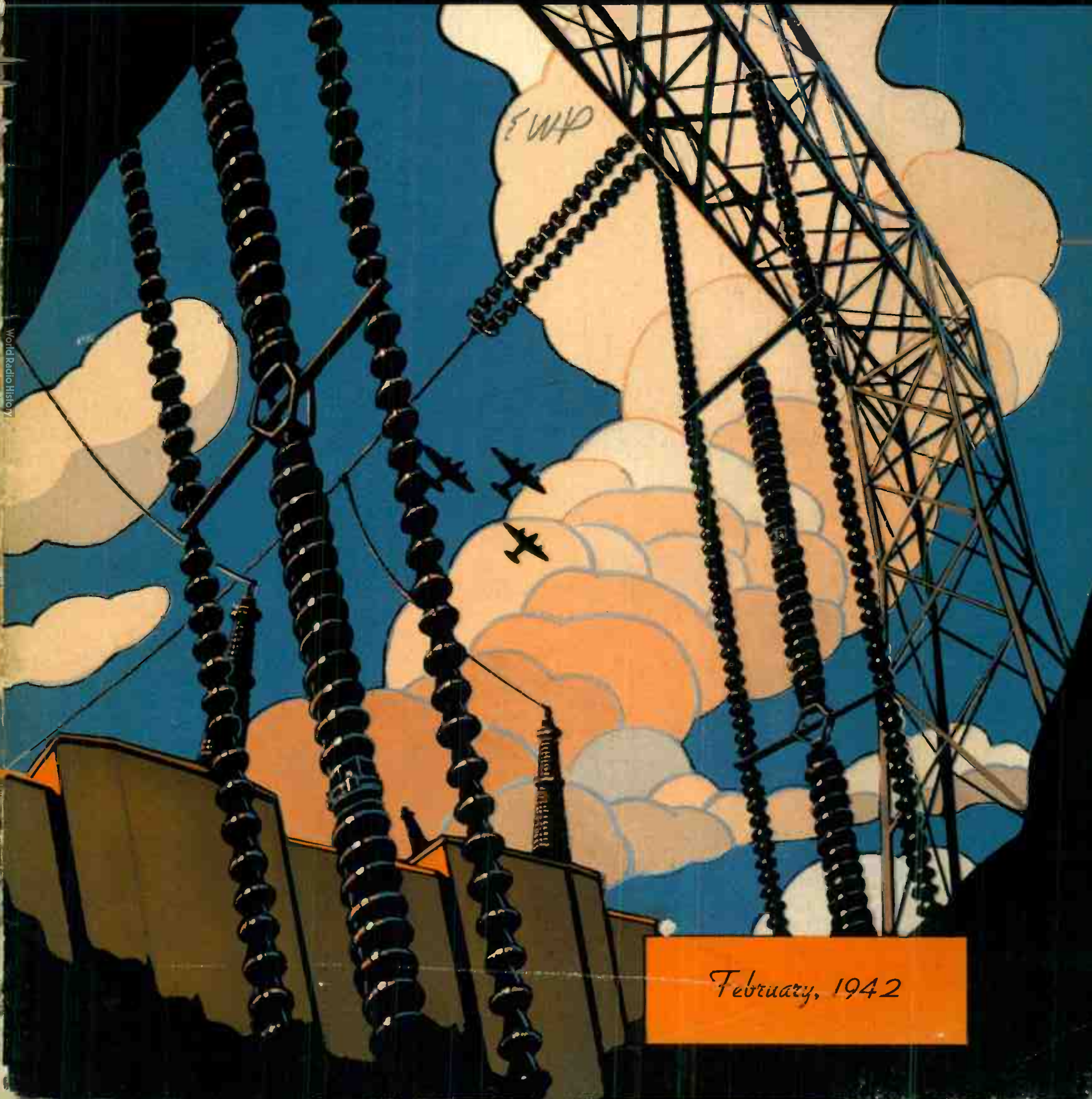
WESTINGHOUSE

Engineer



February, 1942

When LIGHTNING STRIKES . . .

GRANTED that lightning puts on a good show and that its principal actors—the stroke, the thunder, and the damaging effects—perform most dazzlingly. The less spectacular side-shows going on when lightning strikes are not as well publicized, yet are quite interesting, and the supporting cast—the air, the soil, the clouds—deserve a credit line. The lightning stroke, meaning the electrical discharge from the clouds to the **earth**, is but one-half of the story. The other unobserved half is the constant flow of electricity from the earth to the clouds. In a way, lightning is like rain, a sudden tangible precipitation of something that has been accumulating invisibly.

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THE normal charge on the surface of the earth is negative and about 500 000 coulombs. Were air a perfect insulator, this charge could not leak off the earth. But air ionizes and thereby becomes conducting. Thus the electrons leak gradually away from the earth into the surrounding clouds. This flow of electrons from the earth is only five microamperes per square mile, *BUT*—on a clear day this represents about 1000 amperes (coulombs per second). In fair weather, if this rate of loss were maintained, the earth would lose its negative charge in less than ten minutes. It is lightning that returns the escaping electrons to the earth.

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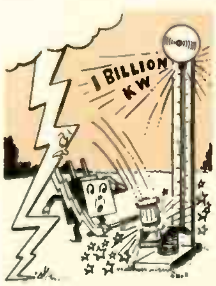
THE average lightning stroke carries an electrical wallop of 30 coulombs. (This sounds small, but it represents about one billion kilowatts—more than the total generating capacity on earth.) To offset the total leakage current flowing, the earth's entire surface must be struck fifty times per second—more than two billion times a year. Nobody has counted these as yet, but this means that the average number of strokes per square mile is 7 or 8 each year. Records of strokes on power lines, made by transmission engineers, show that there are about 10 annual strokes per square mile—thus correlating the calculated and actual figures.



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THE taller the object, the more likely it is to be struck by lightning—this is both an obvious and old story. But there is a difference between the way medium-height and tall bodies are struck. Lightning to buildings or transmission towers less than about 600 feet is started by streamers *from* the cloud *to* the object. Taller structures (the Empire State Building has been a subject of many lightning investigations) actually start the streamer to the cloud. In fact, we can say that a lightning stroke travels from a cloud to a transmission tower but is hurled from the Empire State Building to the cloud. For practical lightning protection, studies of strokes to low objects are more important.

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SOME investigators in Europe claim that the geological formation of the terrain affects the streamer formation, and therefore the frequency with which a given area is struck by lightning. Complete proof of this has not yet been assembled. However, there are indications that the resistivity of the earth has something to do with duration of the lightning stroke and with the damage that it does. Earth of high resistivity—where ancient rock formation is close to the ground—sustains the surge current longer. In these areas lightning arresters are more likely to be damaged.

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LIGHTNING is creative as well as destructive. The power developed in each lightning stroke releases large quantities of nitrogen, in the form of nitrous acid, that is essential to the soil for plant production. In fact, with some 16 000 000 storms occurring over the entire face of the earth annually, the production of nitrous acid from lightning is estimated at nearly 100 million tons. This gigantic amount exceeds by far that produced by all the fertilizer plants in the world.

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WESTINGHOUSE Engineer

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Mountain Mover ★ ★ ★ ★ ★ ★ ★ ★ ★ ★ ★

Important in the economical recovery of copper from a mountain of low-grade ore at Morenci, Arizona, are nine electric locomotives, the heaviest and most powerful used in open-pit mining. To get the two and a third million tons of copper in this Phelps Dodge surface mine, some four hundred seventy million tons of earth and rock must be moved. The 125-ton locomotives, each with four motors totaling 1520 hp, can operate either from a 750-volt trolley or from storage batteries. Brakeshoe wear while descending the heavy grades is greatly reduced by dynamic braking.

Fighting Bacteria with Ultraviolet*

Bacteria have their weak moments, have individual personalities, pass on to successive generations their weaknesses or strengths, and in other ways behave as do animals and man. These and other facts come to light in the intensive research on how best to use the new bactericidal tool, short-wave radiation, for which many practical tasks have been found.

THE sun is a great healing agent, a powerful cleanser. Although responsible for all life, the sun also emits a band of invisible radiation that kills microorganisms. Radiated energy, from whatever source, of wave lengths shorter than 3000 angstroms**are bactericidal.

Since the secret of the sun's bactericidal ability was discovered, scientists have tried to make an effective bludgeon for the never-ending war between man and microorganisms. The passage of electricity through any metallic vapor results in radiations in various wave bands, some of them in the bactericidal region. Efforts have centered, however, about the use of a low-pressure mercury discharge because no other metal gives as strong an emission in the region of maximum bactericidal effect, 2500–2660 angstroms, as mercury. The 2537-angstrom line, which predominates in the spectrum of a low-pressure discharge through mercury is only about 15 per cent less effective than the most potent wavelength, in the neighborhood of 2650 angstroms.

Various mercury-vapor generators of ultraviolet have been successfully used in a modest way, such as for the purification of swimming pools and for other purposes as for the irradiation of milk for production of vitamin D. However, there have been two obstacles to extensive practical use of bactericidal rays. One has been the lack of a generator possessing the necessary requirements of simplicity, economy, constancy of output, and long life. The other has been lack of means of measuring ultraviolet output; without it the use of bactericidal rays is like trying to kill an unseen enemy by shooting an unknown quantity of invisible bullets. These two obstacles were removed almost simultaneously in 1932. A new generator, consisting of a low-pressure mercury discharge in a simple tube of special glass, was developed and became known as the Sterilamp.† A simple meter to measure its radiation in the bactericidal region was fashioned out of a tantalum photoelectric cell.

A Fact-Finding Campaign

The Sterilamp, obviously, is a powerful tool to use against harmful bacteria. But, how much ultraviolet radiation is required to kill a bacterium? Do bacteria differ, or are all types killed by the same amount of radiation? Is the lethal action of the rays dependent on temperature, humidity, or other factors? Is a small amount of radiation over a long period as effective as a high intensity over a short period? The answers to these and many other questions vital to the scientific use of the new tool were unknown.

To find the answers Dr. H. C. Rentschler, Director of the Westinghouse Lamp Research Laboratory, launched an intensive program of investigation of the bactericidal effect of ultraviolet radiation. Being an engineer, Rentschler approached the bacteria problem from an engineering angle, with interesting results, both as to method and findings.

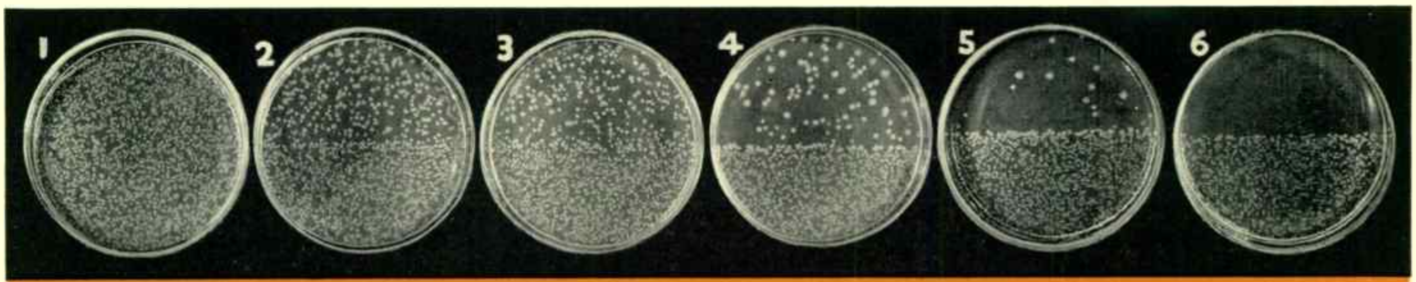
The way to find out how to kill bacteria with short-wave radiations was to seed bacteria and irradiate them under different conditions. This called for a method of seeding bacteria uniformly. Dr. Rentschler devised an ingenious technique of accomplishing this. He built a box five feet on a side. Into the box he sprayed, under pressure from a nitrogen tank, a solution of broth that contained *E. coli*, the harmless bacteria that were to serve as the guinea pigs. After waiting a couple of minutes for turbulence to subside and for the large drops to settle out, a sliding door in the bottom of the box was pulled back exposing a tray of the uncovered Petri plates, used by bacteriologists as farms for the growth of microorganisms. By this method the bacteria-laden spray

The long lamps produce bactericidal radiation that reduces mold formation. Meat is kept in prime condition longer; trim loss is less.

*This article is based on information supplied by Dr. H. C. Rentschler, T. R. Porter, and R. E. Williams.

**An angstrom is one hundred-millionth of a centimeter.

†Trade mark registered in U. S. Patent office.



These are typical of the results of the experiments in which Petri plates, simultaneously and uniformly seeded with bacteria, were exposed to bactericidal radiation. In this particular experiment the upper half of all plates (except 1 which was used as a control) were exposed to the same total amount of radiation, but over different lengths of time (ten minutes for no. 2, 38 hours for no. 6). The longer but weaker exposures are more effective because the longer time allows all bacteria to be caught when their resistance to ultraviolet is lowest.

settled on the plates uniformly. After the simultaneously seeded plates had been incubated at a warm temperature for several hours all the plates were found to have within three per cent of the same number of bacteria. This method of seeding was used in each test, two or three of the seeded Petri plates being used as controls, that is, given the same treatment, except ultraviolet radiation, as the test plates. After incubation these controls gave the number of bacteria originally present on the test plates.

The first group of tests indicated some curious behavior on the part of bacteria. Several plates were simultaneously seeded and all but the two control plates were exposed to various amounts of bactericidal rays. All plates were then incubated for several hours to cause colonies of discernible size to appear, which could be counted to give the number of bacteria that had survived the amount of radiation to which each plate had been exposed. The results of several successive tests are given in table I. In test 2, for example, 27 per cent of the bacteria were killed with four clicks (units) of ultraviolet radiation, whereas in test 8, the same total radiation killed 59 per cent. Why more than twice as many bacteria were killed in one case than in the other could not be believed an experimental error.

Resistance of Bacteria to Rays Varies with Age

Perhaps the age of the bacterium at time of exposure to the rays affected the results. To determine this, simultaneously seeded plates were exposed to the same total radiation. For some plates the radiation was concentrated in a short time; for others the same amount of radiation was spread over longer periods. The results were striking. Many colonies survived on the briefly exposed plates; those exposed for longer times had but few remaining colonies. This and subsequent supporting experiments led to the important conclusion that a bacterium is more susceptible to the killing action at some time in its life cycle than at others. (The life cycle of a bacterium is considered as the period from the instant it is formed by subdivision until it itself divides. For many bacteria, at the most favorable temperatures, this is about 20 minutes.)

A bacterium is at some time in its life at least five times more resistant to ultraviolet than at other times, which is not unlike the variation in resistance of a man throughout his life to different diseases. This fact is important in the use of bactericidal radiation as it indicates the period of exposure required for most effective results.

In the tests made to show variation in radiation resistance, the plates given weak but long exposures showed an apparent reversal of this effect. After irradiation the plates had more bacteria colonies than those exposed for shorter times. Bacteria seemed to be thriving instead of dying. It was as though some bacteria were weaker than others and were killed while the strong ones survived and reproduced. Such indeed proved to be the case, leading to the new concept that bacteria of the same strain, like people of the same race, have individual differences. Furthermore, it was proved that these

The Sterilamp as a Source of Bactericidal Rays

The Sterilamp is a slender tube made of ultraviolet-transmitting glass. It contains electrodes, one sealed into each end, a small quantity of mercury, and inert gases of low pressure (about 17 mm). The lamp is connected to 60-cycle, 115-volt supply circuit through a small current-limiting transformer. When the power is applied the transformer provides the necessary voltage to create a discharge through the lamp. This discharge vaporizes some of the liquid mercury. Because the mercury vapor has a smaller ionizing potential than the gases the discharge shifts to the mercury and operation continues at a reduced electrode voltage. The inert gases are used for starting the discharge and controlling the temperature of operation. They contribute nothing to the emission in the bactericidal region.

The lamp is of the cold-cathode type and therefore operates at low temperatures. The tube itself is cool to the touch, there being but only 12 watts consumed by a 10-inch unit. This amounts to a few degree F rise in temperature. This feature of the lamp is especially important in air-conditioning and cold-storage boxes where heat loss is a problem. The lamp has a long life; it will burn continuously or intermittently for about 4500 hours (about six months). The useful life is ended not by failure of the discharge but by a loss of the short-wave radiation.

As is so often the case, when we learn how nature does something we are able to improve on it. Actually the sun as a bactericidal agent is a piker. It is, roughly, only one two hundredth as effective as the Sterilamp. Whereas the noon sun at midsummer delivers enough bactericidal radiation to register one unit on the ultraviolet light meter in thirty minutes, the Sterilamp at two feet will produce the same amount in about ten seconds. As a generator of ultra-violet the Sterilamp is extremely efficient; 84 per cent of the lamp's radiation occurs in the 2550-angstrom region. Less than ten per cent is in the visible spectrum, that is, above 4000 angstroms.

The output of the Sterilamp can be controlled, so that its radiation can be maintained essentially constant throughout its life. This is accomplished by increasing the current through the lamp to compensate for the reduced output.

TABLE I—PER CENT OF *E. COLI* KILLED BY ULTRAVIOLET

Test Number	Colonies on Control	RADIATION EXPRESSED IN METER CLICKS									
		2	4	7	10	13	17	20	24	28	32
1	570	..	31	45	66	79	90	94	98.6	99.2	100.
2	566	5	27	54	67	86	90	96.7	99	99.4	99.9
3	640	9	39	54	71	84	..	95.6	98.4	99.8	99.8
4	700 •	23	43	63	81	88	..	95	98.4	99 3	99.7
5	668	25	35	59	72	83	92.6	95.7	98	99.6	100.
6	640	36	45	62	66	88	94.	96.7	99.1	99.5	99.7
7	543	30	50	52	..	77	91	91	97.5	98.5	99.2
8	530	19	59	65	79	..	93.	96	97	99 7	99.8
9	165	15	32	44	66	79	83	85			
10	1125	18	..	55	68	75	85	91.3			

Tantalum Cell Measures Ultraviolet

THE scientific use of any new tool rests on the ability to measure its performance. At the time the Sterilamp was first created there was no meter or unit of measure of batericidal ultraviolet radiation. The meter itself, however, was not long in coming. It is based on the fact that the standard tantalum photoelectric cell responds only to radiations in the 2000–3000 angstrom region. When radiations fall on the cathode of the cell, current from a battery passes through it, proportional to the effective intensity of the radiation, and charges a condenser. After the condenser absorbs a certain charge it "spills over," discharging through a special trigger tube, which trips a mechanical counter. Each discharge makes an audible click (i.e., when the relay operates). This click is considered one unit of ultraviolet energy, which has been calibrated to be equivalent to 220 microwatt seconds per sq. cm. of 2537-angstrom radiation.

The unit of bactericidal energy still has no name. The word "click," which describes the action of the ultraviolet meter, will do nicely until the standardizing agencies select one.

individual characteristics are passed on from generation to generation. By creating several cultures, each from a single bacterium, and then testing part of each culture for its relative short-wave resistance, and repeating this for several generations, it was possible to develop a strongly resistant strain of bacteria. For example, a non-resistant and a resistant strain having been developed, ten clicks of radiation killed 99.5 per cent of the weak ones, but only 65 per cent of the "strong" ones.

In the course of the experiments it became evident that a bacterium can be injured by a sublethal dose of ultraviolet radiations. The life cycle is somewhat lengthened by the injury but subdivision eventually takes place in the usual way. This retarded rate of subdivision is continued for several generations before again reaching the normal rate.

The ability to injure a bacterium throws some light on the mechanism by which bacteria are killed by short-wave energy. One theory, still held by some, states that a bacterium is killed if directly hit by one photon of energy. The new evidence leads to the definite conclusion that destruction is caused by the absorption of the radiation by the microorganisms and not by the fact that a photon hits a vital spot.

Many other practical questions have been settled by the experiments. Temperatures, within normal ranges, have no bearing on the effectiveness of the radiations because as many bacteria are killed at 5° as at 37°C, nor has relative humidity any effect on the action of waves.

In applying bactericidal radiation it is important to know whether the results of an instantaneous surge of radiation is the same as a like amount of radiation spread over a period of minutes. Tests indicate that the effects are the same, provided the time is not long enough to include an important part of the life cycle of a bacterium, during which the resistance of a bacterium itself changes.

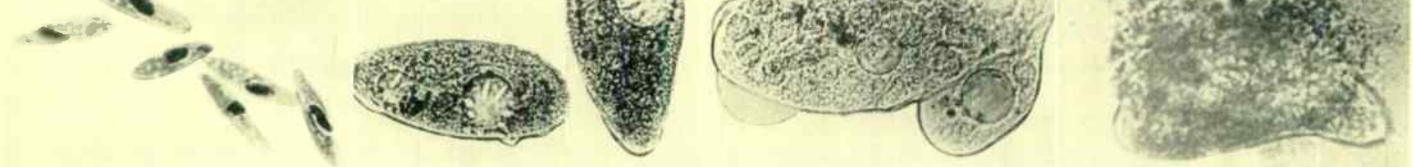
The investigation of the effectiveness of 2537-angstrom radiation has been extended to include other bacteria than the harmless *E. coli.* Bacteria with more sinister influence on humans, have been studied and their reactions to the lethal rays catalogued. Molds and yeasts also have been studied.

Exploring the World of the Virus

Bacteria can be considered as simple forms of animal life; molds and yeasts are elementary plant life. There is still another form of "life" which is neither. It is the virus.

Viruses are exceedingly tiny things that cause influenza, the common cold, yellow fever, small pox, infantile paralysis, and scores of other diseases. Nobody has ever seen a virus, because they are too small to be detected with ordinary optical microscopes. Shadow pictures of viruses have been taken with electron microscopes. Viruses don't move; in fact, scientists are not sure whether viruses are animate. Under most conditions they act like chemicals and exist in crystalline form, but given the proper host they "come to life," thrive and multiply. How one is to tell whether ultraviolet inactivates a virus is a little puzzling. A virus is identified only by its action or effect on an animal or a plant. Many believe that some viruses attack bacteria in the same way that influenza virus attacks man. Such a bacteria "virus" has been classified as bacteriophage. Although the work on viruses is just beginning, it appears that one of the solutions to this problem of determining the effects of the ultraviolet

Progressive stages in the killing of bacteria by short-wave radiation. At the left are normal paramecia. Next are two paramecia after thirty seconds of irradiation, showing distension just beginning. Distension continues in the third view, followed by bursting of the cell wall. Death of a bacterium is caused by a change in the osmotic tension of the cell wall, which causes the organism to swell and break.



radiation in inactivating viruses is to use bacteria as hosts for the corresponding bacteriophage.

