$

2—The energy associated with a given amount of mass is

$$M = \frac{E}{c^2}, \quad E = M \times c^2$$

E per gram $= 1 \times 6 \times 10^{20}$ ergs

E per ounce $= 28.35 \times (9 \times 10^{20}) \times (2.78 \times 10^{-14})$
$= 707$ million kilowatthours

3—Packing fraction is equal to $f = D/A$
where D is the mass defect, and A is the number of particles in the nucleus.

*For discussion of formation of x-rays see inside front cover, *Westinghouse ENGINEER*, July, 1945.

Banking of Distribution Transformers

—*The Methods and Their Merits*

Teamwork is as important in the grouping of distribution transformers on electrical circuits to carry the load as it is in the arrangement of football players on the gridiron to carry the ball. Economies in material, less voltage flicker, and reserve strength to meet the unexpected are all gained by coordinating the individual units into an integrated whole. In this article—one of three on the subject in this issue—are mentioned various schemes of tying distribution transformers into banks. The advantages of each of the several basic schemes and the various methods of protection are discussed.

JOHN S. PARSONS, *Distribution Engineer, Westinghouse Electric Corporation*

THE interconnection of the secondaries of distribution transformers that are supplied by the same primary feeder—referred to as banking—has several conspicuous and long-recognized advantages. Outstanding among them is the reduction of voltage flicker. A reduction of maximum voltage flicker on the secondaries of from 40 to 70 percent is obtainable economically. Other important advantages include better average voltage conditions on the secondaries, a saving in transformer capacity and secondary copper, and greater flexibility for handling load growth. Experience indicates that a saving, in many cases as high as 35 percent, can be made in installed transformer capacity, and that the secondary copper can be one or two sizes smaller. It is unnecessary to change the secondary circuits to take care of load growth. Usually the installation of one more transformer in the bank accommodates load increases in several locations on the secondaries.

Tying together the secondaries of a number of distribution transformers permits advantage to be taken of the greater load diversity existing among a much larger group of consumers. Loads are shared by several transformers, and at least a two-way secondary feed is provided to consumers' services. These are the factors that produce the advantages named. They may also result in improved service reliability when compared with radial secondaries. Whether improved service reliability is obtained depends to a considerable extent on the protective methods used when the transformers are interconnected.

In short, most of the normal-operation merits of the eminently successful secondary-network system are achieved without the special apparatus required with secondary networks. A banked-secondary installation, however, is supplied by a single primary feeder. Hence the banked-secondary system cannot offer the same high degree of service reliability under fault conditions provided by the secondary network.

Secondary banking is by no means new. Several power companies have devised systems of their own, almost all of them relying upon some scheme of fuses for protection. The general idea has grown markedly in favor during the past ten years. A survey made in 1943 showed that, of 166 power companies contacted, 48 percent bank some of their distribution transformers. The increase of motor-driven appliances in residences, such as washers, refrigerators, forced-air heating systems, and air-conditioning equipments is resulting in complaints of light flicker from customers supplied by the usual radial secondaries. In many areas, voltage flicker, not voltage regulation, is the determining factor in the size and arrangement of distribution transformers and secondary circuits. Efforts to overcome this flicker problem economically are probably largely responsible for the growing popularity of banking, as the other

Fig. 1

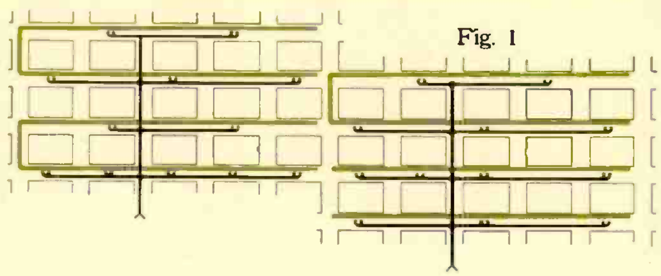


Fig. 2

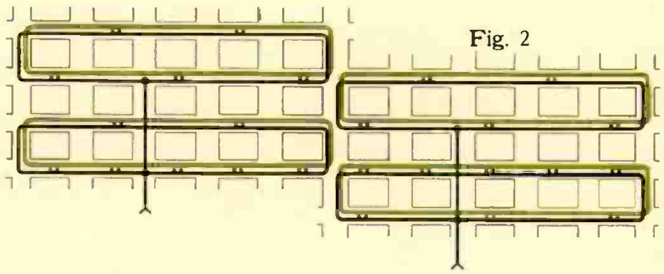


Fig. 3

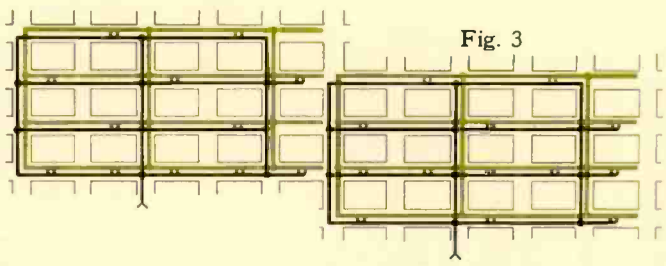


Fig. 1—In line-type banking, secondaries (shown in color) are connected into one continuous circuit supplied by several transformers, all energized from the same primary phase.

Fig. 2—The two-way feed obtained by tying the ends of the secondaries into continuous loops markedly increases service continuity at only a slight increase in secondary copper.

Fig. 3—Adjoining secondary loops can be connected together to form a grid. The ultimate in the reduction of voltage troubles and the least installed transformer capacity are found in this connection, but the expense is greater and the necessary back-up facilities are more difficult to provide.

important advantages of banking at the present do not appear to be so generally recognized.

Three Schemes of Banking

Distribution transformers can be banked in three ways. The line type, the loop type, and the grid type shown in Figs. 1, 2, and 3, respectively. The line type of banking requires the shortest length of secondary copper. However, it does not permit the maximum utilization of secondary-banking advantages. The secondaries at the two ends are radial. Hence, in the line-type system the voltage flicker is not reduced as much or the voltage held as uniform as with the loop and grid types. More transformer capacity may be required to prevent overloading when an end transformer is out of service. The service reliability obtainable with other types of banking cannot be matched with the line-type system using any economical protection scheme.

The loop type of banking of Fig. 2 is the most desirable form for general use. The additional secondary copper required over that utilized by line-type banking is relatively small, frequently no more than ten percent. Loop banking requires no more protective equipment than does the line type, but it provides the maximum service reliability obtainable with banking. All other advantages of banking are also provided to a greater degree than is found with line-type banking.

Both line and loop banking generally reduce voltage flicker to an acceptable level. Voltage flicker can be reduced further, however, by using the grid type of banking shown in Fig. 3. To obtain any marked reduction in voltage flicker over what can be obtained with the loop type of banking, the grid type requires at least 15 percent greater length of secondary copper than the loop type. The amount may be much larger than this, depending upon the degree to which the secondaries are gridded. If the secondaries are gridded to a

Methods of Protecting


Fig. 4

Fig. 4—No protection on primary or secondary side of transformers. On a transformer failure the feeder breaker trips or the branch fuse blows. The result is an outage to all customers on the feeder or branch. A secondary fault that does not burn clear causes either the primary circuit to be de-energized or failure of one or more transformers. In either case, service is interrupted or impaired. A prolonged overload also results in one or more transformers being burned out. In case of trouble, the extent of the outage is greater than when using the usual radial secondaries. Transformers may burn out. This arrangement requires minimum initial investment.


Fig. 5

Fig. 5—Fuses on primary side of transformers; no protection on secondary side. A transformer failure causes the fuse associated with the faulty transformer to blow and probably also those associated with the good transformers. If the fuses on some of the good transformers do not blow, the transformers probably burn out. In either case, service is interrupted or seriously impaired to all customers on the banked secondaries. When a secondary fault does not burn clear, all primary fuses blow, or if some fuses do not blow, the transformers probably burn out and service is interrupted or impaired. A prolonged overload results in one or more transformers being burned out. In case of trouble, the extent of the outage is greater than when using the usual radial secondaries and transformers may burn out.


Fig. 6

Fig. 6—Fuses on secondary side of transformers; no protection on the primary side. A transformer failure causes the feeder breaker to trip or the branch fuse to blow resulting in an outage to all customers on the feeder or branch. On a secondary fault that does not burn clear, all secondary fuses blow, or if some fuses do not blow the transformers probably burn out and service to all customers on the banked secondaries is interrupted or impaired. A prolonged overload results in one or more transformers being burned out. In case of trouble the extent of the outage is greater than when using radial secondaries and transformers may burn out.


Fig. 7

Fig. 7—Fuses on primary and secondary sides of transformers. A transformer failure causes the primary and secondary fuses associated with the faulty transformer to blow and disconnects the transformer from the system. If no other fuses blow, there is no interruption to service. However, the secondary fuses on one or more of the good transformers may blow, leaving the remaining transformer or transformers overloaded so they may burn out and service to all customers on the banked secondaries is interrupted or impaired. A secondary fault that does not burn clear causes all secondary fuses to blow, or if some fuses do not blow, their associated transformers probably burn out, and service is interrupted or impaired. A prolonged overload results in one or more transformers being burned out. In case of trouble, the extent of the outage is greater than when using the usual radial secondaries and transformers may burn out.


Fig. 8

Fig. 8—Protective links on primary side of transformers and internal secondary breakers on the secondary side. On a transformer failure the primary links blow and the secondary breaker associated with the faulty transformer trips to disconnect the transformer from the system. If no other secondary breakers open, there is no interruption to service. Possibly one or more breakers associated with the good transformers may open leaving the remaining transformers to carry the entire load. This is much less likely to occur, however, than when secondary fuses are used. If the remaining transformers are seriously overloaded, their breakers trip and prevent any transformers from burning out. Should this happen, service is interrupted to all consumers on the banked secondaries. A secondary fault that does not burn clear causes all secondary breakers to trip if the current through the transformers is high enough for serious overheating. On a prolonged overload the secondary breakers trip, also preventing the transformers from burning out. In case of trouble, the extent of the outage is greater than when using the usual radial secondaries. The transformers are protected against burnouts.


Fig. 9

Fig. 9—Fuses on primary side of transformers; fuses or breakers for sectionalizing secondaries; no protection in secondary leads of transformers. A transformer failure causes primary fuses associated with the faulty transformer to blow and the secondary fuses or breakers associated with its secondaries to open. Service is interrupted only to those consumers fed from the faulty transformer. A secondary fault that does not burn clear causes the secondary fuses or breakers at the ends of the faulty secondaries to open and probably the primary fuses associated with the transformer connected to the faulty secondaries to blow. If the fault current is not large enough to cause the primary fuse to blow, the transformer will burn out. In either case service is interrupted to only those consumers fed from the faulty section of secondaries. A prolonged overload on a section of the secondaries causes the secondary fuses or breakers at the two ends of the section to open and the transformer connected to that section will probably burn out. This results in a service interruption to those consumers fed from the overloaded section. In case of trouble, the extent of the outage is no greater than when using the usual radial secondaries but transformers may burn out.

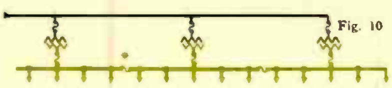


Fig. 10

Fig. 10—Fuses on primary and secondary sides of transformers; fuses or breakers for sectionalizing secondaries. A transformer failure causes the primary fuses associated with the faulty transformer to blow and usually the sectionalizing fuses or breakers associated with its secondaries to open. Service is interrupted only to those consumers fed from the secondaries associated with the faulty transformer. In some cases, the transformer secondary fuses may blow instead of the sectionalizing fuses or breakers. When this happens,

Legend

- Fuse or Protective Link
- Distribution Transformer
- Thermal-Overcurrent Breaker under Oil in Transformer Tank
- Consumer's Service Tap
- * Could Use Air Breaker Instead of Fuse

there is no interruption of service. On secondary fault that does not burn clear the sectionalizing fuses or breakers at the ends of the faulty secondaries open and the secondary fuses associated with the transformer connected to the faulty secondaries blow. Service is interrupted to only those consumers fed from the faulty section of secondaries. A prolonged overload on a section of the secondaries causes the sectionalizing fuses or breakers at the two ends of the section to open. The transformer connected to that section probably burns out. This results in a service interruption to those consumers fed from the overloaded section. In case of trouble, the extent of the outage is no greater than when using the usual radial secondaries but transformers may burn out.

Fig. 11

Fig. 11—Protective links on primary side of transformers; internal secondary breakers on the secondary side; fuses or breakers for sectionalizing secondaries. A transformer failure causes the primary links associated with the faulty transformer to blow and usually the sectionalizing fuses or breakers associated with its secondaries to open. Service is interrupted only to those consumers fed from the secondaries associated with the faulty transformer. In some cases the transformer secondary breaker opens instead of the sectionalizing fuses or breakers. When this happens there is no interruption of service. On a secondary fault that does not burn clear the sectionalizing fuses or breakers at the ends of the faulty secondaries open as well as the secondary breaker associated with the transformer connected to the faulty secondaries. Service is interrupted to only those consumers fed from the faulty section of secondaries. A prolonged overload on a section of the secondaries causes the sectionalizing fuses or breakers at the two ends of the section to open. The internal breaker associated with the transformer connected to that section opens when the transformer reaches the maximum safe temperature and thus prevents it from burning out. This results in interruption to consumers fed from the overloaded section. In case of trouble, the extent of the outage is no greater than with radial secondaries and transformers are protected against burnouts.

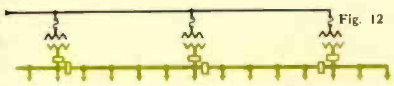


Fig. 12

Fig. 12—Protective links on primary side of transformers; internal secondary breakers for sectionalizing secondaries, tripped by current in the low-voltage leads of their associated transformers. Each sectionalizing breaker and its associated transformer-secondary breaker are tripped by the same current. However, the sectionalizing breaker is arranged to trip at a lower bimetal temperature and consequently in a shorter time than the transformer breaker for any given value of current. One transformer breaker and one sectionalizing breaker are located in each transformer tank. On a transformer failure, the primary links associated with the faulty transformer blow and the sectionalizing breakers associated with its secondaries open. Service is interrupted only to those consumers fed from the secondaries associated with the faulty transformer, except in the case of an end transformer. The sectionalizing breaker of an end transformer is connected in the end of the last tie circuit rather than in the radial circuit on the other side of the transformer. This is done so that a fault in the tie circuit does not interrupt service to the consumers on the radial circuit. This connection results in two sectionalizing breakers in the last tie circuit, and a failure of the end transformer results in a service interruption to the consumers fed from both the tie and radial circuits. On a secondary fault that does not burn clear, the sectionalizing breakers at the ends of the faulty secondaries open as well as the secondary breaker associated with the transformer connected to the faulty secondaries. Service is interrupted to only those consumers fed from the faulty section of secondaries. A prolonged overload on a section of the secondaries that is heavy enough to damage a transformer opens the sectionalizing breakers at the two ends of the section and the secondary breaker associated with transformer connected to that section before the transformer is damaged. This results in a service interruption to those consumers fed from the overloaded section. In case of trouble, the extent of the outage is no greater than with radial secondaries, and transformers are protected against burnouts.

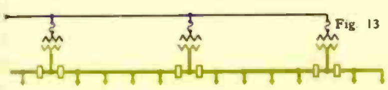


Fig. 13

Fig. 13—Protective links on primary side of transformers; internal secondary breakers (two in each transformer tank) for sectionalizing secondaries; no breaker or fuse in secondary leads of transformers. One sectionalizing breaker in each transformer tank is tripped by the current through its secondary section. It is arranged to trip at a lower bimetal current and consequently in a shorter time for any given value of current than the other sectionalizing breaker in the tank. The second sectionalizing breaker is tripped by the current in the secondary leads of the transformer. On a transformer failure, the primary links blow and the two sectionalizing breakers associated with the faulty transformer open. If the transformers are connected with a fast sectionalizing breaker in one end of each tie circuit and a slow sectionalizing breaker in the other end, service will not be interrupted to any consumers. There are two exceptions to this when line-type banking, shown in this figure, is used. If the end transformer that has the slow sectionalizing breaker connected in its associated tie circuit fails, the breaker at the far end of the tie opens. Thus service is interrupted to those consumers fed from both the tie and radial circuits associated with the faulty transformer. If the end transformer that has the fast sectionalizing breaker connected in its associated tie circuit fails, this sectionalizing breaker opens. Service to those consumers fed from the radial circuit associated with the faulty transformers is interrupted. Use of the secondary-loop type of banking eliminates severe interruptions when a transformer failure occurs. A secondary fault that does not burn clear causes the sectionalizing breakers at the two ends of the faulty secondaries to open. Service is interrupted to only those consumers fed from the faulty section of secondaries and all transformers remain in service. If the impedance of the tie circuits is appreciably less than that of the transformers, a sectionalizing breaker may open in one of the sections adjacent to the faulty section. This does not, however, increase the extent of the outage beyond the faulty section. A prolonged overload on a section of the secondaries that is heavy enough to damage a transformer causes the sectionalizing breaker or breakers in that section associated with the dangerously overloaded transformer or transformers to open before a transformer is damaged. This usually results in a service interruption to those consumers fed from the overloaded section of secondaries. In case of trouble, the extent of the outage is less or no greater than when using radial secondaries, and transformers are protected against burnouts.

high degree, that is, if secondaries are run on all east-west streets and on all (or every other) north-south streets and are tied together at the street intersections, the additional investment in secondary copper may be partially offset by using somewhat smaller size copper and less distribution-transformer capacity.

Faults on the secondaries of a banked transformer installation are relatively infrequent and most are self-clearing. The heavier fault currents obtained when the secondaries are gridded tend to make secondary faults clear quicker and more of them self-clearing than when the line or loop systems are used.

Which scheme of banking to adopt in any particular case to provide adequate service at the lowest cost is strongly influenced by the topography of the area. When all factors—such as quality of service, initial investment, operation, and maintenance—are considered, for most areas the loop type of banking, or a combination of the loop and line types proves most satisfactory.

Application Considerations

The number of distribution transformers in actual systems that have been connected on their secondary sides to form a bank varies from 2 to about 200. This depends upon the load density of the area, the type of primary circuit arrangement used, the type of banking, the protection method employed, and other factors. In general the number of transformers in a bank should not be less than 3, so as to keep the amount of installed transformer capacity down and not to overload dangerously the remaining transformers when one unit is out of service. The load served from any one bank should be kept relatively small so that, should a primary feeder fail, its load can be cut over to the three or more adjacent primary feeders. In such an emergency, about an equal amount of approximately balanced three-phase load should be connected to each of the adjacent feeders. The emergency connection should not result in transformers in any one bank being tied to different primary feeders. Various factors, including the ability to provide this emergency service, make it desirable in general to limit the transformers in a line or loop bank to about 10, and on a grid system to about 20.

Usually all transformers in a bank can be of the same size, and reasonably uniform loading can be obtained by properly locating them. Because loads are shared by transformers, the loading is seldom critical with respect to transformer location. This general rule has an exception, namely, where the secondary-tie impedances far exceed transformer impedances. The lower the secondary-tie impedances compared with the transformer impedances, the more uniform is the transformer loading and the less critical is the load with respect to transformer locations.

When more than one rating of transformer must be used in a bank, the largest transformer should preferably not exceed the rating of the smallest transformer by more than 67 percent. This is to minimize the necessary transformer capacity and the danger of seriously overloading a small transformer when a large one is out of service.

