WESTINGHOUSE

Engineer

May, 1942

LIGHTING FOR *Obscurity*

FROM the invention of the fagot, man has been working to provide more and better light. The making—and selling—of darkness is as complete a technical about face as can be imagined. It finds us with no simple instruments for measuring faint light, and with little knowledge of the frailties of human vision. The problem—that of providing maximum light for the friend and none for the foe—is complex. It involves, and more than just casually, the sciences of physiology, illumination, electrical transmission—not to mention military tactics and ballistics.

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THE human eye is one of the most adaptable instruments known. It is quite capable of seeing well in intense sunlight, as much as 10,000 footcandles. Also, the dark-accustomed eye is able to distinguish objects in starlight, about 0.0002 footcandle. Thus the eye is adaptable to a range in brightness of over fifty million to one. For comparison, illumination in the average office is between 10 and 20 footcandles; a "brightly" lighted store or modern factory, 30 to 100 footcandles; the gay, white way of Broadway, about 1 footcandle; maximum moonlight, 0.025 footcandle, or a hundred times brighter than starlight, an illumination which London authorities have been trying to obtain during blackouts.

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AT extremely low illuminations, several curious reversals occur in the phenomenon of seeing. The center of the eye no longer is the most sensitive area. At starlight levels one can see better out of the side of the eye. This is because the eye has two kinds of light-sensitive cells. Rods, which work in dark surroundings, are not uniformly distributed over the entire retina. The cones, by which color and form are seen, are concentrated within a few degrees of the retina center. In the dark most of our seeing is by the rods, which explains why objects are seen as colorless masses. London bobbies reporting accidents during blackouts have not been able to give the color of the automobiles involved.

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WE might think of blue light as being the best during blackouts, certainly much better than red. On the contrary, the reverse is true. Blue is more easily seen from 5000 feet up than any other color, deep red least visible. At this height, even if a red light is seven times as bright as a blue one, only the latter can be seen. In other words, in a blackout blue light is more helpful to a bombardier and least useful to those on the ground of any color. Actually, nothing is to be gained by choosing a colored light over a white one.

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THE eye accustoms itself to darkness slowly. From 20 to 30 minutes are required for normal eyes to become fully dark accustomed—probably long after a surprise raid is over. Also, it is essential that the night adaptation be maintained. Brief exposure of dark-accustomed eyes to surfaces no brighter than pale moonlight results in glare blindness that requires minutes to overcome. This is also why a surprise air attack is at an advantage. The attacking pilots have a head start of several hours' dark flying, while the defenders must get into their clothes and be ready for action in a few minutes, before they can see in the dark.

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IT is folly to try to make bright colored roofs of buildings or other large objects less conspicuous by painting somber colors—as indeed one community undertook to do. In the dark, the reflection factors of all colors, except white, are about the same.

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WESTINGHOUSE Engineer

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Editor—CHARLES A. SCARLOTT · *Editorial Advisors*—R. C. BERGVALL · T. FORT · R. E. WILLIAMS

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POWER TO SEE THE INVISIBLE

To insure their proper operation, rectifier tubes for X-ray machines are subjected to a high-potential test, at 150 000 volts, for a period of fifteen minutes. The experimenter shown above is safeguarding against accidental damage to himself or to the equipment, by discharging, with a grounding stick, the residual electricity that remains stored in the various components of the circuit after completion of the test.

Storage Reservoirs of Light

The soft light of the firefly, the eerie will-o'-the-wisp, the pale glow in the dark of paints on toys and novelties have only been curious phenomena. However, the war, just as it has changed the relative values of many things, has catapulted phosphorescence to a place of importance. Materials are now available, usable as paints, fabrics, enamels, in which the phosphorescent ability is highly accentuated. Charged during the day by sunlight or any artificial light source, they give off a soft glow throughout the night that means safety in a blackout.

S. G. HIBBEN
Director of Applied Lighting, Lamp Division, Westinghouse Electric & Manufacturing Co.

If a military blackout consists merely in discontinuing past methods of illumination, it well may delay and confuse the defenders as well as the enemy. If unmodified darkness should interfere radically with necessary traffic movement, or if it should cripple production, facilitate sabotage or lead to panics, then its result would be much the same as if the enemy actually destroyed property and morale by bombing. But since blackouts seem necessary under present conditions, it is comforting to know that through the development of new luminous materials it is possible to alleviate some of the inconveniences and hazards of complete darkness; it is possible to provide "storage batteries" of light as substitutes for lamp bulbs, luminous signs, or the usual signals and markers during emergencies.

Phosphorescence, a By-product of Fluorescence

More than 20 years ago lighting engineers recognized the commercial and military possibilities of fluorescent materials.* Certain organic dyes were studied along with minerals and chemical mixtures because these would absorb invisible radiant energy of one wavelength and emit visible light—cold light—of a longer wavelength. The wavelength of the radiation initiating the fluorescence was usually within the invisible band roughly between 3000 and 4000 Angstroms**; the emitted visible radiation can be of almost any color of the spectrum but was chiefly in the light yellow-green region of approximately 5500 Angstroms.

Because of its invisibility, this exciting energy was popularly termed "black light" and the responsive materials were generally classified as "luminescent." The action and its return to normalcy were instantaneous, and visible emission ceased with the exciting irradiation. Chief usage was in stage costumes, decorative murals, criminology, ore explorations, and oil analyses.

With the advent of high-intensity mercury lamps black-light applications underwent a notable stimulation. These sources, from which the visible light was screened with filters of nickel-cobalt glass, provide ten times as much effective excitation as obtained from the same wattage of filament sources. However, for many commercial and military usages there still remained the troublesome necessity of black-light generating equipment and the fact that the fluorescent responses instantly cease at the termination of the black light.

Phosphors or the inorganic coatings of the modern fluorescent lamps represented another great stage in this development but these were altogether responsive to a band of shorter wavelength, namely in the general ultraviolet region of 2000 to 2500 Angstroms. Curiously enough, some of these phosphors exhibited not only the instantaneous or *fluorescent* response characteristics but also a slightly lethargic decay of luminescence, merging into the classification of *phosphorescence*. This tendency was studied and encouraged, as it offered a possible solution to a problem with fluorescent lamps, that of stroboscopic effect. The early fluorescent lamp phosphors used were almost entirely fluo-

The author here proves that one can leave his shadow behind him. Done as a stunt, nevertheless it shows the possibilities of the new phosphorescent materials. The author stood for a few seconds between a fluorescent lamp and a phosphorescent painted background so that all but the area of his shadow became light "charged." He then turned around and moved to one side while this picture was made as a time exposure in complete darkness.

*Fluorescence and phosphorescence are sometimes confused. They both represent the ability of certain substances to transform some form of energy into visible light. The results are indistinguishable to the eye, but between them there is one important difference. Fluorescence lasts only while the exciting energy source is present; phosphorescence continues after the exciting source has been removed. In either case it is caused by a distortion or warping of the atomic lattice of the material by the initiating or exciting energy source. As the atomic lattice returns to its stable form it releases the energy it has absorbed, but with a wavelength visible to the eye. The atomic lattice has simply acted as a wavelength transformer.