The particular virus under observation is *Staphylococcus bacteriophage*, a type that does not attack humans, but thrives only on *Staphylococcus* bacteria (which cause boils and other skin infections). The method of determining the action of ultraviolet radiation is somewhat roundabout. A culture of *Staphylococcus* is grown in a test tube, and after it has flourished the culture medium becomes cloudy.

Irradiation of cosmetics prevents the formation of mold.

Bacteriophage introduced into the murky growth immediately attacks the bacteria and the culture clears. If the culture is not cleared by the phage (virus) that has been irradiated with ultraviolet, it seems logical to conclude that the phage is no longer potent.

Bactericidal Rays Roll Up Their Sleeves

With the development of a suitable source of bactericidal radiation and a means of measuring it, practical uses of these rays for man's betterment bloomed in profusion. Many have become commonplace. Industries supplying packaged goods were quick to adopt the new means of protection. Bakeries, for example, have found that by irradiating the wrapping areas the mold-free life of bread and cake is increased by one or two days, which greatly reduces the spoilage loss bakers and merchants have been accustomed to accept. Other package products like face creams, tooth paste, foods, serums, vaccines, even empty medicine bottles are being delivered to the user in a sterile condition because the final packaging and sealing has been done in bacteria-free air. Vats of syrup for soft drinks are now kept mold free, whereas formerly the top surface frequently had to be skimmed off. Glasses and silverware in many public eating places are being sterilized in this fashion.

Mortality among baby chicks is greatly cut down by installation of Sterilamps in brooder houses. In dairy barns the bactericidal rays not only improve the general health of the cows but also reduced to one-fifteenth the bacterial count in the air to which the milking utensils are exposed. Sterilamps are used in stables for race horses, in pet-shop hospitals, and the like.

Much progress has been made to date in the use of ultraviolet radiation in air-conditioning systems. Placing lamps in the ducts of a recirculating system in apartment houses, offices, theaters, etc., has obvious advantages in decreasing the spread of colds and other air-borne diseases. Also they offer an economic return by reducing the percentage of fresh air required to avoid building up bacteria concentration. The result is a reduced heat load, which may, in itself, be sufficient to cover the cost of the irradiation equipment.

Many other applications are being studied. It may be possible to use the lamps to raise the purity of small water-supply systems. The spread of colds, influenza, and other diseases in army camps where large bodies of men from many areas are concentrated is always a serious potential hazard. Investigation is being made of the value of bactericidal radiation in barracks to forestall such contagion.

The beef you eat for dinner tonight may be much more tender than the same steak would have been a couple of years ago, because of ultraviolet radiation. Tenderizing beef is essentially a matter of aging. Time is required for the enzymes to transform the tough connecting tissue into a soft gelatin. This process proceeds fairly rapidly at warm temperatures but, unfortunately, under this condition the meat spoils quickly. Hence, to make meat tender it has been necessary to hang meat in low-temperature rooms for several weeks, which makes it too expensive for general use. In the new process, however, known as Tenderay, the temperatures in the hanging rooms can be raised so the tenderizing is accomplished in two or three days. The ultraviolet radiations furnished by the Sterilamps hold the mold and bacteria in check, eliminating spoilage.

Ultraviolet Radiation at Work in the Hospital

Several years ago Dr. Deryl Hart, a surgeon at Duke University, came to the conclusion that air-borne bacteria are a cause of post-operative infections. By the most rigid aseptic measures he was not able to reduce the rate of infection following surgery below about 12 per cent. (Dr. Hart considers any post-operative rise in temperature as indicative of infection.) He confirmed his belief by thousands of bacterial counts in samples of air taken before, during, and after operation in his own and many other operating rooms. With Dr. Rentschler's help he applied the newly developed Sterilamp in his operating room, arranging eight lamps in a square circumscribing the the light source over the operating table. Success was immediate. Severe post-operative infections almost disappeared, and the total number of infections declined amazingly. Hart recently reported that the percentage of infected wounds at Duke fell from 11.9 to 0.24 per cent, and not one patient in 2463 cases has died from post-operative infection. At the North Carolina State Sanitarium infection incidence in chest operations has been reduced from 22.7 to only 1.09 per cent.

Hospitals are using bactericidal radiation in other ways. "Curtains" of ultraviolet are established around each crib in nurseries, preventing cross infection during that critical first few days of a baby's life. Similar sterile zones are used in wards for children with contagious diseases.

Ultraviolet radiation is a powerful new tool with which to fight bacteria, not only when human life is in the balance, but also to improve the general health. It constitutes another great contribution of the engineer to the comfort and well-being of the modern individual.

Selection of Lightning-Arrester Voltage Ratings

The selection of lightning arresters is like the choice of men for a dangerous outpost. The arresters must be on the alert to prevent damage to the equipment, and must be robust enough to withstand risks to themselves. One of these hazards, overvoltage caused by single and multiple line-to-ground faults, can now be readily determined from two charts, and lightning-arrester rating can thus be selected with greater accuracy. A new arrester rating is suggested for some systems.

R. D. EVANS
Consulting Transmission Engineer
EDWARD BECK
Lightning Arrester Engineer
Westinghouse Electric & Manufacturing Company

A SIMPLE method has been developed to determine the highest power-frequency voltage to ground that can occur under any fault condition of system operation. To determine analytically which set of conditions — ground resistance, amount of resistance in the fault, type of fault, connected generating capacity, etc.—will combine to give the worst condition on any phase of a system is both tedious and difficult. It is now possible to make this determination quickly from two new sets of curves, the use of which entails a knowledge only of the simple sequence components of the system in question.

Ready means of arriving at the highest possible voltages to ground on a system are in themselves valuable for several purposes. However, they have particular significance in selecting the proper lightning arrester to apply to a specific system. With them, arresters can be selected on the basis of the maximum rms voltage of power frequency against which it must interrupt current after a lightning discharge.

Why System Line-to-Ground Voltage Rises

When a single line-to-ground fault occurs, the drop produced by current flowing through impedance in the neutral or in the ground connections is added to the line-to-neutral voltage of the unfaulted phases. Also, when a single line-to-ground fault occurs in a transmission line, the fault current flows through a loop consisting of the faulted phase, returning in the ground wire and earth. This loop is coupled inductively to the two unfaulted phases, and the short-circuit current therefore produces an additional voltage between these lines and the ground. The magnitude of that added potential depends upon many variables, such as the fault resistance and the various system impedance constants. But the nature of these constants is such that the induced voltage is likely to be additive, resulting in a line-to-ground overvoltage that has an important bearing on the lightning-arrester application.

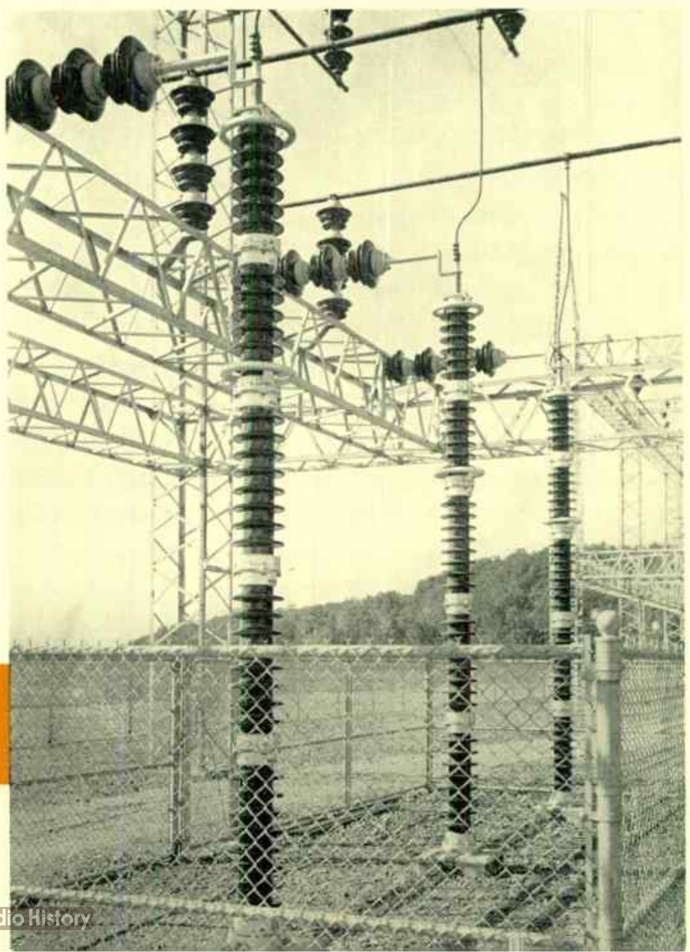
The total line-to-ground voltages are best calculated by the method of symmetrical components,[1,2] using the positive-, negative-, and zero-sequence impedances of the system as viewed from the point of the fault. Qualitatively, it can be readily seen that the most important factors influencing the voltage magnitudes are the ratios of the zero-sequence impedance components (R_0, X_0) to the positive-sequence subtransient reactance component (X_1).

The sequence-impedance ratios X_0/X_1 and R_0/X_1 vary with the system characteristics but are dependent primarily on the way the system is grounded. It is therefore convenient to group all systems into the following three classifications:

1—*Impedance-Grounded Systems*, with neutral grounded solidly or through a resistor or reactor in a manner to make the zero-sequence reactance inductive; the ratio X_0/X_1 is therefore positive. Under fault conditions the line-to-ground voltage seldom exceeds the unfaulted line-to-line voltage, and is most likely to be less.

2—*Ground-Fault Neutralizer or Petersen-Coil Systems*. Under conditions of accurate tuning, the line-to-ground voltage under single line-to-ground fault conditions equals the unfaulted line-to-line voltage.

3—*Isolated-Neutral Systems.* For these the zero-sequence reactance is capacitive, and the ratio X_0/X_1 negative. Under fault conditions the line-to-ground voltage may rise above the unfaulted line-to-line value.



Each phase leg of this 169-kv, three-phase, three-pole arrester (Westinghouse type SV) consists of five units in series. In this manner any rating can be built up of standard unit sections.

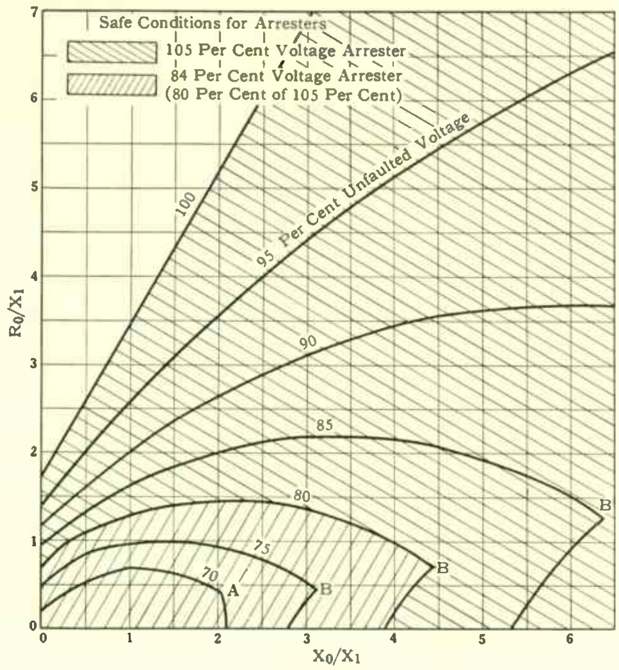


Fig. 1—*Line-to-ground voltage chart for grounded systems. To determine the safe arrester rating, the per cent voltage obtained from the curves above must be used with the unfaulted line-to-line voltage under emergency (or 5 per cent overvoltage) conditions.*

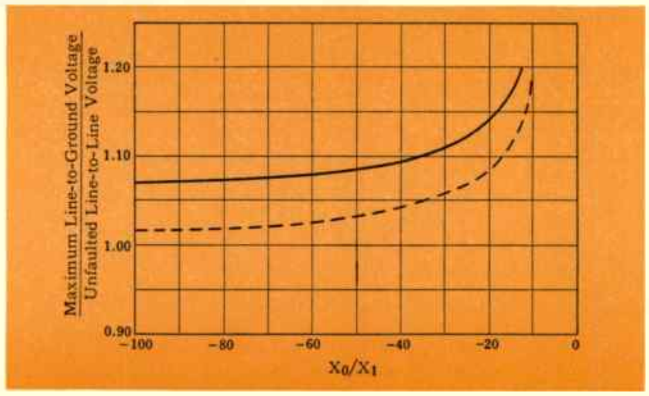


Fig. 2—*Line-to-ground voltage chart for isolated-neutral systems. The maximum line-to-ground voltages for single line-to-ground faults are expressed in terms of the unfaulted line-to-line voltage. Selection of lightning-arrester ratings must be based on the maximum voltage possible under emergency operating conditions.*

The line-to-ground voltage for a particular system for specified conditions can be calculated from equations 1, 2, and 3 given below and from the various impedance constants. However, a large number of conditions must be investigated before the maximum line-to-ground voltage can be obtained by this means. To avoid this labor the curves of Fig. 1 for impedance-grounded systems and Fig. 2 for isolated-neutral systems have been prepared. To use these curves it is merely necessary to determine the zero-sequence impedance constants R_0 and X_0 and the positive-sequence subtransient reactance X_1.

The curves of Fig. 1 cover the practical range of constants for impedance-grounded systems and assume $X_2=X_1$ and $R_1=R_2=R_L=0$. They show the maximum zero-sequence impedance ratios R_0/X_1 and X_0/X_1 for which a definite percentage of the unfaulted line-to-line voltage will not be exceeded between any phase to ground. These curves hold for any type of fault and for any amount of fault resistance.

The curves of Fig. 1 are irregular because they are composed of parts that represent limiting voltages on different phases or for different types of faults. Thus, the principal parts of the curves are arcs of circles corresponding to the voltage on phase c for a single line-to-ground fault with zero fault resistance. For parts of the 70, 75, and 80 per cent curves near the R_0/X_1 axis, the effect of introducing fault resistance is to increase the voltage on phase c. For the 75, 80, and 85 per cent curves the portions between the points B and X_0/X_1 axis are determined by the voltage on phase b for a single line-to-ground fault with the fault resistance such as to give maximum voltage. Part of the 70 per cent voltage curve between the point A and the X_0/X_1 axis is determined by the voltage on phase a for a double line-to-ground fault on phases b and c.

The curves of Fig. 2 for isolated-neutral systems show the range of maximum line-to-ground voltages encountered for a single line-to-ground fault. The line-to-ground voltages in an isolated-neutral system are greatly affected by line resistance; curves are therefore shown for the ratios $R_1/X_1=R_0/X_1$ of 0 and 1. These two curves show the probable maximum range of line-to-ground voltages that may be expected for the entire range of positive- and negative-sequence line resistances and for the fault resistance that gives the maximum voltage on a sound phase during fault conditions. In systems represented by the plotted range on Fig. 2, the maximum line-to-ground voltage caused by a single line-to-ground fault will be higher than for a double line-to-ground fault. However, in the rare systems having X_0/X_1 between -2 and 0, the maximum line-to-ground voltage may be greater for a double line-to-ground fault than for a single line-to-ground fault. The curves assume that $X_2=X_1$ and $R_2=R_1$.

Equations Used in Calculations

For a fault to ground on phase a of the system, shown schematically in Fig. 3(a), the line-to-ground voltages on phases b and c at the fault location are given [1, 2] by:

$$E_b=E_{L\text{-}L}\left[\frac{-\sqrt{3}(Z_0+R_f)-j(Z_0+2Z_2+3R_f)}{2(Z_0+Z_1+Z_2+3R_f)}\right]\ldots\ldots\ldots\ldots(1)$$

$$E_c=E_{L\text{-}L}\left[\frac{-\sqrt{3}(Z_0+R_f)+j(Z_0+2Z_2+3R_f)}{2(Z_0+Z_1+Z_2+3R_f)}\right]\ldots\ldots\ldots\ldots(2)$$

Where $E_{L\text{-}L}$ = normal or unfaulted rms line-to-line voltage
R_f = fault resistance
$Z_0=R_0+jX_0$ = system zero-sequence impedance
$Z_1=R_1+jX_1$ = system positive-sequence impedance
$Z_2=R_2+jX_2$ = system negative-sequence impedance
(All sequence impedances viewed from fault)

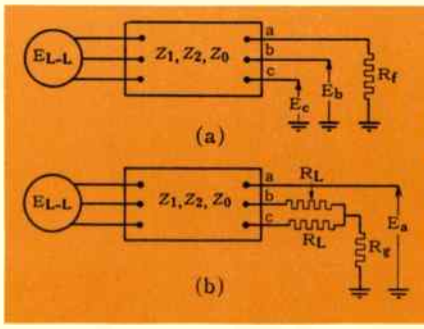


Fig. 3—System conditions assumed for the calculation of the single and double line-to-ground voltages under fault conditions.

For a double line-to-ground fault on phases b and c of the system, shown schematically in Fig. 3(b), the line-to-ground voltage on phase a at the fault location is given [1, 2] by:

$$E_a=\frac{\sqrt{3}E_{L\text{-}L}(Z_2+R_L)\ (Z_0+R_L+2R_g)}{(Z_1+R_L)\ (Z_2+R_L)+(Z_1+Z_2+2R_L)\ (Z_0+R_L+3R_g)}\ldots(3)$$

Where R_L and R_g are the fault resistances shown in Fig. 3(b).

A neutral impedance must be multiplied by 3 in order to obtain the equivalent zero-sequence impedance per phase. When this is done, all impedances are readily expressed in terms of the zero-sequence impedance per phase. This multiplying factor of 3 is sometimes overlooked in the calculations.

Important in the application of lightning arresters is the often-ignored fact that under some switching conditions the impedance ratios of a system change drastically. The system may even change from one classification to another. For example, it is quite possible that in the process of clearing a fault on a system a circuit with a grounding point may be disconnected, thereby changing the system constants and producing a sufficient voltage rise to damage an arrester that is not rated high enough.

Application of Lightning Arresters

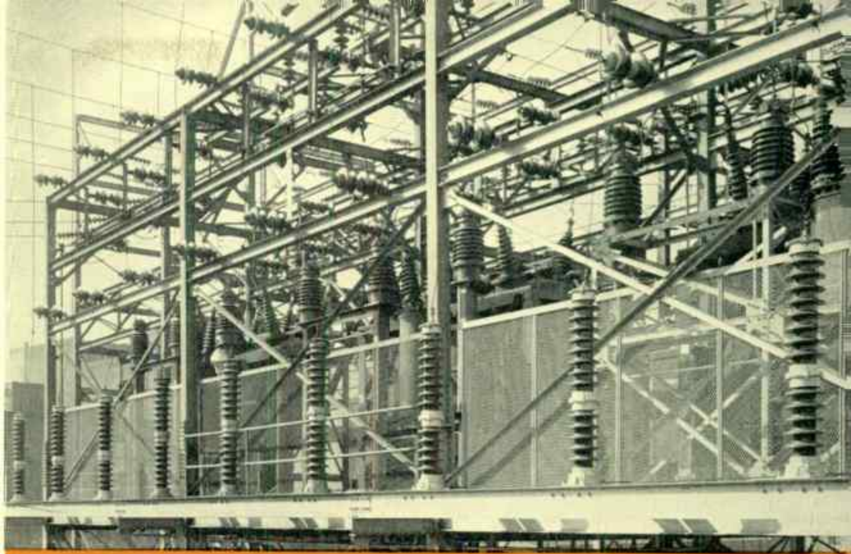
The principal function of the lightning arrester is maintenance of service. The arrester should protect insulation against damage and outage, and should not itself cause outages by becoming damaged. Proper selection of lightning arresters must therefore take into account the excess power-frequency voltages to ground that are likely to occur during faults. A lightning arrester has a voltage rating that must not be exceeded under any condition of system operation, if risk of failure is to be avoided. Sometimes, when a choice must be made, it is better to run the risk of damage to the arrester in the interest of greater protection to apparatus and economy in arrester investment. Nevertheless, the condition should be recognized so the risk can be properly evaluated when arresters are applied.

Power circuits have "circuit voltage" ratings[3] and, in accordance with accepted practice, the system voltage may rise five per cent above the rated circuit voltage for emergency operation[3]. In order to simplify application and standardize arrester ratings, two arrester ratings for each preferred circuit-voltage rating have been used to cover all types of systems, from isolated to solidly grounded neutral. One has a line-to-ground voltage rating equal to the emergency line-to-line voltage of the system. This has been called the 100 per cent arrester (although it is actually 105 per cent of the rated circuit voltage) and is sometimes referred to as the ungrounded-neutral arrester because on such systems this rating has been commonly used. The other[4] is one with a line-to-ground voltage rating 80 per cent of the emergency line-to-line voltage. It has been called the 80 per cent (actually 105 x 80 or 84 per cent of rated circuit voltage) or grounded-neutral arrester.

Whenever the curves, the check rules, or rigid mathematical determination show that line-to-ground voltages can be in excess of 105 per cent of unfaulted line-to-line voltage, it is suggested that an arrester with 115 per cent of the rated circuit voltage (110 per cent of the accepted emergency voltage) be considered. This rating is a logical extension of the existing ones, and a study of the curves shows that it will be suitable for most isolated-neutral systems.

Curves Simplify Selection

Exact calculation of the actual line-to-ground voltages that will occur is possible for any particular set of conditions; in a few cases no short-cut method will suffice. However, to determine the complete range of voltages that can appear across arrester terminals for all conditions of system operation is laborious. It is necessary to determine, for each arrester location, the fault location giving the highest line-to-ground fault voltage at the arrester. This



This 66-kv outdoor substation is protected by the nine single-pole 60-kv lightning arresters that are mounted in the foreground.

fault location is normally close to the arrester, but occasionally it may be nearer the source, if such fault location gives higher ratios of R_0/X_1 or X_0/X_1 than at the arrester. Fortunately, the complete calculation is not generally necessary. From two simple sets of curves, one for grounded systems and one for ungrounded systems, it is possible to determine with accuracy whether a proposed arrester voltage rating is safe or if there is risk of arrester failure. These curves only entail knowledge of the system constants, the zero-sequence resistance R_0 and reactance X_0, and the positive-sequence reactance X_1. They may be used in the determination of the line-to-ground voltage at any fault location. Also, it is possible to give rough-and-ready rules for quick approximation.