Usually banked distribution transformers are supplied over radial primary feeders having radial single-phase laterals just as are distribution transformers with radial secondaries. A single-phase branch and laterals of a three-phase primary feeder are shown supplying the transformers in Fig. 1. In some cases, primary feeders with looped single-phase laterals, as shown in Fig. 2, or gridded single-phase laterals, as shown in Fig. 3, have been used. These latter two arrangements of laterals permit all transformers to remain energized or be quickly re-energized when a lateral fault burns the conductor in two. The increased fault current resulting from either of these arrangements of primary laterals tends to increase the possibility of lateral faults burning clear. This is particularly true when the grid arrangement is used. Also the grid arrangement may permit a smaller conductor than can be used in the other two.

Any one of the primary lateral arrangements can be used with any of the three types of banking. It is doubtful whether the loop or grid arrangements can be justified where it is necessary to install pole lines just to carry the laterals. However, they often can be justified when it is a case of installing only one or two conductors on existing poles, although an additional 30 percent or more of primary conductor length is required than when using the radial laterals. The radial lateral is usually the most economical but it does not provide quite as good service and is not as flexible for load growth.

Protection and Cascading

The troubles experienced with banking have centered in the method of protection. It has been difficult to provide economical protective measures that function as desired during fault or overload conditions. The various methods of protecting banked transformer installations are illustrated and described in Figs. 4 to 13. The survey of banking practice shows the scheme of Fig. 9 is the most popular. Seventy-seven percent of the companies employing banking use it. The scheme of Fig. 7 is a poor second with six percent of the companies using it. Twenty-two percent of the companies employ one of the other methods of protection shown. These percentage figures total more than 100 because some companies use more than one method of protecting their banked transformer installations.

Most of those companies employing or considering banking are troubled by the possibility of cascading. By cascading is meant the disconnection of some or all of the good transformers in a bank following a transformer or secondary fault. Should cascading occur, the area affected is much larger than with a similar fault condition on a radial-secondary system.

In a well-designed system, cascading occurs infrequently when using any method of protection. However, the possibility of cascading varies widely with the protection method. With the method of Fig. 9 the chance of cascading is practically nil. This fact plus the small amount of protective equipment involved doubtless accounts for its popularity. An objection to this scheme is that small sectionalizing fuses must be used in the secondary tie circuits so as to clear all transformer and secondary faults that are not self-clearing. This severely limits the amount of load that can be transmitted over the secondary-tie circuits, and also increases the chance of having these fuses open unnecessarily.

The different transformer loadings that may occur with various parts of a bank out of service plus the difficulty of determining the magnitude of these loads probably increase the chance of transformer burnouts beyond that obtained with radial secondaries. The schemes of Figs. 4, 5, 6, 7, 9, and 10 do not provide protection against transformer burnouts. The development of the CSP distribution transformer made it possible to eliminate the burnout problem when banking transformers. The schemes of Figs. 8 and 11 are similar to those of Figs. 7 and 10 respectively, except that CSP transformers are used instead of conventional transformers and fuses.

A protection method employing fuses introduces the problem of securing proper fuse coordination to prevent unnecessary fuse openings. Even if the desired coordination is secured, the difficulty of fuses blowing due to lightning remains. To overcome these difficulties a special CSP distribution transformer having two secondary breakers was developed. Operation of these transformers in a bank is shown in Fig. 12.

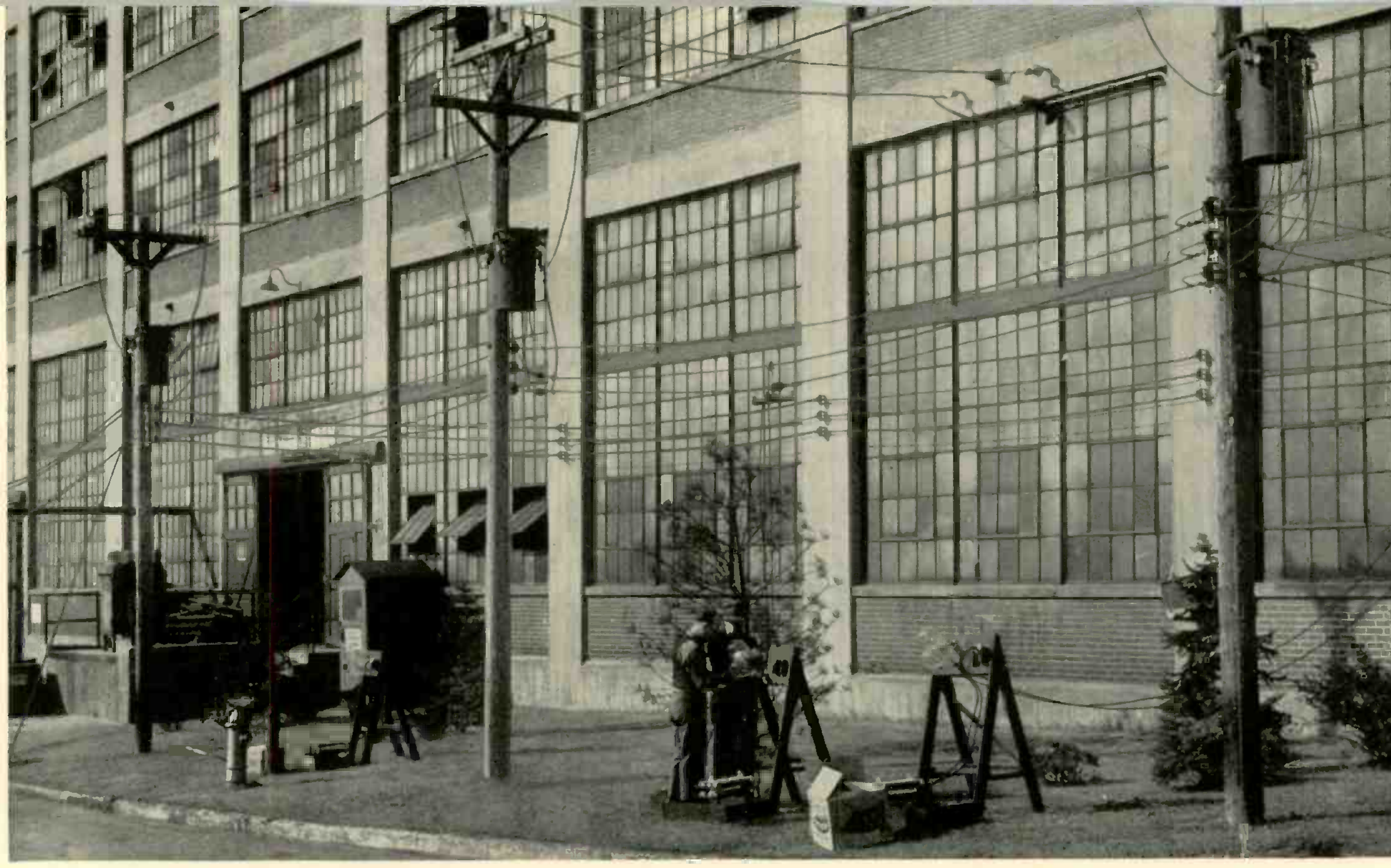
A trial installation of this kind, using loop banking, was made by a power company early in 1943. Nine companies now have in service or are completing such trial installations. Their operating experience has been satisfactory.

While this scheme, Fig. 12, eliminates the fuse problems it has two features which it was felt should be improved. First, a transformer failure interrupts service to those consumers fed from the secondaries associated with the faulty transformer. Second, a secondary fault causes the disconnection of both the defective secondary section and the transformer associated with it. This could lead to cascading if a fault occurred on one lightly loaded section of secondaries to cause the dropping of a small part of the total load and of a considerably larger part of the total transformer capacity within the bank. With a properly designed bank, this possibility of cascading is extremely remote.

To eliminate these objectionable features, the special two-breaker CSP transformer has been modified so that the breakers are connected and function differently. This modified transformer is known as the CSPB, and the way it operates in a bank is shown in Fig. 13.* The schemes of Figs. 12 and 13 were developed for line and loop banking and function best when used in the loop type. They are not used for grid banking unless the transformers are supplemented by separately mounted line-sectionalizing breakers or fuses.

This latest method of protection for banking eliminates most of the uncertainties and objectionable features previously experienced. Its principal advantages are a saving in the installed capacity of transformers, a reduction in the size of secondary copper, and an economical method for taking care of load growth and improved service considering both regulation (reduction in voltage flicker) and continuity. This new method, by permitting the greater utilization of these advantages, should permit a large increase in the practice of banking distribution transformers.

*See the companion article by A. D. Forbes, on p. 43.



This experimental banked-secondary system, with impedances between poles, is the equivalent of a one-mile line.

The Banked Secondary Transformer

Like many good ideas, widespread use of the banked secondary system of power distribution has had to wait on the practical implement. The completely self-protected transformer with two built-in circuit breakers avoids the difficulties that haunted earlier protective schemes.

A. D. Forbes

Transformer Engineer
Westinghouse Electric Corporation

The principal deterrent to the widespread application of banking of distribution transformers, with its attractive advantages, has been the lack of a thoroughly acceptable method of protection from short circuits and overloads. Until the introduction of the completely self-protecting transformer with built-in circuit breaker, most systems relied on fuses, with their attendant uncertainties and difficulty of coordination. Use of a breaker is a great advantage over fusing schemes and the early systems using CSP distribution transformers, in general, met with success. A recent improvement, in which two breakers instead of one are built into the transformer (called CSPB), removes the remaining weaknesses of the breaker-type protection and extends the zone of usefulness of the banking idea.

The new circuit connection as shown in Fig. 1 eliminates the fuses for sectionalizing a secondary circuit. This is accomplished by means of circuit breakers built into the transformer. These breakers, unlike fuses, can be coordinated with the thermal capacity of the transformers, making it possible to carry the maximum short-time overloads without risk of damage to the transformer. A further discussion of the circuit and comparison with older circuits for banked-secondary service is given in another article.[1]

[1]"Banking Distribution Transformers," by John S. Parsons, in this issue page 39.

The new transformer is illustrated in Figs. 2 and 3. The core and coils are identical to those of a standard transformer of the same rating. However, two double-pole circuit breakers (in contrast to a single breaker on the usual CSP) are mounted side by side inside the tank on the top frame of the core. Each breaker controls one of the two secondary circuits from the transformer. To provide the necessary secondary connections, five secondary bushings are furnished for supplying the two three-wire circuits (the neutral bushing is common).

It is necessary to use a tank having a minimum inside diameter of 15¼ inches to provide sufficient space to mount the two circuit breakers. Although this is a larger tank than otherwise required for the smaller kilowatt ratings it does not pose a serious problem because weights are still comparatively low as indicated by table I. The size is remarkably small for the amount of equipment included in this completely factory-assembled unit.

The detailed electrical connections of the CSPB transformer are shown in Fig. 1, and the principal connections of a bank of four are given in Fig. 4. One set of breaker contacts is in series with each of the secondary circuits. Hence a fault on one circuit can be cleared by the breaker contacts in that circuit alone. The transformer winding remains in service at all times to energize the remaining circuit.

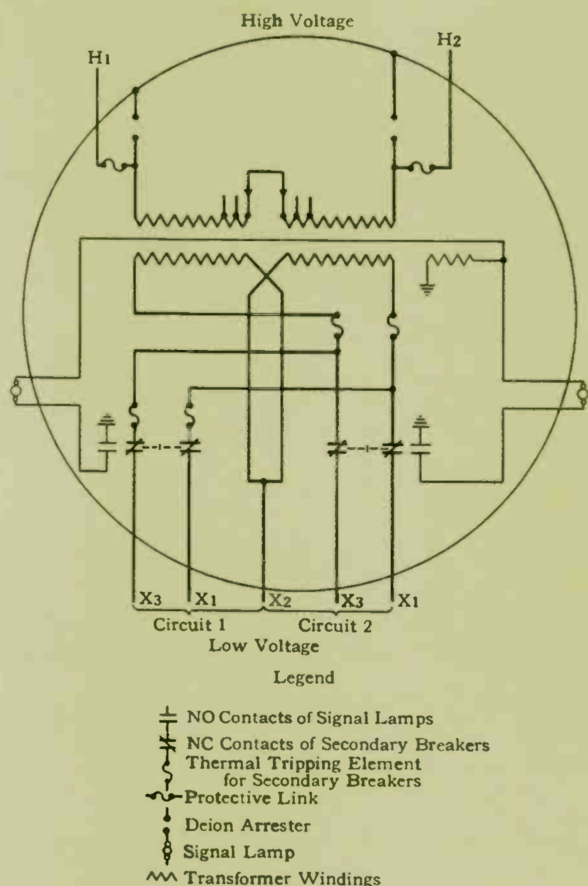


Fig. 1—The internal equipment of the CSPB transformer includes two sets of double-pole breakers for automatically disconnecting a faulted section. The difference in the connection of the breaker tripping units is important.

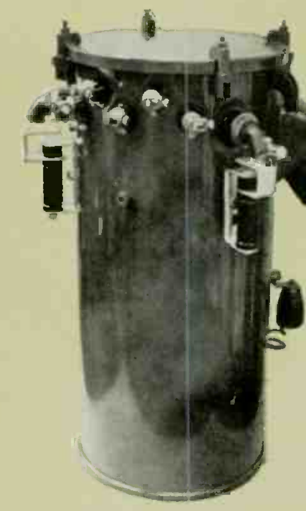


Fig. 2—Five secondary bushings project from the tank of this CSPB transformer for banked-secondary operation. Two secondary-circuit sections are supplied by connecting one to the two left bushings and the second to the two on the right. The middle stud is a common neutral for both sections.

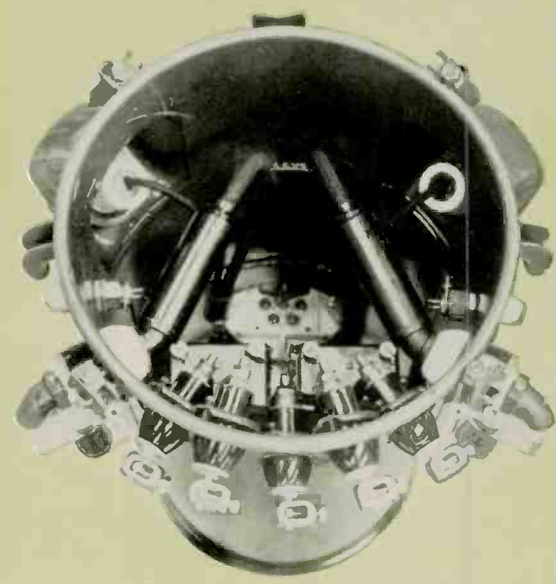


Fig. 3—Internally, the CSPB transformer is much the same as the standard CSP. The difference is in the two double-pole circuit breakers shown mounted on the top frame of the core directly under the five low-voltage bushings used for sectionalizing the secondaries.

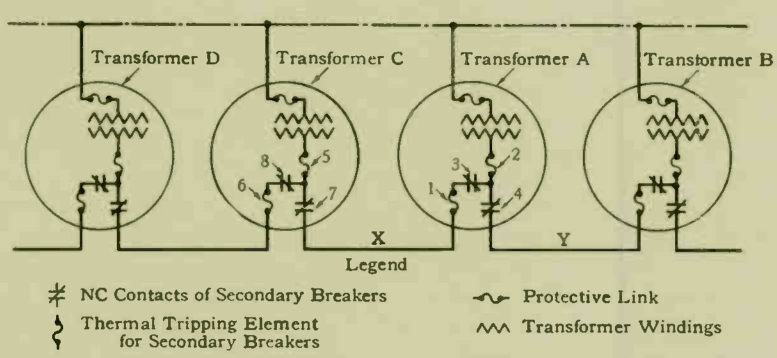


Fig. 4—Connections of four double-breaker distribution CSPB transformers into an interconnected bank.

Fault Conditions—Assume a fault on the secondary at X. Fault current is then drawn from transformer A through both bimetals *1* and *2*. Because bimetal *1* is calibrated to trip at a lower current (all breakers not having the tap between bimetal and contacts are calibrated to trip at a lower current), contact *3* opens earlier than contact *4*. This opens the circuit between transformer A and the fault but leaves transformer A connected to its other circuit. When transformer A is not the last one of a bank and before contact *3* opens, the next transformer B also furnishes some fault current that flows through bimetal *1* but will not flow through bimetal *2*. This increases the differential of operating time between these bimetals.

Fault current is also supplied by transformer C through bimetal *5*. Because the fault current supplied by transformer D through bimetal *6* usually is very much smaller because of the secondary line drop between transformer C and D, bimetal *5* trips before bimetal *6* in practically all cases, although *6* is calibrated to trip on less current. This opens contact *7* and completes the isolation of the fault.

In service, the action is similar for either line-to-line, or line-to-neutral faults. In either case, both poles of a breaker trip so that no power is furnished to the faulted section. In most cases this operation takes place without the removal of any transformer from service.

Overload Conditions—Assume that transformer A has been loaded to the point where its insulation is endangered and a portion of its load is to be disconnected by the circuit breaker. Bimetal *2* is calibrated to protect the transformer because it always carries the full winding current. Therefore, it is certain that contact *4* will open, dropping the portion of the load fed to the section Y at least in time to protect the winding. This would probably relieve the load sufficiently so that bimetal *1* does not trip and transformer A continues to supply section X. If, however, for some reason the load on section X should abnormally increase before contact *4* has been manually reclosed, bimetal *1*, which then carries the entire load current and which is calibrated to trip at a lower current, furnishes winding protection by opening contact *3* if necessary.

If a special condition is assumed where the load on transformer A from section X is considerably greater than that from section Y then it is obvious that bimetal *1* opens contact *3* before bimetal *2* opens contact *4*. If, on the other hand, the load from section X is only moderately greater than from section Y, then bimetal *2* may trip first (although it has a higher trip temperature) because it carries current to both sections X and Y whereas bimetal *1* carries current only to section X.

One set of bimetals is directly in series with the winding and controls the total load applied before a portion of it is disconnected. Protective links are connected in series with the high-voltage winding to disconnect the unit from the primary on the occurrence of a primary fault. The operation of the protective equipment of the new-type banked transformers under both fault and overload conditions is described in detail in Fig. 4. The operation, however, can be summarized as follows.

1—Faults are isolated under all conditions with transformers remaining in service to feed unfaulted sections.

2—Under fault conditions, all transformers usually continue to feed unfaulted sections.

3—The transformer is protected under all conditions.

4—In case of overloads, the circuit tripped out depends on load balance and oil temperature at time of trip. Whichever is tripped usually reduces the load sufficiently so that the other does not go out of service.

Overload conditions usually develop gradually and actual breaker tripping can usually be prevented by observance of the warning provided by signal lights. Associated with each breaker is a signal light that gives an advance warning of tripping. This is accomplished by operation from the same bimetals that trip the breaker but at a slightly lower bimetal temperature so that loading can be reduced.

Transformers of this type can be installed using either a line or loop type of secondary. The usual installation practice is to mount the secondary conductors on secondary racks. The secondary neutral is continuous throughout its length but insulators are inserted in the secondary-line wires close to each transformer pole. Transformer connections are run to each side of these insulators and connected to the two secondary sections thus produced.

TABLE I—WEIGHTS OF CSPB TRANSFORMERS

Kva	Weight in Pounds
5	288
7½	322
10	339
15	434

To simplify the connections on the pole, one circuit is brought to the three right-hand secondary bushings on the transformer and the other circuit to the three left-hand bushings, the center bushing serving as the neutral for both.