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

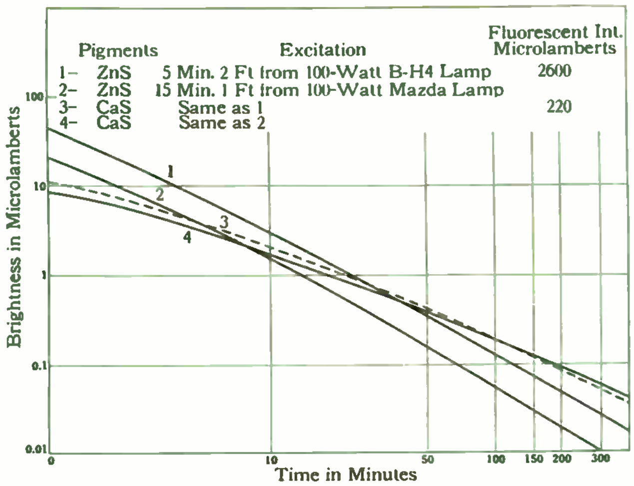


Fig. 1—*The light from phosphorescent pigments decays rapidly at first and then very slowly. Drawn on a logarithmic scale the decay is linear.*

rescent, i. e., their illumination ceased once each half cycle of the alternating current. Some time lag of the illumination was desired. Such studies inevitably concentrated further interest in the strictly phosphorescent materials having a very slow response or which persisted at a slowly decaying rate in their luminous radiation for several minutes and even for a number of hours after the exciting source of radiation had been removed.

Phosphorescence Becomes Practical

Incited by the impact of blackouts and stimulated by wartime needs, phosphorescent materials have developed rapidly and are now becoming useful tools in the lighting art. Generally speaking, these materials are zinc and cadmium sulphides in one group (greens, yellows) and calcium or strontium sulphides (blues) in another, with important traces of other inorganic compounds. They are excited or "pumped up" by almost any radiant energy either of daylight or of many of the common artificial illuminants; they do not require some of the invisible light bands to charge them, and herein lies their present importance. They can be impregnated into fabrics, oilcloth, or used as an enamel baked on sheet metal. They are available as ground pigments in such vehicles as urea-formaldehyde resins, and in the powder form the phosphorescent material may be molded into plastics of almost any shape. Heat does not destroy the phosphorescent properties.

For convenience in classification, the zinc and cadmium sulphides or the phosphorescent coatings characterized by green, yellow or orange color are designated type A. Type B materials such as calcium and strontium sulphides have a violet, light blue, or bluish-green phosphorescence. Type A pigments can be used in paint vehicles much like lithophone and zinc sulphide. The type B pigments are quite sensitive to moisture and often reactive to the materials with which they are mixed. On exterior exposure they may fade or darken.

When used indoors type A materials can be seen by the dark-adapted eye for as long as six hours after strong irradiation. The type B materials are usually not as bright immediately after exposure, but have a moderate intensity for a considerably longer period, as much as ten hours. From 2000 feet or more in the air, small patches of phosphorescent materials are not sufficiently bright to be seen.

The importance of phosphorescent materials in connection with military operations is increasingly great. Among the various services are the wall coatings of the interiors or exteriors of vehicles; the painting of hazardous objects; the softly luminescent tapes, signs and other field markers; instrument dials; plastic buttons to mark a route, or phosphorescent fabrics for various portions of a uniform.

During blackouts the phosphorescent yard-goods eliminates many of the hazards when banded around the arms or legs of pedestrians or to outline fire extinguishers, first-aid cabinets, switch handles, exits, and stair-treads. Excited by natural daylight the phosphorescent plastics or metal enamels may serve after sundown as a supplement to dim or non-existent street lighting. Indoor panels of several square yards area permit safe movements in refuge rooms as during air raids or when the normal lighting must be extinguished.

Because many of the phosphorescent products are being improved rapidly, it is possible to report only on certain general but typical characteristics.

1—Immediately upon the termination of the exciting radiation, the apparent brightness of phosphorescent material decreases rapidly, but after some two or three minutes a fair condition of stability is reached and thereafter the rate of decay is slow. Plotted logarithmically, the

Fig. 2—*How quickly the phosphorescent pigments reach maximum "charge" is dependent upon the type of the exciting light source. Fluorescent and mercury-vapor lamps are somewhat superior to incandescent filament lamps.*

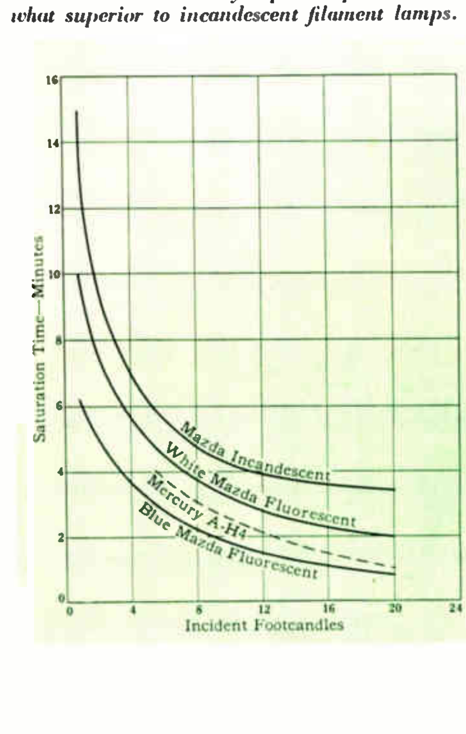
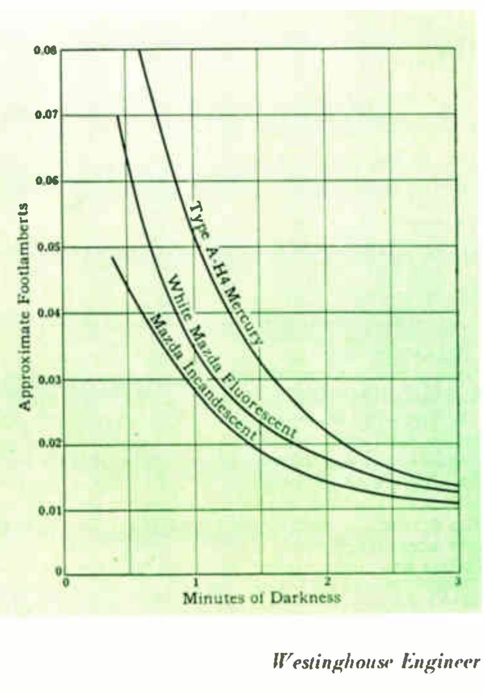


Fig. 3—*The maximum intensity of illumination obtained from a phosphorescent pigment is dependent upon what light source energized it. These curves, taken at identical excitation, compare mercury, fluorescent and filament lamps.*



brightness-decay curve is essentially a straight line as Fig. 1 indicates.