The voltage at an arrester location remote from the fault is ordinarily lower than at an arrester close to the fault, except in long lines (exceeding about 50 miles) carrying light loads or ungrounded at the remote end.

Arresters for Grounded Systems

The voltages to ground on systems grounded solidly, or through resistance or reactance, can vary over a wide range during faults, depending on the system constants, as shown in Fig. 1. The data of this figure provide a convenient guide to the selection of an arrester for any system of this class.

The 115 per cent arrester can be used with safety on any resistance- or reactance-grounded system, if the zero-sequence reactance X_0, is positive, since the maximum expected line-to-ground voltage under a fault condition will rarely exceed 110 per cent of the unfaulted line-to-line voltage for any operating condition. In fact, practical systems are designed to pass sufficient current for relaying purposes, and under these conditions the line-to-ground voltage rarely exceeds the unfaulted line-to-line voltage.

The 105 per cent arrester can be applied with safety to resistance- or reactance-grounded systems with constants in the area under the 100 per cent voltage curve of Fig. 1 for any condition of system operation including circuit changes incident to the isolation of a fault.

The 84 per cent arrester (80 per cent of the 105 per cent arrester) can similarly be used with safety when the constants lie in the area under the 80 per cent voltage curve of Fig. 1, under the same conditions applying to the 105 per

TABLE 1—PREFERRED RATED CIRCUIT VOLTAGES AND ARRESTER RATINGS

Rated Circuit Voltage in Kv	Emergency Voltage 1.05 x Circ. Voltage	Arrester Ratings in KV., r.m.s.		
		115 Per cent Arrester (a)	105 Per cent Arrester (b)	84 Per cent Arrester (c)
2.4	2.52	3		
2.5	2.63	3		
4.15	4.36		6	3
4.3	4.52		6	3
4.8	5.05	6		
6.9	7.25	9		
7.2	7.55	9		
11.5	12.1	15	15	9
13.8	14.5	20	15	12
23.0	24.2	30	25	20
34.5	36.2	40	37	30
46	48.3	56	50	40
69	72.5	79	73	60
115	121	136	121	97
138	145	160	145	121
161	169	187	169	136
230	242	266	242	195

(a) These arrester ratings are 115% or more of rated circuit voltage.
(b) These ratings are 105% or more of rated circuit voltage. They are the ratings that have hitherto been called "ungrounded neutral" or 100%.
(c) These ratings, except the 3 and 9 kv, are 84% or more of the rated circuit voltage. They are the ratings that have hitherto been known as "grounded neutral" or 80% (in reality 80% of 105%).

cent arrester. This curve gives a broader application base than the rules set for the grounded-neutral arrester[5].

Should a fault occur to the arrester ground, the curves of Fig. 1 still apply provided the arrester ground resistance is included in the zero-sequence impedance of the system. A fault to the common ground of a three-phase arrester may subject an arrester in the same group on another phase to full line-to-line voltage even on solidly grounded systems if the arrester ground resistance is high.

Arresters for Systems with Ground-Fault Neutralizers

Systems with neutrals grounded through ground-fault neutralizers are not subjected to overvoltages provided the ground-fault neutralizer is tuned with the system. Arresters rated 105 per cent of the rated circuit voltage are considered safe for these conditions. If the system is not correctly tuned, there is a risk of arrester damage, but this small risk may be preferable to the reduction in protection brought about by using overrated arresters. Switching operations on ground-fault-neutralizer systems can produce voltages to ground that may lead to damaged arresters. However, it is not feasible to select an arrester of sufficiently high rating to avoid completely this infrequent hazard.

Selection of Arresters for Isolated-Neutral Systems

The two curves of Fig. 2 give the range of voltages to which arresters on isolated-neutral systems may be subjected. The proposed arrester rating 115 per cent of rated circuit voltage can be applied safely if the ratio of the system constants X_0/X_1 lies between -40 and $-$infinity. When the ratio lies in the unusual region of -40 and zero, even higher ratings of arresters must be considered.

As an approximate rule-of-thumb, it has been found that the 115 per cent arrester can be safely used if the length of aerial transmission line, in miles, is less than a factor

$$K = \frac{4kva_{sc}}{kv}$$

where kva_{sc} = maximum instantaneous symmetrical three-phase short-circuit kva possible when the system is operating with the minimum connected generating capacity.

kv = maximum unfaulted line-to-line kilovolts.

If K is greater than the length of the line in miles, specific calculations should be made and the proper arrester selected, as it is likely to call for a rating higher than 115 per cent. (If the system includes cables, they should be replaced by aerial lines having the same capacitance to ground.)

The foregoing rule and the solid curve of Fig. 2 are based on assumptions that are more pessimistic than are encountered on all systems. As indicated in Fig. 2, the voltages to ground lie in a zone between the extreme values indicated by the solid- and broken-line curves. Furthermore, systems do not operate continuously at the emergency voltage. Hence there is some safety margin. This explains why many isolated-neutral systems have operated satisfactorily over a period of years with 105 per cent arresters. This experience should be taken into account in making the choice between the 115 per cent and the 105 per cent arresters. It may sometimes be desirable to sacrifice total immunity to arrester damage in order to secure better margins of protection, together with reduced size and cost of arresters. Calculations of voltage should be made when necessary to evaulate these factors.

Curves Applicable to Most Systems

Exceptions to the above rules for arrester selection on isolated-neutral or grounded systems must be made when:

a—No equipment is used to limit the overvoltages caused by the sudden loss of load on water-wheel generators.

b—Harmonic overvoltages can be caused by short circuits on rotating machines that do not have properly designed amortisseur windings, when the machines are disconnected from the load or system, or when overvoltages at fundamental frequency can occur on systems with such machines when subjected to faults.

Aside from these exceptions, the rules in general are conservative. A detailed system study may indicate the use of an arrester with a lower rating.

A proposed list of practical arrester ratings that apply to the conditions discussed is given in table I. The ratings do not in every case match exactly the voltages listed, especially for circuits below 34.5 kv where the margins of practical ratings may be large so that some ratings serve for several classes. On systems whose rated circuit voltage differs from the preferred standards listed in table I, arrester ratings suitable to the particular *maximum emergency* line-to-line voltage should be that determined by Figs. 1 and 2.

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Heating by High-Frequency Induction

The fundamentals of induction heating, presented in the previous issue as part of the author's article on melting, are also operative in the heat-treating field. The difference in the job to be done, however, calls for radically new equipment. Unlike the melting furnace, intended for but a single purpose, induction heat-treating machines must be versatile, providing through or surface hardening for a variety of products, greatly differing in shape, size, or physical characteristics.

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MANY heating operations to which high-frequency induction is ideally suited have not heretofore been fully exploited commercially. The operating cost has appeared to be higher than the cost of heating by fuel, and many of the economies caused by longer tool life, uniformity of product, automaticity, speed, easy control, and saving in floor space have not been learned. With much of the cost data now at hand and with the added incentive for wartime production, the heating field is expanding rapidly, and it is certain to continue its growth even after the war.

The principal advantage of induction heating is that heat can be induced into metal just where it is wanted, at the intensity desired, and under the most exacting control. The amount of heating depends upon the frequency of the supply current, the ampere turns in the inducing coil, the coupling between coil and charge, and the heat insulation. In most melting installations the diameter of the charge is uniform, and it is possible to select the most economical frequency for each material melted. In the heating field, on the other hand, it is difficult to standardize on any one frequency. The charges vary in diameter and shape, and the degree of heating to be effected covers a wide range of temperatures. For example, if the charge is to be heated throughout to a uniform temperature, as for forging, the frequency selected should give a high depth of penetration, and the power should be low enough to allow the interior of the charge to be heated by conduction from the surface nearly as fast as the surface is heated by induction. On the other hand, if surface heat only is desired, high frequency and high power are required. At present, frequencies from 60 to 12 000 cycles are employed in the heating field with a tendency toward higher frequencies as suitable generating equipment is becoming available.

Induction Confines Heating to Desired Area

Automatic Operation and Controls—Most induction-heating installations can be rendered fully automatic. Where successive charges are to be similarly heated, the most common practice is to maintain constant power and to control the heating cycle by timing devices. Other control methods depend upon the shape or movement of the piece heated, or upon changes in its resistance, magnetic properties, or other characteristics. Heating or cooling of the charge can be effected in a controlled atmosphere, or even in a vacuum, and as rapidly or as slowly as desired.

Concentration of Power—By using inductors, which concentrate the power (focus inductor, Fig. 1), and an adequate supply of high-frequency power, extremely fast heating can be effected in a localized portion of a charge piece.

The same law that explains why alternating current travels at the surface of a single conductor also explains why, when two adjacent conductors carry alternating current in opposite directions, the current tends to flow only in adjacent portions of the two conductors. This "crowding" effect is more pronounced as the frequency of the current is increased and since heating is proportional to the square of the current, it is extremely useful in selective or differential heating.

Coil Design—In induction-heating applications, the space required by the inductor or heating coil is small. The space required generally is insignificant compared with that occupied by the charge-handling equipment, and the coil can be mounted at a strategic point in the production line. If the charge to be heated is large or irregular, the coil can be parted circumferentially or a flexible insulated inductor can be wrapped about the charge.

Coils for high frequencies usually are of a single layer but can be of several layers for lower frequencies, and of square or irregular section, flat or dish shaped, to fit the contour of the charge. If non-uniform heating is desired, coils are wound with turns concentrated about some parts of the charge and loosely spaced at others. The heating inductor can be sufficiently small to fit the inside of a tubular charge as for

A steel bar is being heated by induction for a piercing operation.

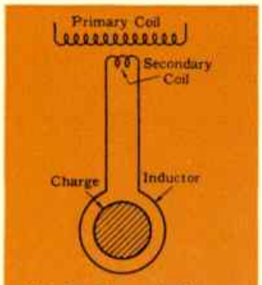


Fig. 1—Focus inductor.

To concentrate the heat required to harden small objects quickly, it is necessary to use a "focus" or energy-concentrating inductor, consisting of (1) a relatively large primary coil of many turns (2) a secondary coil of few turns. These two coils act as a transformer to step up the relatively low current from the generator. High current then flows through (3), the inductor itself, a small coil usually consisting of a single turn, which induces in (4) the charge, a high current not readily obtained by other methods.

internal-surface heating, or comprise merely a single conductor zigzagged across a flat charge, and close to it. In short, the form of the conductor is dictated by the heating problem.

Induction Heating Covers Many Fields

The possibilities of induction heating are only now beginning to be appreciated. Automotive engineers predict that ultimately more than two-thirds of their industrial heating will be done by induction. Similar expansion is apparent in other industries. The equipment used takes on many forms depending on the job to be done and in each case there is some particular advantage to be gained by induction heating.

Roll Hardening—The inductor used in the process of hardening the surface of a steel rolling-mill roll is a single-layer helical coil having turns extending slightly beyond the active surface of the roll, and spaced to heat the surface uniformly. The roll is heated to a low or medium temperature throughout, over a period sufficiently long to insure equalization of temperature. Power is then applied quickly to heat the surface to the quenching temperature before the temperature of the inner part is materially increased. By the proper selection of frequency and rate of power input, practically any desired heating and hardening gradient can be obtained. The roll can be quenched by lowering it into water or oil, or by a jet spray. The operation gives the roll a hard surface without impairing the toughness of the inner portion. If the roll is too large or too long for the power available, it can be heated and quenched progressively from end to end with considerably less power input than would be required to treat the whole surface at one time.

Surface Hardening of Bearings, Etc.—The same treatment afforded rolls is being widely applied to the hardening of engine bearings, the internal or external surfaces of cylinders, camshafts, gear teeth, and similar pieces. For small-diameter charges, the frequency required is high, the rate of power application must be fast, the quench must be quick, and the shape and type of inductor employed are important. Generators of frequencies from 1000 to 12 000 cycles are usually used for large-scale work and spark-gap or vacuum-tube converters are used for small-scale work.

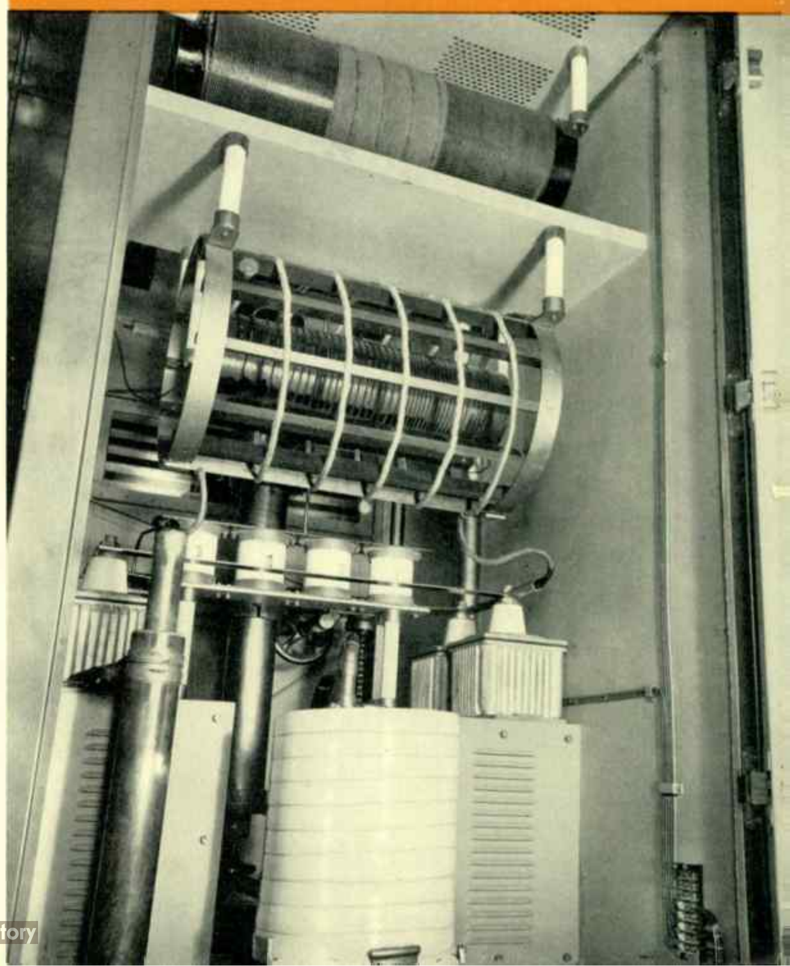
Some sort of energy-concentrating inductor is almost essential for work of this kind, similar to that shown diagrammatically in Fig. 1. Power is transferred from the usual water-cooled, helical-type inductor to a larger or collector loop. This loop usually is of one turn, laminated to reduce eddy-current losses, and grounded to prevent electrical leakage to the charge. Usually it is water cooled. A smaller or distributing loop is connected in series with the collector loop and can be hinged or sectioned to admit the charge piece. This part of the inductor usually is a copper casting, made hollow to admit a cooling medium and having holes or jets in its charge-adjacent portion for spraying the quenching medium onto the charge after heating. The distributing loop can be continuously water cooled or cooled by a periodic quenching operation or by both means as desired. In many applications where the quenching speed is not important, it is done by a separate device not associated with the heater.

Internal hardening by induction is being used on a large scale for hardening cylinders, bearing races, and the like. The procedure is generally similar to external-hardening operations although for certain internal-heating applications an iron-core inductor is found to be useful.

Hardening of Shear Blades and Rail Surfaces—Because of the mutual crowding of alternating current of opposite direction in adjacent conductors, the hardening of the top surfaces of railroad rails, the cutting edges of steel-mill shear blades and like charges becomes possible by a combination of induction and resistance heating. A high-frequency current is passed through the charge and then returned through a conductor as close as possible to the part heated. The return current thus concentrates the heating current in the treated part, which is quenched and drawn after heating in the usual manner. The desired heating or hardness gradient is controlled by the frequency and rate of power input.

Other Hardening Applications—Differential heating is not limited to creating temperature gradients between surface and interior. Heating of a mid-part or an end of a piece is often desirable, for local hardening or annealing. For example, the rim edge of an automobile poppet valve, or the end in contact with the cam, can be hardened by selective heat-

Vacuum-tube oscillators are used for frequencies above 100 000 cycles. The one shown here delivers 200 kw at 1.7 megacycles.



ing and quenching. Gear teeth or tool ends are but two of the many cases where similar treatment produces a better working surface. These operations can be controlled automatically, and even the smallest type of laboratory equipment can be used effectively for small-scale production.

Removing and Installing Rings, Liners, Casings—Annular pieces, like rings or cylinders, are particularly suitable for induction-heating operations. A simple helical coil can be placed inside or outside such a piece and heating can be effected quickly. On heating, the ring expands and can be placed around a preformed base piece and shrunk to fit. Such an operation can be used to place tires over railroad car wheels, or to line guns. A low-frequency current can be used, as neither fast nor differential heating is required.

The process can also be reversed, and the ring or cylinder once installed can be removed by differentially heating and removing it before the base piece has become heated by conduction. However, for this reversed operation, a large amount of power at a high frequency is desirable, to limit heating to the piece to be removed.

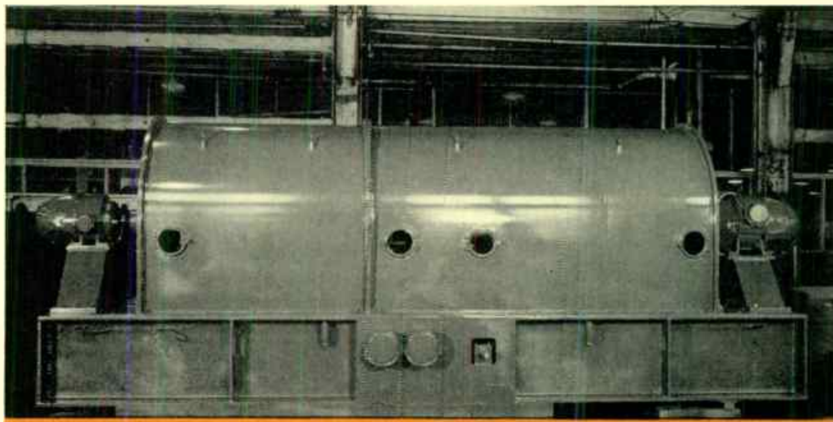
Welding, Forging, and Upsetting—Induction heating is particularly adaptable to welding, forging, upsetting, and like operations, and in defense work, where speed is essential, it is being widely employed for making ordnance parts.

Induction heating has several advantages in ordnance work. The equipment requires relatively little floor space. The furnace proper represents but a small investment as compared to the total installation, and well over nine-tenths of the installation cost is for equipment that can eventually be returned to peace-time operation.

In forging, the temperature of the charge piece can be made uniform from end to end and from surface to center throughout the portion to be worked, insuring results of high quality with few rejects. Because heating is relatively fast, only a light soft scale is formed. This greatly extends the life of the forming punches and dies, and reduces substantially the unit cost of operation. Working conditions near induction heaters are better than around gas- or oil-fired furnaces as almost all the heat involved is generated directly in the charge piece within a closed and insulated muffle. The only heat to which an operator is exposed is the heat from the charge as it is removed for forging.

Miscellaneous Heating Applications—The possibilities of induction heating are being recognized and applied in other than metallurgical fields. The heating of autoclaves and large chemical vats, for example, where the temperatures required are low, can be effected in pots of magnetic material with ordinary 60-cycle current. Where a magnetic pot is not desired the same results can be obtained by attaching a magnetic shell to the outside of a pot of another material. In installations of this kind, the coil or heating parts require a minimum of space. There are no open flames to ignite explosive mixtures, and the life of the pots is considerably longer because of uniform heating and absence of flame shock.

Another application is the testing of refractory materials. Samples are placed within a graphite or high-melting-temperature metal muffle. The muffle is inductively heated, and the samples are heated by conduction and radiation from the muffle. Temperatures can be checked by pyrometers, suitably arranged, or by refractory cones placed with the samples. In a similar manner, targets may be heated under the control of a master pyrometer while other pyrometers are sighted against it for calibration or checking.



A totally enclosed 3000-cycle motor-generator set for a steel heat-treating machine. The generator delivers 600 kw at 800 volts.

Gas analysis, special-atmosphere, and vacuum-heating operations are performed in much the same manner as vacuum melting. The special-atmosphere conditions are obtained by placing the charge and heat insulation inside a gas-tight container, and placing the heating coil outside. For gas-analysis work, the assembly is evacuated, and as the charge under test is heated the gases are led off and measured in suitable apparatus. If the piece to be heated is too small to absorb energy, a nickel sleeve or crucible of known characteristics may be used to absorb the energy and to transfer it to the charge by conduction and radiation.

Higher Temperatures Possible with Induction Heating

Controlled temperatures of 3600°C have been attained in induction furnaces and in sizable chambers. Since energy can be induced into a charge as long as it is conducting, the temperature can be increased to a point where the heat insulation fails or to where the charge proper vaporizes. Graphite vaporizes at 3600°C and since a special carbon heat insulator has been developed to operate at this temperature, reactions in a graphite chamber of any size can be studied under fully controlled conditions up to that temperature.

While the high-temperature field is relatively untouched, it is nevertheless one offering great potential interest. Carbides are now being fabricated in high-temperature induction furnaces, and graphitization studies have been made. The vaporization reduction of ores and the vaporization separation of metals seem to offer possibilities and many opportunities await in the field of fusion electrolysis.

Induction heating is still on its way up. All the important steel works of the world as well as many of the arsenals, navy yards, mints, and other such establishments are big users of induction-melting equipment. Industrial plants are using induction-heating equipment to an ever increasing extent for heating or heat-treating operations, and research laboratories everywhere are developing further uses and applications that are being continuously loosed to industry and made to take their place in the production line.

External Surface Hardening by Induction Heating

By means of induction heating the metallurgist comes very close to "eating his cake and having it, too." He can selectively harden a cam or a crankshaft to give it an extremely hard outside wearing surface, yet leaving the strength and machineability of the interior body intact. Furthermore, the process can be made to fit admirably in high-speed production lines.