The CSPB transformer has been developed in ratings from 5 to 15 kva and will be extended upward in the near future to include the 25- and 37½-kva sizes. There appears to be little application for units smaller than 5 kva.

This new transformer makes banking possible where load density is not great enough to justify the expense of underground or overhead networks involving several primary feeders and network protectors, but where the density is heavier than in rural areas or lightly loaded residential areas. Under these conditions, this unit improves quality and reliability of service with an appreciably smaller installed transformer capacity by using both the principle of loading by copper temperature and secondary banking.

Experience with Banked Secondaries

St. George Tucker Arnold, *Engineering Department, Boston Edison Company*

The case history of one of the early banked-secondary distribution systems gives practical proof to the prophesied merits of the secondary-banking idea.

In the fall of 1943 the Boston Edison Company made an experimental installation of four 10-kva, single-phase, two-breaker, CSP transformers as a secondary bank in one of its suburban residential towns. Its service has been without incident. In that time none of the main or section breakers have operated or have the primary links blown.

The original primary and secondary layout with radial secondary distribution is shown in Fig. 1. The secondary mains are of three number-4 or number-2 conductors with a few sections of two-1/0 and a single number-2 conductor. Of the 70 customers served, 50 have electric ranges. Before banking, the area was served by three 25-kva, single-phase transformers and by one half of the capacity of a 15-kva transformer. This capacity, 82-½ kva total, had a maximum winter demand of 69 kva and a summer demand of 55 kva.

The bank of four 10-kva, two-breaker, CSP transformers is illustrated in Fig. 2. To establish this bank, it was necessary to install only one 115-foot section of three number-4 secondaries. The secondaries form a complete ring, a desirable feature for the two-breaker transformer-bank type of operation.

The locations of the transformers were carefully selected from a study of the loads on the four transformers in the radial set-up and with due consideration to the location of range customers. The peak loads on the four 10-kva transformers during the Christmas week of 1943 were 16, 15, 19, and 18 kva, a total of 68 kva. The loads indicate that the choice of locations was satisfactory.

The winter weekday load cycle for B-phase of the primary circuit is shown in Fig. 3. The 68 kva within the area being considered constitutes one third of the load on B-phase. An analysis of the daily load cycle at four seasons of the year indicates an annual yearly copper-loss factor of 17.3 percent.

The comparisons as listed in table I show 42½ kva less transformer installed capacity in the banked scheme than in the radial. This reduction of about half represents a significant saving in transformer investment. The banked transformers are loaded in the neighborhood of 170 percent of rated capacity during the winter peak of about two hours' duration. For a load of this type, the overloading of the transformer to 170 percent of the nameplate capacity is an economical practice provided the voltage supplied to the end customers remains satisfactory. The banked operation improves the general level of the voltage along the secondary circuits.

The banked scheme has 0.797 kw more system-peak loss than the radial, which must be evaluated against the saving in transformer investment. This

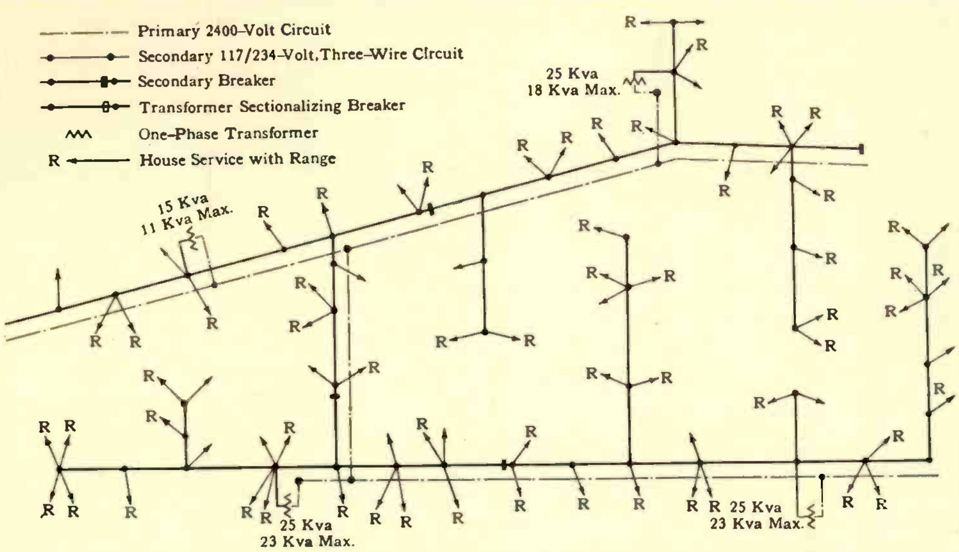


Fig. 1—The area selected for the banking experiment contained mostly residential-type load with an unusually large percentage of electric ranges. Secondary distribution was radial.

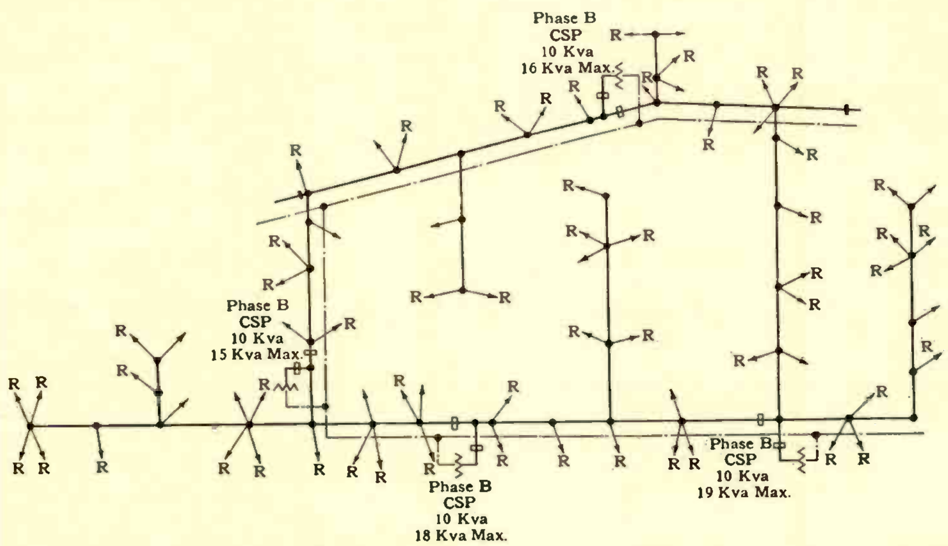


Fig. 2—The same area shown in Fig. 1 has been converted to banked-secondary distribution using CSP transformers with sectionalizing breakers integral within the transformer tanks.

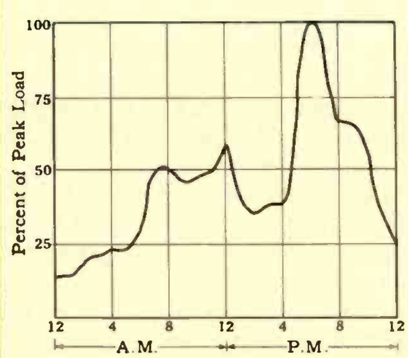


Fig. 3—Range and lighting loads combine on a late afternoon in winter to produce a typical short-time peak demand on the particular phase of the primary feeder supplying the experimental bank. Because the peak is of such short duration, the bank can be loaded considerably over its rated capacity without concern for failures.

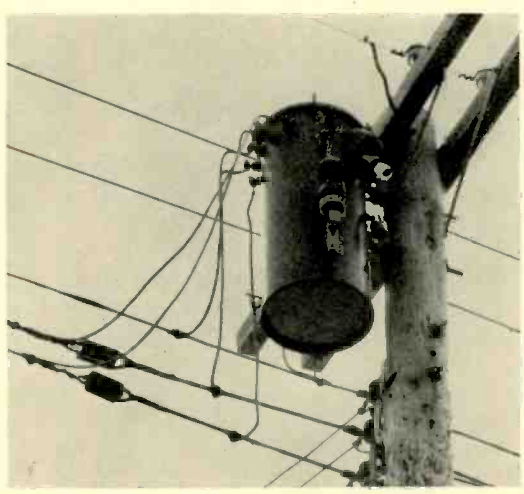


Fig. 4—Typical installation of a banking transformer shows the method of tying the two secondary sections to the five low-voltage bushings.

increase in loss results from the heavy overload on the transformers. The annual energy losses for the two schemes are nearly equal notwithstanding the fact that the banked-secondary transformer capacity has been reduced by half.

Recording voltage charts for a 24-hour period taken at six locations before and after banking, show essentially the same average voltage for the two methods. The voltage improvement effected by banking the secondaries was about equally offset by the additional drop in the transformers when overloaded.

The chief objection to banking single-phase transformers is the possibility of the transformers cascading in case of a sustained secondary short circuit or severe overload.[1] The two-breaker transformers are less liable to cascade than single-breaker transformers or the conventional transformers with secondary fuses. The operation of the transformers following three typical disturbances illustrates this.

A sustained short circuit on the secondary main causes three breaker operations: first, the section breaker opens on one transformer; next, a section breaker opens on the adjacent transformer; and lastly, the main breaker opens on the transformer feeding the fault. The faulted main is thus cleared. Unfortunately, however, one transformer is disconnected from its entire secondary load by the opening of the main breaker.[2]

In the event of extreme overload on one or a group of two-breaker transformers, the overloaded transformers protect themselves by the opening of their section breakers, transferring a part of their load to adjacent transformers. If the adjacent transformers are capable of handling this load, the operation is stabilized at this point. If not, their section breakers open and the entire bank may revert to radial distribution. Should any transformer be excessively loaded, the main breaker opens and the

[1]See discussion of cascading in companion article by Mr. Parsons.

[2]Editor's Note: Subsequent changes in design since these experimental units were installed have eliminated these objections. See the two companion articles on this subject in this issue.

oad is dropped. An unfortunate feature of this operation is that the exact location of the excessive load is not positively determined by the breaker operations. Load tests are necessary to determine the proper places where additional transformer capacity will be required.

When a short circuit develops in a transformer winding, the faulty transformer is cleared from the secondary system by operation of the section and the main breaker, and is cleared from the primary by the protective link.

An objection expressed by the operating people to the two-breaker transformer is the difficulty of giving the trouble men sufficiently simple instructions for the operation of the bank for the breaker openings that might take place under the several types of trouble or on overload.

The two-breaker transformer would be better adapted to banking if each of the two secondary breakers were a section breaker and design features incorporated so that, in the event of overheating of the transformer, the section breaker that is carrying the heavier load would open first.[2] Such an arrangement would indicate positively the location of excessive loads. The operation of such transformers in a bank would be simplified greatly, and the possibility of a transformer being disconnected from the secondary mains in case of severe overload would be considerably lessened.

The actual installation of one of the ten-kva, two-breaker transformers is shown in Fig. 4. Note the five secondary leads and the simple method of separating the main and the section secondaries by means of strain insulators.

TABLE I—COMPARISON OF RADIAL AND BANKED SECONDARY DISTRIBUTION SYSTEMS

		Radial Secondary Distribution	Banked Two-Breaker Distribution Transformers
Total Number of Customers		70	70
Total Number of Ranges		50	50
Transformer Nameplate Kva		82.5	40.0
Transformer Nameplate Kva per Customer		1.180	0.572
Winter Peak Kva		69	68
Peak Load on Transformer, Percent		84	170
Peak Losses Kilowatts	Transformer Core	0.380	0.248
	Transformer Copper	0.932	1.961
	Secondary Copper	0.525	0.425
Total Losses, Kw		1.837	2.634
Annual Energy Losses Kwhr	Transformer Core	3300	2170
	Transformer Copper	1400	2970
	Secondary Copper	800	645
Total Losses, Kwhr		5500	5785

The two-breaker CSP transformer is a distinct contribution to the art of secondary banking. Its acceptance by the utilities will depend on its cost relative to the conventional transformer or to the one-breaker CSP transformer, the ease with which a bank can be designed and operated, and the savings that can be effected in reduced transformer capacity.

Story of Research—The Resnatron

World's Most Powerful Microwave Tube

COUNTER-MEASURE activities against enemy radar during the war have slipped into the background, overshadowed by the feats of our own radar. But the enemy had radar too, and counter measures were crucial in screening our planes. When, for example, allied bombers swarmed over the Channel on D-Day to bomb the Normandy beaches, it was vital to conceal them from the searching radar of the enemy. The trick was done by broadcasting jamming noise covering the frequency range of enemy equipment. This barrage of noise effectively saturated enemy receivers and our bombers flew to their targets undetected.

For this purpose, a powerful high-frequency tube capable of broadcasting over an appreciable bandwidth was necessary. Conventional radar tubes like the klystron and the magnetron do not provide sufficient power. The klystron, for example, is a continuous wave tube with a maximum output of about 100 watts while the magnetron, ordinarily pulsed at high power cannot operate continuously much above 10 kw. The resnatron fulfills the desired conditions, operating continuously at 50 kw.

The resnatron consists essentially of a cylindrical cathode having 24 emitting filaments, a control grid, an accelerating grid, and an anode. In addition, there are two resonant cavities—one between the cathode and the control grid, the other between the accelerating grid and the anode—which behave much as the ordinary inductance-capacitance output (tank) circuits. Except for conditions imposed at high frequencies, the resnatron differs little from certain ordinary oscillator tubes.

In the oscillating tube, some of the high-frequency energy of the output is fed back to the control grid, which is biased negatively in such a fashion that electrons are attracted from the cathode only during a small, positive portion of the radio-frequency cycle. This period is almost unbelievably small—one ten-thousandth of a millionth of a second—and repeats a thousand million times each second.

The bunches of electrons pass through slots in the control grid at low speeds. The field of the accelerator grid is so strong that the electrons of a particular bunch pass through this grid at about the same speed and in the same time. The phase relations established in the tube are such that the electrons passing through the anode cavity find themselves in a negative field. Slowed up, they give up their acquired energy to the field, and arrive at the anode with negligible velocity. The effect is like rhythmic blows on a swinging pendulum: the blows sustain the oscillation of the pendulum, while the electron energy in the resnatron sustains the oscillations in the anode resonant cavity.

Except for small power outputs, the difficulties at ultra-high frequencies were so serious that no high-power tubes were constructed until the resnatron was designed by Dr. David H. Sloan. Dr. Sloan conceived the basic idea in 1938, but it was not until 1942 that he constructed the first practical tube at the Westinghouse Research Laboratories. Some 42 of these 500-pound counter-measure tubes were built. Rated at 50 kw, they have been operated at as high as 70 kw, and still higher outputs are within reach. This feature—high power at high frequencies—extends the useful role of the resnatron from war to peace, and the resnatron promises to be extremely valuable in television and high frequency communications in general.

This giant radar tube helped make D-Day a success.


COILS-A
SWITCH A
COILS-B
SWITCH B
POWER SUPPLY B

Mechanical Problems Solved Electrically

Electricity was, for years, explained in terms of hydraulic and mechanical analogies. Now electricity comes to the aid of mechanics and physics, solving problems of motion, vibration, and heat flow for which the calculation becomes hopeless or too costly in time. The mechanical transient analyzer, first cousin of the network calculator, provides dependable solutions to complex physical problems in a few days instead of in weeks or even years.

G. D. McCann
Transmission Engineer

H. E. Criner
Design Engineer

Westinghouse Electric Corporation

THE analogy between electrical circuits and other physical systems is the basis of a new method of calculation by which many knotty problems in mechanics, thermodynamics, hydraulics, and electrical systems individually or in combination can now be solved more easily. The method consists of connecting electrical units of inductance, resistance, and capacitance appropriately to represent the physical elements of the problem. Voltages or currents, exactly duplicating in amplitude and time variation the disturbing physical forces, are applied repeatedly at the proper point on this electrical system. The resulting electrical waves, representing the solution to the problem, are reproduced in cathode-ray oscilloscopes to provide traces that can be measured or recorded.

The electrical analogy has several important advantages over models or existing mechanical calculators. Suitable circuit elements to represent a wide range of physical constants, although they must be of a special low-loss type, are inexpensive. They can be arranged in a form suitable for quick connection to represent a great variety of physical systems. Either steady-state or transient solutions can be produced on the screen of a cathode-ray oscilloscope from which all or any desired part (such as a crest magnitude) can be easily read or recorded.

The possibility of representing physical systems by electric circuits lies in the analogy that exists between the physical laws governing that system and the currents and voltages in an electrical circuit. Depending upon how the various elements or variables of the two systems are compared, there are several of these analogies that are usually set up. Two of the most common and important for mechanical vibration are illustrated in Fig. 1.

The Mechanical-Vibration Analogies

Two analogies exist between the physical mechanical elements (mass, spring constant, and damping) and the electrical circuit elements (inductance, capacitance, and resistance). These are classified in Fig. 1 as: (a) the mass-inductance circuit analogy in which inductance is analogous to mass, a capacitor is analogous to a spring, and resistance is analogous to damping; (b) the mass-capacitance circuit in which capacitance is analogous to mass, an inductance is analogous to a spring, and resistance is again analogous to damping. Either scheme can be used. The choice depends upon the problem. Some problems are more easily represented by one method than by the other.