2—The initial brightness, and the brightness for a considerable period of time after exposure, depends upon the quality of the exciting radiation. Among the artificial illuminants, the fluorescent Mazda lamps are excellent exciters; the radiation from the blue fluorescent lamp is particularly effective. The excitation from the high-intensity mercury lamps (on a basis of equal footcandles) ranks close to that of the best fluorescent lamps, while the exciting radiation from the incandescent filament source is least effective although still useful.

3—Although most phosphorescent materials are "charged" to a considerable degree by an almost instantaneous exposure to the exciting radiation, yet the brightness is dependent upon exposure time until at least a saturation point is attained, as shown in Fig. 2. In any case, virtually maximum phosphorescence is reached in a few minutes. After the material is fully "pumped up" or saturated, a longer exposure is ineffective—doing neither harm nor good. A typical phosphorescent fabric similar to oilcloth attains its maximum brightness after about 12 minutes' exposure to 2 footcandles of incandescent illumination or after about 4 minutes' exposure to 12 footcandles. With the blue Mazda fluorescent lamp as the exciter the saturation is in about 5 minutes under 2 footcandles or 1.5 minutes under 12.

4—Starting with the same phosphorescent material but exposing it to different qualities of radiation generally results in decay curves that are essentially parallel, as Fig. 3 shows. After an hour or two, however, the apparent brightness differences are negligible.

5—After exposure to saturation and under ten footcandles of visible light, and after reaching a reasonable degree of stability of brightness (say after five minutes of darkness) the apparent brightness of a typical phosphorescent surface is on the order of 0.005 to 0.015 footlambert.* This brightness may be compared roughly to the brightness of a new concrete highway of 50 per cent reflection factor viewed under full moonlight.

6—On the basis of equal wattage, all standard-color fluorescent lamps produce approximately the same phosphorescent brightness.

Phosphorescent materials or "storage reservoirs of light" thus become valuable accessories during wartime and should later take their place as invaluable adjuncts to full intensity artificial illuminants.

*A footlambert is a unit of brightness and is defined as the brightness of a surface that emits one lumen per square foot.

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Blackout Control of Outdoor Sign and Street Lighting

It is generally agreed that blackouts, except during actual raids, would retard the productive war effort and unnecessarily increase traffic hazards. The Office of Civilian Defense has therefore refrained from ordering general blackouts. Orders have been issued in many areas requiring users or operators of outdoor lighting to be prepared to extinguish all lights upon receipt of an air-raid warning. But this is not simple. Only a small percentage of street lights is supplied through independent circuits controlled from a few central locations. More often the street lights, signs, etc., are time-clock controlled and are in parallel with loads that must not be dropped even in an air raid. The heart of the street blackout problem, particularly in a large city, is how to operate simultaneously many thousands of switches that are sometimes miles apart.

A *hand-operated switch* located in an accessible position on the transformer or regulator pole or adjacent to a sign or show window is the least expensive scheme. The installed cost may be as low as $10 per switch. However, the immediate attendance of an air-raid warden or other designated person is required.

An obviously preferable blackout method would be to centralize the control of all outdoor lighting circuits. One of the most effective schemes is to run a *pilot circuit* from each disconnect switch or circuit breaker to a central switchboard. Unfortunately, this requires literally miles of copper wire, now essential for other purposes.

It would be possible to adapt to street-light control some of the *supervisory control* schemes, such as Visicode, which have been developed for controlling and supervising power apparatus at a distance. Direct-current or carrier impulses are transmitted over a single channel to operate circuit-controlling relays. However, this scheme is better suited to controlling a number of functions at a few points than for a single function at many scattered points. The initial cost of this system makes it impractical at present for the sole function of controlling the lighting.

Lights could be turned off by a *radio receiver* tuned to a carrier wave of a local broadcast station. Uncontrolled carrier impulses and static may impair the correct functioning of this device. The cost is not excessive.

A special shockproof relay developed some time ago for the remote control of outdoor circuits offers considerable promise as a means of removing a circuit from time-clock control. The circuit can be opened from the substation by momentarily opening the feeder circuit breaker. Loss of relay-coil voltage allows the contacts to open and remain open even on resumption of voltage. All equipment powered by this feeder is subject to a momentary loss of power. Each relay must be reclosed manually by an air-raid warden at the conclusion of the raid. Such a ten-ampere relay can be installed complete for approximately $20.

An *impulse-operated oil switch* can be used to control a street-lighting circuit or a large sign. When connected between the main feeder and the normal circuit switch, it provides complete control from the substation, yet does not interfere with normal operation of the circuit. A three-second interruption of the feeder will either open or close the contacts of the oil switch. This eliminates the need for manually reclosing each switch, but does interrupt all equipment connected to the feeder for three seconds. The installed cost is approximately $150 per circuit.

Many other schemes, such as cascading circuits, photoelectric cells, radios tuned to sirens, etc., may be considered. Each is subject to certain limitations of cost, material, and dependability. Regardless of the scheme, until the War Department or the local Office of Civilian Defense issues definite orders, it is undesirable to purchase or install blackout control equipment. However, it is not too early to *plan*.

—*C. S. Woodside*

Lightning Protection of Domestic Watthour Meters

Domestic watthour meters can be protected against lightning damage by means of a small, easily installed arrester. Not every watthour meter must be protected; in fact, this "ounce of prevention" is necessary only in a few isolated cases, in localities where the exposure of the primary and secondary circuits of the power supply to lightning is greater than usual.

A. M. OPSAHL

Switchgear Engineer, Westinghouse Electric & Manufacturing Company

ENGINEERS realize the futility of preventing lightning. They therefore try to prevent the stroke from damaging electrical equipment. Their success in this effort is well known — damage to equipment on primary transmission lines is rare. However, in some distribution systems, particularly where the secondary lines are long, the insulation of low-voltage domestic watthour meters can be damaged by lightning. Watthour meters are relatively inexpensive, and it may be more economical to repair a few meters than to install a protective device in every residence. In some locations, however, the number of lightning strokes and the percentage of failures of unprotected meters is high enough to warrant the protection of each meter by a lightning arrester to avoid meter repairs and loss of service.

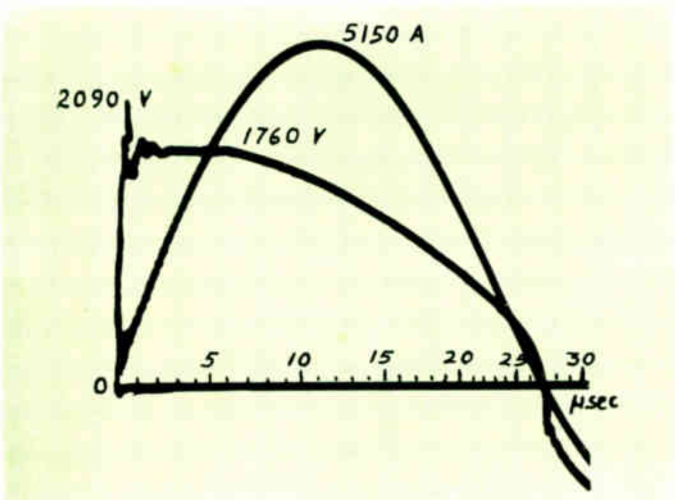


Fig. 1—*Oscillogram of lightning-arrester discharge.*

Surges in 120- or 240-volt services originate in two places—the primary or the secondary circuits of the system. When lightning strikes a high-tension wire the resultant disturbance can be transmitted to the secondary circuit through the transformer. The surge may also originate in the secondary circuits, either by a direct stroke, or by induction from a stroke to a neighboring line. The probability of damage is low, except in the case of long unshielded service wires. But, regardless of the frequency of occurrence of hazardous surges, a meter will fail if the resulting voltage exceeds the dielectric strength of its insulation.