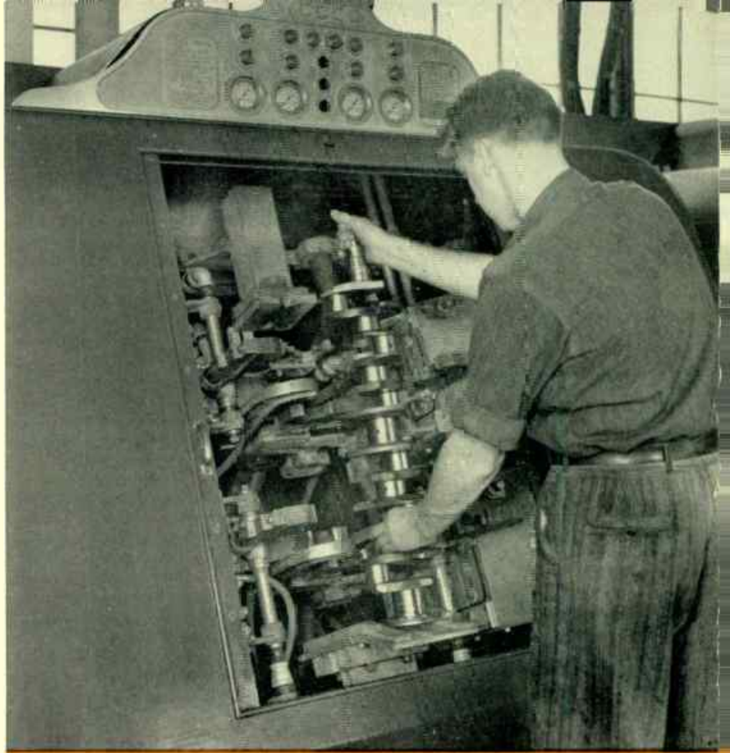


Fig. 1—A vertical crankshaft being loaded in an automatically controlled heat-treating machine. One man operates four units.

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One of the most rapidly growing developments in the heat-treating field has been the application of induction heating to localized surface hardening. Starting a comparatively short time ago as a long-sought-after method for hardening bearing surfaces on crankshafts (several million of these are in use), today finds this selective surface-hardening method producing hardened areas on a multiplicity of parts.

Induction hardening results in the production of locally hardened steel objects with the desired magnitude and depth of hardness, essential metallurgical structure of core, with almost no distortion and without scale formation. It permits design of equipment for completely mechanized production-line operation. Time cycles of only a few seconds are maintained by automatic regulation of power and split-second heating and quenching intervals, assuring exact duplication of parts. Induction equipment permits the user to surface-harden only the requisite portion of almost any steel object thus maintaining the original ductility and strength; to harden articles of irregular shape, which cannot be feasibly treated in any other way; to eliminate expensive pretreatment such as copper plating and carburizing and subsequent costly straightening or cleaning operations; and to harden a fully machined piece without subsequent finishing operations. In almost every case the ease and speed of hardening by induction are accompanied either by an increase in quality or by a decrease in cost, or by both.

Different Metallurgical Results

Within the past few years the progress made in the wider application of induction heating has opened up new avenues of inquiry regarding steel hardening. Induction-heating methods have been considered by many as merely a rapid method of producing carbide solution and the creation of desired hardness, but otherwise having no different effect on the metal than other heat-producing methods. The time-worn custom of holding the metal at supercritical temperatures for long periods to bring about carbide solution is going into discard. Recent research data have demonstrated that the solution speed need be only several seconds. More recent induction-hardening data further indicate that a time as short as 0.2—0.3 second is sufficient to bring about complete hardening in some steels. This fact alone is one of the major advantages of the use of high-frequency current for hardening.

The precision obtainable with induction hardening is readily evidenced by Figs. 2 and 3, showing, respectively, macrostructures of a sprocket and a cam. In every case the full hardness is uniformly maintained through 80 per cent of the hardened zone and falls off gradually through the zone of demarcation between the case and the core. Microstructures disclosing this gradual transition in hardness and the inherent bond are shown in Fig. 4.

Microscopically, the structure of an induction-hardened area has a distinct appearance. The usual needle-like crystals (acillary martensite) resulting from furnace hardening are definitely absent; instead we find a more homogeneous structure with finer nodular crystals, i.e., more closely approximating spheroids. This marked difference in the crystalline structure is shown in Figs. 5 and 6.

Fig. 2—Only the teeth in this sprocket are induction-hardened. The body itself is unaffected.

Fig. 3—Macrostructure of an induction-hardened soft-iron cam.

It would be impossible to make any definite statement concerning all the steels to which the induction-hardening method could be applied and all those to which it could not. There are certain requirements, however, which are quite obvious. Generally speaking, any material that can harden upon heating and cooling can be hardened or heat-treated with induction. The carbon content must be sufficient to produce the desired hardness, although higher hardness is possible with induction heating than with other methods of hardening, because induction heating permits faster recombination of free carbon with iron to produce the hardenable steel. Fine grain is preferable yet not always essential. Low-carbon steels with carburized case, medium- and high-carbon steels, both regular and alloyed, and malleable cast iron with sufficient combined carbon can all be hardened as desired.

Surface-Hardening Applications

The variety of parts that can be surface-hardened by induction is so large that it is impossible to describe adequately

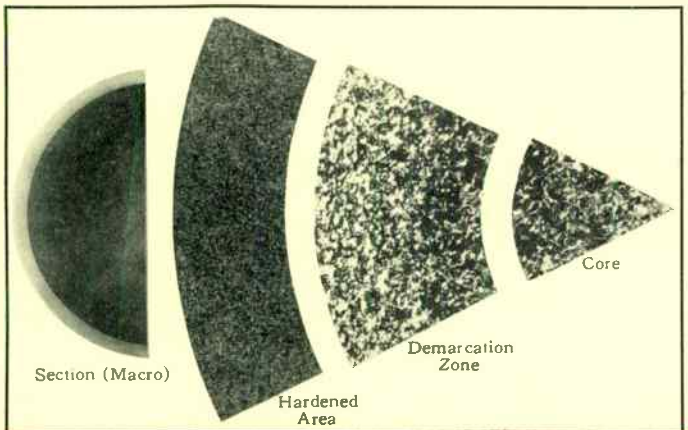


Fig. 4—Each portion of an induction-hardened section has a different microstructure, grain being much finer in the hardened area.

each and every successful application. The pieces treated range from small parts, easily hardened in the smaller heat-treating units, to the bearing surfaces on a large Diesel crankshaft, shown in Fig. 7. Parts like the latter are handled in a horizontal position in a long tunnel-line unit in which each bearing is hardened by means of an inductor block, or heating core, of design similar to that drawn in Fig. 8. The complete equipment of this type is shown in Fig. 9 together with its control unit which makes possible the production of identically duplicated results.

High-production crankshafts that can be handled manually are treated in vertical units in which three or four bearing surfaces are hardened in one automatically controlled operation. A picture showing the details and loading operation for one of these units is presented in Fig. 1. Four such units, each set for a different series of bearings, can be operated by one man, to permit a continuous output of twenty-five 13-bearing crankshafts per hour. Bearing surfaces are hardened to 60 Rockwell C up to the fillet, leaving the core ductile.

In the automotive field the successful and economical hardening of camshafts is of utmost importance. Expensive pretreatment, hardening, straightening, and cleaning operations all add up to cause high production costs. By its selective nature the application of induction hardening to surface-hardening of camshafts eliminates these high costs and produces a shaft free of distortion or scale, and hardened only where necessary. Each camshaft-treating unit automatically hardens two shafts with one loading operation. The surface hardness follows the contour of the cam, as shown in Fig. 3. The cams are hardened to 60 Rockwell C and the integral helical gear to 52 Rockwell C, whether made of cast iron or plain carbon steel.

The usual procedure of putting bearing races on automobile axle shafts, by placing a hardened material on the portion of the shaft requiring a bearing race, is expensive. The application of induction hardening to this operation results in surface hardening the shaft at the desired areas and making the shaft act as its own bearing race. Equipment for such operations hardens two surfaces simultaneously (Fig. 10).

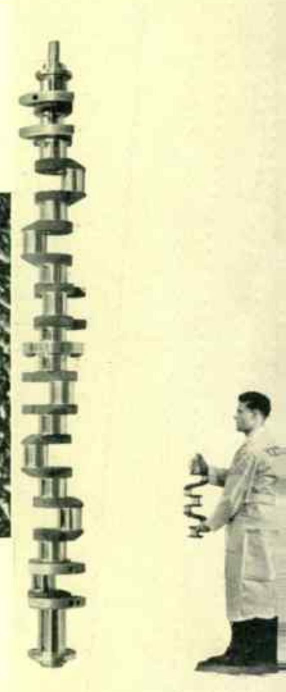
Mechanization of induction-hardening equipment to fulfill production-line requirements is merely a matter of design. The foregoing illustrations point out a few such representative units. In addition, there are installations for continuous rather than intermittent operation. A machine for hardening push-rod seats on automobile tappets (Fig. 11) is illustrative of this point. The production can be as high as 7200 tappets per hour. Further equipment is available that is not only continuous in operation but also does a progressive job of hardening. Track pins of variable sizes, up to 2 inches in diameter and 10 inches long, are surface hardened for their entire length to a selected depth of 3/16 inch with hardness of 64 Rockwell C, using SAE 1045 steel. The 1¾-inch diameter track pin for tractors is super-hardened at the rate of 40 inches per minute.

Rocker-arm shafts for combustion engines are surface-hardened in the areas on which the rocker arms operate. Distortion is reduced to a minimum and production rate is extremely high. The shaft moves through an inductor, is stopped by an indexing mechanism to allow each area to harden, and is then discharged from the machine. A timing device controls the entire operation and makes it automatic once the shaft is placed in the machine (Fig. 12). One thousand shafts per hour are treated on one unit.

Fig. 7—Crankshaft for a Diesel "streamliner." →

Fig. 5—Microsection of induction-hardened steel (Nodular Martensite). ↓

Fig. 6—Microsection of furnace-hardened steel (Acicular Martensite). ↓



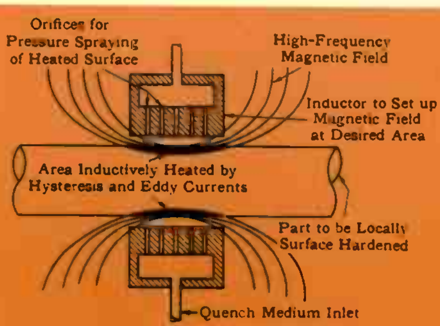


Fig. 8—Typical surface-hardening inductor block combines the coil that induces current in the work, and the quenching orifices.

Equipment

All surface-hardening equipment consists of a high-frequency generator, an inductor, quenching auxiliaries, suitable transformers and capacitors, and automatic timing controls. In addition, provisions are made for handling the parts intermittently or continuously.

Primary

The high-frequency current is usually generated at high potentials ranging from 200 to 1000 volts, depending upon the particular unit. It is then transformed and fed into the inductor. The transformer is tailor-made for the specific frequency and the inductors to be used with it. However, where a multi-turn coil is employed, the transformer is eliminated and the coil connected directly across the generator.

The inductor can be a single turn of copper tubing to fit the piece to be hardened, or can consist of several turns. Symmetrical inductors can be used to surface-harden asymmetrical objects because of the natural tendency of the high-frequency current to follow the contour of the piece. The higher the frequency, the more pronounced is this concentration of energy. Conversely, to treat an object of small diameter, it is necessary to use a higher frequency than for larger pieces. The quenching medium flows through the inductor and is applied by means of orifices in the tubing, as shown in Fig. 8. One automatic timing device both controls the heating cycle and operates an electric quench valve.

Fig. 9—Extra long shafts are hardened in a tunnel line, a long machine with an inductor block for each bearing, all controlled from one panel.

In order to obtain high efficiency, the high-frequency power factor is adjusted and maintained as near unity as possible. This is accomplished by connecting into the circuit the proper amount of capacitance. Variations in capacitor requirements are readily accommodated by a mechanism that automatically changes the number of condenser units in the circuit. The high-frequency power input is adjusted by generator-field control.

Automatic control and accuracy are keynotes in induction hardening. They make each hardening operation and hardened object an exact duplicate of all others. Furthermore, total elimination of human error avoids the variations characteristic of manual control.

Fig. 10—Certain surfaces of an automobile axle shaft are hardened and made into bearing races. Two shafts are here hardened simultaneously.

Fig. 11—Induction hardening is ideally suited for mass production. Here 7200 automobile tappets are hardened each hour.

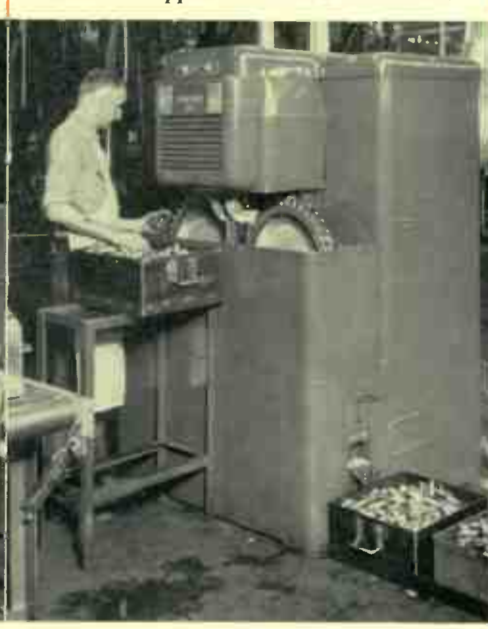


Fig. 12—Three automobile-valve rocker shafts and nine bearing surfaces are heat-treated simultaneously in this fast semi-automatic machine in Michigan.

Internal Surface Hardening by Induction Heating

Although akin to other induction heat-treating methods, and particularly to external surface hardening, internal surface hardening is not merely an extension of these processes. To gain entry into a cylinder bore and ultra-harden its surface, is not merely a mechanical problem. It is also necessary to "crowd" the current and detour it from its natural path, the external surface.

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THE latest extension of induction heating—hardening of internal surfaces—is in itself an interesting process, representing as it does a successful solution to many intricate machining and hardening problems. Of greater interest, however, is the fact that the new method literally makes new materials out of old, imparting to them radically different physical properties. Specifically, inexpensive steels and irons, never before considered suitable for hard, wear-resisting parts, such as cylinder sleeves, can now be selectively hardened so that the internal surface is harder than many high-grade alloys, yet the remainder of the cylinder retains its machineability. A large portion of the parts hardened by this new process is for airplane and tank engines, wheels for army trucks, and many other parts required by the national emergency.

The Process

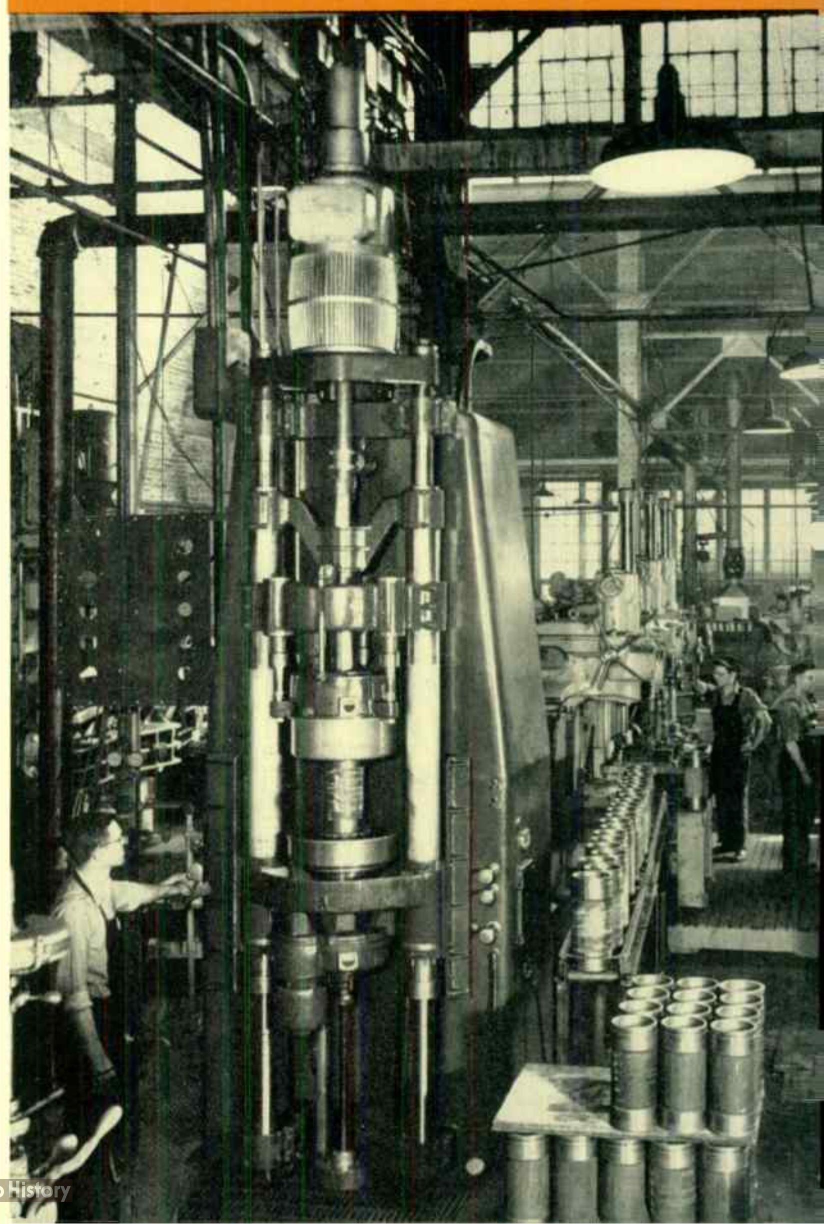
The fundamentals of the procedure in all internal surface hardening are quite simple. A shallow layer of an internal surface, usually not more than a few thousandths inch thick, is quickly brought to a high temperature by causing to circulate in it large induced currents of high frequency. Before this heat can creep inward to any appreciable depth, the currents are stopped and the hot surface is quenched with water. The resulting metallurgical changes in the heated layer produce the desired hard, wear-resisting surface without disturbing in the least the toughness, ductility, machineability, and dimensions of the main body.

High-frequency power is supplied, usually, by a motor-driven generator at about 200 to 1000 volts. This power is transmitted by two-conductor, lead-sheathed concentric stranded cable to where the hardening is to be done. The power source can be located some distance away from its load, but the distance should be as short as possible to reduce transmission losses.

At the scene of the hardening operation the power is delivered to a heating head, a copper tube coiled around an iron core, all on a mandrel. Cooling water is circulated through the tube, since in some operations the currents reach densities as high as 200 000 amperes per square inch. The quenching device operates directly under the heating head. It is attached to the lower section of the machine, rises toward the head during the heat treatment, and is retracted downward during loading and unloading.

The entire process is automatic and is timed by a motor-driven controller made up of several precision cam-operated switches. Thus—in operation—the machine is set for any desired heat treatment within its range by a convenient adjustment of the controller and the selection of a suitable heat head and work-holding fixture. The latter closes and automatically raises the cylindrical work-piece so that it surrounds the heating head, and in some cases the part being treated is simultaneously rotated and moved axially with respect to the heating head while the high-frequency current is applied. The quench follows at the correct interval, and is automatically shut off

The internal diameters of all the liners for the Caterpillar Tractor Company's Diesel engines are all inductively hardened in this heat-treating machine, directly in the production line. More than a hundred liners can be hardened hourly on one machine.



after a predetermined period. The operation—precisely reproducible for an indefinite number of repetitions—may require no more than three seconds for the complete cycle. The hardening machines are compact and lend themselves to insertion in the production line at appropriate points.

To secure the proper depth, area, and hardness for an internal surface of given shape and composition requires coordination of several interrelated variables. These include the shape of the inductor head, its rate of travel, the amount of power induced into the surface, frequency of the current, the time, the quench, and the power factor.

The Scope of the Process

Internal surface hardening differs from other induction-hardening applications only by the physical limitations imposed on the equipment. It is not practical, for example, to harden bores less than about one inch in diameter, simply because of the difficulty of designing suitable heating and quenching fixtures. On the other hand, when the internal surface to be hardened reaches about 15 inches in diameter, the application of the induction principle becomes limited by the amount of power necessary to induce the required heat. At 10 000 cycles, for example, a medium-sized internal surface can be hardened with about 40 kw-seconds per square inch. At this rate, an internal surface 15 inches in diameter requires about 2000 kw-seconds for each inch of length. It is easy to see that if the 15-inch bore is relatively long, and if the heat treatment must be effected at high speed, that the large generating plant necessary for such a treatment becomes too expensive.

Specific Applications

Outstanding among present uses of high-frequency currents is for hardening the internal surfaces of cylinders for airplane and Diesel engines. Cylinder barrels of forged steel (1 per cent chromium and 0.20 per cent molybdenum) are being regularly hardened for aircraft engines.