In Fig. 1 the force-voltage, mass-inductance analogy can be used as an example. In this analogy voltage represents force; charge, displacement; and current, velocity. Newton's second law of motion states that when a mass is accelerated the force exerted is equal to the product of the mass times the acceleration (or, mathematically, the first derivative of the velocity). The

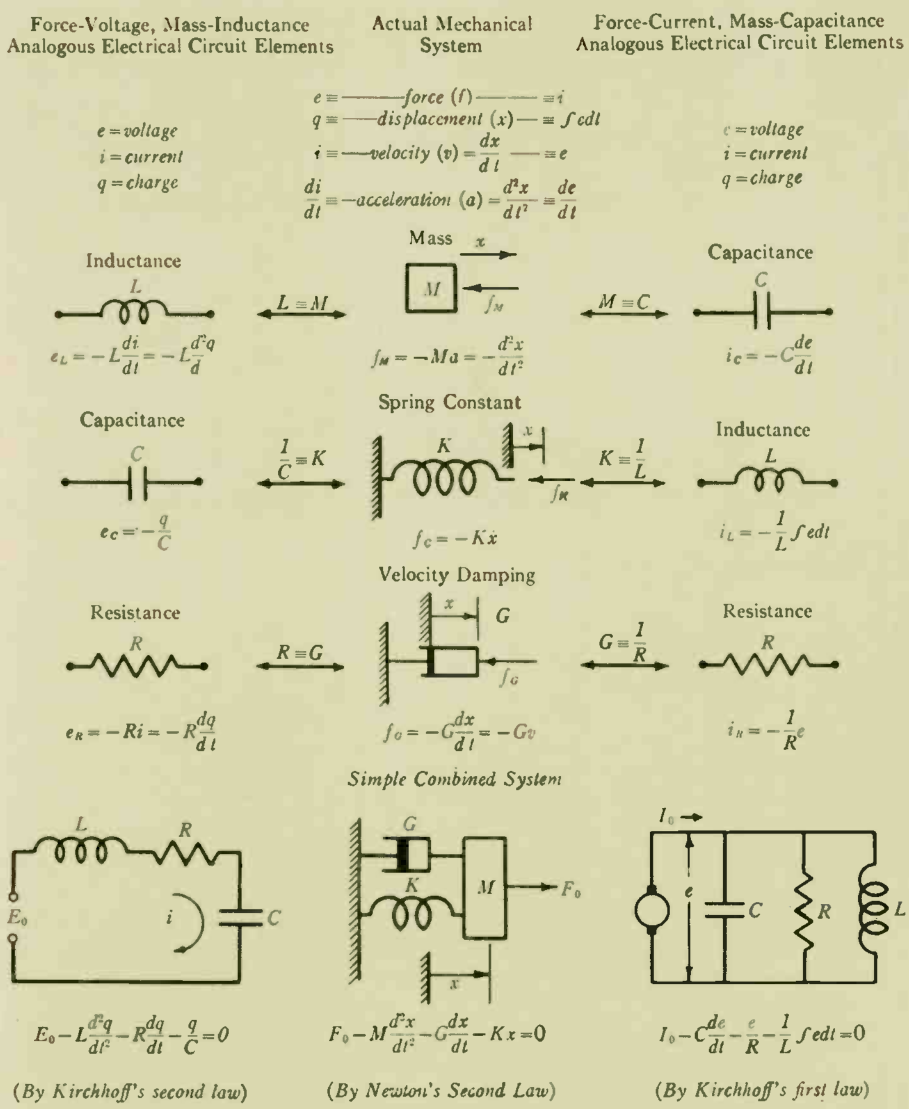


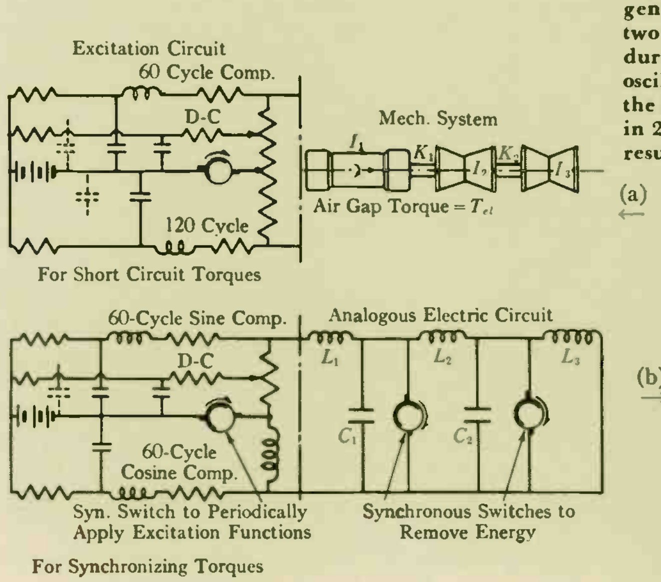
Fig. 1—Physical mechanical elements can be represented by two analogous electrical systems, one in which the analogue of mass is inductance, in the other, capacitance.

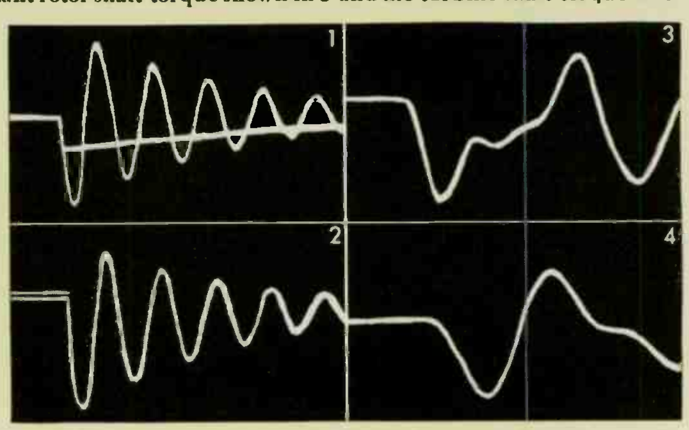
electrical circuit element, inductance, is analogous to the mass because its voltage drop (representing force) is proportional to the product of the inductance and the derivative of the current (representing velocity).

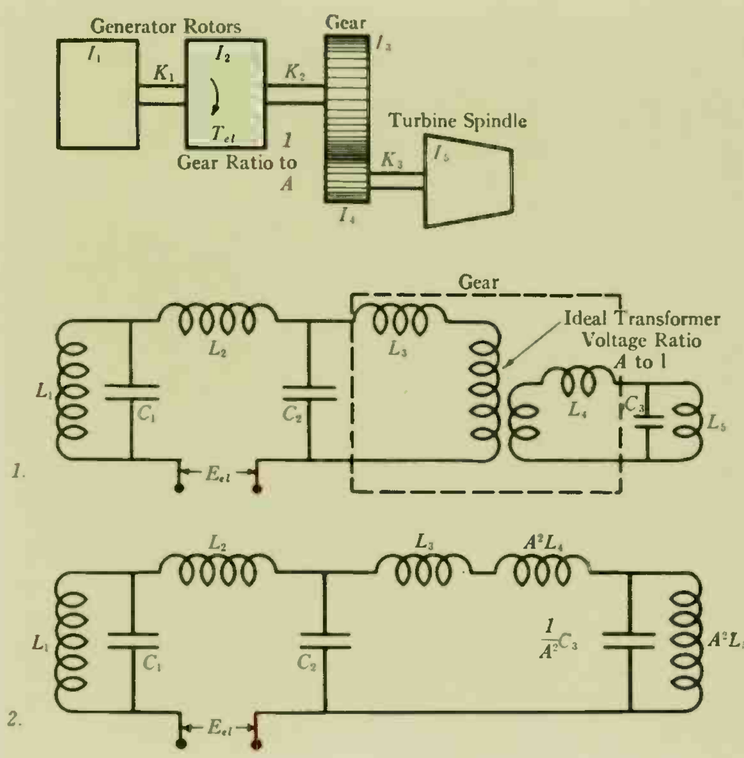
The similar analogous relations between the other elements are shown in Fig. 1. Now (as shown at the bottom of Fig. 1) when deriving the equations of motion for a mechanical system all of the forces acting on each body are equated by Newton's second law of motion. The analogous equations for the electrical system result from the application of Kirchoff's second law that the summation of the voltages around any closed circuit is equal to zero. Thus in the simple example of Fig. 1, the mass, spring, and dashpot are so connected that each receives the same displacement. A single force is applied externally and is resisted by the sum of the forces developed in each of the elements. The analogous electric circuit is formed by connecting the three analogous circuit elements together in series so that the same charge flows through each (or each has the same "displacement") and the applied voltage is equal to the sum of the voltage drops across each of these elements.

Equivalent circuits for rotational mechanical systems are set up in the same way except that the rotational mechanical quantities replace the translational ones. Systems involving more general motions that will include combinations of translational and rotational motions can be combined into one analogous circuit for

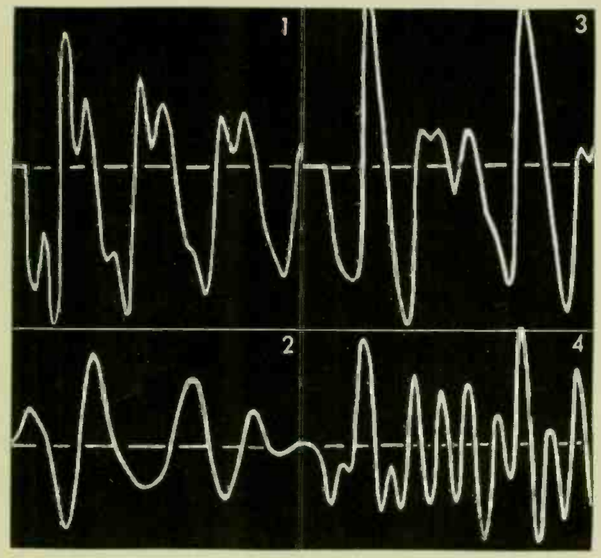
Fig. 2—The determination of shaft torques of high-speed turbine-generators. (a) shows the mechanical system, its electrical analogue, and two circuits, one for imposing the electrical equivalent of the stresses during synchronizing and the other to simulate a short circuit. In (b), oscillographs of the electrical equivalent of a short circuit are shown on the left. The d-c and fundamental electric-torque component is in 1 while in 2, the total torque is included. The solutions are at the right with the resultant rotor shaft-torque shown in 3 and the turbine shaft-torque in 4.







(a)



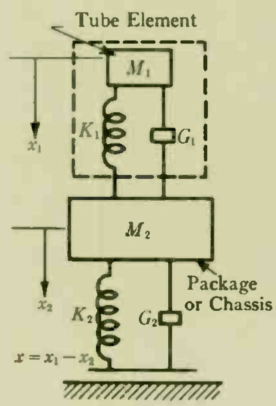
(b)

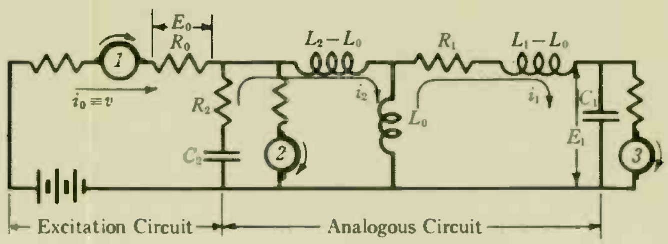
Fig. 3—In a geared-turbine problem, the gear can be represented by a transformer. The elements of the mechanical system and two electrical analogues, the second a simplification of the first, are shown in (a). Oscillogram 1 in (b) represents three-phase short circuit while 2, 3, and 4 indicate the resulting torques in the generator-generator shaft, in the generator-gear shaft, and in the gear-turbine shaft respectively.

solution by the method of analogous electrical circuits.

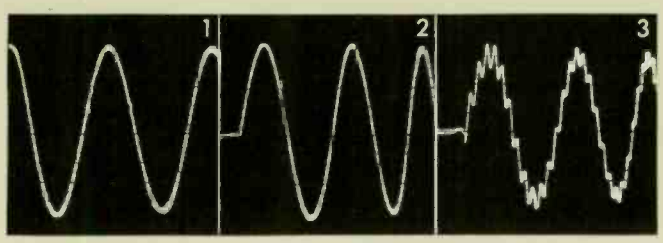
For any practical problem certain applied disturbances are known or assumed. These can be excitation functions introduced to one or more parts of the system. These excitation functions may be forces, displacements, velocities, all functions of time, or other quantities that cause or start the transient condition in the problem at hand. Examples might be the impact of a falling body, the stresses on a short-circuited generator, the application of heat to a body, or the impulses produced by the firing of an internal combustion engine.

In setting up an analogous electrical circuit by the relations of Fig. 1, if the impedances and electrical excitation functions, such as the sudden application of voltage, are





(a)



(b)

Fig. 4—A novel use of the method of analogies is for the determination of stresses in radio-tube elements when the packaged tube is dropped. In (a) the physical masses of the tube and its package and their electrical analogue are shown. In (b), the velocity and acceleration of the large mass, M_2, are shown in oscillograms 1 and 2 respectively while the resulting measure of the displacement of the small mass (the tube element) relative to the much larger mass (the package) is shown in oscillogram 3.

TABLE I—CONVERSION FORMULA FOR CIRCUIT CONSTANTS

Actual Electric Circuit	*Force-voltage Mass-Inductance Circuit*
$L' = \frac{aL}{n}$	$L' = \frac{aM}{n}$
$C' = \frac{C}{an}$	$C' = \frac{1}{ank}$
$R' = aR$	$R' = aG$

a is arbitrary constant, n is ratio of frequencies in analogous circuit to those in actual system.

(1) If known excitation function is represented by a voltage E'_0, actual voltages or quantities they represent are given by equations

$$e_n = \frac{E_0}{E'_0} e'_n \qquad f_n = \frac{F_0}{E'_0} e'_n$$

and currents or their analogies by equations:

$$i_n = \frac{aE_0}{E'_0} i'_n \qquad v_n = \frac{aF_0}{E'_0} i'_n$$

(2) If known excitation function is represented by current I'_0

$$i_n = \frac{I_0}{I'_0} i'_n \qquad v_n = \frac{V_0}{I'_0} i'_n$$

$$e_n = \frac{I_0}{aI'_0} e'_n \qquad f_n = \frac{V_0}{aI'_0} e'_n$$

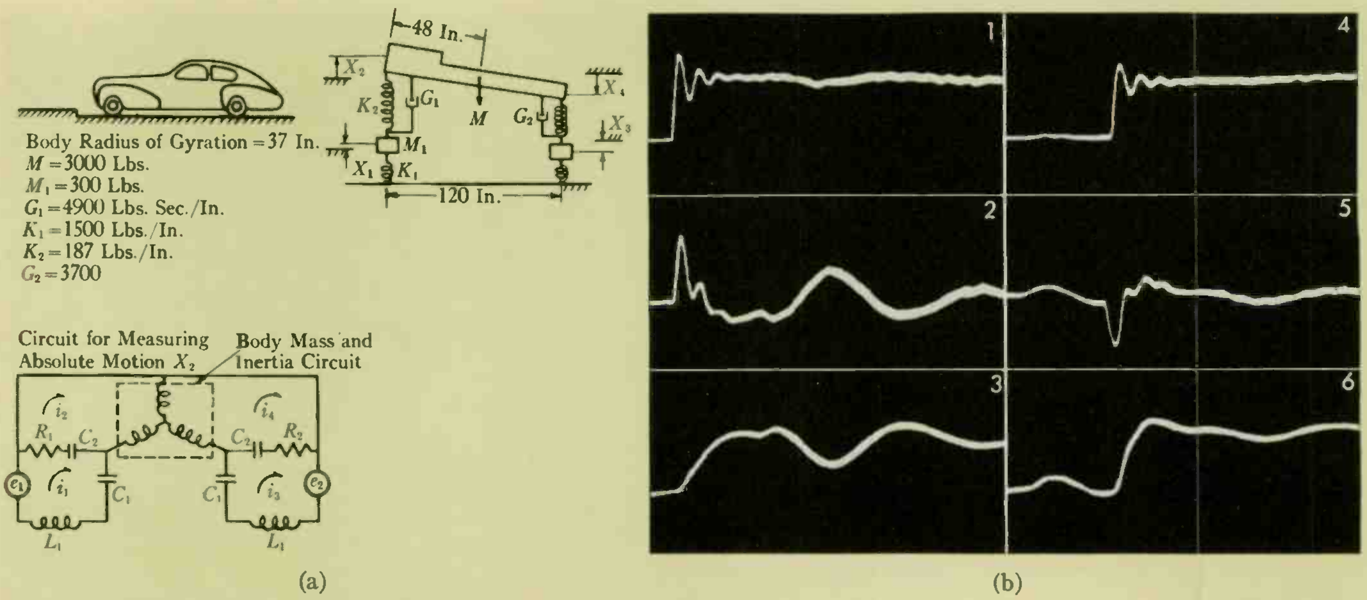


Fig. 5—The rideability of an automobile has been determined by the analyzer. The physical system and its electrical analogue are given in (a) while the resulting motions as the car goes over a bump are shown in (b). The front wheel action is shown in the left three traces while the right three indicate the motions caused as the rear wheels hit the bump 0.45 second later. Wheel motion alone is shown in 1 and 4, the relative motions between wheels and body in 2 and 5, and resulting body motions are in 3 and 6.

made equal to the mechanical quantities (in consistent systems of units), all electrical solutions will be numerically equal to the true mechanical solutions. However, it is usually desirable to change the electrical circuit constants by a fixed ratio so that it is not necessary to provide an excessively wide range of variation in the calculating device. Frequently the time base must also be changed for the same reason or so that the solution can be recorded more readily. A consistent set of conversion formula for accomplishing this is given in table 1. In practice it is also usually more convenient to set the electrical variable representing the known excitation function at an arbitrary value and record the solutions as ratios of this by the equations of table 1.

Mechnical-Transients Analyzer

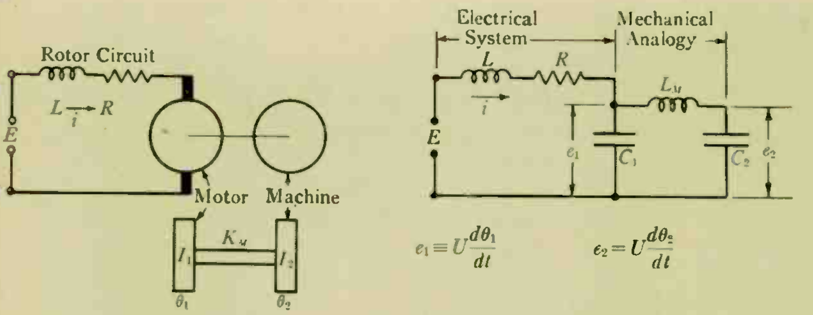
Certain physical problems involving impact, short-circuit torques, vibration conditions, and the like occur so frequently that a special calculating board has been devised based on the principle of the electrical analogue.

This mechanical-transients analyzer contains special low-loss electrical circuit elements capable of representing practical low-loss mechanical systems. Special circuits have been developed to introduce a wide range and large number of excitation functions in the form of either transient or steady-state voltages or currents to represent the known forces. For transient problems, synchronous rotating switches are used to apply the various excitation functions periodically to the analogous electrical system so as to produce a standing wave representing the solution on the screen of a cathode-ray oscilloscope. During the short period between each application, other synchronous switches short circuit the various capacitors in the mechanical circuit, thereby removing the energy from these circuits and placing them at rest for the succeeding application of the excitation function.

Representative Problems Solved by the Analyzer

Transient Shaft Torques in Turbo-Generators—In modern high-speed turbine-generators a knowledge of the shaft torques that can be set up by various types of short circuit or synchronization out of phase are important to both design and operation. Here the known excitation function is the torques developed in the rotor air gap as a result of the particular disturbance. These can be calculated and are known to consist of a combination of damped unidirectional and oscillatory components at fundamental and harmonic frequencies. The transients-analyzer excitation circuits used to introduce these types of excitation and the mechanical system and its analogous mass-inductance circuit are shown in Fig. 2 (a). The air-gap torque developed by the short circuit consists of a damped sinusoidal oscillation at fundamental electrical frequency and a damped unidirectional component, as shown by the oscillograms in Fig. 2 (b). Because the force-voltage analogy was used here, a voltage proportional to the air-gap torque was impressed on the analogous electrical circuit by means of the excitation circuits of Fig. 2 (a) by charging condensers and discharging them with a synchronous switch through resistance and inductance of proper magnitude for the desired wave shape. The combined components are applied to the analogous circuit by a multiple-tap slide-wire resistor. The resulting transient voltages across capacitors C_1 and C_2 are proportional to the rotor and turbine-shaft torques, respectively, and are shown in the oscillograms.

Salient-Pole Generator with Geared-Turbine Drive—A more complicated mechanical system is that of Fig. 3 (a). Here it is likewise desired to determine the shaft torques resulting from a three-phase short circuit from no load on one of two generators driven by a geared turbine. As shown by the analogous circuits of Fig. 3 (a) a gear is represented by a transformer, which, in the case of the force-voltage analogy (Fig. 1), steps up the current in the direction of increased speed and steps down the voltage in the same direction to represent the corresponding decrease in torque. However, just as in power-system problems, where unity-ratio transformers are substituted for actual ones during the course of calculations, the transformer can be removed by referring all constants and variables to one of the velocities.