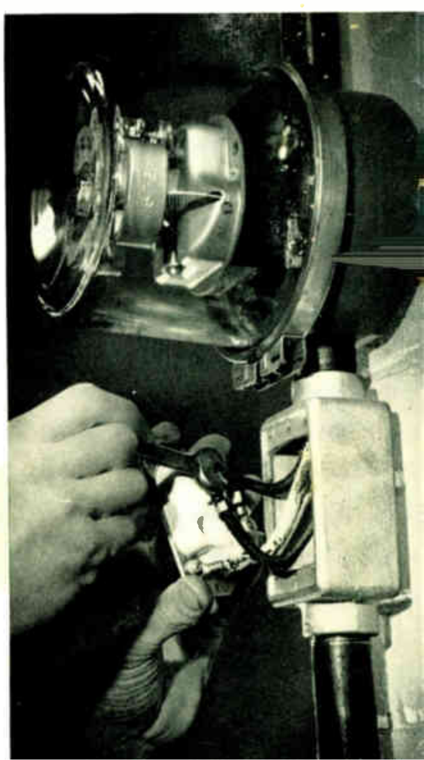
The circuits beyond the watthour meters contain many spots of low insulation strength, such as switches, lamp sockets, or outlets. These will flash over at relatively low voltages, but the discharge does not necessarily cause failure because the power arc seldom continues beyond a half cycle at 120 volts. The watthour meter, however, is vulnerable. A spark and a half cycle of arcing terminating on the small wire of the potential coil can damage it. Furthermore, the meter is always energized, and is always the closest to the overhead lines. Therefore lightning protection can be economical in some areas.

A lightning arrester with low impulse breakdown and discharge voltage installed close to the meter from lines to the ground frame will prevent meter damage, except perhaps in the case of severe direct strokes to the service wires.

A new lightning arrester designed for this service has two poles in a porcelain case mounted on a plate that fits most condulet boxes. Each pole of the arrester consists of an air gap between brass electrodes in series with a conventional autovalve silicon-carbide discharge block. As shown in Fig. 1, the arrester does two things. It limits the surge voltage to a safe amount, about 2000 volts (ordinarily a domestic watthour meter can withstand a 5000-volt surge). Also, after the surge has passed, the arrester limits the 120-volt power-follow current to almost zero.

The neutral wire of the secondary service is grounded at or close to the meter and tied to the meter frame. This is convenient for the installation of an arrester. By connecting it directly between phase and neutral wires and locating it close to the meter, the potentials across the meter insulation are limited and also a direct connection to ground is provided. No separate ground for the arrester is necessary. In fact, a separate ground would be less effective than grounding it to the neutral, because the voltage between meter leads and the meter could become higher than the arrester characteristics and result in damage.

By providing close coupling between the neutral and line wires, the lightning arrester protects adequately all equipment beyond the meter.



The lightning arrester fits into a standard condulet. The leads from the meter terminals to the protector need be only a few inches long.

Electric Dynamometers for Engine Testing

From a relatively prosaic place in college engineering and automobile laboratories, electric dynamometers have skyrocketed to positions of national importance. Almost overnight they have grown from one of two hundred horsepower to 4000, with twice that just around the corner. The cradled dynamometer, the eddy-current brake, and the two in combination are playing an important part in the development of better, more powerful aircraft.

R. H. WRIGHT

Industry Engineer,
Westinghouse Electric & Manufacturing Company

Each step in the development of an advanced aircraft or automobile engine must be proved by hours of operation under load. The complete characteristics of the final engine must be determined beyond question under all operating conditions. For the accurate determination of engine performance at all speeds and loads nothing is as satisfactory as the electric dynamometer.

All dynamometers, of whatever type, have as their primary purpose, the measurement of force. In the case of rotating machines, as gasoline engines, their function is to provide data for the determination of turning effort or torque. This rotational effort is measured on an ordinary weight scale as force in pounds at some distance or lever arm from the center of rotation. This force multiplied by lever arm and by the speed of rotation gives accurately the work done by the machine.

Mechanical Brakes

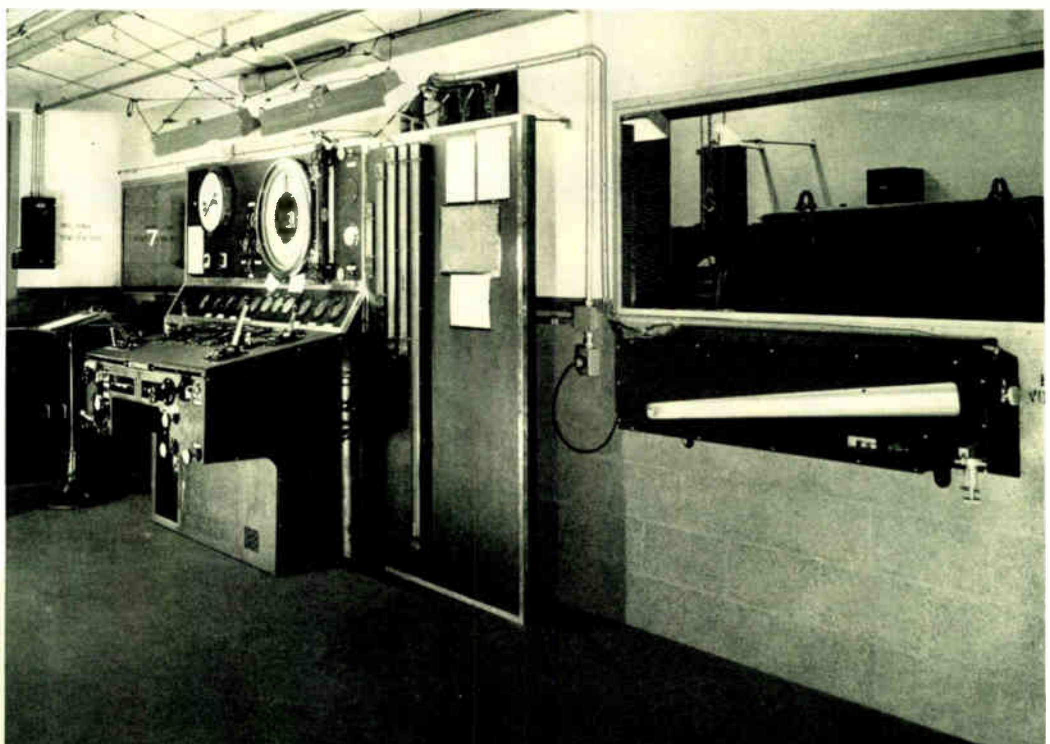
The Prony brake has been the classic example of a dynamometer for many years. It consists of an adjustable friction brake on the shaft of the machine being tested. To the brake is attached an arm resting on a scale so that the tendency for the arm to turn is measured in pounds. With it the output torque of an engine or motor can be determined in a fairly satisfactory manner. The principal difficulties of the brake are twofold. Because the friction varies with wear of the shoe or lining and with heat, the loading applied by the brake to the engine is not constant. This may make difficult the accurate determination of engine performance. Also, means must be provided for dissipating the heat developed within the brake, which may be considerable.