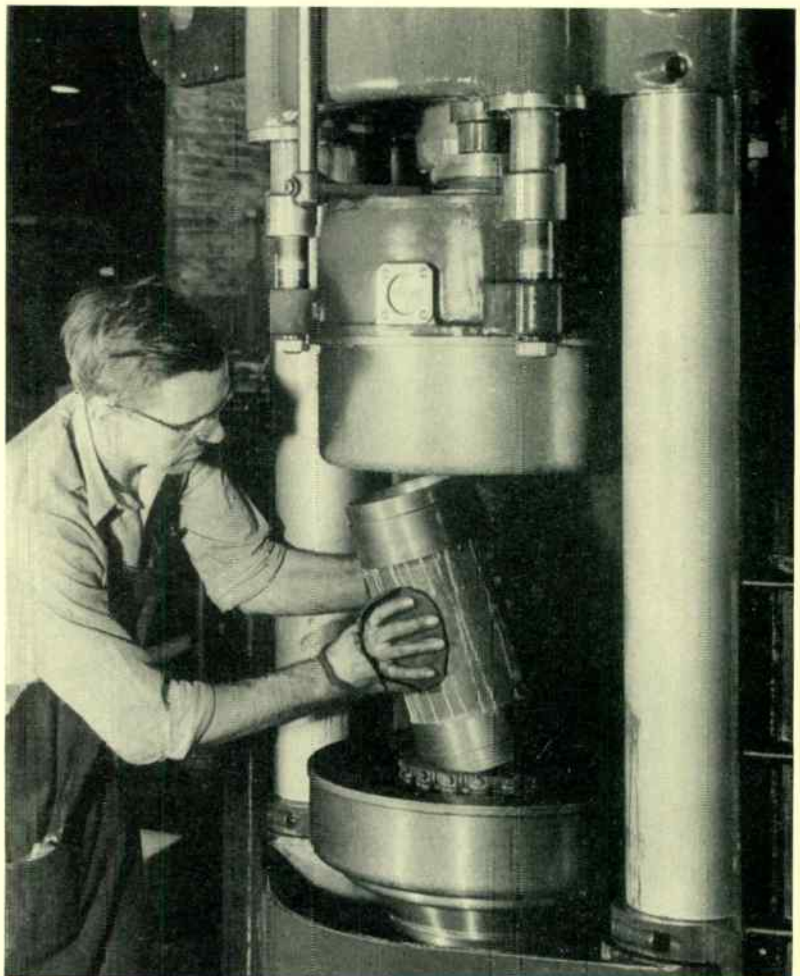
The rough-machined forging is first "core-hardened"—heat-treated throughout by oil quenching and tempering—to, say, 32 Rockwell C. Then the cylinder is bored and the bore is rough-honed to a few thousandths of an inch under finished size. The outside surface is then turned concentric with the inside and the ends are faced to length.

At this point the bore is induction-hardened to 62–64 Rockwell C, the depth of hardness being accurately preset at about 0.045–0.050 inch. After hardening, the bore is finish-machined, the outer surfaces are semifinished and the bore is honed. Distortion in this treatment is so slight that only 0.004 to 0.007 inch honing is required—usually just enough to remove tool marks.

The case produced is more durable, deeper, and more uniform concentrically than the nitrided case previously used, and since there is no composition change in the treatment, the hardened surface does not flake off.

High production rates are possible; as many as 500 uniformly hardened cylinder barrels a day per induction-hardening machine can be readily achieved.

At the Peoria, Ill., plant of the Caterpillar Tractor Co., all cylinder liners for Diesels are now being treated by this process. The liners, of low-alloy cast iron, of a wide range of diameters and lengths, are all treated in the same machine, which is installed directly in the liner production line. Hardnesses equivalent to 60–66 Rockwell C are obtained and these are subsequently tempered to slightly lower values. The depth of the hardened zone is about 0.070 inch. Between 75 and 105 sleeves, depending on size, are hardened hourly on one machine. After hardening, the sleeves are honed to final finish before "surfiding" and the outside surfaces are finish-turned. In spite of the hardness achieved, four subsequent milling operations are being performed in the hardened zone.



A Diesel cylinder sleeve is placed in the induction heat-treating machine for the hardening operation.

One of the first large-scale uses of the process is hardening the inside surface of automobile hubs. The hubs are of steel forgings, and the bore is hardened to provide an integral race for roller bearings. More than five million of these hubs have been used without any report of service failure.

The operation as carried out on a truly mass-production scale is typical of the results that can be expected when using the process on plain carbon-steel parts. The complete cycle requires 20 seconds, and production is normally 180 hubs per hour per machine, although the machines can be timed to operate as fast as 240 parts per hour, if necessary.

For this particular application, hardness tolerances are broad (specifications are 56 to 64 Rockwell C), yet they are turned out consistently with hardnesses between 60 and 62 Rockwell C. The depth of hardness is about 0.10 inch.

The machining practice associated with this hardening operation is unusually interesting. The body is irregular in shape, and consists of the hub bore to receive the roller bearing, an adjacent flange for mounting the wheel and the drum, and a tapered bored stem for the axle. All boring and turning are done before induction hardening. The hub bore is hardened, and then the bearing bore is ground (actually only to remove tool marks) and finished by honing.

By drawing the heat-treating and quenching tool progressively through the bore, long objects, such as oil-well pipes, can be hardened in one continuous operation. The heat-treating head, with an effective length of about two inches, travels in relation to the pipe at the rate of about one or two inches per second, until the whole bore is hardened. At this heat-treating speed, the power requirement is about 100 kw. for each inch of diameter of bore.

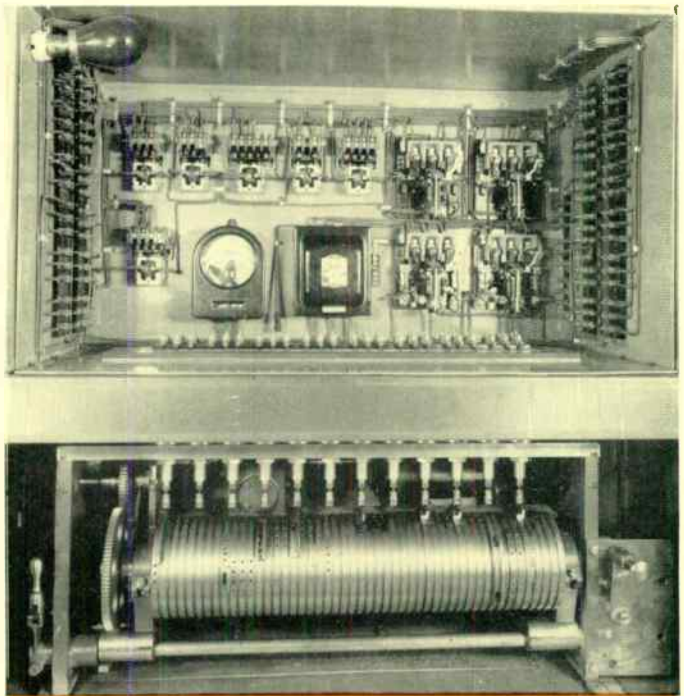
The method is also being used for hardening the bores of hydraulic cylinders and of slush-pump cylinder liners for pumping colloidal mud in oil-well drilling, as well as for heat-treating oil-well casings to increase joint strengths.

Advantages

The new process, in effect, makes available a new type of engineering material and permits new basically less expensive designs. Parts can be redesigned with lowered weights and costs through localized heat treating and the metallurgy of a casting or forging altered sufficiently to make any predetermined internal surface hard and wear resisting. In some cases a lower grade material can be used. For example, aircraft-engine cylinder barrels can be made of SAE 1040 steel instead of the highly alloyed steels that have been used to obtain top hardness. This, incidentally, releases quantities of this vitally needed steel for defense purposes.

The short heating cycle, followed by an almost instantaneous quench, reduces oxidation to a minimum; where essential, oxidation can be entirely eliminated. Similarly, heating at high speed and confining the treatment to a shallow layer reduces distortion to a minimum. Annealing or normalizing treatments are less frequent for parts hardened by induction.

The slots in this cylinder liner for a Caterpillar Diesel engine were milled in after the induction-hardening operation. The hardness, its depth (approximately 0.070 inch), and the area hardened were carefully controlled.



The "brains" of most induction-hardening machines is the automatic sequencing controller, consisting of a series of precision cam-operated switches. The revolving drum on which the cams are mounted, shown in the lower part of the photograph, is arranged to receive four sets of cams, each set controlling the heat-treatment of a different cylinder size.

The process lends itself ideally to production-line methods. It surpasses flame hardening, hard-chromium plating, nitriding, hard-surface layers, etc., because the machines lend themselves for rapid changeover from one internal diameter to another. Thus efficient production of different-size units is possible with a minimum number of production lines. Process operations can be arranged so that no trucking or handling of parts is necessary between departments.

In all its applications a large factor in the selection of the new method has been the convenient machining practice it makes possible. Thus, where design permits, the outside surface or body of the unit can be machined after hardening the bore. One new possibility is the practice of composite heat treatment—hardening a bore after the cylinder has been heat-treated throughout and machined to finished dimensions. But the most remarkable feature from the machining standpoint is the fact that internal surfaces hardened to 66–69 Rockwell C by this process can themselves be milled or drilled, if necessary, by careful machining.

One valuable by-product of the process is that it facilitates inspection. Where the part being treated is porous or cracked, an abnormality of the heating current occurs within the piece and manifests itself by a melting of the surface or wall adjoining the defect; in the case of porosity marked signs of overheating can be observed. Consequently, defective stock can be easily identified—in fact, defects otherwise discernible only by magnetic or microscopic inspection are readily revealed in this way. Although defects in steel cylinders are also revealed during induction hardening, this inspection phase is particularly applicable to cast-iron treatment.

Electrical Equipment for Induction Heating

The "wireless-flameless" wonder, as the first induction furnace was called, would remain nothing but a laboratory device, were it not for the electrical manufacturers' efforts to produce reliable equipment to supply power at the high frequencies essential to the success of the new process. Generators, capacitors, oscillators, instruments—each requires a radically different design before it can be successfully used for induction heating.

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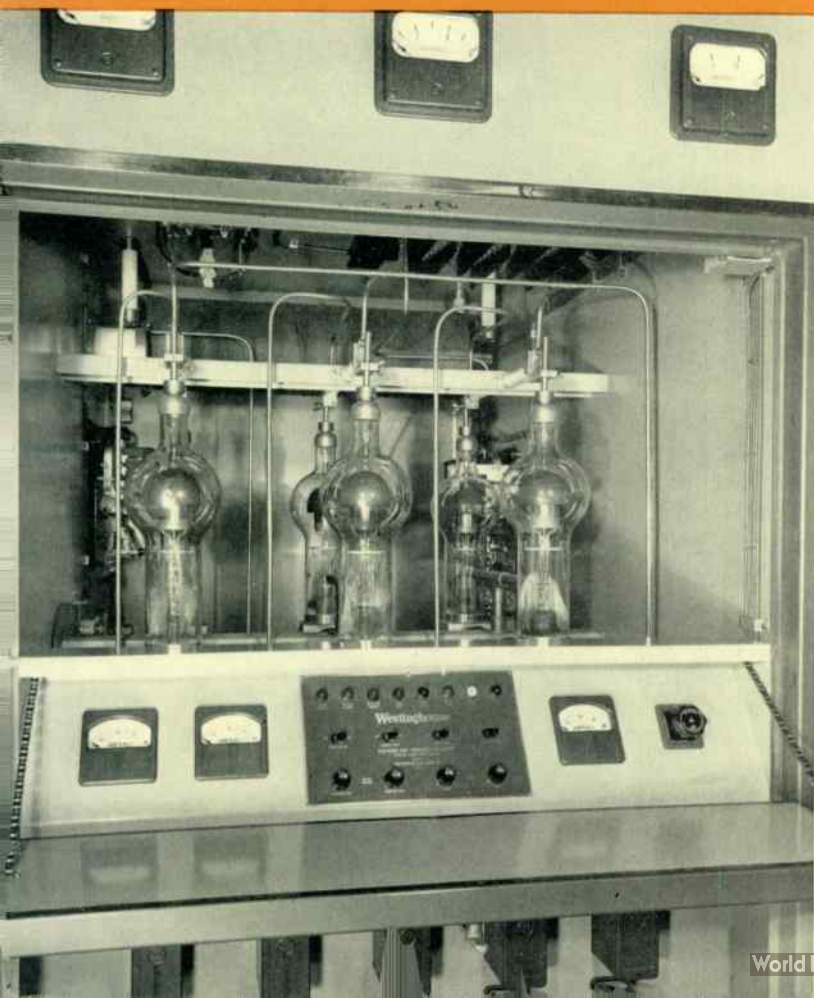
ELECTRICAL equipment for high-frequency work differs from that supplied for other purposes. In almost all other applications the frequency for which apparatus is built is determined solely by the power-supply frequency, generally 60 cycles. For induction heating the nature of the product heated and the particular treatment determine the frequency selected. Some high-speed melting or surface hardening must be done at frequencies well over 100 kilocycles, while in other cases a 500-cycle supply is adequate. A variety of generating equipment and of instruments is therefore necessary to meet all induction-heating requirements.

Theoretically, there is one optimum frequency for each individual application. In practice, however, the choice is not quite as rigid, and there is considerable latitude in frequency selection without loss in efficiency. In many cases, therefore, the frequency is based on the economics of the electrical equipment rather than any special requirement of the process.

While there has been no formal adoption of standard frequencies, rotating equipment has been designed for mainly 500, 960, 1920, 3000, 9600, and 11 520 cycles. Frequencies above 100 kilocycles are best obtained from electronic oscillators. Spark-gap equipments are also used in small units for frequencies of 20 to 100 kilocycles. The upper limit of frequency for rotating equipment is about 15 000 cycles. The use of vacuum-tube oscillators is quite recent, the applications have not been sufficiently numerous to indicate what the limits or desirable standards might be in this range.

For induction heating at frequencies above 100 000 cycles, power is supplied by vacuum-tube oscillators. An important auxiliary of any oscillator is the source of direct current. The mercury-vapor rectifier shown above is housed in the oscillator cabinet and delivers 9 amperes d-c from an 11 000-volt three-phase source.



Rotating Equipment Used for Lower Frequencies

Motor-generator sets for induction heating comprise a 60- or 25-cycle motor driving a high-frequency generator, in most cases of the inductor type, and either air cooled or air and water cooled; in some large sets both motor and generator are hydrogen cooled. A small d-c generator is often coupled to the set, to provide the excitation.

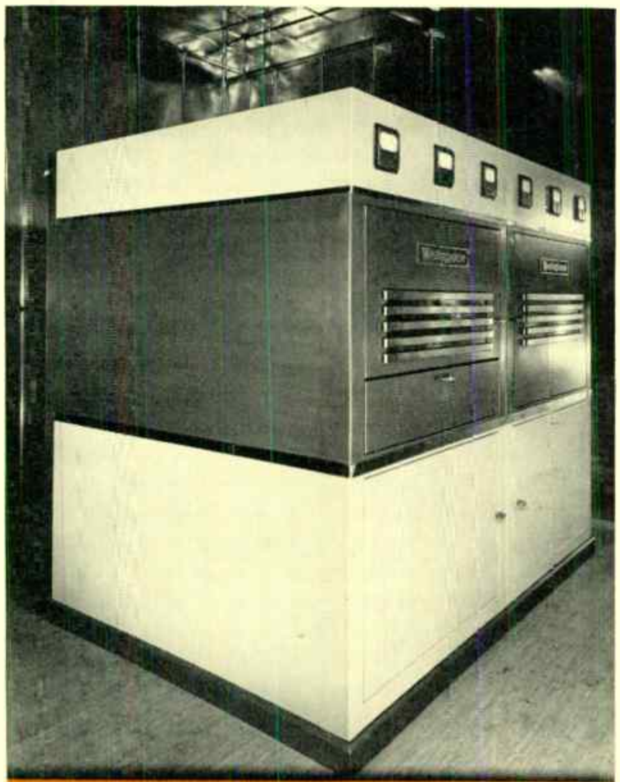
The high-frequency inductor generator differs from the conventional pole-excited type in two important features. The first is the absence of a winding on the rotor; the second is the unique arrangement of the magnetic circuit. The stator is slotted, and is excited by means of direct current flowing in a single coil. The rotor is also slotted and as it turns, the magnetic path in the machine varies. That is, when a rotor tooth is exactly below a stator tooth the reluctance is a minimum and the flux therefore is highest, and vice versa. At full speed the varying reluctance produces flux pulsations that induce in the stator winding voltages of a frequency depending on the speed and on the number of teeth. The rotor itself consists of two parts, the teeth in one lining up with the slots in the other. In this way the voltage induced in one-half of the armature winding adds to the voltage in the other half, and full voltage is available at the terminals.

For higher frequencies, such as 10 000 cycles, only 3600-rpm motors are practical. When increased capacity requires large diameters, friction and windage losses increase. These losses are greatly reduced in hydrogen-cooled motor-generator sets. An adequate supply of clean ventilating air is important to the life and trouble-free operation of the machines, and an enclosed design, with means for recirculating and cooling the air, has many advantages.

Oscillators

Generators for higher frequencies have not yet been developed to the same extent as motor-generator sets for the lower frequencies. Frequencies of the order of 100 000 cycles up to 500 000 cycles have been applied only recently, particularly for heating small objects where, to compensate for volume available for the flux, it is necessary to induce current at a much higher frequency than for larger pieces.

In contrast with motor-generator sets, oscillators have the advantage of being static and of being readily adaptable to changes in frequency. (Oversized generators and variable-speed drives must be used where variable frequency is essential.) Also, oscillators do not require capacitors for power-factor correction; in fact, they operate best at low load power factors ranging from 5 to 20 per cent.



This cabinet houses both the high-frequency oscillator and its rectifier. The rating is 200 kw at 1.7 megacycles.

Spark-Gap Oscillators operate at frequencies from 20 000 to 100 000 cycles, in sizes from 3 to 40 kw. They are used primarily in laboratories to supply power for melting, heating, gas analysis, and similar work.

Vacuum-Tube Oscillators give the highest frequencies used for induction heating, ranging from 100 000 cycles to several megacycles. The smaller units, up to about 20 kw are built with water-cooled tubes and, when more capacity is required, several oscillators are connected in multiple.

Because an oscillator has no moving parts, and because its output frequency is variable, there have been attempts to replace motor-generator sets in the 500- to 12 000-cycle field by electronic generators. However, the cost of the vacuum-tube oscillator rises as the frequency is reduced, and at present no economical low-frequency oscillators are available.

Capacitors for High-Frequency Applications

Induction-melting furnaces operate at a low power factor, about 10 per cent. Induction heat-treating loads are not much better. It is obviously uneconomical to design generators to supply the total kva of such loads and therefore capacitors are as essential as the generator supply.

If the voltage stress in the capacitor is held constant and the frequency increased, the kva rating increases as do the losses. By efficient water cooling these losses can be dissipated, and it is possible then to operate the capacitors at high frequency at a much increased kva rating over the normal frequency rating. For example, a 230-kva, 9600-cycle unit with internal water cooling is of the same size as a 15-kva, air-cooled, 60-cycle unit.*

*Reference—"High Frequency Capacitors for Low Voltages," *Westinghouse Engineer*, August, 1941, p. 62.

Control

Even where full-voltage starting is permissible, the motor starters used must be amply rated for the comparatively long accelerating time caused by the high inertia of the inductor generator. Inductor generators, because of the construction of the field, have a high residual voltage and relatively long time constant, both of the field winding itself and of the iron damping circuit. The terminal voltage therefore does not respond rapidly to changes in excitation. If short-time heating cycles require rapid readjustments of voltage, special forcing of the voltage and as low a potential drop in the field as possible must be used for satisfactory operation of the equipment.

The control of high-frequency oscillators is different from that of rotating equipment, as is to be expected. The essential apparatus for such equipments includes, in most installations:

A transformer and rectifier to supply the plate voltage.

The oscillator tube.

A starting resistor to insure that when the main circuit breaker is closed the full voltage of the circuit is not immediately applied to the rectifier tubes. A blower for air-cooled tubes or pump for water-cooled tubes.

The associated circuit breakers, contactors, capacitors, resistors, filament transformers, and control relays.

When adjustable output to the load is required, a limited amount of grid control is available. This can be supplemented by taps on the rectifier transformer or an induction regulator in the primary winding of this transformer when wider voltage range is necessary.

Instruments Perform Different Tasks

Electrical instruments suitable for most induction-heating loads are subject to operating conditions different from those of instruments for other applications. The range, 600 to 12 000 cycles, is above the industrial frequencies but below those used in radio. Similarly power used in induction heating, 10 to 1500 kw, is small compared with 60-cycle loads, but much greater than usually measured at radio frequencies. The character of induction-heating loads, on one hand, and the frequency characteristics of conventional instruments, on the other, necessitate many changes in standard listed instruments before they can be adapted to high-frequency use.

Proper control of induction heating calls for accurate measurements of voltage, current, power, power factor, and reactive kva. All high-frequency power for melting and hardening is supplied at relatively high voltages (220 to 1000), and reduced at the devices to safe operating potentials. Correct indication of voltage, power, and current is therefore essential. The measurement of reactive kva and power factor is important for several reasons. High-frequency loads are of low power factor, about 10 per cent in induction furnaces. The permeability and conductivity of the charge vary with temperature; it is necessary to read power and power factor or reactive power frequently and make adjustments for best operation. Furthermore, in heat-treating operations lasting only a few seconds, the varmeter and power-factor meter keep the heating at the correct stage, so that treatment of identical parts can be duplicated exactly.

Instruments for induction heating must have the durability, high overload capacity, quick response, and other characteristics usually found in 60-cycle instruments. These requirements preclude the use of the thermal meters used for radio-frequency measurements, because they are slow in responding and are easily damaged by light overloads. On the other hand, power-frequency instruments lose their accuracy above a few hundred cycles. Design modifications, special adjustments, and calibration all go into the making of an instrument suitable for induction heating.

Ammeters—Iron-vane-type ammeters have been found to be the most suitable for audio-frequency work, because the mechanism is sturdier and their scale more uniform, giving better accuracy of readings, especially at light loads. Excessive temperature rise caused by high-frequency currents is eliminated by making the metal parts of special high-resistance alloys and by laminating the iron vanes.

Voltmeters—The relatively high inductance of electrodynamic and moving-iron type voltmeters limits them to frequencies of a few hundred cycles. Electrothermal voltmeters have low overload capacity, and are therefore not suited to induction-heating circuits with poor regulation. The most practical voltmeter for audio frequencies is of the rectifier type. Because such instruments measure average and not effective voltages, they must be calibrated on the basis of a sine wave, with the scale marked in rms values, and wave-form errors must be eliminated by the use of a suitable filter network. This is particularly important in induction-heating applications, where the wave form varies with load conditions. Rectifier units have been developed to the point that frequency and temperature errors in the audio range have been reduced to the commercially allowable limits.

Wattmeters—The chief source of error in electrodynamic wattmeters at the upper frequency range is the inductance of the voltage circuit. At power frequencies the voltage-circuit current is practically in phase with the voltage applied; the angle of lag may be of the order of 10 to 20 minutes. However, at higher audio frequencies this phase angle becomes great; at 9600 cycles it is about 40 degrees. This would reduce the wattmeter reading about one-quarter. Compensation for this frequency error is provided by connecting a capacitor across the non-inductive resistor of the voltage circuit.