$e_1 = U\frac{d\theta_1}{dt}$ $\qquad e_2 = U\frac{d\theta_2}{dt}$

For electrical circuit

$$E = L\frac{di}{dt} + Ri + U\frac{d\theta_1}{dt}$$

For mechanical system

$$Gi = I_1\frac{d^2\theta_1}{dt^2} + K(\theta_1 - \theta_2)$$

$$O = I_2\frac{d^2\theta_2}{dt^2} - K(\theta_1 - \theta_2)$$

$$C_1 = \frac{I_1}{UG} \qquad C_2 = \frac{I_2}{UG} \qquad \frac{1}{L_m} = \frac{I_2}{UG}$$

Using current-force, capacitance-inertia analogy for mechanical system

$$E = L\frac{di}{dt} + Ri + e_1$$

$$i = C_1\frac{de_1}{dt} + \frac{1}{L_m}\int(e_1 - e_2)dt$$

$$O = C_2\frac{de_2}{dt} - \frac{1}{L_m}\int(e_1 - e_2)dt$$

Fig. 6—Problems involving complex combinations of various physical systems can be solved by electrical analogies. This shows the method of setting up a problem of a separately excited, d-c motor-driven, mechanical system.

The generator in this problem has salient poles. The air-gap torque, resulting from the short circuit, consists of a damped unidirectional component and a series of damped sinusoidal components at fundamental and harmonic electrical frequencies. The equation for the air-gap torque including components up to the fourth-harmonic frequency is:

$$\text{Per unit } T_e = \epsilon^{-4.3t}(6.2 \sin \omega t + 4.65 \sin 3\,\omega t) - \epsilon^{-3t}(2.13 \sin 2\,\omega t + 1.95 \sin \omega t) + 1.2\,\epsilon^{-3}$$

The total applied torque and the resulting transient torques on each of the three shafts are shown in Fig. 3 (b). It is obvious that the analytical solution of this problem would be extremely difficult, to say the least, but a solution was readily obtained on the analyzer with an accuracy of plus or minus five per cent, or better if desired. In addition to shaft torques, it is also possible to obtain data on maximum stresses in the gear teeth and, by measuring velocities, some estimate of impact forces on the gear teeth during torque reversal.

Mechanical Vibrations in Electronic Tubes—In the mechanical design of electronic tubes, the grids and electrodes must be strong enough so that they are not broken by the shocks or vibration received in handling or in service. The simplified mechanical system of Fig. 4 (a) is representative of many problems of this sort. The Bell Telephone Laboratories were interested in obtaining the general solution for the motion and stresses present in the tube elements when a mounted or crated tube is dropped to the floor. This is representative of the more severe types of shocks to which tubes are subjected, particularly when in shipment.

The solution to this problem involved determination of the maximum deflection of a tube element in relation to the velocity at impact and for a wide range of ratios between the natural frequencies of the tube element and the mounting and of the damping in these two parts of the system. The general solution therefore involved nearly a thousand values of the maximum displacement of the element relative to the chassis (or box) to enable plotting the solution as a set of curves. Any

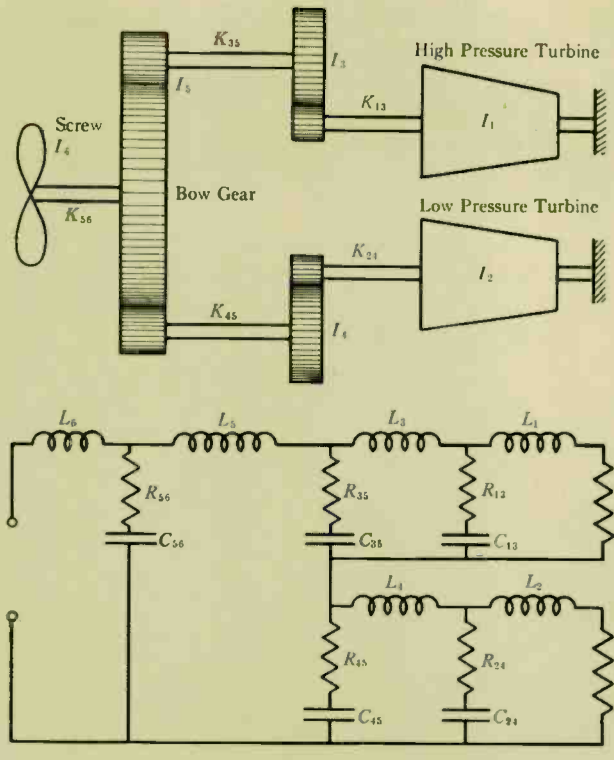


Fig. 7—A geared-turbine drive for a ship presents a most complicated problem to a designer. This system can be easily represented by an electrical analogue as shown here.

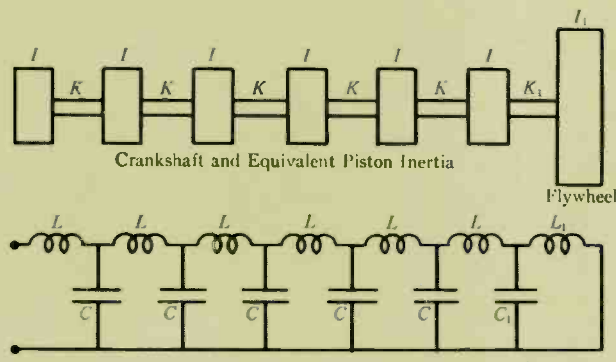
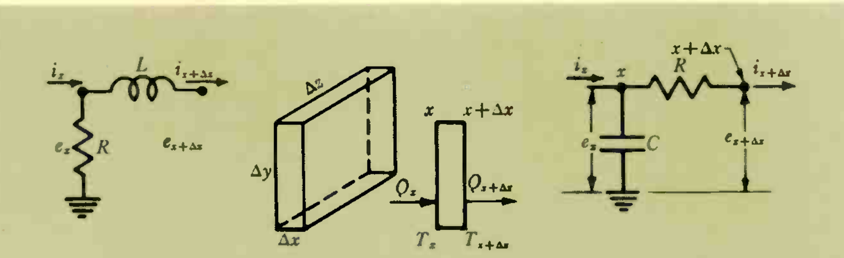


Fig. 8—The crankshaft of a reciprocating engine is subjected to complex stresses. When the method of the electrical analogue is used, the design problem becomes much simpler.

one of these solutions could be solved without too much difficulty in a few days. However, to obtain the complete solution by calculation would require more than two years' work. On the analyzer, it was completed in less than two weeks. This type of problem is typical of many that are not too complex for limited analysis but would require too long a time to obtain a comprehensive solution by any means other than by that of electrical analogy.

The analogous electrical circuits used on the transients analyzer are shown in Fig. 4 (a). It is practical to assume that the box does not bounce. Also, the mass of the tube part in question is so small that its reaction on the entire case can be neglected. In addition, the force of the impact alone is considered. However, none of these simplifications are necessary for obtaining a solution by means of the transients analyzer as the complete problem can be set up readily.



Analogous temperature—current electrical circuit | One dimensional element of thermal conducting medium | Analogous temperature—voltage electrical circuit

Law: Rate of heat storage in element is product of thermal capacity and rate of increase of temperature

$$e_{x+\Delta x}-e_x=-L\frac{\partial i}{\partial t} \qquad Q_{x+\Delta x}-Q_x=-(\Delta x\Delta y\Delta z)c\rho\frac{\partial T}{\partial t} \qquad i_{x+\Delta x}-i_x=C\frac{\partial e}{\partial t}$$

Law: Flow of heat is in direction of greatest temperature drop and proportional to rate of change of temperature with space

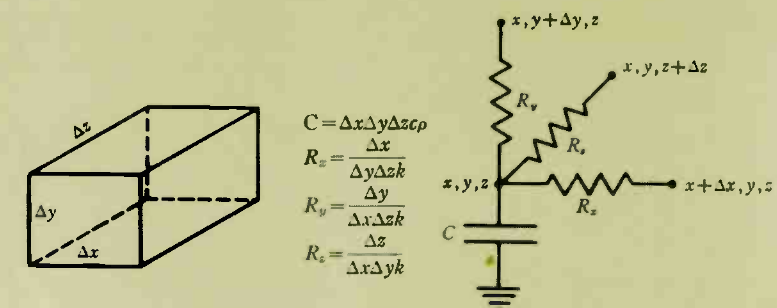
$$e_x=-\frac{1}{R}(i_{x+\Delta x}-i_x) \qquad Q_x=-(\Delta y\Delta z)k\frac{T_{x+\Delta x}-T_x}{\Delta x} \qquad i_x=-\frac{1}{R}(e_{x+\Delta x}-e_x)$$

$$L=(\Delta x\Delta y\Delta z)c\rho \qquad C=(\Delta x\Delta y\Delta z)c\rho$$

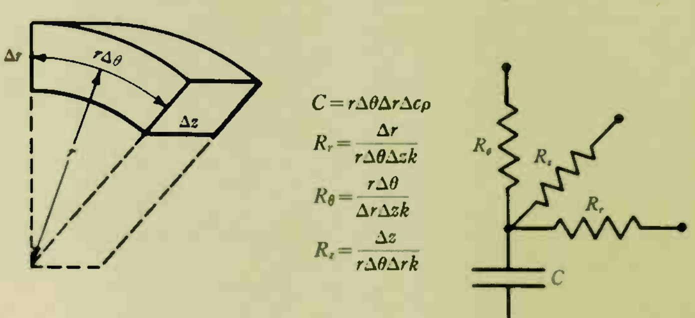
$$R=\frac{\Delta x}{(\Delta y\Delta z)k} \qquad R=\frac{\Delta x}{(\Delta y\Delta z)k}$$

Symbols:
T = temperature
Q = rate of heat flow per unit time across given surface
C = specific heat
k = thermal conductivity
ρ = density

(a)



$$C=\Delta x\Delta y\Delta zc\rho \qquad R_x=\frac{\Delta x}{\Delta y\Delta zk} \qquad R_y=\frac{\Delta y}{\Delta x\Delta zk} \qquad R_z=\frac{\Delta z}{\Delta x\Delta yk}$$



$$C=r\Delta\theta\Delta r\Delta c\rho \qquad R_r=\frac{\Delta r}{r\Delta\theta\Delta zk} \qquad R_\theta=\frac{r\Delta\theta}{\Delta r\Delta zk} \qquad R_z=\frac{\Delta z}{r\Delta\theta\Delta rk}$$

(b)

Fig. 9—Non-mechanical problems such as heat flow through a solid, conducting medium can be solved by electrical analogies. The derivations of the various analogues for a one-dimensional element are shown in (a) while in (b) are shown the equivalents of a three-dimensional heat-flow medium using first, Cartesian coordinates, and in the second, cylindrical coordinates.

Also, similar solutions for more complex systems containing more degrees of freedom, or natural frequencies, can readily be solved with this device. In the analogous electrical circuit of Fig. 4 (a) the mass-inductance, force-voltage analogy has been used. At the instant before impact, the system is falling with a given velocity $\frac{dx_2}{dt}=v$. This is represented in the analogy by having switch 1 closed with a steady current i_2 flowing through the coils representing the mass m_2. No voltage is produced across R_2 and C_2. This is correct for, until contact with the floor is made, the spring is not displaced and no damping forces exist. The condition representing impact is simulated by opening switch 1, which forces the initial current (velocity) through R_2 and C_2, after which the system oscillates freely. The complete transient solution in the form of an oscillogram is obtained on the screen of a cathode-ray oscillograph by having this operation of closing and opening switch 1 cyclically imposed by the synchronous rotating switch. This produces a standing wave on the oscillograph. The other two rotating switches shown in Fig. 4 (a) are simply for the purpose of damping the oscillations in the intervening period so that the system is at rest at the beginning of each cycle. Thus, the switches are open circuited during the period in which the solution is being obtained and short circuited in the intervening period. This is necessary only when the circuits contain low loss, because high-loss circuits are self-damping.

An Automobile and a Bump—The motion of the wheels and body of an automobile as it passes over a stepped surface in the roadway at a given velocity has been determined. Represented in Fig. 5 (a), it illustrates the application of the electrical-mechanical analogy to the combination of translational and rotational motion, both in one plane. When relatively small angular motion is assumed, analogous circuits can be developed even when the motion is not confined to a plane. In these cases the circuits for all masses must combine both mass and rotational inertia constants. They become either multi-winding transformers or multi-terminal networks.

When the mass-inductance analogy is used, the effect of the stepped surface in the roadway is introduced into the electrical circuit by the voltages e_1 and e_2. The voltage e_1, which is proportional to the sudden upward displacement of the bottom of the front tires, is a constant voltage suddenly applied at time zero. The voltage e_2, which represents the sudden displacement of the bottom of the back tires, was applied 0.45 second later, which corresponds to a velocity of 15 mph. The currents i_1 and i_3 in Fig. 7 (a) are the analogous velocities of the wheels, while the currents i_2 and i_4 are the analogous velocities of the two ends of the body. The displacement of the wheels and the relative displacement between wheels and body are proportional to the voltages across c_1 and c_2 respectively, and are shown in the oscillograms in Fig. 5 (b).

The absolute motion of the body cannot be determined directly from the mass-inductance circuit. However, reasoning from the analogy of Fig. 1, charge is proportional to this displacement, which in turn is proportional to the voltage impressed across a condenser which can be inserted in the circuit diagram in Fig. 5 (a) large enough so it does not affect the current in the circuit. Oscillograms representing the motions of both ends of the car are shown in Fig. 5 (b).

The mechanical-transients analyzer provides a means for studying a wide variety of designs and the effect of various road surfaces on the motion of the vehicle.

Electro-Mechanical Systems—Devices that comprise the interaction of several types of physical systems are usually considerably more complex than is the case when only one system is involved. The method of electrical analogy can thus become a particularly powerful tool in this field. The more common interacting systems are electrical and mechanical systems. Typical of these are various electrical motor drives such as motor-generator sets, electro-dynamic loud speakers, voltage and speed regulating systems, and many other servo-mechanisms. Several of these electrical-mechanical systems may be combined in one analogy as, for example, in the determination of the various transients in a variable-speed wind-tunnel drive.

The simple example of Fig. 6 illustrates the general method of setting up an all electrical analogy to represent such systems. In this case it was more convenient to use the mass-capacitance circuit for the mechanical system. Then the voltage e_1 of Fig. 6 (which is proportional to the velocity of the motor rotor) represents the internal voltage of the motor in question.

Other mechanical problems that have been solved by these methods are shown in the diagrams of Fig. 7 and Fig. 8.

Non-Mechanical Problems

The method of electrical analogy can be put to the solution of many problems outside purely mechanical ones. One of the most complex types of problems from the standpoint of mathematical analysis is the one in which the physical phenomena take place in a distributed irregular region or medium. Examples of this are high-frequency electromagnetic wave propagation through space or wave guides, etc., current through a conduction medium of irregular shape, or the flow of heat in a thermal-conducting medium.

Most practical shapes are such that adequate analysis is impossible by conventional methods. However, for several types of physical systems of this nature it is possible to derive an analogous lumped-constant electrical circuit that accurately represents a small volume of the medium. An example of this is illustrated here by the analogy for heat flow through inert conducting media.

The fundamental laws for heat flow and the derivation of their analogy are given in Fig. 9 (a) for simple one-dimensional flow. As shown, either of two analogous circuits can be

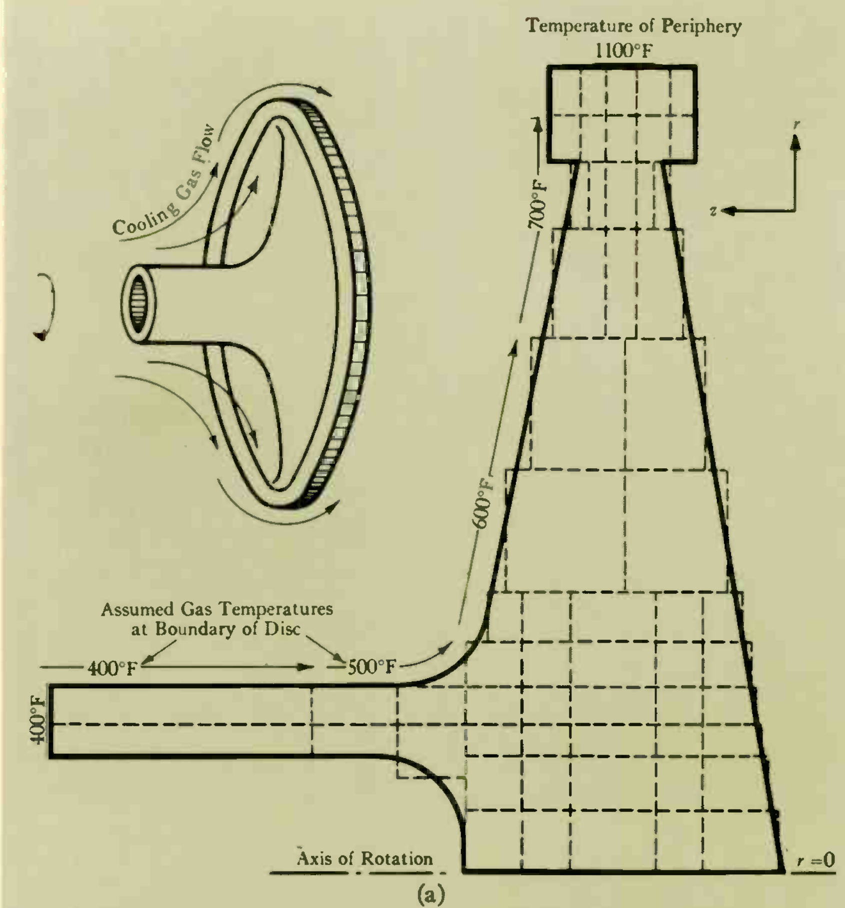
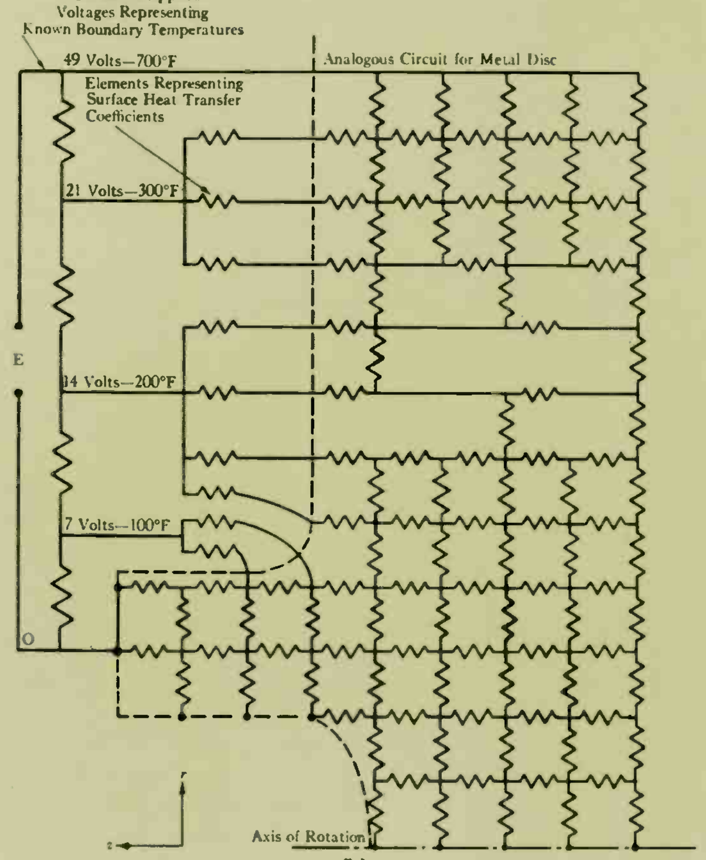
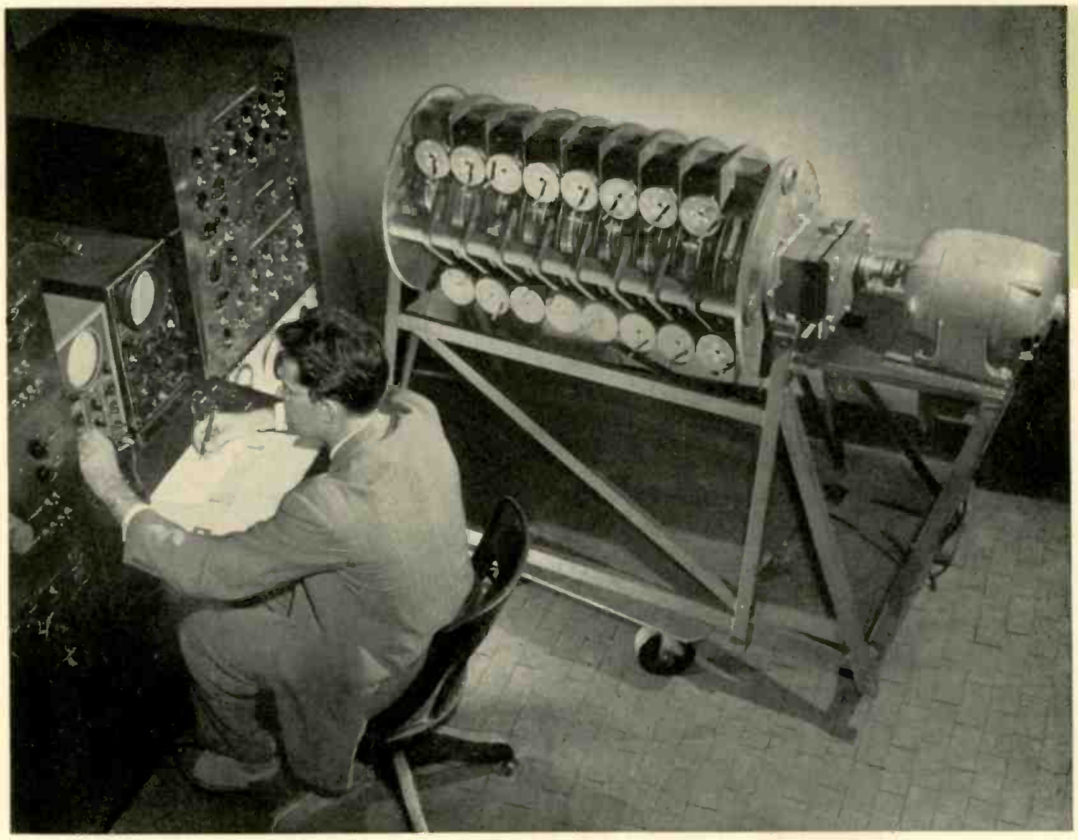


Fig. 10—This illustrates a typical heat-flow problem in a gas-turbine disc. In (a) are shown the known boundary conditions and the method of setting up the heat-transfer elements while in (b) is the corresponding electrical analogue.