To overcome some of the inherent defects of the Prony brake, water brakes were developed. They have the same operating characteristics as the Prony brake. Although they provide a better means of dissipating heat than the friction brake, they are not suitable for the exacting demands of the modern engine laboratory.

The Cradled Dynamometer

The electric dynamometer is more versatile because in addition to making possible the determination of engine torque, it solves three other problems of engine testing. It provides a convenient means of applying any desired constant load, acts as an engine starter, and drives the engine for light-load and special tests. Also the efficiency and other characteristics of a power-transmission device, such as a gear or fluid drive, can be determined by the use of two electric dynamometers, one to measure power input, the other power output.

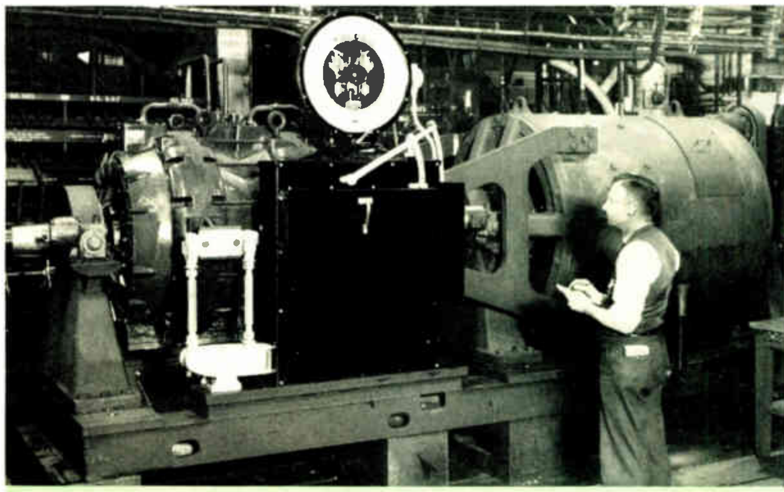
The cradled-type dynamometer is now the most common form. Electrically the dynamometer is a motor or generator of conventional design. Mechanically it differs from an ordinary generator only in that the stator instead of being fixed to the foundations is supported in bearings so that it can



Shown through the window is a combination dynamometer consisting of a 2000-hp eddy-current brake, cradled with a 700-hp d-c machine. All meters and controls mounted on a central benchboard.

turn through a small arc. When the rotor turns in any energized electrical machine, the stator attempts to turn with it as a result of interlocking of the magnetic fields. In the dynamometer, turning is restrained by a lever arm that bears on a scale so that the force with which the stator tries to turn is measured. The scale readings are not affected by electrical losses in the dynamometer and are affected only minutely by its mechanical losses (friction and windage). Therefore the torques measured by a dynamometer are, within fine limits, the net torques delivered to or exerted by the dynamometer.

The scale linkage is arranged so that the scale reads the reaction on the stator with the dynamometer acting either as a generator or motor, that is, either absorbing energy from the engine or delivering energy to it. Attachments for reading speed are often incorporated in the dynamometer to make it easy to calculate horsepower. Other accessories are a cradle-locking device and a checking knife edge or checking frame for calibrating the scales.


This combination dynamometer for high-power Pratt & Whitney aircraft engines has a total absorption capacity of 4000 hp.

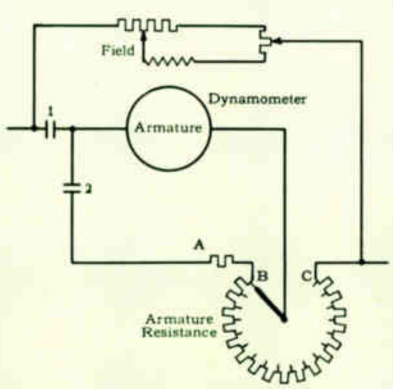


Fig. 1—*Fundamental diagram of the electric dynamometer.*

The control scheme shown includes a main potentiometer rheostat and vernier for the field, and an adjustable armature resistance designed for continuous duty. The armature resistance shown in the diagram can be adjusted either directly, by hand, or remotely, through contactors and a master drum switch. For engine tests it is common practice to use the dynamometer for starting. A normal start is made with little or no field current and with the armature connected to the resistance at point *B*. Line contactor 1 and armature shunting contactor 2 are both closed to form a potentiometer circuit. The field is gradually strengthened until the armature starts to rotate. By adjusting both the armature and field resistance, very fine speed control at low speed and light load can be obtained with this connection.

When heavy starting torque is required, the dynamometer is started with full field and with contactor 2 open and contactor 1 closed. After the engine begins to fire, there are two ways of loading it. If the dynamometer output voltage is less than that of the supply line, the dynamometer is loaded with the adjustable armature resistance by closing contactor 2 and opening contactor 1. This connection is used at low engine speed or when the engine speed is high but the torque is low; in either case only part of the absorption capacity of the dynamometer is used. For heavier loads the output of the dynamometer can also be absorbed by the armature resistor or it can be fed back into the d-c line. For feed-back loading, contactor 2 is open, contactor 1 is closed, and the armature connected to point *C*.

If the dynamometer is used primarily as a generator and the speed range is moderate, the armature resistance can be used only for starting and all loading can be done by feeding back into the d-c line. For such installations it is necessary to have ample generator capacity in the d-c system. For precision work on a constant-voltage feed-back system it is necessary to regulate the d-c bus voltage within close limits.

The manner of supporting the stator is important, as it may adversely affect the results. The armature and shaft are supported in two bracket bearings attached to the stator. The brackets and stator in turn are supported in two anti-friction trunnion ball bearings so that the stator can rotate within the limits of its mechanical stops. The trunnion bearings support the entire weight of both rotor and stator and normally move only when the lever arm changes position. The maximum angular movement is only a few degrees. Under this condition the bearing race tends to wear in one spot. This wear increases static friction and causes loss of accuracy. To overcome this tendency, means for rotating the trunnion bearings are sometimes provided. These mechanisms can be operated either by a motor or manually by a handwheel. Dynamometers of 150 hp or smaller usually have manually operated rotators. By giving the handwheels an occasional turn the bearing races are moved to a new position and wear is equalized.

Dynamometers with motor-driven rotators, which turn the bearings continuously at low speed, are more accurate because the running friction is less than static friction. The two trunnion bearings are rotated in opposite directions so as to counterbalance the effect of bearing drag. Most large dynamometers used for laboratory tests on aircraft engines are equipped with motor-driven rotators.