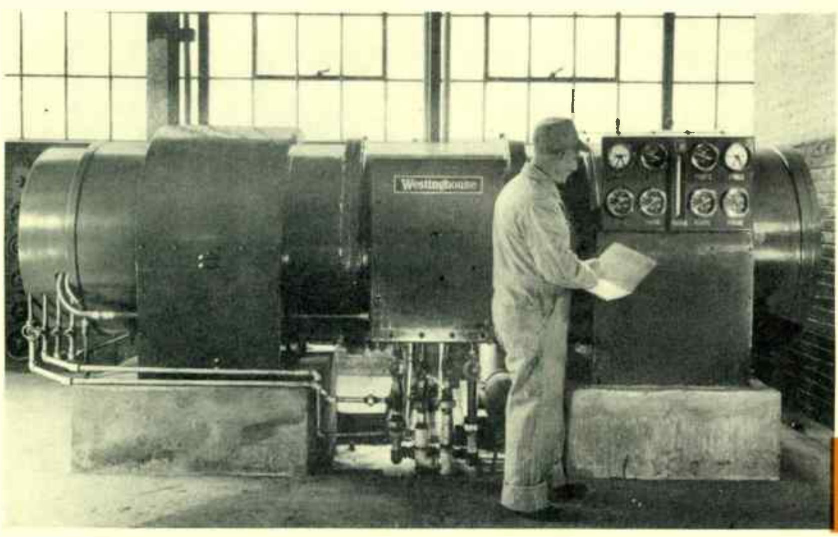
Power-Factor Meters—Power-factor meters for audio-frequency work are similar to the electrodynamic instruments used for power frequencies except that it is more practical to use a capacitance instead of an inductance in the resistor-reactor network used for developing the rotating field in the moving-coil voltage circuit.

Varmeters—A frequency-compensated wattmeter can be provided with a phase- shifting circuit to rotate the impressed voltage by 90 degrees, and thus indicate reactive power. Most varmeters are provided with zero-center scales, to read both leading and lagging vars.

Varmeters afford a more accurate indication of the reactive conditions of interest to this application than power-factor meters, because of the larger scale deflection particularly at light loads, at which power-factor meters develop low torque. For this reason varmeters have been replacing power-factor meters in recent installations.

It must be pointed out that both varmeters and power-factor meters are influenced by the wave-form of the circuit voltage, and that harmonics invariably present in induction-heating apparatus affect the accuracy of both instruments. They should therefore be used only for control purposes; exact determination of power factor should be made from the voltmeter, ammeter, and wattmeter readings.

Instrument Transformers—Care must be taken in the design of current and potential transformers for high frequencies that none of the leakage flux around the windings gets into the core and thereby causes excessive heating of the iron. Furthermore, unless such a transformer is housed in a non-metallic case, it will become overheated by eddy currents caused by the leakage flux. It is therefore obvious that the transformer windings must be designed for minimum flux leakage. For this reason current transformers are made of the ring (or through) type, with the secondary symmetrically and uniformly wound. Potential transformers are built with the high- and low-tension windings thoroughly interleaved, to reduce leakage. In all high-frequency instrument transformers the flux density is low, to limit hysteresis and eddy-current losses. Because a very small working flux is required, high-frequency current transformers can be built for lower current ratings than those for 60 cycles.



This totally enclosed, hydrogen-cooled, 9600-cycle motor-generator set delivers 500 kw.

Single-Pole Fault Clearing for Greater Stability

The idea of clearing a fault on a transmission line by opening and closing only that phase, rather than all three conductors, is—now that it has been accomplished—as obvious as the use of one word when it can be adequately substituted for three others. However, between the simplicity of the idea and its practical realization, several complex problems in switchgear and relay design had to be successfully hurdled before the full benefits of the proposed fault-clearing method could be realized. Performance tests on a 138-kv power system substantiated the theoretical increase in stability and reliability claimed for the scheme.

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SOME faults on power systems must be isolated by opening all three conductors to the affected area. Under other circumstances it is sufficient to disconnect only the faulted conductor, so that single-pole opening and reclosing clears the fault. Installed recently on a 50-mile section of a 138-kv line of the Public Service Company of Indiana, Incorporated, the scheme permits clearing transient single line-to-ground faults by opening only the breaker pole connected to the faulted phase and reclosing it rapidly. If the fault has cleared, the line remains connected; if it has not, all three phases are permanently disconnected.

This, concisely, is *how* single-pole reclosing works. *Why* the scheme has been chosen over three-pole reclosing, and particularly what gains it offers, can be stated even more concisely. The reason is greater transient stability.

The stability of a power system is its ability to maintain equilibrium, or synchronism, between its various synchronous machines. This rotating equipment must be kept in synchronism under steady-state conditions. Furthermore, it is essential that synchronism be regained after a disturbance, otherwise the system will fall out of step and service continuity will be interrupted. Usually, the limiting factor in considering system stability is the transient rather than the steady-state stability limit, and it is the transient limit that is improved by the use of high-speed, single-pole reclosing breakers. A system is said to be stable if it develops restoring forces between its elements, subsequent to a disturbing force, which are great enough to restore a state of equilibrium between these elements. A transmission-line fault is the most frequent disturbing force present on high-voltage systems, and since high-speed single-pole reclosing minimizes the disturbance to a system created by a transmission-line fault, it inherently improves the transient power limits.

Stability Limit on the Rise

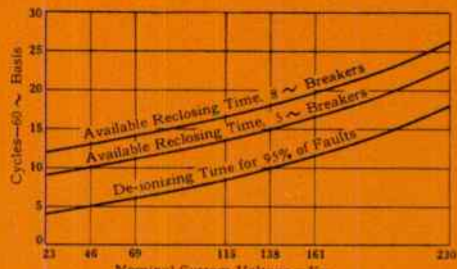
Ever since the factors influencing power-system stability were recognized, means have been sought to improve the performance of power systems during transient disturbances. At first particular attention was focused on improvements through better design characteristics of machines and transformers, bussing arrangements, location of intermediate switching points, and design of the transmission line itself.

It is not economical to design lines so that faults will never occur, although this ideal can be approached. Granted that a certain number of faults will occur, it is important to minimize their effect on the connected system. When a fault develops, the objective is to remove the fault and re-establish the circuit without losing synchronism between the systems, so that there is no interruption in service.

In the last decade high-speed relays and circuit breakers have materially improved system performance by minimizing the duration of transmission-line disturbances. The use of reclosing circuit breakers furthers the advantages of high-speed apparatus used for rapid fault isolation. Reclosing is particularly advantageous on a single-circuit transmission line that forms an interconnection between two systems. Not only must a fault be cleared promptly, but the line must be rapidly reclosed after the fault is removed lest the two systems drift far enough apart to cause loss of synchronism after the line is re-established. It is not inferred that high-speed reclosing does not have application on multi-circuit systems. Reclosing on multi-circuit lines can be considered as an alternative to the construction of additional parallel circuits to obtain a higher transient stability limit, and can therefore result in large savings in capital investment.

The foregoing discussion deals with simultaneous tripping and reclosing of all three circuit-breaker poles, and is known as gang-operated or three-pole reclosing. It must also be remembered that, where high-speed reclosing is applied to line sections having sources of power at both ends, simultaneous operation of the circuit breakers at both ends of the transmission line is essential, otherwise the time the line is de-

Fig. 1—Typical arc de-ionizing times.



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energized is shortened and it is possible for the fault to be re-established upon energizing the section from which the fault has been cleared. Simultaneous tripping is accomplished by pilot-wire or carrier-current relaying, or, where possible, by high-speed impedance-type relays that are set to cover the entire section of the line.

The time that a line can remain open without loss of stability is in most cases very short, being a matter of cycles rather than seconds. The circuit breakers serving the line must therefore be reclosed rapidly. Reclosing time is measured from the time the circuit-breaker trip coil is energized until the breaker has opened its contacts and reclosed. Commercial breakers are available today with reclosing times of 35 and 20 cycles at 138 kv and several installations employing such reclosing times are in service. The limit to which the reclosing time may be shortened depends upon breaker opening time and the speed attainable with reclosing mechanisms. Another factor, the actual de-ionizing time of the arc, is of primary importance because if the breaker is reclosed before the arc path has been de-ionized the fault will restrike. Approximate data of the minimum reclosing time permissible without re-establishment of the arc, obtained from tests on typical systems, are shown in Fig. 1. The de-ionizing time is

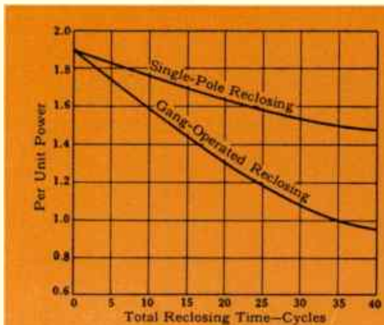
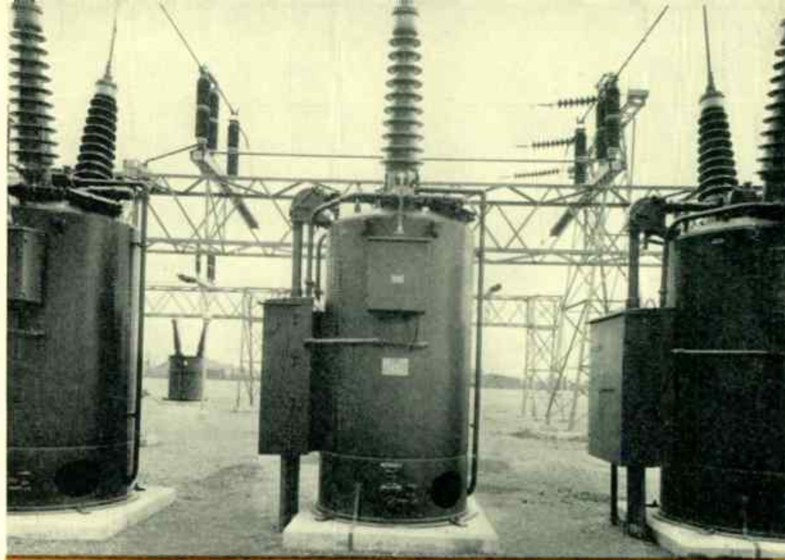


Fig. 2—Typical comparison of transient power limits on a hypothetical system using single-pole and gang-operated reclosing.

of course variable, depending on many factors such as line design and wind conditions, but the curves of Fig. 1 can be considered typical of what de-ionizing time is to be expected under average conditions.

Even employing high-speed relays and breakers, and operating these breakers at the highest reclosing speeds practical, occasionally cases arise where the desired power cannot be transmitted without loss of stability during fault conditions. Since a high percentage of all high-voltage transmission-line faults are single line to ground in nature, single-pole reclosing of circuit breakers is a step toward raising the transient power limits. By opening only the breaker pole connected with the faulty phase, and reclosing this pole after the fault has cleared, the transient stability limit is raised over that permissible with gang operation for the same reclosing time, because considerable power may be transmitted over the two sound phases while the faulty phase is isolated. For a given amount of power transmitted over a particular transmission line, the permissible de-energized time to maintain synchronism is appreciably longer (slower reclosing possible) if single-pole reclosing is used than under three-pole operation. Hence in high-voltage systems, usually above 138 kv, where the three-pole reclosing time necessary to maintain stability



There is no mechanical linkage between the operating mechanisms of these three 138-kv circuit breakers in the Newcastle, Indiana, substation. Each breaker is equipped with a single-pole reclosing mechanism.

may be less than that required for arc de-ionization, single-pole reclosing permits slower speeds, providing ample time for the arc to clear and still maintain stability conditions.

The actual gain in the transient stability limit attained with single-pole operation is shown in Fig. 2. The curves were drawn for an assumed single-machine station feeding a high-voltage line terminating in a very large system, assumed to have infinite inertia. The curves show that for the system assumed a transmitted per-unit power of 1.4 to 1.6 is easily attained with stability if single-pole reclosing is used, but is not possible with the speeds of three-pole reclosing circuit breakers commercially available at present.

Application

The first high-voltage line equipped with single-pole reclosing breakers is the 50-mile Lenore-Newcastle line of the Public Service Company of Indiana, Incorporated. Its operating record since March, 1941, the installation date, and numerous field tests embodying fault conditions, have proved conclusively the satisfactory operation of the scheme. This single-circuit, 138-kv line was built to supply power to Newcastle and to form an interconnection with the Indiana section of the American Gas and Electric System. The constants of the system are such that an interruption on this line would cause transient instability. Although well protected against lightning strokes, it was considered necessary to equip the line with high-speed reclosing breakers, to keep interruptions to the load at an absolute minimum.

Both gang-operated (three-pole) and single-pole reclosing were considered, and the power limits were calculated for both cases, as listed in table I. Because the line was so constructed that most faults would originate as single line-to-ground arcs, primary consideration was given to the transient power limits during such fault conditions. The figures of table I show that during a single line-to-ground fault, 35-cycle single-pole reclosing offers higher transient power limits than 20-cycle gang-operated reclosing although it must be remembered that the limits may be lower for other faults. The transient power limit for 20-cycle single-pole reclosing is, of course, even higher, but the gain in power limit was not considered sufficient to justify the increased cost of the faster breakers and mechanisms (breakers and mechanisms for 35-

TABLE I

CALCULATED TRANSIENT POWER LIMITS, AT 20 AND 35 CYCLES, USING 8-CYCLE BREAKERS WITH CARRIER-CURRENT RELAYING

Type of Fault	Breaker Operation		Comparative Transient Power Limits	
	Reclosing Time	Type of Reclosing	Megawatts	Percent*
Single Line-to-Ground	35	Gang	74.5	100
	20	Gang	95.8	129
	35	Single-Pole	105.9	142
	20	Single-Pole	116.8	157
Double Line-to-Ground	35	Gang	71.1	100
	20	Gang	91.1	128
	35	Single-Pole	81.3	114
	20	Single-Pole	97.3	137
Three-Phase	35	Gang	70.4	100
	20	Gang	90.1	128

*Transient Power Limit obtained with 35-cycle, gang-operated breakers taken as 100% for each type of fault.

cycle, single-pole reclosing cost about as much as equipment for 20-cycle, three-pole reclosing).

The fundamental relaying problem* introduced by single-pole reclosing is how to indicate which phase is faulted. In gang-operated reclosing the fault is detected by any of the usual transmission-line relaying schemes, which indicate the presence of a fault but do not discriminate between phases. The scheme for selecting the faulted phase in single-pole reclosing installations must be sensitive, so that a ground fault of high resistance (that is, a fault that does not permit a large flow of ground current) still provides enough discrimination between the faulted and unfaulted phases.

A solution to the problem, meeting these requirements, operates on the phase-angle relation of the sequence components of the fault current. During a single line-to-ground fault, the negative- and zero-sequence currents for the faulted phase are in phase, but the negative- and zero-sequence components for the remaining two unfaulted phases differ in position by 120 degrees. The negative- and zero-sequence currents for each phase are segregated by suitable filters and applied to one element of a three-element relay. Thus, when the fault is on, say, phase *A* only the *A* element in the relay carries sequence components that are in phase; this element closes contacts and initiates the breaker operation. In the *B* and *C* elements the currents are not in phase and there is not enough torque to close the contacts.

In addition to the special fault-selecting scheme, the relay system includes conventional phase protection. All relaying is controlled by carrier-current apparatus to permit simultaneous operation of the breakers at the two ends of the line. The equipment has been designed to operate as follows: single line-to-ground faults cause the breaker pole connected to the faulted phase at each end of the line to be tripped and reclose; if the fault persists after reclosure, all three breaker poles are tripped and locked out. All breaker poles are tripped and locked out for all faults involving more than one conductor. It is possible to have two poles opened and reclosed for two-phase faults, and three poles tripped and reclosed for three-phase faults, but such operation has not been considered necessary on this installation; at least not until the transmitted power becomes higher.

*Reference—"Relays and Breakers for High-Speed Single-Pole Tripping and Reclosing," by S. L. Goldsborough and A. W. Hill, presented before the *A.I.E.E.* winter convention, January, 1942.

Tests

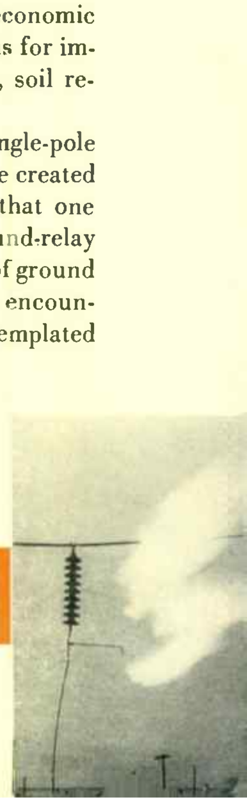
Extensive field tests were made on the system of the Public Service Company of Indiana, Incorporated, in March, 1941, primarily intended to check the relays and reclosing equipment. Faults were applied to the system at several points selected to provide a comprehensive test for the relays, reclosing mechanisms, and breakers associated with the line. Since it was necessary to stage the tests on Sunday morning, during light load conditions, the tests did not indicate directly the ultimate power limits which can be achieved. Indirectly, however, the records provided a very good indication of disturbance to the system initiated by the fault. Arcing faults were initiated by closing a breaker connecting a line conductor with ground through a fine wire suspended across an insulator string. Solid faults were initiated with a breaker.

Test Results—The tests were entirely successful, the single-pole reclosing relays and breakers operating satisfactorily in all tests. Typical of the performance recorded for all tests, the Newcastle breaker interrupted 1300 amperes in six cycles after initiation of the fault and four cycles after the trip circuit was energized. The line remained de-energized nineteen cycles before reclosure, giving a reclosing time of 23 cycles. The breaker remained closed after an arcing fault but tripped a second time and locked out on a solid fault. The reclosing times for the Lenore breakers were somewhat longer, averaging about 29 cycles, but still well under 35 cycles. The time to extinguish the arc and to reclose the breakers was remarkably consistent on all tests.

The disturbance to the remainder of the system on all tests was negligible. During one test the total Newcastle load, 40 000 kw, was supplied over the tested line, with all paralleling ties open. No disturbance was noted at Newcastle or other points on the system and oscillograms revealed that very little swinging occurred in the connected machines.

Although the virtue of single-pole reclosing lies principally in improved transient stability limits, and it has certain other advantages, it must not be considered as a panacea for all transmission-line problems. Other methods of raising transient stability limits and improving service continuity are available. In each case the choice of apparatus or method is a function of several variables. On new lines, the economic choice between high-speed reclosing and other means for improving performance is determined by line length, soil resistivity, stability considerations, line costs, etc.

The two principal objectionable features of single-pole reclosing are the possibility of telephone interference created by the flow of ground current during the period that one phase is de-energized, and the possibility of false ground-relay operation in adjacent sections caused by circulation of ground current during the de-energized period. Neither was encountered in this installation. In fact, practically all contemplated installations are expected to be free from these troubles, since ground current caused by an open phase is small. The disturbance to other ground relaying is negligible if good grounds are available at either end of the section.

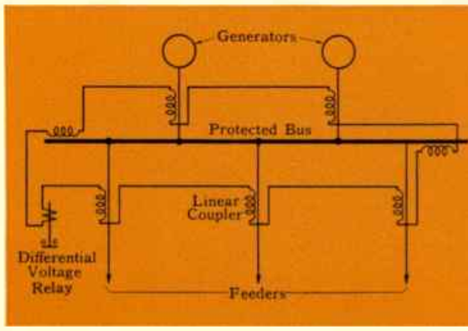


The single-pole reclosing scheme proved its worth under many exacting field tests.

What's New!

Air-Core Coupler for Bus-Differential Use

An anticipated nuisance—an upstairs neighbor prompt at dropping the other shoe—is not half as troublesome as an unpredictable fault. Disturbances in electric power systems do not schedule their appearance, and when they do occur, it is at any point of the voltage cycle. A short circuit at the instant the voltage is at the crest of the wave causes a symmetrical, or purely alternating current, but a fault current occurring at zero voltage produces in addition to a symmetrical portion also a d-c component. Proper protection of the system depends on the reproduction of this fault current by the current transformers used to operate the protective relays. The ordinary current transformer is unable to reproduce the d-c component in the fault current if it lasts more than two cycles. To make matters worse, the d-c component tends to saturate the core of the current transformer and thereby reduces the accuracy even more.

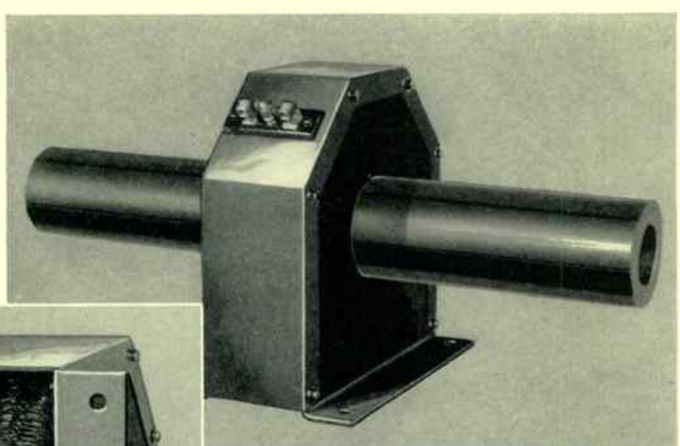


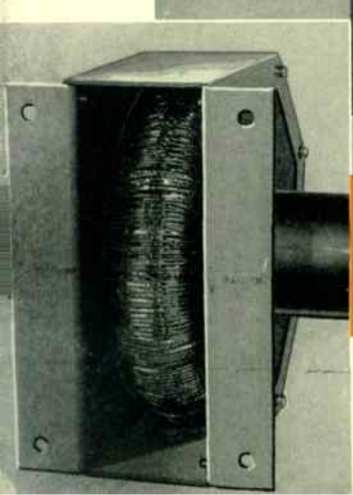
Example of a bus protected against an internal fault with linear air-core couplers.

Faithful representation of the symmetrical part of the primary current is made possible by the linear coupler, an inductance coil bent in the shape of a doughnut. Alternating current in a conductor through the hole of the doughnut induces in the coil a voltage proportional only to the magnitude of the current in the conductor, and barely affected by the fact that the current is asymmetrical. This is exactly what an iron-core transformer cannot do. Used in a bus-differential protective scheme, as shown in the one-line diagram, the voltages in all the couplers will cancel for a through fault. An internal short circuit, however, will produce a differential voltage which is used to trip the breaker and isolate the bus.