Mr. G. D. McCann is shown operating the mechanical-transients analyzer. In the rear can be seen the motor-driven commutator that is used to apply and remove the electrical transients to the analogous electrical circuits set up to represent the physical system in question.

used. In one, temperature is represented by voltage with rate of heat flow indicated by electric current. In the other, temperature is represented by current, and heat flow by voltage. The former analogy is usually more practical because it is easier and cheaper to build capacitors with sufficiently low loss than inductors. The form of the analogous circuits in three dimensions is shown in Fig. 9 (b).

For a given system the body is divided into volume elements whose size is governed by the configuration of the body, boundary conditions, and the required accuracy of the solution. For each element the analogous circuit consists of a capacitance representing the thermal capacity of the element and three resistances each representing the temperature gradient per unit of heat flow per unit time through the element in the direction of the respective coordinate. Connection of the resistances into a grid in accordance with the respective positions of each element and connection of the bottom terminal of all capacitors to a common ground forms the analogous circuit representing the entire body. The choice of coordinate system depends, of course, upon the shape of the body and the boundary conditions of the problem. Where symmetry with respect to one axis exists, a two-dimensional circuit results. The differential dimension of the elements in the direction of the axis of symmetry is the entire dimension of the body at the respective values of the other two coordinates. Coefficients of surface heat transfer can also be represented by resistances. The choice of magnitude of the electrical circuit elements and the relations between the measured electrical quantities and the true solutions can be determined exactly as shown in table 1.

For transient problems the transient boundary conditions such as a sudden application of heat or change in temperature can be produced as excitation functions by the circuit methods employed in the mechanical-transients analyzer. Under steady-state conditions, inasmuch as temperature is not varying with time, no heat is being stored in each element. Thus, in the analogy no current is flowing into the capacitors and they have no influence on the solution. The circuit can then be formed entirely of resistors. Problems of this sort can be solved on a conventional power-system d-c calculating board consisting of a d-c voltage supply and resistors.

Heat Conduction Through a Gas-Turbine Disc

The example of Fig. 10 illustrates the use of an analogous circuit for heat-flow media. The rotating gas-turbine disc has circular symmetry in that equal temperatures exist at all points having the same value of the coordinates (r,z). Thus the differential elements can be circular rings, and $\Delta\theta$ for the equation of Fig. 9 (a) becomes 2π. Figure 10 (b) shows the equivalent circuit representing the disc for the assumed elements given in Fig. 10 (a). Because the problem is one of steady-state conditions, the capacitors are omitted. The known boundary conditions are the temperature at the periphery of the disc, the temperature at the left end of the disc, and the given distribution of temperature at the boundary of the cooling gas that flows out to the periphery. The resistors representing the surface heat-transfer coefficients are shown in Fig. 10 (b) together with the voltage circuit for establishing the boundary conditions.

The use of analogous circuits for distributed media of this sort opens a field of analysis of great importance. The only limitation to the accurate representation of the most complex shapes lies in the number of circuit elements that may be required. While in general more elements are needed for heat flow problems especially, these are quite inexpensive.

The foregoing discussion has necessarily been confined to a fundamental treatment of some of the basic electrical analogies and a few simple examples of their application to practical problems. The development of the Westinghouse Transients Laboratory, component elements such as the A-C Network Calculator, the Mechanical Transients Analyzer (with its devices for simulating arbitrary forcing functions), and synchronous switches are being coordinated so as to provide a wide range of facilities for the solution of the most complex problems.

Additional devices include special amplifier circuits for representing the power sources of servomechanisms with their time delays and feed-back circuits. These used with the other elements permit the solution of a very broad group of servo-systems such as voltage regulators, speed regulators, angle-position regulators, and control systems.

Direct-Current Power for Aircraft

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Aviation Industry Engineer

H. E. Keneipp
Aviation Generator Engineer

Westinghouse Electric Corporation

Direct-current power systems of the nominal 28-volt variety are now standard in the U.S. on all models of military airplanes produced in quantities including the B-29 and its most recent cousin, the B-32. The present outlook for the a-c system anticipates the still larger ships that have not yet taken to the air.[1] Where the boundaries of usefulness between a-c and d-c power plants for airplanes will eventually be drawn no one knows. Both systems will be used extensively. The 28-volt d-c system has proved excellent for aircraft service and has been fully adequate until the conception of the super-ship with its heavy loads and "long" transmission lines. The d-c system has paced the growth of the airplane itself, continuing to meet the demands of designers for larger power outputs from the same or reduced weights, and with better reliability. Further developments can be confidently predicted for the future.

The Development of the D-C System

Early airplanes used electricity only for the magneto-ignition system of the engine. Flying was confined to daylight and there was little, if any, need for an electric power system aboard. As development of airplanes progressed, the need for electric power became apparent. First uses were for lighting and radio, functions that could not be performed by any other means. A six-volt system was used first and was entirely adequate for a time because loads were light and distribution was not a problem.

Airplane development, however, has never remained static; as planes were improved, it was found that many functions could best be performed electrically. Increase in size of airplanes also increased the electric load. The six-volt system became unsatisfactory because of the excessive weight of wire and cable needed to limit voltage drop. When the 12-volt system was adopted, four times the kilowatt load could be carried with the same percent voltage drop.

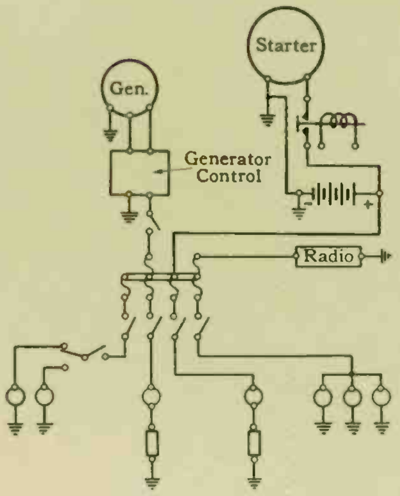
The 12-volt system was adequate for a time and is still used on many planes, but that system too became inadequate for large airplanes. Shortly after 1938, the 28-volt system was adopted. It is the present standard for the Army and Navy and is that used by some present commercial airliners.

To supply the rapidly expanding load and to satisfy combat operating requirements, a great deal of effort has been focused on building up the load capacity, weight efficiency, and reliability of this system. Blast cooling and higher speed accessory drive shafts have made possible major increases in generator rating without proportionately greater weight. Improvements in the design of brushes, generator-voltage regulators, and generator relay switches have increased the reliability and stability of the system. These changes, along with a multitude of developments in electric utilization devices, have brought about a major increase in the reliability and effectiveness of both military and commercial airplanes.

Proposed growth in electrical load and aircraft size demand

The 400-cycle a-c power system[1] being developed for the giant airplanes of tomorrow has by its novelty stolen the spotlight from the traditional direct-current system. But the shift is in attention only. The d-c system is not obsolete; nor is it likely to be replaced as the power supply for airplanes of the range of sizes now commercially familiar.

[1] See "A-C Systems for Aircraft," J. D. Miner, *Westinghouse ENGINEER*, September, 1945, p. 148.



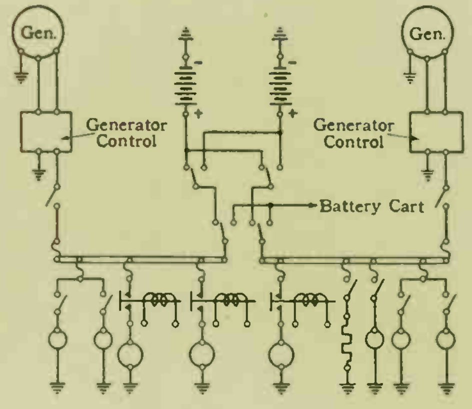
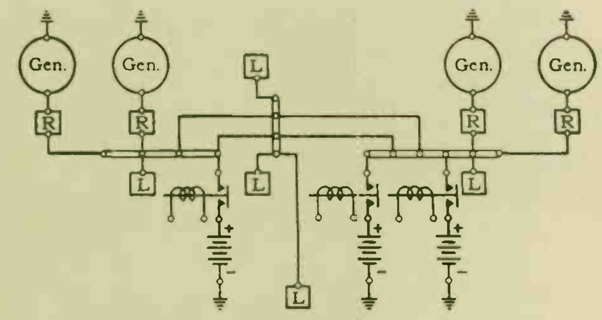


Fig. 2—A double system of electrical distribution having two generators and two buses is sometimes used for twin-engine airplanes.



L—Group of Loads Connected To Distribution Panel With Fuses or Circuit Breakers
R—Generator Relay

Fig. 3—If two or more generators are used, they are frequently connected in parallel to provide greater capacity for heavy loads and to obtain the advantages of diversity. Radial-type distribution is used in this example.

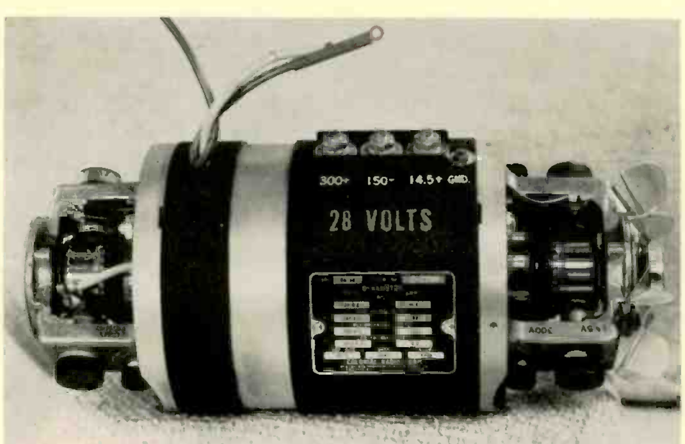
Fig. 1—For a single-engine airplane equipped with one electrical generator for accessory power, the radial system of distribution is generally adequate.

consideration of a further increase in system voltage. Standardization at a single voltage level greatly reduces the problem of supplying replacement parts and allows the electrical manufacturers to concentrate on a single line of apparatus. On the other hand a voltage high enough for the coming super-planes would materially handicap the electrical system design of small- and medium-size planes. If two standard system voltages are to be chosen, full consideration should be given to the relative advantages of a-c and d-c systems.

Various electrical systems are being proposed for planes requiring more power than can be supplied economically by the existing, highly reliable, 28-volt, d-c system. Although some of our present large planes will probably be changed over to higher voltage, the bulk of the small- and medium-size airplanes will continue to use the present system.

Combat efficiency of military airplanes has increased directly with the use of electric power, resulting in a rapid increase in system load. Peak load of a plane equipped with four 200-ampere generators may be as high as 650 amperes on a 28-volt system or about 18.5 kilowatts total consumption.

All system components must be foolproof and reliable as possible. Indefinitely long life is not expected because of weight limitations, but trouble-free operation is required between periods of inspection and engine overhaul.



Like a transformer, this dynamotor used on the famous Flying Tiger planes converts the 28-volt, d-c supply, to 14.5, 150, or 300 volts direct current as may be required.

Present Direct-Current Systems

Distribution System Design

Determination of a particular system begins with an analysis of the peak and average loads for each flight condition. From this, the number and size of main- and auxiliary-engine generators and batteries can be selected.

After power sources have been selected, a distribution system must be laid out to provide a reliable and economical link between these sources and various loads. For a single-engine airplane, this may be similar to Fig. 1. In this case, all of the system components are relatively close together and controlled from a single location. Only the starter draws sufficient current, and is located so as to justify a remotely operated switch. The radial system shown is effective and simple. Short circuits in load feeders can be cleared by fuses or by thermal circuit breakers. Fuses have also been used in generator and battery circuits, but this is not the best arrangement because it is not selective. It should be replaced by adequate reverse-current protection.

When two generators and two batteries are required, the system shown in Fig. 2 is sometimes used. This nonparallel system has two advantages: (1) only half of the system is affected by a short circuit or other fault and (2) provision for dividing load between generators is not required. Battery capacity is usually provided to carry the load long enough to permit manual operation of the transfer switch should one generator fail. There is a loss in maximum generating capacity in comparison with a parallel system because of less diversity, but this may be of no importance if 100-percent standby capacity is provided. This system is particularly suited to airplanes with a concentrated load or with one that divides naturally into two groups so that the double bus does not impose a weight handicap.

When two or more generators are required, they are usually operated in parallel. This arrangement gives the maximum capacity for starting large motors or clearing short circuits and also takes full advantage of diversity among loads. It also permits a simpler and lighter distribution system when loads are widely distributed throughout the plane, particularly if more than two generators are necessary for the load.

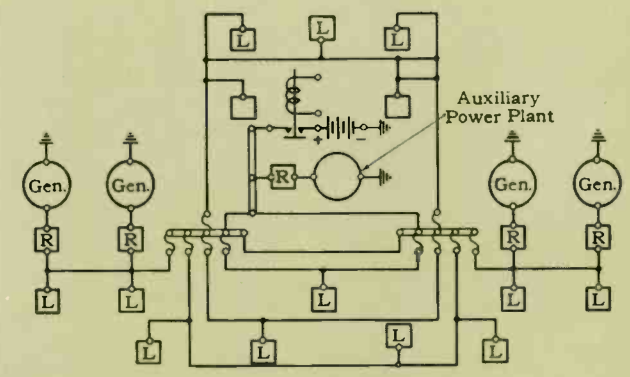
Examples of parallel operation in the distribution-system layout are set forth by Figs. 3 and 4. The loads usually can be grouped into locations corresponding to crew stations, although too many essential loads should not be supplied from the same junction box. The radial system shown in Fig. 3 is simple and thus easy to operate and maintain, but is somewhat vulnerable to either open- or short-circuit faults. The loop system in Fig. 4 is much less vulnerable to open circuits but a short circuit on a feeder that does not burn clear quickly causes the fuses at both ends of the feeder to open and interrupt service to those loads.

The system in Fig. 5 was originally intended to provide open- and short-circuit protection for one fault in any area between junctions. It was proposed that fuses be installed at each end of each cable run. However, the short-circuit current delivered by existing generators was inadequate to insure satisfactory clearing under conditions of minimum generation and the system was installed without fuses. In this form, it offers protection against open circuits at less weight than would be obtained with a system similar to Fig. 4 if both were designed to provide adequate regulation and thermal capacity after the open circuit. A multi-circuit feeder is lighter than a single conductor where current-carrying capacity, rather than voltage regulation, determines the conductor size.

After the system arrangement has been selected, cable sizes must be chosen to give satisfactory voltage regulation and current-carrying capacity under normal and emergency conditions. In a 28-volt system, the cable sizes should be such as to supply 27 volts to continuous-duty devices and 26 volts to intermittent-duty devices under normal conditions with 28 volts maintained at the generator bus. An allowance should be made for voltage drop in contacts and in fuses or thermal circuit breakers. Under these conditions, current-carrying capacity is usually adequate in the main feeders of 28-volt and lower voltage systems, but may be the limiting factor in higher voltage systems or on short individual load circuits. Normal current ratings for aircraft wire are given in Army-Navy Specification AN-W-14 and are reproduced in table 1. Under emergency conditions with reduced generating capacity and one or more cables open circuited, either voltage requirements or current-carrying capacity may be the criterion. The emergency load limits of aircraft cable are now under intensive study by a cooperative group of service and industry engineers, and the results of these studies should point out proper load limits for these conditions. No general criterion for satisfactory voltage under emergency conditions has been established, although recent preliminary specifications for motors call for satisfactory operation at ten percent above or below rated voltage.

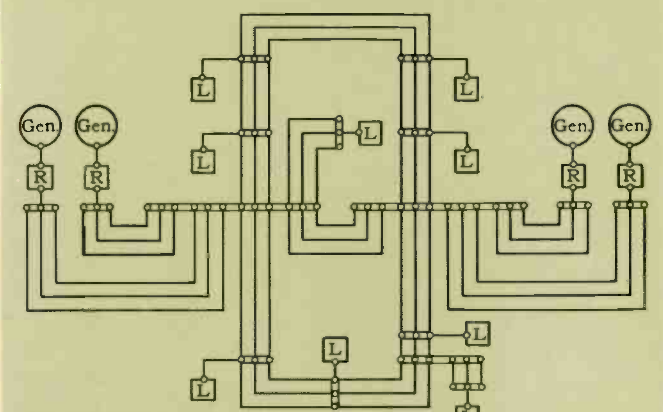
Load Division

With parallel operation, proper load divisions between generators is required. The following methods are possible: (1) design of the regulating system to give a drooping volt-ampere characteristic, (2) resistance in the generator leads, (3) a load-differential regulating system as shown in Fig. 6. In this system one end of the load-division coil in each regulator is connected to an equalizing bus and the other end is connected to a paralleling resistor whose potential above ground is made proportional to the load carried by the corresponding generator. Any difference in load causes current to circulate through the load-division coils in the direction required to reduce the inequality in load division by raising the voltage



L—Group of Loads Connected To Distribution Panel With Fuses or Circuit Breakers
R—Generator Relay

Fig. 4—The generators are paralleled here in a similar fashion to that shown in Fig. 3 but the load circuits are now looped to provide improved voltage and service continuity.