Modern engine testing requires that the dynamometer frequently act as a motor to drive the engine instead of absorbing power from it. For example, the engine is cranked by the dynamometer for starting. Some tests must be made on engines running idle, not firing. Aircraft engines have grown so large that their accessories, such as superchargers, consume sizeable amounts of power and must be independently tested. For all of these duties the dynamometer draws power from some supply line.

Nearly all cradled dynamometers can be made to operate either on direct or alternating current, but for general-purpose work they are made for direct current. However, when large amounts of power are required at high speed, say above 2000 rpm, it may be desirable to use an a-c machine instead to avoid problems of collection of heavy current on commutators of high peripheral speed. An a-c dynamometer can consist of a squirrel-cage motor connected to a variable-frequency motor-generator set, in turn connected to a d-c system or, if only a-c power is available, a variable-voltage motor-generator set.

Direct-current cradled dynamometers can be operated either from a constant-voltage source or from separate variable-voltage generators. Until recently most dynamometers in industrial plants were used for laboratory tests on automobile engines. The capacity of the individual units was relatively small, seldom over 200 hp. Most laboratories of this class use a constant-voltage system supplied by generators having capacity only to enable the dynamometers to start the engines or to supply a few dynamometers making idling tests. During load tests the power absorbed by the dynamometers is dissipated in resistance, by the scheme shown in Fig. 1.

For larger engines the absorption of large amounts of power by the dynamometer, if spent in resistance, requires large resistance banks and entails a considerable waste of energy. It is now common practice to feed this power back into the plant d-c system. The means for doing this is also indicated in Fig. 1.

When large amounts of motoring energy are required of the dynamometer, or when the dynamometer is motoring over a wide speed range, it is best to use a separate variable-voltage generator for each dynamometer. As shown in Fig. 2, the control can be arranged so that each field circuit has a separate exciter. The speed is then controlled by small rheostats that carry only the small field currents of the exciters. These rheostats are sometimes combined for operation by a single handwheel. Complete control of starting, motoring, or loading is thus obtained from a compact master control station. Loading is entirely regenerative and the change from motoring to regenerative loading is accomplished without any change in connections.

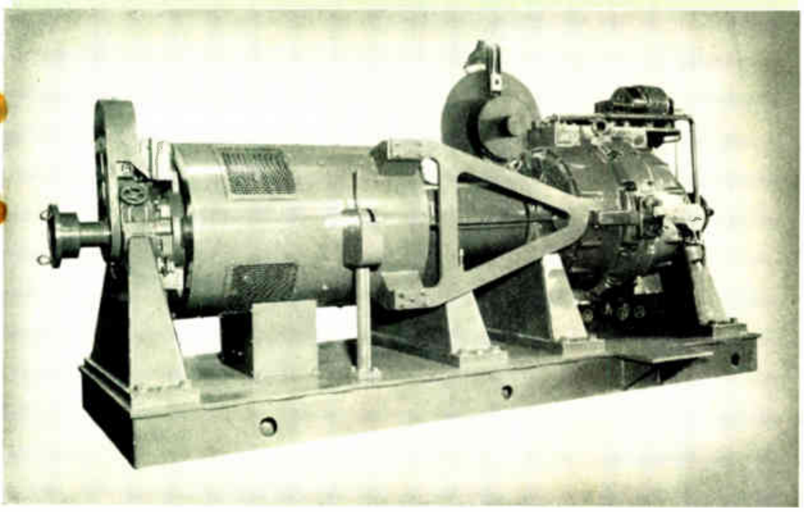
The Eddy-Current Brake

A recent development in dynamometers is the eddy-current absorption brake. It serves the same purpose as a Prony brake or water brake, that is, it absorbs energy from an external rotating source, and the reaction of its stator is measured to determine engine torque just as with the cradled dynamometer. The most common form of eddy-current brake is shown schematically in Fig. 3. The construction is quite similar to that of a high-frequency inductor alternator except that the stator has no teeth and no winding for collecting current. The rotor is made of steel and has teeth in its periphery. A circular field coil in the stator, excited from a d-c source, provides a magnetic flux that follows the paths indicated by arrows. Rotation of the rotor in this field produces eddy-current losses in the stator that resist rotation and provide a load for the external driving machine. Water is circulated through the stator to carry off the heat produced by the losses. The stator is cradled and the torque is measured in the conventional way.

When an eddy-current absorption dynamometer is used for loading large aircraft engines, it is usually necessary to have an electrical stabilizing device. A common means of obtaining stability is to have a belted exciter supply a separate field winding. The stabilizing exciter is self excited and compound wound so that the armature voltage varies approximately as the square of the speed. By this means any tendency for the engine speed to rise is checked by the increased braking torque of the dynamometer and hunting is reduced to a minimum.

Eddy-current brakes can be built for higher speeds in small capacities and can be made for a greater speed range at high capacities than any other form of electric dynamometer. The load setting is adjusted by regulating the excitation. The losses, of course, cannot be recovered except as heat in the cooling water. Also, the eddy-current brake cannot deliver power to the engine, either for starting or for idling tests, and a separate motor is required for cranking the engine. Originally developed for loading large aircraft engines, its use has now been extended to many

Rear view of the combination dynamometer shows how the eddy-current brake is fastened to the d-c machine to form one unit.



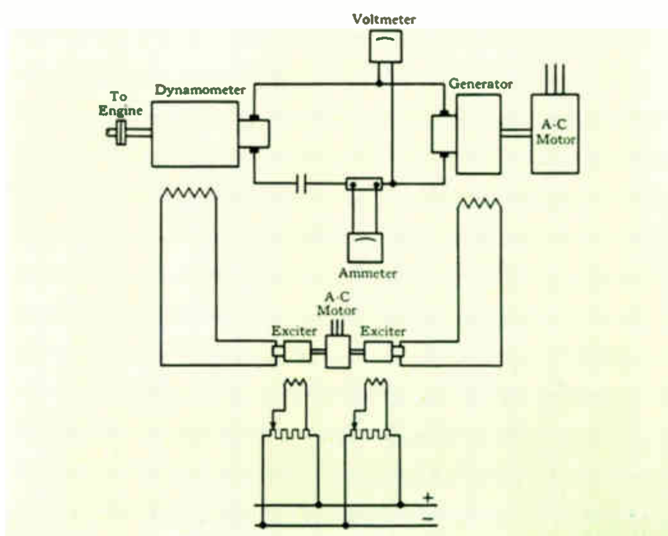


Fig. 2—*Instead of controlling the large field currents of the generator and in the dynamometer with rheostats, each field is supplied from a separate exciter, in which the voltage is adjustable with a small resistor.*

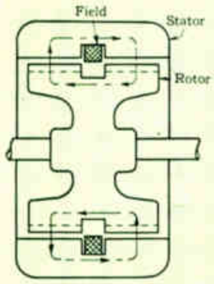


Fig. 3—Currents induced in the rotor of the eddy-current brake interact with the magnetic field produced by the stator field, and result in opposing torque that can be used to load large engines.

other fields where the tests call for only a power-absorption device, not a supply of power.