The linear coupler is distinctly different from a current transformer. There being no iron to saturate and no effect of the d-c component, the performance of the system can be predicted in advance within the accuracy of the equipment used, without fear that the circuit breakers may open at a wrong time. The most remarkable feature of the linear couplers is that they can close the relay in less than one cycle, about a sixth of the operating time of a current-transformer scheme. An interesting principle in the theory of linear couplers is that the voltage in the secondary can be shown to be independent of the position of the primary lead, as long as it is in the hole of the doughnut. Conversely, currents in conductors outside the coupler cannot induce a voltage in the secondary. This astatic property permits placing unshielded couplers in confined spaces without fear of interference and false tripping of the circuit breakers.

Linear couplers can be made to fit all standard circuit breakers used for buses, and can also be placed on the bus bars. They are particularly suitable for bus-differential protection where the setting need not be less than one twenty-fifth of the maximum through fault. Since such a requirement is usual in systems having low impedance grounding, linear couplers can be substituted for current transformers in more than half of the conventional bus-differential schemes.





The winding of a linear coupler (left) is a long cylindrical coil bent like a doughnut. Outwardly (above) the coupler is similar to the conventional current transformer.

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Induction-Voltage Regulator Is Air Cooled

A new induction feeder-voltage regulator (Westinghouse type SA) for distribution service is cooled by a natural draft of air rather than by oil or Inerteen. Modifications of standard regulators with air cooling by forced ventilation have been used occasionally in the past, but the natural air-cooled distribution-type unit is new. Elimination of fire and explosion hazards is the main virtue of such an air-cooled unit. A regulator that will not burn or explode can be placed in indoor substations without requiring separate vaults or fireproof partitions. Even in the case of Inerteen-filled transformers, the elimination of maintenance, storage, and handling of the non-inflammable liquid is a marked advantage. (Furthermore, some of the ingredients used in the manufacture of Inerteen are needed for more vital defense materials.)

The new (type SA) regulator uses flameproof inorganic solid insulation that will neither explode nor support combustion. It is available in standard ratings, 12 to 72 kva for both 2400- and 4800-volt service. These units are comparable in weights and dimensions to liquid-filled units taking no more floor space. The control is the same as used with the conventional (type SU) oil-insulated induction feeder regulator.

This air-cooled regulator is rated 48 kva at 2400 volts, four times the capacity and four times the voltage of the previous largest natural-draft air-cooled feeder regulator available (12 kva at 600 volts)

This precision electronic timer automatically divides the time required for a spot weld (1/2 to 2 seconds) into the several shorter periods necessary for the component operations.

Airplane Instruments Glow in the Dark

To a pilot flying at night, the instruments on his dashboard are almost the entire contact with the rest of the world. It is therefore essential that the dials on these instruments be illuminated for unmistakable visibility, yet not so bright that the glare blinds the pilot when his vision shifts from the darkness outside to the illuminated dashboard. This is effectively done by illuminating the pointer and the figures only, and not the dial background, thereby keeping down the area of brightness. A simple method of accomplishing this is to paint the pointers and markings with fluorescent materials and irradiate them with ultraviolet, causing them to glow in the dark.

Heretofore, the only sources of ultraviolet light for aircraft use have been argon-glow lamps and small-size fluorescent lamps operating only on 110–125 volts, and thus requiring special voltage-transforming devices to be operative on the standard 24-volt airplane battery circuit. A new 4-watt, 24-volt fluorescent lamp now produces radiation that passes through the cover glasses of the instrument dials and activates the fluorescent paints used for the pointer and figures. It is about the same size and shape as an automobile-headlight lamp, and is equipped with a similar bayonet base.

An ingenious triple transformation of energy in the new lamp makes for improved efficiency and better performance. The gas in the bulb emits radiation predominantly 2537 Angstroms in wavelength (an Angstrom is one ten-millionth millimeter, or about four billionths of an inch). The inner walls of the bulb are coated with a fluorescent paint that converts a large portion of this radiation to one of approximately 3000 Angstroms. The converted radiation is still invisible but is highly effective in making the dial markings fluorescent. A small fraction of the energy in the lamp is in the form of visible light; this is effectively screened by a dark-purple filter.

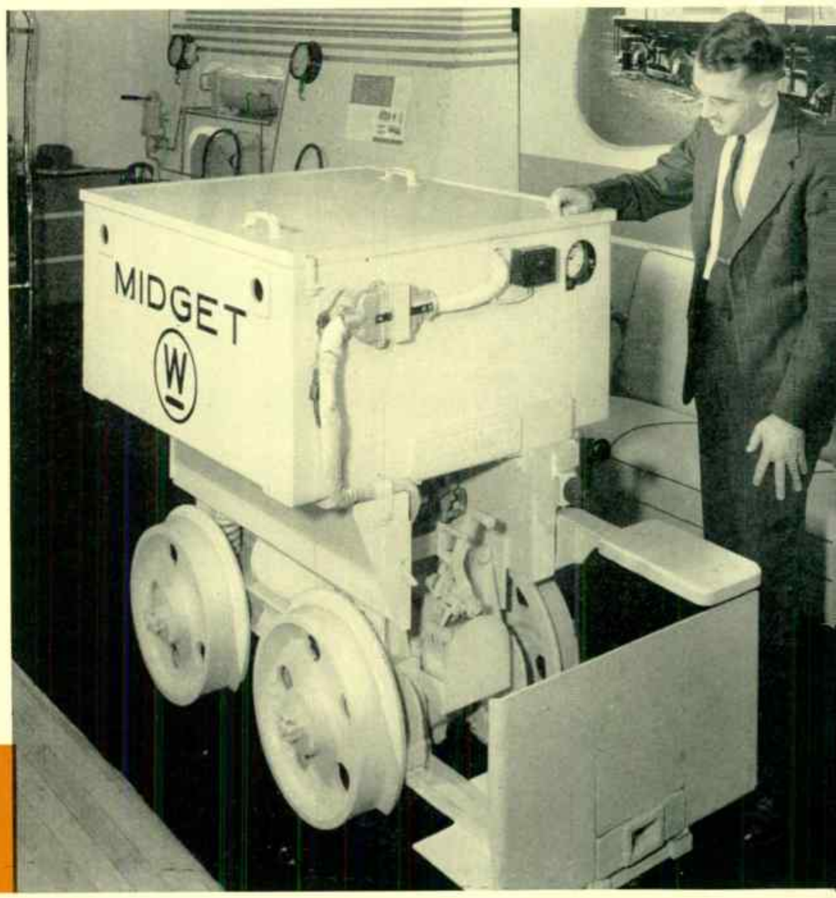
To operate the lamp, the circuit switch is closed for about two seconds to heat the cathode. After the cathode has become incandescent, electrons are liberated from its coated surface. This thermionic emission ionizes the air in the bulb and lowers its breakdown voltage, so that when the switch is opened, the resulting surge voltage is sufficient to overcome the resistance of the tube and thus cause a current flow and a glow in the mercury-argon atmosphere in the bulb. A small tungsten-filament type Mazda lamp in series with the battery serves as a ballast to limit the current.

Timing Control for Spot Welds

Resistance spot welding is a rapid process and also an exacting one. The complete operation lasts only about one-half to two seconds, depending on the metal welded and the thickness of the work pieces. This short time is further divided into brief steps, each one-twentieth to one second long (3 to 60 cycles), during which the welding machine exerts pressure on the work, welds, removes pressure from the welded pieces, and prepares for the next operation. All these steps are now timed by a newly designed controller using compact plug-in telephone-type relays that are actuated by thyratrons. The desired time for each period in the operating sequence is adjusted with calibrated dials. A simple switch offers the operator the choice of either stopping the machine at the end of the weld or repeating the welding cycle automatically; the timer is thus suitable for rapid mass production of many identical welded parts.

Sometimes, when thick plates or plates of brass or stainless steel are to be welded, the operation is not in one, but in several intermittent cooling and heating steps. A controller for this service has an "overall weld" timing sequence, subdivided in several "heat" and "cool" steps of 3 to 30 cycles each.

The complete control is contained in a cabinet of dead-front construction, compact and easy to mount conveniently near the welding machine. The relays and thyratrons are all mounted on a panel that swings to permit easy inspection and maintenance. All other parts are mounted on a sub-panel that unfolds, like a billfold, when a single bolt is removed, allowing easy access to every part of the apparatus.



The country's smallest storage-battery haulage locomotive weighs but 1½ tons. Designed for use in small mines where it can negotiate a curve with radius as short as 6 feet, this midget locomotive is run by a 5-hp, 40-volt, d-c 770-rpm traction motor. The rated drawbar pull is 400 pounds.

Predicting Performance of Bus-Differential Systems

Any watchdog can tell his master from a prowler and act accordingly. Bus-differential protection, on the other hand, does not have animal intelligence; however sensitive, a relay shows an unvarying response to the voltages and currents actuating it. A step-by-step method of calculation, outlined here for the first time, insures that a protective scheme does not trip breakers falsely. The computations need not be repeated each time a bus-differential scheme is projected. Once criteria for selection of the equipment are established and the performance of this equipment is predicted, the scheme will yield the same performance wherever the established criteria hold.

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Bus-differential protection seldom fails to operate when it should, or disconnects the whole station when there is no internal fault. Yet, it has been heretofore difficult to predict in advance whether a scheme will or will not operate under specified conditions. Only recently, by taking into account all the phenomena associated with a fault, and particularly by a careful analysis of the effects of saturation and the d-c transient on current-transformer cores, has it been possible to anticipate with assurance the performance of any differential system.

Behavior of Bus-Differential Protection

In a bus-differential protective scheme, the current transformers, relays, and circuit breakers are a team working together to isolate the fault in the protected bus. Each is assigned a definite function, but the current transformers call the signals. The differential relay is itself seldom at fault, but the various current transformers used may have ratio errors during an external fault. Under such conditions, the relay receives a false current and may operate although no bus fault exists. This is particularly true if the external fault current is initially offset, or asymmetrical. If the fault occurs near large generators, it may be as long as 20 cycles before the asymmetry caused by the d-c component of the short-circuit current is reduced to 37 per cent of its initial value (the period known as the d-c time constant). An asymmetrical fault current with a large d-c component is poorly reproduced by a transformer, inherently an a-c device.

WHAT MAKES BUS-DIFFERENTIAL PROTECTION INTRICATE?

The only purpose of bus-differential protection is to distinguish between an internal fault in a bus structure and a fault occurring somewhere else but supplied from the protected bus. All the refinements made in bus-differential protection since its introduction have been intended solely to make foolproof the discrimination between internal and external faults.

Fundamentally the differential scheme is like a balance—the incoming current is compared to the outgoing. If the two are equal, all is well. An internal fault, however, causes a difference in the two, and this differential of current, through suitable current transformers and relays, causes the faulty bus to be disconnected from the power system. A diagram of the protection of a six-circuit bus is shown in Fig. 1.

Whether it is possible, with this scheme, to discriminate between an external and internal fault depends first on the current transformers and their ability to reproduce faithfully the primary current. There are several reasons for inaccuracy in transformer performance. No two transformers, even of the same make and style, are identical. Slight differences in the windings and in the core cause ratio errors, and produce thereby a differential current in the secondary circuit, even though the primary currents balance. This differential current, under normal conditions, is too small to operate the relay. But should there be an external fault in one circuit, the ratio error may be sufficient to cause false operation of the relay. Even worse is the effect of saturation on the performance of a current transformer. A fault current is seldom symmetrical, especially if the fault occurs near a generator. It is more likely to be fully offset, that is, its d-c component may have a long time constant. On the other hand, a transformer is inherently an a-c device, and trying to reproduce any d-c at all, its core becomes saturated. This aggravates the situation because, once saturated, the transformer cannot even reproduce the alternating current accurately.

What to do about it?

The first remedy suggesting itself is improvement of the current transformers; indeed, the modern current transformer represents the utmost in quality and performance consistent with economics. Ratio errors are almost negligible, and usually no saturation is caused by the a-c component of the maximum fault current assumed for the transformer. Unfortunately, however, it is not economical to design a transformer large enough to prevent saturation by the d-c component; more than a hundred-fold increase in core is necessary.

The other alternative is to design relays that compensate for the errors caused by current-transformer saturation. The most common way of accomplishing this is to use restraint windings. These produce a torque opposing the operating winding, and are so arranged that on large through faults the restraint torque is larger than the operating torque, and the relay does not operate. The fact that an external fault current both enters and leaves the bus through the current transformers is important. The fault current thus becomes effective twice in producing restraint. For an internal fault, however, only the current flowing into the bus produces restraint, and the entire fault current flows through the operating coil, as it should. The operating coil is designed to overpower the restraint torque and to cause relay operation. This type, known as "percentage-differential relay," is thus extremely sensitive to bus faults, but does not trip on through short circuits when energized by current transformers meeting certain performance standards, easily specified.

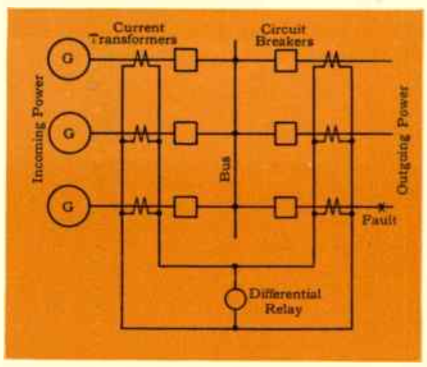


Fig. 1—*Single-line diagram of a typical bus-differential protective scheme.*

If the time constant for decay of the d-c component is less than 0.05 second (3 cycles), the transient will usually have passed before the relay can operate. The time constant is usually less than 0.05 if more than 2000 feet of bus or transmission line intervene between the generator and the fault. The decay of a fault current with a time constant of 0.05 second is shown graphically in Fig. 2. A transformer

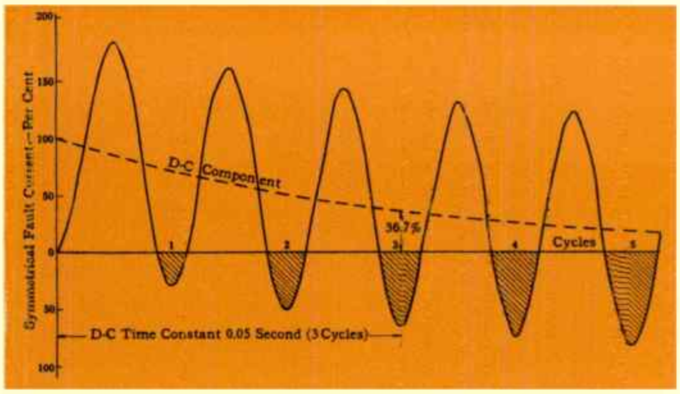


Fig. 2—*Only a fraction of the primary current is reproduced in the secondary of a saturated transformer. The positive and negative loops of the secondary currents approximately equal the shaded areas above.*

carrying a fully offset current may saturate within a few cycles and become practically ineffective. It recovers its transforming ability when the current drops below the zero axis, but loses it again when the current rises once more. Only after the current has become nearly symmetrical does the transformer operate as it should.

At each cycle, a peak of differential current in the relay tends to close the contacts. No single peak is sufficient to bring the moving relay contact all the way to the stationary contact and to complete the operating circuit. It does, however, close it part way, and before the restoring spring can return the contact to its resting position, the next current peak occurs. Thus, cycle by cycle, the moving contact inches toward the stationary one. Unless the transient saturation of the current transformer passes before the contacts close, the relay operates to disconnect the bus. The problem is to calculate just how soon the saturation disappears, and whether the cumulative effect of the fractional operation of the relay is enough to close the contacts.

Generally there are four steps to be followed:

1—Choose the worst operating condition and location of an external fault. Several combinations may have to be studied if one is not obviously the worst.

2—Knowing the current, burden, and transformer characteristics, calculate the number of cycles between the start of the fault and the time the transformer saturates.

3—Calculate, cycle by cycle, the peaks of error current appearing in the relay, from the time the transformer saturates until the transient decays.

4—Determine from this error current and from the impulse-current curves of the relay (taking into account restraint, if present) whether the relay can or cannot operate.

Step (*1*)—Since many circuits are usually connected to the protected bus, there are many possible operating conditions under which an external fault can occur. The operation or non-operation of the relay must be considered for every possible connection, but usually the two or three worst conditions that need be calculated in detail are apparent at first glance.

Step (*2*)—The time required for the transformer to saturate can be found from Fig. 3. The actual computation is self-explanatory, but it must be kept in mind that, of the five quantities used in this curve, two (T and I_p) are estimated from the system characteristics, two (N_s and R) are known characteristics of the current transformers and their burden, and the fifth (E_s) must be obtained from the saturation curve of the current transformer, as shown in Fig. 4.

Step (*3*)—The peak of the relay current I_r in any one cycle can be calculated from the relation

$$I_r = K\,I_s\left(\frac{R}{R_r+R}\right) \qquad (1)$$

Where K is read from Fig. 5 and

I_s = Theoretical symmetrical fault current in secondary of current transformer, as calculated from the current transformer ratio and the primary current.

The curves in Fig. 3 are based on a formula derived in an earlier article*

$$t=-\frac{T}{0.434T_o}\log\left\{1-\frac{B_sNA}{10^8R_2TI}+\frac{1}{\omega T}\right\}$$

This formula is useless unless B_s, A, and N are known, and usually only the designer of the current transformer knows them. However, using the relation

$$E_s=4.44nf\,B_s10^{-8}$$

these unknown quantities are replaced by a corresponding voltage that is easily read from saturation curves, such as shown in Fig. 4, for three Westinghouse transformers (Types R-22, R-15, and R-7.5).

The use of Fig. 4 is very simple. If a study of the protective scheme shows that the minimum current to operate the differential relay is, say, 10 amperes, then the secondary voltage corresponding to 10 amperes is assumed to be the "saturation voltage," and the figure read from the curve is used in the calculations shown in Fig. 3.

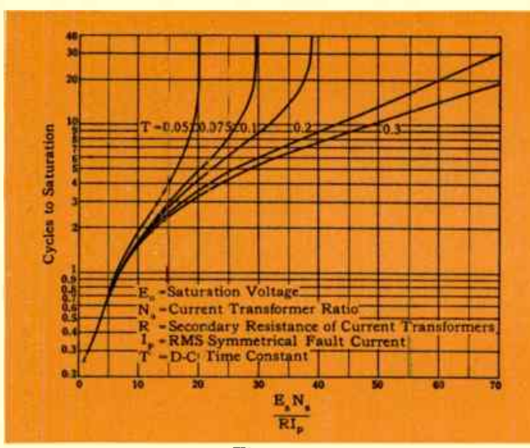


Fig. 3—
Time to saturate current transformer.

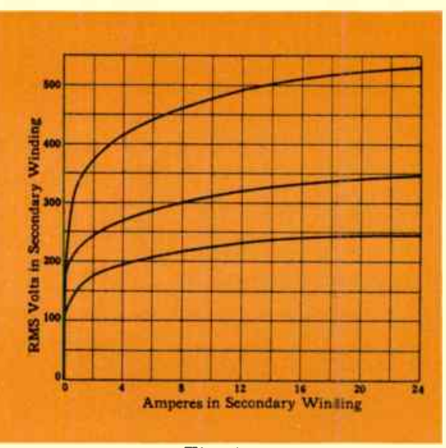
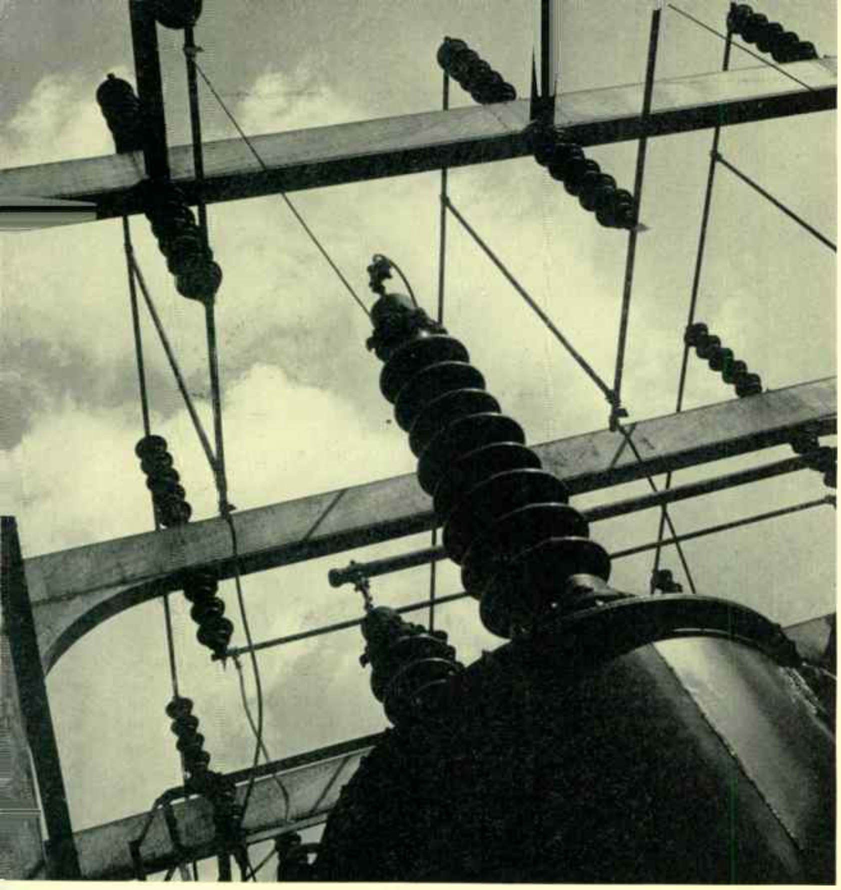


Fig. 4—
Saturation curves for three transformers.

*"Current Transformers and Relays for High-Speed Differential Protection," by E.C. Wentz and W. K. Sonnemann, Transactions A.I.E.E., August, 1940.



R = Resistance of secondary circuit of current transformers, including leads to relay.

R_r = Resistance of relay operating coil.

Step (4)—Once the peaks of the relay current are known, the impulse curves of the particular relay show whether it will operate or not. Curves for a relay without restraint windings, and the complete calculations are shown in Fig. 6.