L—Group of Loads Connected To Distribution Panel With Fuses or Breakers
R—Generator Relay

Fig. 5—By using multi-circuit feeders, the total weight of the conductors can be reduced while at the same time better protection against open circuits is attained in emergencies.

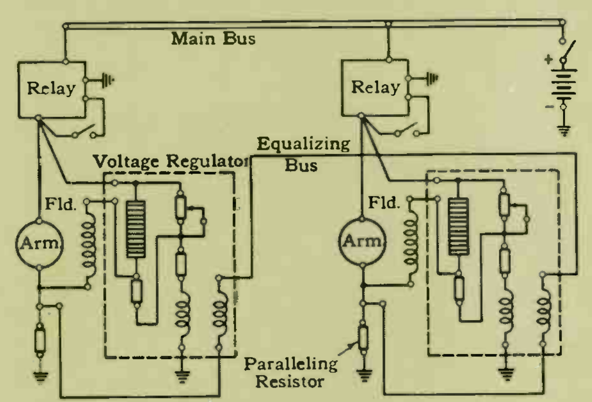
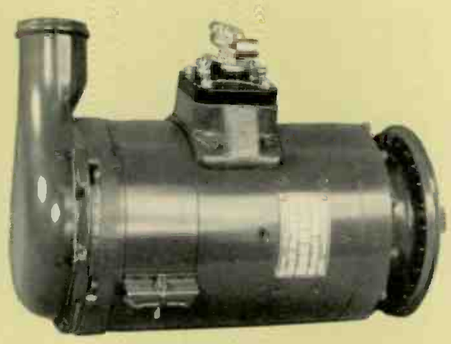
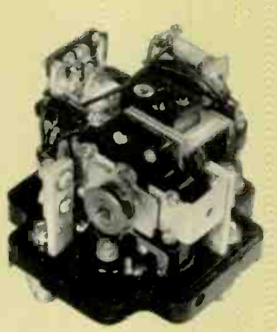


Fig. 6—Load can be divided among generators in parallel in several ways. A method that keeps voltage droop to a minimum is use of a load-differential regulating system.

of one generator and reducing that of the other. This system has the advantage that load division is obtained with minimum voltage droop, which is important on a system having rapid and extreme load changes. Joints between the paralleling resistors and ground must offer low resistance in order to avoid excessive load unbalance.

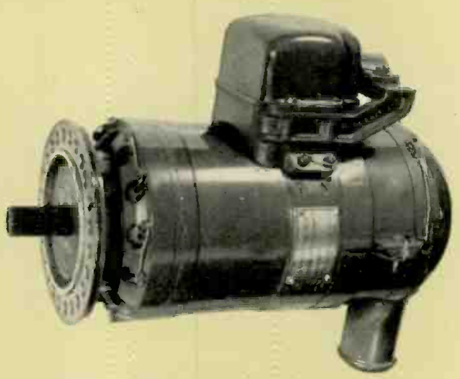


Many types of electrical generators are required for aircraft. This is a blast-cooled unit that will deliver 200 amperes at 30 volts direct current over a wide speed range.



This differential generator-control relay automatically connects the generator to the system when it can carry load and disconnects it if current reverses due to low engine speed or generator failure.

This carbon-pile voltage regulator is used on 28-volt, d-c aircraft generators rated from 50 to 300 amperes in capacity to hold voltage constant as the direct-connected generator speed varies with engine speed.



Both alternating and direct current are produced by this blast-cooled aircraft generator which is rated at 30 volts, 100 amperes direct current and 120 volts, 10 amperes alternating current at either 800 or 1600 cycles.

D-C Aircraft Generators

Standard generating equipment in the vast majority of airplanes is the engine-mounted, d-c generator. Although small in physical size and light in weight, these machines deliver their power with the high degree of reliability required in aircraft service. Table II shows the salient characteristics of typical aircraft generators.

Blast cooling is a necessity on aircraft generators. High output combined with light weight requires that electrical and magnetic parts be worked to the utmost. Thus, losses per unit volume are high, although efficiencies compare favorably with much larger machines. Self-cooling cannot be used on these generators because sufficient pressure cannot be developed to force the required cooling air through the restricted passages of the machine. Six inches of pressure are required and this cannot be obtained with a built-in fan.

Conventional industrial temperature standards are entirely unsuitable for aircraft electric motors and generators. Operating temperatures of 150 degrees C and higher are encountered in these machines. Insulation used is adequate for this application, but the long life required by industrial machines is obviously not necessary.

Batteries

The electric systems of smaller planes use storage batteries of relatively high capacity. Thus, in case of generator failure, the battery carries some load until the plane is able to land. Storage batteries are also used on larger planes, but loads are so heavy that a battery of reasonable size can carry only a fraction of the normal load, and then for only a short time and at reduced voltage. Primary use of batteries is to start the main or auxiliary engines and to carry light loads while on the ground. The battery also helps stabilize the system during transient loads of short duration, such as starting large motors and clearing faults, but continuity of service depends upon the generators. Reserve capacity can be carried in generators at a much lower weight than in storage batteries.

Direct-Current Aircraft Motors

In general, two types of motors are used with regard to the requirements of the load—for continuous duty and for intermittent duty. Continuous-duty motors, for example, are those that drive windshield wipers, fuel pumps, and blowers. Intermittent-duty motors are used for starter, landing-gear retractor, wing-flap, and similar applications.

In addition to the duty-cycle classification, motors are also classified with regard to enclosure and ventilation. These classifications are listed below with typical applications.

1—Totally enclosed, radiation cooled; used for intermittent-duty actuators and radar scanning.

2—Enclosed, cooled by directed air; used for motors in dirty locations and frequently used actuators. a—Direct-connected fan. b—Separately driven fan. c—Blast cooled.

3—Explosion proof; used for fuel pumps and all motors that are located near gasoline tanks.

4—Blast-tube cooled; used on large motors such as super-chargers and for turret control where external blast cooling is not adequate.

Low weight is an important requirement of aircraft motors. Lightweight materials such as magnesium or aluminum are used for castings. All electrical and magnetic materials are worked at highest possible densities. Magnetic materials are selected for high permeability and low losses.

Conversion Equipment

Most airplanes have some electronic equipment that operates at voltages not available from the main power system. This requires conversion equipment to obtain the necessary voltages or frequencies.

In military aircraft, dynamotors are the most common means of transforming direct-current voltages. They are sometimes referred to as d-c "transformers." A dynamotor is essentially a d-c motor and generator combined in a single unit with a common magnetic circuit but a separate winding and commutator for each output voltage.

Rotating-armature inverters are largely used on military aircraft for converting d-c into a-c power. This type of inverter is similar to a motor-generator set in which the a-c and d-c units are mounted in a common set of mechanical parts. The two units are magnetically and electrically independent. Driving power is supplied by the d-c motor unit. The following types of inverters are used:[2] a—motor-generator set, b—dynamotor type, c—inductor dynamotor, d—cascade inverter, e—inverted rotary converter with transformer, f—dynamotor-generator inverter, g—dynamotor with booster, and h—cascade inverter with booster.

Control and Regulating Equipment

Without suitable means of regulation and control, any electric system would be inoperative. On airplanes, the problem is greatly complicated by the fact that the d-c generators are coupled directly to the engines and do not operate at constant speed.

The carbon-pile voltage regulator is widely used with d-c aircraft generators. It is a rugged piece of equipment that has given excellent performance. Weight of a typical regulator used on 50- to 300-ampere generators without plug-in base is 2.5 pounds. This unit will dissipate 75 watts, and is suitable for most generators now in use. The carbon stack is connected in series with the shunt field of the generator. Resistance of this stack is automatically varied over the wide range required with load change and a speed range that may be as great as 3 to 1.

A special device in the regulator reduces instability and chattering, which may cause short regulator life. Parallel operation and load division are obtained by utilizing the voltage drop across a grounding resistor. This drop is only 0.50 volt at full load.

A relay switch known as a differential relay connects each d-c generator to the bus and prevents interchange of power and reverse-current flow between generators of a multi-generator system when operating at light loads. One differential relay is required for each generator.

A differential relay prevents discharge of the aircraft battery when the generators are not operating. Furthermore, this relay will not connect any generator to the bus until the generator voltage is higher than that of the bus. This feature prevents chattering which would occur if the generator voltage were lower than that of the bus.

Future Higher Voltage Systems for Larger Aircraft

On some of the largest airplanes, more electric power will be required than can conveniently be provided with the present low-voltage d-c system. To avoid excessive weight in conductors, switches and commutators, a higher voltage will be required. If this increased voltage were provided in a d-c system, the advantages of direct main-engine drive for the generators, simpler load division and generator paralleling, and simpler wiring would be retained. On the other hand, the commutation of small motors and d-c arc interruption in switching devices become much more difficult as the voltage and altitude are increased. High-voltage batteries are much heavier than low-voltage batteries of the same kilowatthour capacity. As a result, a high-voltage d-c system would probably have a low-voltage battery used only for supplying very small loads. Some means of recharging the battery would have to be included. One large airplane[3] used 120 volts d-c for large loads in a dual-voltage system with 28 volts for small loads and auxiliary-engine cranking. Alternating-current power must also be provided for certain loads.

[2] "Aircraft Inverter Construction," C. T. Button, AIEE Transactions, 1943, Vol. 62, Page 598.

TABLE I—AIRCRAFT CABLE CHARACTERISTICS

Current-carrying capacity based on maximum conductor temperature 100 degrees Centigrade (212 degrees F) with ambient temperature of 57.2 degrees Centigrade (135 degrees F).*

Cable Size	Single Conductor in Free Air-Continuous Loading Amperes	Cables in Conduit or Bundles Maximum 10 Cables in Groups. Assuming only 3 cables carrying Maximum Current Simultaneously. Continuous Loading. Amperes	Maximum Resistance (ohms per 1000 feet at 20 degrees C)	Average Weight (lbs. per 1000 ft.)
20	11	7.5	10.25	7.0
18	16	10	6.44	9.2
16	22	13	4.76	12.0
14	32	17	2.99	17.9
12	41	23	1.88	26.2
10	55	33	1.10	40.4
8	73	46	.70	64.3
6	101	60	.435	96.0
4	135	80	.274	148.4
2	181	100	.179	237.5
1	211	125	.146	
0	245	150	.114	371.5
00	283	175	.090	454.0
000	328	200	.072	
0000	380	225	.057	

*Reproduced from Army-Navy Specification AN-W-14

For large airplanes that do not require a high percentage of a-c power and that will not operate at extremely great altitudes, a higher voltage d-c system will probably be most economical. The suitability of such a system for high altitudes is problematical at present.

The 208/120-volt, 3-phase, 400-cycle system[1] also offers attractive possibilities for large airplanes. Commutators are not required except in the alternator exciters. Arc interruption is relatively easy and transformers can be used economically to supply small loads at low voltage. Development of a proper drive for the alternators is the principal problem.

Future Direct-Current Systems

Although airplanes have been equipped with d-c electric systems for many years, most of the development of the present 28-volt system took place within the past four years. It is now a reliable power system that has done much to bring both commercial and military airplanes to their present state of perfection. So many conflicting factors enter into the design of an aircraft electrical system that at least two voltage classes in both a-c and d-c will probably be used. Higher voltage d-c systems, probably 120 volts, will undoubtedly be used in the near future on large airplanes. Development work now in progress indicates that the 120-volt system will be as reliable as the 28-volt system.

[3] Refer to "A 120-Volt D-C Aircraft Electric System," L. M. Cobb, AIEE Transactions, 1944, Vol. 63, P. 1327.

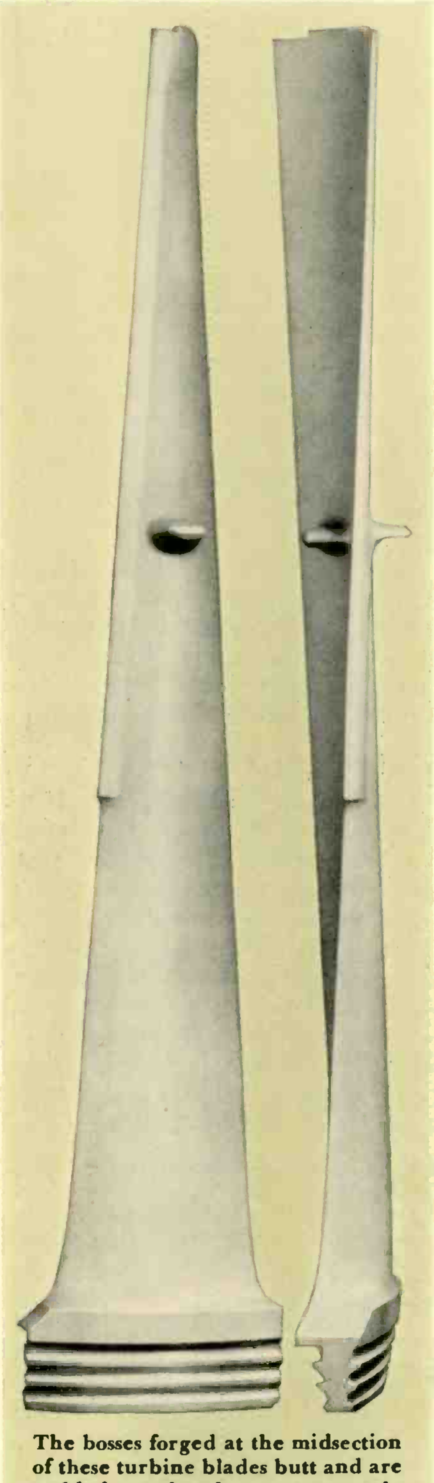
TABLE II—D-C AIRCRAFT GENERATORS

Kw	3.0	5.7	6.0	9.0	12.0
Volts	30	28.5	30	30	30
Amperes	100	200	200	300	400
Speed (rpm)					
Minimum	4 000	2 500	4 000	4 400	4 400
Maximum	10 000	4 500	10 000	10 000	10 000
Cooling Air					
CFM	55	75	67	84	105
Inches of Water	6	6	6	6	6
Max. Temp. °C	60	60	60	60	60
Weight, Pounds	25.5	44.5	39	49.5	55

What's New!

Better Bracing for Low-Pressure Blades

THE blades in the last rows of very large condensing steam turbines are so long that they must be tied together to form groups for mutual support. In addition to being fastened at their outer ends, they are frequently tied at about their midsection. The more common method of lashing has been to join adjacent blades by welding a stainless-steel wire to them. This scheme has been generally satisfactory but turbine engineers have never quite liked the idea of welding directly to the main body of the blade. There is always the possibility that the heat of the arc may impose unrelieved strains or alter the metallurgical structure in the blade.



The bosses forged at the midsection of these turbine blades butt and are welded together for extra strength.

All risk of this eventuality is circumvented by forging two bosses as an integral part of the blade. Then when the blades are stacked together around the spindle the forged bosses of adjoining blades closely butt together. They can then be welded without the blade section being significantly heated.

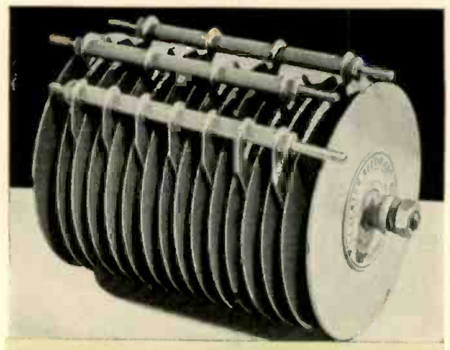
Selenium Rectifiers

WHY a metallic dry-disc rectifier works as it does is as much a mystery to most people as what electricity is. But work it does, and well too, as proved by the performance of literally millions of these converters built since the early twenties when copper-oxide units first provided the power to charge the storage batteries used with the radios of those days. The selenium rectifier has taken its place beside the familiar copper-oxide rectifier. Doing many of the jobs that its better-known partner can accomplish, it has some advantages all its own.

Where space and weight must be limited, such as in airplanes, the selenium rectifier has the edge. It has better characteristics for operation over a wide range of temperatures than does the copper-oxide. The Westinghouse rectifier, in addition, is notable for its ability to work in ambient temperatures well above the usual 70-degree C limit, although not for continuous operation.

Life tests have been in progress for over two years. It is still too early to predict the full life history of a selenium rectifier because accelerated life tests on it are impossible. But, to date, the increase in forward resistance and the corresponding decrease in efficiency have been exceptionally low. Units, after operating on life tests for a year, showed an increase of only six percent in forward resistance—some in fact showing no measurable increase during that time.

The rated cell voltage of the selenium rectifier is fixed, but intermittent current overloads can be tolerated depending upon the ambient temperature and the duration of the overload. On the other hand, the selenium cell is less likely to be permanently damaged if punctured by surge voltages. A selenium disc has considerable ability to heal itself.



Selenium rectifiers appear quite similar to copper-oxide units with discs arranged on an insulated stud.

The appearance of a selenium rectifier is quite similar to the copper-oxide type. The individual cells consist of metal discs or plates on one side of which is a thin layer of selenium. Over the selenium is sprayed an alloy coat. Rectification then takes place between the selenium layer and the outer alloy. The direction of current flow is from the selenium to the alloy, so that the selenium or rather the back plate is the negative terminal while the alloy layer is positive. The metal plate takes no part in the rectification and serves only to support the active materials. The units are assembled on insulated studs with proper spacing for ventilation. A light spring contact washer is used with each cell. After assembly, the complete unit is given three coats of insulating varnish for protection against humidity. Other methods of protection are used where exposure is unusually severe.

Six sizes of selenium cells are made by Westinghouse at present, varying from one to four and three-eighths inches in diameter. Ampere and voltage ratings depend upon the method of connecting the cells or the ambient temperatures in which they are operated.

The Story of a Great American

ONE hundred years ago next October was born the man who contributed more to industry generally than any other person of our industrial age—George Westinghouse. Celebrating this event is a new, short, fascinating biography of the man. The centennial of the birth of so great an inventor and industrialist would be reason enough for a review of his life and works. But the character of the times in which we find ourselves in 1946 makes a study of such a citizen of genuine benefit. All of us are trying to understand in our day the fast-moving changes in our industrial structure, the new and revolutionary developments in technology, the industries that seem to lie just behind the horizon. Of great value in helping to understand where we are going is to see where we have been. Because the life and productivity of Westinghouse cut across so many fields—marine transportation, railroads, the electric industry, the gas industry, and others—and laid the basic foundations for some, a review of his life helps us understand our world today.

This new brief biography has been prepared with that in view. It is a 64-page affair, in color and illustrated with sketches in the manner of his times. By anecdote and story his remarkable achievements are told in an entertaining but informative manner. Copies—within the limits of the supply—may be had for the asking by addressing the *Westinghouse ENGINEER*, 306 Fourth Avenue, P.O. Box 1017, Pittsburgh (30), Pennsylvania.

Fault Finder

Application of the customary high-potential test to an electrical winding tells whether or not there is an insulation weakness. But it does not say where. Thus when the motor or circuit being tested is dismantled, there still remains the problem of locating the fault. Usually the test current is so small that no physical evidence of the detected fault remains.