Combination Dynamometers

To make a complete laboratory test of a large aircraft engine it is necessary to have a dynamometer with motor capacity sufficient to overcome the idle friction of the engine and with absorption capacity to take its full-load power. The cost of a full-capacity d-c dynamometer is prohibitive. For such service it is customary to use a combination dynamometer consisting of a d-c machine and an eddy-current brake. Variable-voltage control is used for the d-c unit. The stator frames of both units are mechanically connected so that the combined reaction is measured without loss through one lever arm. The d-c unit, in addition to providing the necessary motoring effort, assists in holding the speed constant. A slight rise in speed will cause the d-c machine to pick up a relatively large increase in load. A slight drop in engine speed will cause the d-c machine to drop a large part of its load or even to motor. This characteristic helps stabilize the speed.

Chassis-Type Dynamometers

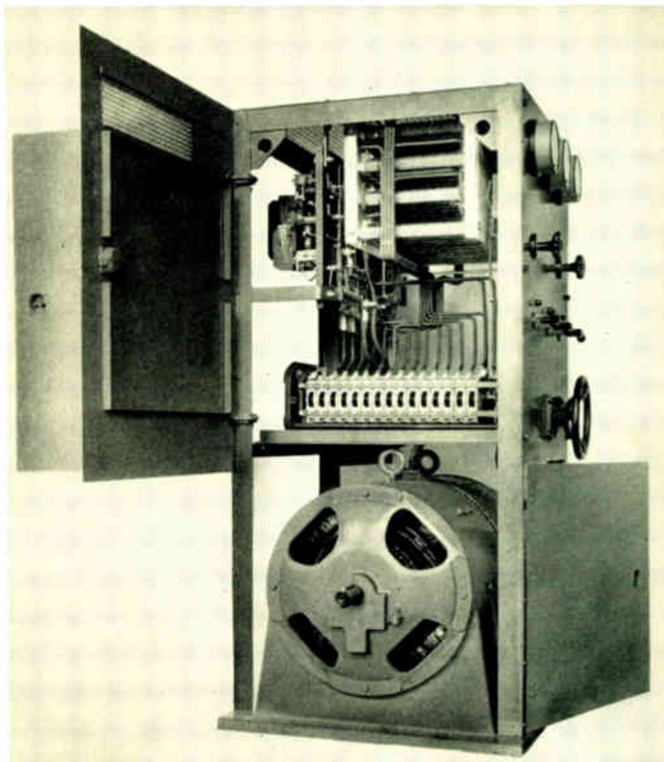
So-called chassis-type dynamometers are used to check the overall performance of automobiles and trucks. Such machines can be either stationary or mobile. A stationary installation consists of a slow-speed cradled dynamometer coupled directly to a shaft that carries two pulleys about 48 inches in diameter. The rear wheels of the car or truck rest on the pulleys and drive the dynamometer by friction. With this type of dynamometer, it is possible to measure the friction from engine to the rear wheels and determine the net horsepower available at the wheels. A complete laboratory installation may include a small wind tunnel to simulate actual road conditions. Both the dynamometer and the wind-tunnel fan are remotely controlled by an operator at a desk in an enclosed pulpit.

Stationary Dynamometers

In addition to the problem of development testing there is the fast-growing one of production testing. Assembled engines are tested to make sure that they will perform satisfactorily when placed in regular operation. In all these tests dynamometers serve to load the engines and to measure the output.

The stationary dynamometer, although not a true dynamometer, is so commonly used that it deserves mention. Stationary dynamometers are used in large numbers for routine production tests of automobile, truck, and tractor engines. It is not unusual to have from twenty to one hundred units in one installation.

A stationary dynamometer is really only a standard adjustable-speed direct-current machine, which serves either as a motor or a generator. As an engine comes from the assembly line it is connected to a dynamometer and driven idle to wear in the bearings and piston rings. Then it is allowed to fire and the engine drives the dynamometer as a generator. The energy thus generated is fed into the direct-current bus, which supplies the production test department. The frame is not cradled, and hence there is no way to measure torque mechanically. However, the electrical output is measurable and the losses of the generator are known to close limits from factory test runs. The sum of the two gives the engine output. This method of engine testing, while not as accurate as by the true dynamometer, is, in general, satisfactory for production testing. The control is a modification of the constant-voltage control previously described, with a separate motor-generator set usually serving a group of production units. It is designed to be as compact and as light as possible, so that it can be mounted near or on the dynamometer itself. A standard ammeter or an ammeter calibrated in horsepower gives a sufficiently accurate indication of load for most installations.



A stationary dynamometer such as this, complete with control, is used for routine testing of truck and tractor engines.

Knowing that the quality of any product is governed by the tools used for its manufacture, it is easy to appreciate the importance of dynamometers, particularly in modern warfare, when the quality and quantity of high-powered engines, whether in airplanes, transport trucks, or torpedo boats, may spell the difference between defeat and victory.

Air-Core Couplers Simplify Differential Protection

The ancient proverb, "if the hand offends, cut it off," has been followed in bus-differential protective schemes. Iron has been banished as the core material for current transformers, thereby eliminating the troublesome magnetic saturation. The resulting device is an air-core linear coupler that helps produce a differential response that is an accurate measure of the fault current, regardless of the point of the voltage cycle at which it occurs and the magnitude of the d-c transient component.

E. L. HARDER

Central-Station Engineer, Westinghouse Electric & Manufacturing Company

THE most troublesome obstacle to simplification of high-speed bus-differential protection has been saturation of the current transformers used to energize the protective relays. This saturation is usually caused by the d-c component that may flow in the transformer during the first few cycles of a fault. Its effect is to reduce the "transforming" ability of the current transformer; the secondary winding no longer faithfully reproduces the primary current. Inasmuch as the current transformer carrying the largest current suffers the greatest error, a large false differential current flows in the relay. This necessitates the use of one of various restraint schemes or of some time delay or both to avoid undesirable operation.* Even though modern relays can operate in a cycle or less, it is necessary to slow their operation so as to allow the differential circuit to recover from the errors caused by saturation of the core. Thus saturation is one of the major obstacles to high-speed fault clearing.

Linear Couplers Cannot Saturate

Linear couplers, bus-differential transformers developed as a simpler solution to this problem of saturation, eliminate this trouble by replacing the iron—which saturates—by air, which does not. However, the mere use of an air-cored transformer in a bus-differential system will not make it operative. What makes linear couplers suited for bus protection is the successful solution of several other problems. Linear couplers have been perfected so that they are accurate, have a sufficient energy output to operate a practical relay, and are relatively free from the effects of external fields and of transients. An important factor in the success of the method is the use of a series differential circuit, which is impractical with conventional current transformers. The result of these developments is a simple and fast protective scheme that eliminates the troublesome problem of saturation and always gives a linear relation between the primary current and the voltage response in the secondary. This response is almost independent of the d-c transient component of the primary current and its performance can thus be calculated accurately and simply. Many tests have verified that a preliminary check of a bus-differential protective scheme, made with low steady-state currents, is sufficient to predict its operation at the largest fully offset fault current estimated for the system.