When a relay with restraint windings is used, it is possible to calculate, cycle by cycle, the restraining torque, and then from the peak current and the restraining torque to calculate the fractional operation, as shown in Figs. 8 and 9.

Sample Calculation

A better illustration of the principles involved is offered by an actual calculation for the bus in Fig. 7, protected by variable-percentage differential relays (Westinghouse CA-6).

The following is assumed:

(a)—High-grade transformers are used, which do not saturate at the maximum fault current if it is symmetrical.

(b)—The maximum *symmetrical* fault current in the secondary of any current transformer is 100 amperes rms. The ratio of the current transformers for a particular system of bus protection should be chosen to meet this condition.

(c)—The resistance of the secondary winding and leads is four ohms (this is felt to be sufficiently pessimistic); the resistance of two relay operating coils in series is 0.8 ohm.

(d)—The fault current is fully offset.

(e)—The d-c time constant of the fault current is ¼ second (15 cycles). This is on the high, or pessimistic, side.

(f)—In the six-circuit bus shown in Fig. 7, the external fault current in circuit 6 is supplied equally through the remaining five circuits.

(g)—The current transformer carrying the fault current suffers instantaneous and complete d-c saturation.

(h)—Only relay no. 1 (Fig. 7) is considered, inasmuch as by assumption (f) identical conditions apply to both relays.

Step 1—Selecting the worst operating condition

It is apparent that the conditions in assumption (f) are those most likely to cause false operation. According to assumption (d) the current is fully offset. This will saturate the core of transformer 6, but the remaining five transformers, each carrying only one-fifth of the current, are assumed not to saturate. This causes the worst unbalance between the secondaries of the current transformers, and is therefore most likely to operate the relay falsely.

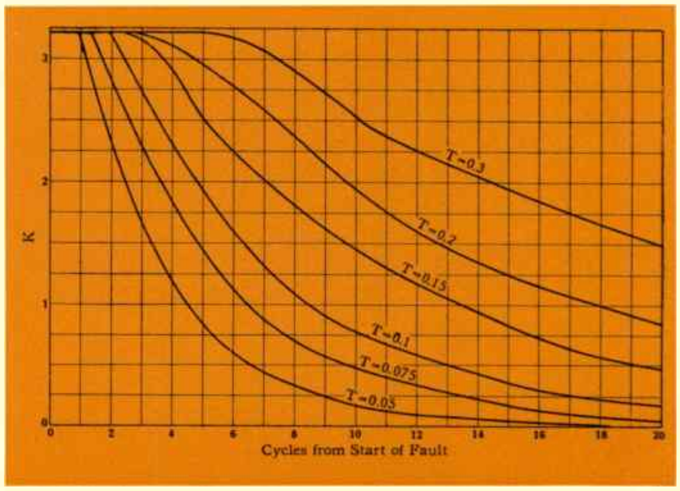


Fig. 5—*Every cycle there is a peak-current impulse in the relay. Its magnitude is found from eq. 1 using the constant* K *from the curve above.*

This curve is derived from the equation $P=\pi IE^{-\frac{t}{T}}$ in an earlier paper* modified for the first period up to $t=T/4$ because the initial peak cannot possibly exceed the double-amplitude peak *2I* (Fig. 2).

Step 2—The time to saturate the current transformer

Mathematically condition (a) is equivalent to

$$E_sN_s/RI_p>1 \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Assuming, at the worst, that $E_sN_s/RI_p = 1$, Fig. 3 shows that the current transformer saturates in ¼ cycle.

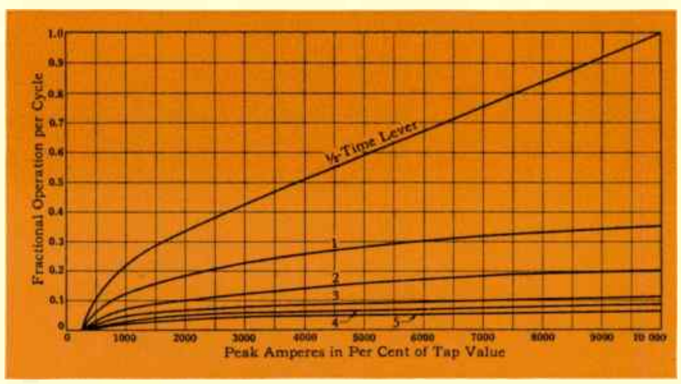


Fig. 6—*Impulse curves for a typical bus-differential relay without restraint coils (Westinghouse type COH). Assume, for example, that computations by means of Figs. 3 and 5 show that the fault currents are 5000 per cent normal in one cycle, 2500 in the next, and 1250 in the following. These peak currents cause the relay contacts to come together, respectively, 0.595, 0.384, and 0.260 of the total distance between them. As the sum of these three fractions exceeds unity, the contacts will close and the relay will therefore trip the circuit breakers unnecessarily.*

*See reference, p. 29

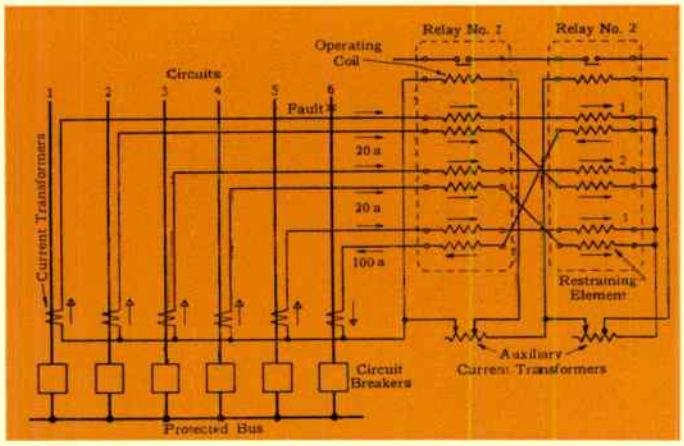


Fig. 7—To get full protection against false tripping of the relay, it is advisable to have at least one restraint element for each circuit. Since there are only three restraint elements (each having two coils) in each relay, two relays per phase are used to protect the six-circuit bus.

Step 3—The peaks of error current, cycle by cycle

Using assumptions (b) and (c), eq. 1 can be rewritten to read

$$I_r = K \times 100 \times \frac{4.0}{4.8} \ldots\ldots\ldots (3)$$

where I_r is the peak current in the relay, and K, for each cycle, is read from Fig. 5. The numerical results are listed in table I.

Step 4—Calculation of performance

Before computing operating and restraining torques for each cycle, it should be remembered that an important characteristic of the CA-6 current-differential relay is that, for a fully offset current, its operating torque is negligible. Since the false differential current can be assumed to be fully offset during an initial period corresponding to $T/4$, the relay will certainly not receive operating torque during the first four cycles, because T was assumed to be 15 cycles.

Beginning, therefore, with the fifth cycle, the curves of Figs. 8 and 9 are used to determine the operating and restraining torques of the relay. Although the restraint current is the same each cycle, the d-c component in the restraint current is not; therefore, the effective torque produced by the restraint current varies. Starting with $n = 5$,

TABLE I

T=.25 SECOND. CURRENT PER COIL=20 a.
SUM OF CURRENTS IN 2 COILS=40 a.
T_0=1/60 FOR 60-CYCLE SYSTEM.

n	nT_0/T	Total Restraint Torque (1)	Peak Operating Amps I_r (2)	Fractional Operation From Fig. 9
1	0.0666	17		
2	0.1333	22		
3	0.2	25.5		
4	0.2667	29.5	283	0.17
5	0.3333	32.5	264	0.14
6	0.4	36.5	246	0.08
7	0.4667	39	229	0.025
8	0.5333	41.5	213	
				Total 0.415

(1) Read torque from Fig. 8 for 40 amperes and proper value of nT_0; multiply by 2, because there are two restraining elements in the relay. (The third element is pessimistically assumed to be non-effective.)
(2) From eq. 3 and Fig. 5.

the corresponding values of nT_0/T and of restraint torque read from Fig. 8 are shown in table I.

Then taking the restraint torque and peak current (I_r) from table I, Fig. 9 gives the resulting fractional operation for each cycle; this is also listed in table I.

The total of the last column is less than 1 by a factor of 1/0.415, indicating that the relay will not trip falsely for the external fault assumed. Prior to the eighth cycle, the summation of the fractional operating impulses per cycle is not sufficient to cause relay operation during that period. After the seventh cycle, the restraint torque exceeds the operating torque, and the excess of restraint torque continues to increase as the d-c transient disappears, hence the relay cannot operate.

In table I all restraint contributed by element C in relay 1, Fig. 7, has been neglected. This was done because the two currents in element C are in opposite directions, and there is some cancellation of ampere turns producing restraint in that element only. Furthermore, the current transformer in circuit 6 has been assumed to suffer instantaneous and complete d-c saturation, from which it recovers, cycle by cycle. It is thus more difficult to calculate the restraint furnished by element C, even though it can be done; hence it has been neglected. Actually, the restraint thus neglected is not small, and probably would result, in many cases, in there being no positive values to show in the last column in table I.

It follows that if the conditions in any actual problem are no worse than those given (and usually they are better), the relay can be counted on for successful operation.

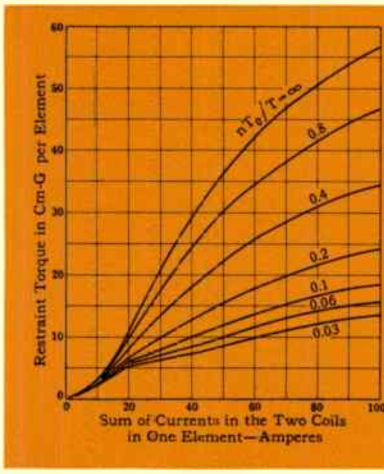
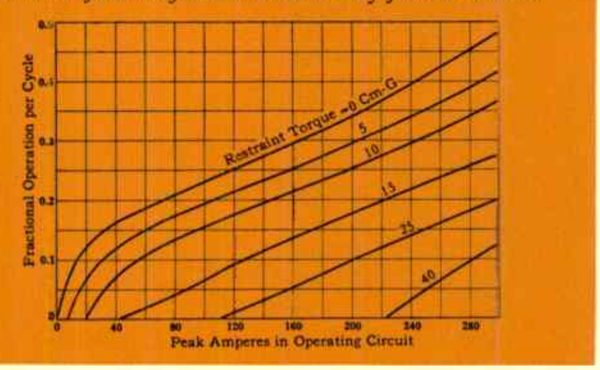


Fig. 8—The torque in a restraint element of a differential relay (type CA-6) depends upon (a) the current flowing in the two coils of the element and (b) a time factor governed by the reciprocal of the system frequency (T_0) and the d-c time constant (T) of the system, and the number of cycles (n) elapsed since the beginning of the fault.

Fig. 9—Knowing the restraint torque (from Fig. 8) and the peak amperes in the operating circuit (Eq. 1), the fractional operation of the relay can be read directly from this curve.



Stories of Research

Lensless Camera Traces Marked Atoms

Just as marked bills are frequently used to trace and trap criminals, so are marked atoms now employed to locate and measure concentrations of elements in various bodies. Some time ago W. E. Shoupp, Westinghouse research physicist, developed a portable Geiger counter with which a group of radioactive tracer atoms mixed with millions of others can be identified and counted. He has now devised a simple lensless camera, which, instead of counting marked atoms, records on photographic film where the radioactive particles are located and how concentrated they are.

A practical example of the use of this method of detection is the measurement of the concentration of phosphorus in iron or steel. Because it makes steel brittle, phosphorus has been suspected of segregating or concentrating undesirably in certain zones of any ingot or casting. By means of his little camera, Shoupp has succeeded in proving photographically that this is so.

He prepared a sample batch of steel, and mixed into it phosphorus that had been made artificially radioactive by bombardment with deuterons. This steel was molded into a disk that was clamped between two pieces of photographic film. Two brass plates were placed outside the films, the stack clamped, and the whole assembly placed in a light-proof ordinary tin can.

The radioactive atoms emit electrons of very high velocity, and these particles affect the photographic emulsion much the way light does. The developed film exposed in such a camera reveals blotches caused by the rays from the phosphorus tracers, the light areas on the positive print corresponding to phosphorus-rich zones in the steel disk. The photographs have shown not only that the phosphorus has concentrated in certain solid portions of the steel, but has also collected in particularly thick films on the inner surfaces of blowholes. The latter was an unexpected effect and may lead to new concepts.

This simple method of photographing radioactive tracers can be used to reveal the location of other substances besides phosphorus. Thus concentrations of sulphur, carbon, manganese, or silicon in steel can be readily studied, and the findings used to improve steel making.

The light areas on the microphotograph (left) show the concentration of phosphorus around blowholes in steel, as photographed with the exceedingly simple "tin-can-and-clamp camera" (above).

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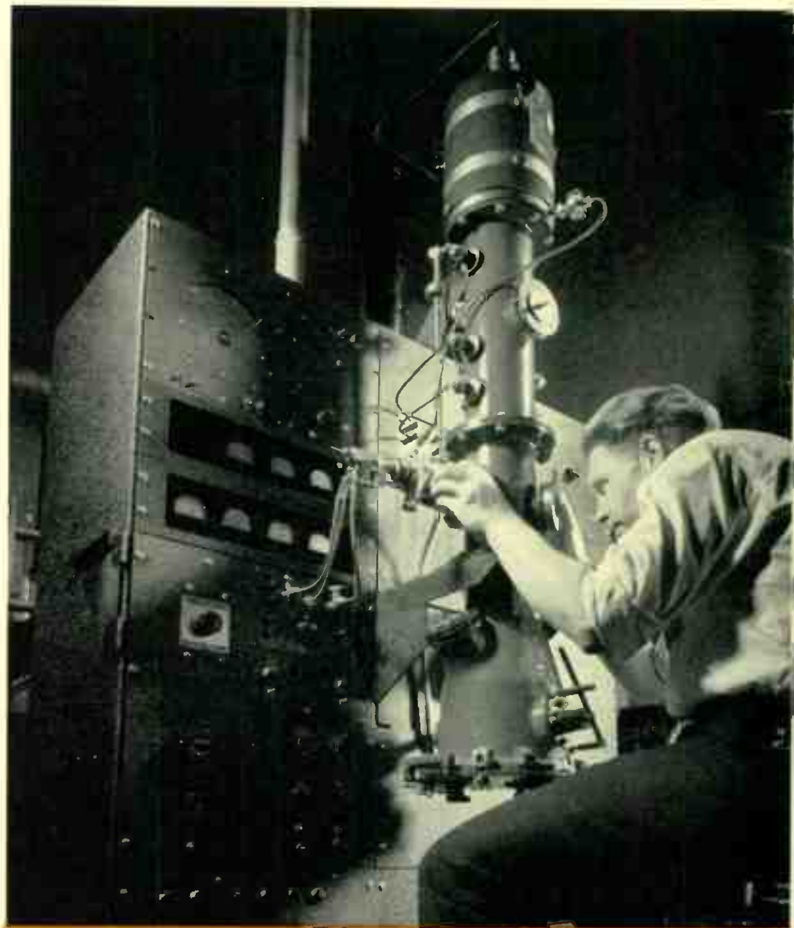


By means of this electro-diffraction camera, Dr. E. A. Gulbransen of the Westinghouse Research Laboratories studies the structure of extremely thin films, such as the oxide coatings on the surfaces of metals. Barely a few atoms in thickness, most films form in a lattice-like array that reacts to electron beams somewhat like the ruled lines on an optical grating react to light. Electron-diffraction patterns, obtained in this camera, will contribute many valuable clues about the nature and effects of the films.

★ ★ ★

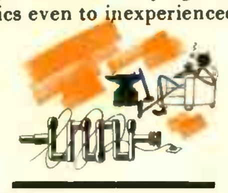
One of the world's most delicate balances can determine accurately the weight of a human hair or a man's signature (a signature of average length, written in pencil, weighs about 0.0008 gram, or thirty millionths of an ounce). The practical use for this instrument, accurate to within forty billionths of a pound, is to check the weight and the diameter of the extremely fine filament wire used in Westinghouse Mazda lamps.

P E R S O N A L I T Y   P R O F I L E S

As a sole or joint author, *R. D. EVANS* has participated in the publication of over forty books and papers dealing with almost every problem involved in the transmission of electrical power. Notable among them is the first and still authoritative textbook on Symmetrical Components, his contributions to the study of system stability, and his work on inductive coordination. He has been with Westinghouse since his graduation from the University of Oklahoma in 1914, and has been associated with the Central Station Department almost all that time, specializing in system problems. He is a prolific inventor, having been awarded over fifty patents. The more important of these cover the quick clearing of faults to improve system stability, quick-response excitation systems and phase-sequence segregating networks . . . *E. W. BECK* is another Westinghouse specialist, having concentrated on lightning protection since joining the Company in 1923, several years after graduation from Columbia (E.E. '17). He has assisted in the development of many lightning-protection devices, lightning generators, and of that important auxiliary to the study of lightning, the cathode-ray oscillograph. At present he heads the group of Westinghouse engineers doing that work. His interest in lightning is not merely academic—he is concerned primarily with the search for new ways to protect against it. He, too, is a busy author and inventor, but has managed to find time to do extensive traveling all over Europe, and devotes his spare time to fishing, gardening, and music.

While he was still an undergraduate at Purdue, one of his professors said of *J. E. HOBSON* that he seldom started anything without making a complete success of it. This statement still aptly fits the man, who, at 30, was chosen to head the Electrical Engineering Department in the Illinois Institute of Technology. From 1938 to 1941 he was Central Station Engineer with Westinghouse, acting as consultant to utilities on transmission problems. The time earlier, from his graduation in 1932, was spent in graduate study (he received his Ph.D. from California Institute of Technology in 1935) and teaching. A tireless worker, he carries numerous engineering, social, and church activities, and finds ample time to listen to his collection of phonograph records . . . *H. N. MULLER*, who has been appointed to assume Dr. Hobson's duties with Westinghouse, is a physicist by training (Dartmouth '35), but with an uncanny practical sense that many engineering-school graduates would do well to possess. His experience in the Central Station Department has covered several fields, such as studies and harmonic analysis of rectifier waveshapes, stability investigations, and general system application problems. His specialty, in addition to his present duties as consultant on central-station problems, are high-tension cables, and he has penned several technical articles on current distribution and general characteristics of cables. Muller is a raconteur of no mean ability, and livens up any party.

Some people have red hair and get away with it. But even before a stranger meeting *E. C. WENTZ* gets used to the scarlet plumage, he realizes that under the colorful mane is stored a veritable encyclopedia of knowledge of current transformers. And no wonder. In 1928, after two years in the Westinghouse Student Course (he's a Minnesota man, '26), Wentz was assigned to the Instrument Transformer Section. There it became second nature for him to whip out a new design or application for a transformer, nicely done to a turn. An author of many articles and a holder of several patents, he is now a recognized authority on current transformers for differential protection. Wentz, being an excellent ice skater, probably cuts some fancy wiring diagrams on the ice. . . . To teach relay application to other engineers requires a thorough knowledge of relays and their circuits. One evening each week *W. K. SONNEMANN* presides over the graduate course in relays and their applications, offered by Westinghouse in cooperation with several universities in the New York metropolitan area. A native of Texas and a graduate of its University (B.S.E.E. '24), he came to Westinghouse in 1925, and has been designing and applying relays since, except for one period of several years, which he used to advantage acquiring practical utility experience with the Texas Power and Light Company. In addition to his technical prowess (he has played a major part in the development of bus-differential relays incorporating the new principle of variable-percentage characteristics) he has the happy knack of clarifying complex technical topics even to inexperienced listeners.



That *W. E. BENNINGHOFF* is an acknowledged leader in the field of induction hardening is attested by the more than thirty lectures on the subject that he was asked to deliver before chapters of the American Society for Metals and of the Society of Automotive Engineers. A graduate of the Case School of Applied Science (B.S.E.E., '19), he reached his present position as Manager of the Tocco (Hardening by Induction) Division of the Ohio Crankshaft Company after a varied and extensive career that includes being chief engineer of a screw-machine works, chief electrical engineer for the National Carbon Company, and other positions of importance. . . . Dr. *H. B. OSBORN*, Jr., who assists Mr. Benninghoff as Research and Development Engineer, is turning a splendid academic foundation into an equally brilliant experience record. He stayed at Lehigh after receiving his B.S. in Ch.E. in 1932 for graduate work leading to an M.S. and a Ph.D. In 1939 he joined the Ohio Crankshaft Company, and in less than a year assumed charge of the Sales Development and Research departments.

C. C. LEVY is on hand whenever electrical machinery is to be applied to metal working, and selecting equipment for induction heating is just a part of his duties. Educated at Jamaica (B.W.I.) College and Toronto University, he has been with Westinghouse since 1913. A member of the Committee on Electrochemistry and Electrometallurgy, A.I.E.E., and of the Electrochemical Society, he has written many technical articles on the subject. . . . *L. J. LUNAS*' work on electrical instruments for high-frequency measurements is but one part of his general activities as design engineer with the Westinghouse Meter Division. He joined the Company in 1926 upon graduation from the University of North Dakota. Several years with the student course and the design school (during which he earned his Master's degree from Pitt) were his preparation for his present work in instruments. As for his technical writing, his forte has been in articles with a practical slant to them, particularly on instrument connections and on special applications of recording instruments, in which fields he has also made numerous important inventions.

FRANK T. CHESNUT, Secretary and Patent Attorney of the Ajax Electrothermic Corporation, was all set to sail for Honolulu to supervise some induction-furnace installations when the Japs got in the way. More was written about him in the "Personality Profiles" of the November, 1941, issue. . . . *H. E. SOMES* is Chief Engineer of the Budd Induction Heating Co., Inc., and an author of many papers on induction heating. . . . Dr. *H. C. RENTSCHLER*, Director of Research, Westinghouse Lamp Division, has been lately devoting much of his efforts to the study of bactericidal ultraviolet radiation. Last June he received an honorary Sc.D. from Princeton.

New tasks FOR ELECTRICITY

Rays from Sterilamps suspended from the ceiling and mounted inside the surgeon's light deal death to air-borne bacteria in the operating room. By greatly decreasing the likelihood of infection during the operation, the patient is assured speedier convalescence. This and other uses of bactericidal radiation are discussed in the article on page 3.