A new test device not only finds any insulation weakness but also marks the spot. This new tester has incorporated into it the usual high-voltage, low-capacity unit and also a low-voltage, high-current source. If a fault develops, the small current of the high-voltage arc actuates a relay that applies the low-voltage power circuit. The result is a current heavy enough to burn the spot with enough smoke and heat for later identification.

The difficulty, heretofore, with this scheme has been that of maintaining the low-voltage arc. After the current wave passes through zero, the voltage may be insufficient to initiate the arc again. The fault-burning set solves this problem by superimposing on the 60-cycle wave a potential of high frequency (below the broadcast band) that insures restriking of the arc. This high frequency is provided by an oscillating circuit consisting of inductance and capacitance.

The entire set is inclosed in a compact cabinet of about the same dimensions as the usual high-voltage test set. It is mounted on wheels so it can be readily moved about the motor test floor or the repair shop as required.

Simpler Industrial Floodlights

The utmost ruggedness and simplicity of operation are required for the industrial-type, heavy-duty floodlights used by the score around factories, railroad yards, shipbuilding ways, etc. Two new 14-inch floodlights now carry these features to even greater limits than ever included before.

The method of focusing the lamps has been reduced to the movement of a single screw instead of three, a simple, positive action that results in better focusing almost automatically. Then too, this adjustment screw is long enough to accommodate both the PS- or G-type bulbs, providing greater versatility in a single floodlight unit.

A floodlight may have been carefully adjusted at night to cover just the area desired, yet it may be necessary to turn the lamp to a more convenient position when the bulb needs replacing. If this were done in daylight, the original setting might be lost. An index and stop on both elevation and base adjustments now make it a simple operation to return the lamp to exactly its original position no matter to what angle it has been turned for relamping.

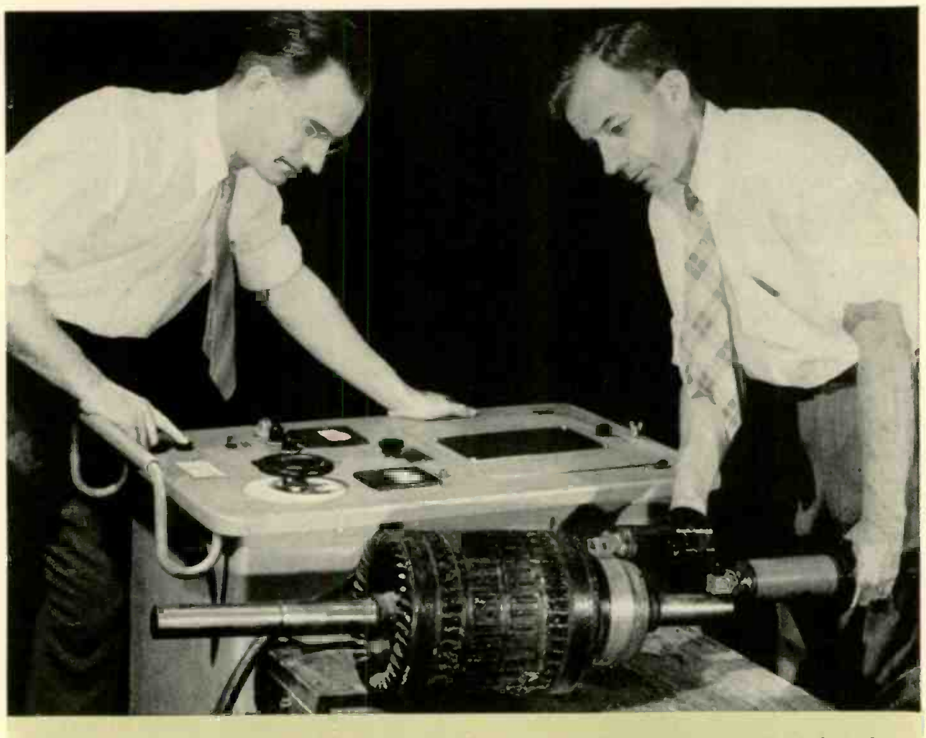
Additional refinements in this industrial-type floodlight make it easier to focus or to return to its original setting after it has been swung around for inserting a new lamp.

The lamp can be adapted to temporary operations requiring portable floodlights. The new unit is equipped with a handle and a wheel base so that it can be converted readily for use in such jobs as construction work or the occasional maintenance operations that must be done outside of the plant itself.

Illumination Training Course

Utilizing the most effective aids to quick learning, a comprehensive course in lighting fundamentals has been designed by Westinghouse for training of sales personnel of utility companies and others interested in the subject. Called "Illumination—Fundamentals and Application," the course combines sound slide films and recordings. This method of presentation has proved itself time and again by the swift, positive results obtained in military training schools.

The course stresses the fundamentals of illumination and their applications in lighting stores, schools, manufacturing plants, filling stations, and the like. There are 18 sound slide films and recordings in all. Each deals with a separate subject and consumes 12 to 15 minutes of running time. The titles of the 18 sections of the course are as follows:



This fault locator indicates the location of trouble in the armature by burning the insulation at the fault. It is being used here only as a fault finder, not as a locator.

Taken from the "Illumination—Fundamentals and Application" training film, this picture gives an example of the results of adequate floodlighting within a train yard.

1—The Mechanism of the Human Eye
2—Light and Vision
3—Illumination Terminology
4—The Quantity Requirements of Good Illumination
5—The Quality Requirements of Good Illumination
6—The Importance of Color in Illumination
7—The Incandescent Lamp
8—Electric Discharge Lamps
9—The Fluorescent Lamp
10—Principles of Light Control
11—Systems of Light Control
12—Calculation of Interior Illumination
13—Office Lighting
14—School Lighting
15—Store Lighting
16—Industrial Lighting
17—Floodlighting
18—Cost and Maintenance of Lighting Equipment

The full course requires about 36 class hours if the recommended time of two hours for each lesson is used. Classes might be held two nights a week for nine weeks to allow members time for supplemental reading and for reviewing lessons covered previously.

All material necessary for a class of ten members is combined into a single package that sells for $225. This includes the 18 films and recordings, 10 sets of pocket-size lesson books, an instructor's manual, and one Westinghouse Lighting Handbook. The Handbook contains easy-to-use tables and many of the new ideas in lighting practice together with information on modern light sources. Extra lesson books are available at $2.50 for each complete set of 18 books.

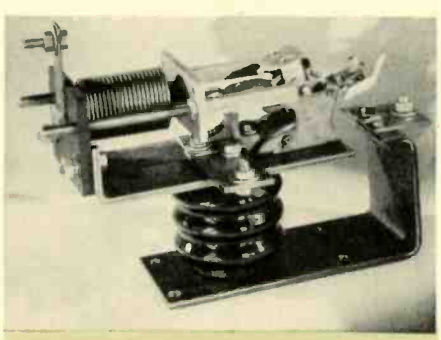
Orders for the packaged lighting training course should be sent to the nearest Westinghouse Lamp Division District office or to the Lamp Division, Westinghouse Electric Corporation, Bloomfield, New Jersey.

One Plus One Equals Zero

Like using one poison to counteract another, the series capacitor neutralizes one undesirable voltage drop in a distribution circuit by adding a second, proportional, but opposite in phase to the first. The net effect is that the two voltage drops cancel one another at all times even under the impact of suddenly applied loads so that sudden dips in voltage for the consumers along the line are reduced to negligible values.

These and other advantages have been known for many years. The most serious deterrent to their greater use has been the problem of protection against overcurrents such as might be produced by lightning surges or line faults beyond the capacitor. The capacitor, being in series with the line, would be damaged by the high voltages built up across it. Devices for by-passing excessive currents and thus limiting these dangerous voltages have been expensive and subject to many troubles in the past.

Now a sturdy, simple by-passing switch has been devised so that heavy currents in excess of the safe limits of the capacitor are harmlessly diverted and the capacitor returns to work again.



The bellows at the upper left operates the switch to shunt high currents around a series capacitor.

Troubles on distribution lines happen quickly. Any protective device must operate in the first half cycle or the capacitor may be damaged. Only a gap connected around the capacitor, calibrated to break down before the impedance-voltage drop across it becomes dangerous, is quick enough.

The shunting gap electrodes, if allowed to carry the overcurrent throughout the period of abnormality would become overheated; so the gap is in turn by-passed by a contactor which, while slower in action than the gap itself, is fast enough to take over the current-carrying function, sparing the gap electrodes.

Difficulties in the past have resulted from two causes. First, the arc was liable to blow out and restrike repeatedly, or an arcing line fault beyond the capacitor —causing much the same effect—would initiate dangerous high-current oscillations within the capacitor. Second, if a magnetic coil in series with the gap were used, the high discharge current from the capacitor burned out the coil windings.

Both these troubles are eliminated by the new gap and by-pass switch.

The gap electrodes are made of special graphite material that limits the voltage across the arc while a cavity within the upper electrode keeps the arc from wandering to the edges and blowing out.

The new by-pass switch is operated by a stainless-steel bellows with its walls directly in series with the gap. Because of its large effective conductor cross-section, its current capacity is tremendous. The bellows is normally in the collapsed position thus holding the switch open. When the gap is discharging, the bellows is heated by the current until a small quantity of liquid within is brought to the boiling point. The resulting pressure expands the bellows and closes the switch. The greater the current, the faster is the operation. Even if the liquid (water has sometimes been used) is frozen, the switch speed does not alter appreciably because the heat from the bellows walls is enough to develop pressure in ample time. The bellows has sufficient time delay so that the capacitor can be drained of its stored charge through the gap before the by-pass switch closes, thus saving the switch contacts from excessive wear.

The contactor is connected so that it short circuits not only the gap and capacitor, but also the bellows. As soon as the switch closes, the bellows starts cooling, and after a short time delay the switch opens. The arc across the gap, of course, is extinguished when the by-pass switch closes; so the capacitor is again put into operation when the switch reopens. The time delay is sufficient so that circuit breakers or fuses have ample opportunity to clear the faulty lines before the series capacitor is reconnected again into the power circuit.

PERSONALITY PROFILES

During 1944 and 1945 Mrs. Frederick Seitz, Jr., thought her husband was playing an uncommon amount of squash when he should have been home to dinner. *Dr. Seitz* had been asked by the Army to do some secret ordnance work, the nature of which he could not disclose to his wife. It has since developed that Seitz wasn't playing quite as much squash as he indicated. His late-for-dinner excuses, although phoney, were justified. He was hard at work on certain phases of the atomic-bomb project, in the Metallurgical Laboratory of the University of Chicago, where the first atomic-energy generator was built. Seitz is an international authority on the physics of solids, having written two outstanding books on the subject—"Theory of Solids," and "Physics of Metals." Because of this the Army had requested the loan of his services from Carnegie Institute of Technology, where he has been Professor and Head of the Department of Physics since 1942, to assist with problems of effects of radio activity on solids.

Although the war is over, Seitz' connection with and interest in atomic energy remains. Last summer he went to Germany as technical advisor to the Army on atomic-energy investigations there. He was recently asked to appear before the Congressional Committee on atomic energy to give his views as a scientist on the subject. He is now engaged with several fellow scientists in writing a book on the subject of atomic energy.

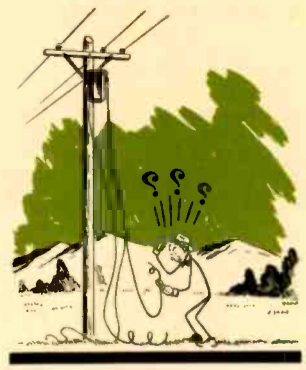
Behind all this lies an impressive record of accomplishment in university scientific work. To his Bachelor degree received from Stanford in 1932 he added a Ph.D. from Princeton in 1934. He served as both Instructor and Assistant Professor of Physics at Rochester University. After

a period with General Electric he became Assistant Professor and later Associate Professor of Physics at the University of Pennsylvania.

One should not gather from this that Dr. Seitz is an oldish man soon to retire. He was born on a noisy Independence Day in San Francisco—in 1911. Neither should one assume that Seitz, being a scientist of acknowledged high rank, dwells solely on matters of Einsteinian profundity. He has been heard when in a gay and carefree mood singing in a lusty tenor the strains of "Old Strassburg" while in a taxi cruising down famed Michigan Avenue.

Boston, in spite of its reputation for conservatism, should be given credit for the progressiveness of its engineers. The local power companies have been willing on numerous occasions to try new engineering schemes. On the distribution department staff of Boston Edison Company was *St. George T. Arnold*. He helped with the banked-secondary distribution system and has carefully accumulated data with it.

Arnold had gathered himself a whole



series of degrees before turning to distribution work. These include a B.S. in Mathematics granted in 1926 by Randolph Macon College, a B.S. in Electrical Engineering from Massachusetts Institute of Technology in 1930, and an M.S. from the same school in 1931. Between times, he spent a year teaching in the Ashland High School in Ashland, Virginia, and during cooperative periods at M. I. T., put the theories he was learning into practice with the Boston Edison Company, which he joined in 1931.

He is active professionally as a member of the American Institute of Electrical Engineers, being chairman of the Technical Group on power and distribution of the Boston Section.

During the war Arnold became interested in another problem of distribution, that of vegetables to his table. He has become a back-yard agriculturist, with noteworthy success—so rumor has it.

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Some people have the happy faculty of being able to transform ideas into objects immediately workable and practical. Since graduating from the University of Michigan in 1930 with the degree of B.S. in E.E. and a year later obtaining his M.S. in Engineering from the same school, *A. D. Forbes* has turned his hand to a variety of useful things at Westinghouse.

After completing the six months' training course at Westinghouse, Forbes spent two years working under the late chief engineer of the Company, R. E. Hellmund, on electronic speed control of motors, then a radically new scheme. During this time, he assisted in development work on a transmission-line conductor protective sleeve used to unload weight at insulator supports where his practical knowledge of materials was most useful. He also spent some time on lightning-arrester research with the Engineering Laboratory before he turned to his present field of distribution-transformer development in 1934.

The workability of one of his ideas bore immediate and most personal fruits for him when he recently designed a house without any basement and, in a cooperative venture with a neighbor of his, proceeded to do most of the building of houses for the two of them. He executed his own novel notions about house heating and air handling. A two-foot cemented space was left under the entire house for a duct to return the heating air to the furnace again. He finds that less heat is lost and that the system is so free from dirt that he needs to clean the filters only once in three years.

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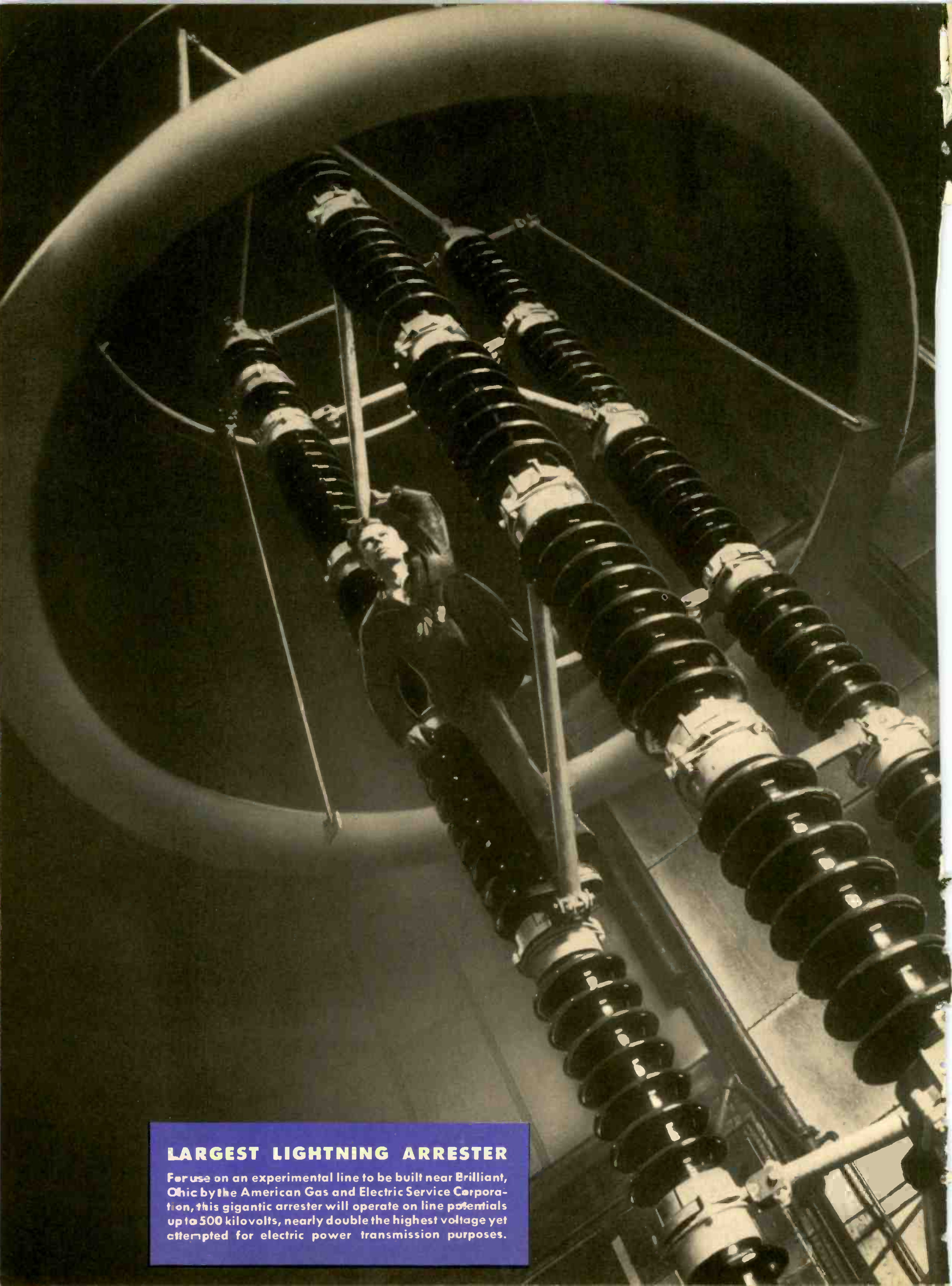
The mechanical transient analyzer of which *H. E. Criner* and *G. D. McCann* speak in this issue can be attributed, in part, to some back-fence gossip. Two years ago these engineers were neighbors. At that time Criner was working in the A-C Generator Design Department at Westinghouse and was struggling with the problem of determining the shaft torques in a turbine generator ensuing from a short circuit. The evenings were hot and as Criner and McCann sat in their adjoining yards they discussed the possibilities of an electrical model to solve the problem. This led to the present analyzer of so many abilities.

Criner is a mechanical engineer. Native of Iowa, he collected his formal training from the University of Detroit, finishing in 1934, whereupon he devoted three

years before coming to Westinghouse to the design of food machinery. Upon joining the Mechanical Section of the A-C Generator Division he concentrated on construction of special manufacturing machinery such as grinders and special machines for gun boring. Lately he has been occupied solving stress and vibration problems of aviation gas turbines.

McCann, known nationally for his studies of lightning and work on lightning protection, is no stranger to these pages. This is his fourth appearance, the earlier three being in August, 1941, November, 1942, and March, 1944.



LARGEST LIGHTNING ARRESTER

For use on an experimental line to be built near Brilliant, Ohio by the American Gas and Electric Service Corporation, this gigantic arrester will operate on line potentials up to 500 kilovolts, nearly double the highest voltage yet attempted for electric power transmission purposes.