Toroidal Winding Is Best

The linear coupler is simply an air-core mutual inductance connected directly in the primary circuit and having induced in its secondary a voltage proportional to the primary current (in couplers built at present 5 secondary volts are induced by each 1000 primary amperes).

To be suitable for reliable and sensitive bus-differential protection, it is obvious that a linear coupler must have the following three properties:

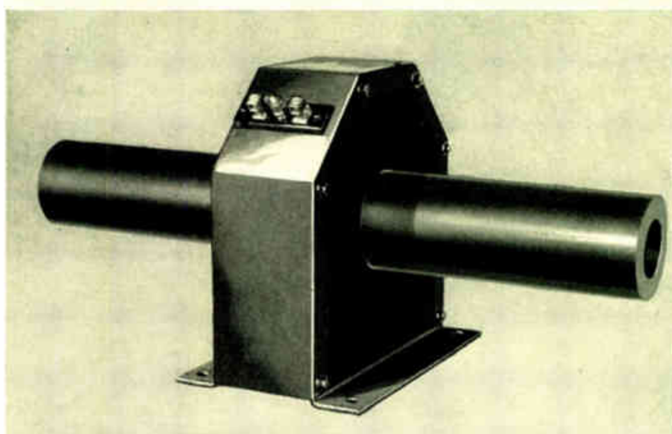
a—The mutual coupling between the primary and secondary must be the same for all couplers so that an identical secondary voltage is always induced by a given primary current.

b—Currents in external neighboring circuits or in the return conductors must have negligible effects on the secondary voltage.

c—The secondary power output must be sufficient for positive operation of the relay.

The last requirement is fulfilled by efficient design of the coupler and relay and by matching the relay impedance to that of the coupler circuit. The first two requirements are best met by winding the secondary coil uniformly around a toroidal (doughnut-shaped) form, similarly to a bushing-type current transformer. Theoretically, voltage can be induced in such a winding only if the current-carrying conductor passes through the center hole of the toroid (doughnut), and it doesn't matter whether the primary lead is in the exact center of the hole or not. This is readily explained in Figs. 1 and 2. In practice, however, some deviation from roundness and uniform winding is inevitable.

Outwardly, the linear coupler looks like a current transformer. The primary lead passes through the central Micarta tube.



*"What Makes Bus-Differential Protection Intricate?," *Westinghouse ENGINEER*, February, 1942, page 28.

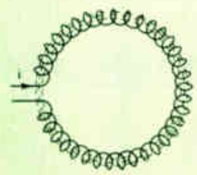


Figure 1

Total flux produced by a current i flowing in a toroidal coil is always confined inside the winding.

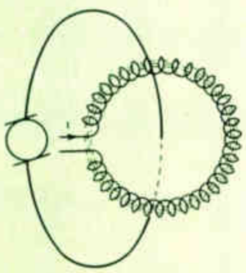


Figure 2

Total flux inside the toroidal coil due to current i links the primary loop. The linkage is constant regardless of relative position of coil and loop, as long as the loop links with the coil. Any external circuit not linked with the coil does not link with the flux, and therefore has no voltage induced in it. Conversely (by the law of reciprocity of mutuals) current in the primary does not induce a voltage in the secondary unless it links with it. If the primary links the secondary, the voltage is independent of the concentricity of the circuits.

Nevertheless, a reasonable approach to an ideal toroid is practicable, and the mutual inductance can be held within ±1.5 per cent. This includes not only the effect of conductor eccentricity and of external fields, mentioned above, but also manufacturing tolerances and variations in testing. Temperature has no measurable effect on the accuracy of the mutual inductance, and of course there is no saturation. In manufacture, linear couplers are balanced against a standard mutual inductance and adjusted within the allowable manufacturing tolerance by using the proper secondary tap or by varying the final number of turns in the secondary winding of the coupler.

Differential Protection with Linear Couplers

The linear-coupler scheme for bus-differential protection appears, at first glance, to be similar to the conventional method employing current transformers. The principle of differential protection is, of course, identical. However, application of the principle differs in the two schemes, even though the devices used are similar in outward appearance, and the circuit diagrams are somewhat alike, as can be seen from Figs. 3 and 4.

The secondary of a current transformer delivers *current* proportional to that flowing in the primary. To form a differential circuit—that is, to get cancellation of the secondary outputs for normal load and through-fault conditions—it is necessary to parallel all the secondary windings. On the other hand, it is the secondary *voltage* of the linear coupler that is proportional to the primary current. Differential protection is therefore obtained by connecting all the secondaries, and the differential relay, in series so that the voltages corresponding to the incoming currents oppose those for the outgoing ones, as shown in Fig. 3. As long as the current entering the bus equals that leaving, the vector sum of all the induced voltages is zero, and the relay does not operate. When there is an internal fault, the voltage differential is proportional to the magnitude of the fault, and the current flowing through the relay is equal to this induced voltage divided by the total impedance of the loop comprising the relay and all the linear couplers employed for the particular scheme.

Only Simple Relay Required

The design of a suitable relay for this scheme involves attention to several important points. Because the energy output of the linear couplers is small compared with that of current transformers, the relay used must be of low energy consumption. However, energy consumption is not necessarily an indication of the reliability of operation. While the energy used in the relay is small, it should not be construed that relay operation is impaired. Actually, the energy used by the most sensitive relay for the linear-coupler scheme is some 4000 times that drawn by a standard d-c relay (Westinghouse type D-2) that has been used successfully, for many purposes, for almost 20 years, and has proved itself thoroughly reliable.

It is well known that maximum power can be drawn from a supply circuit if the impedance of the burden is matched (made equal) to that of the source. Because the number of

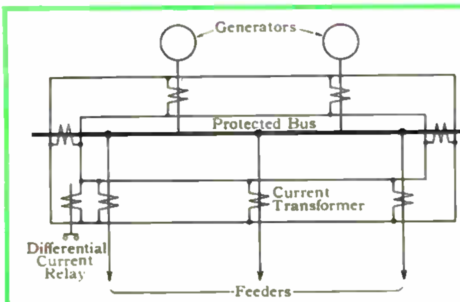


Fig. 3—Current transformers are paralleled in the conventional bus-differential scheme.

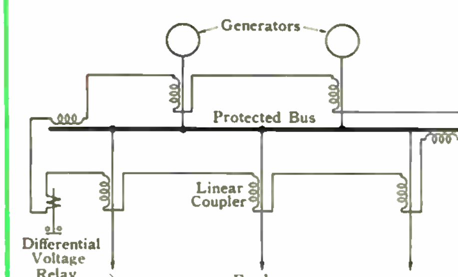


Fig. 4—Air-core linear couplers are connected in series.

linear couplers depends on the number of circuits connected to the protected bus, their total impedance varies, and the relay must be adjustable in impedance to match it. This is readily accomplished by taps in the relay.

If both phase and ground relays are used in a bus-differential linear-coupler scheme, the setting required on the ground relay is usually much lower than that on the phase relays. In order to get the maximum energy into the ground relay, the phase relays should not be matched with the coupler circuit but should have low impedance relative to the coupler loop. This permits matching the ground relay with an impedance that is only slightly higher than the combined impedance of the three coupler loops in parallel.

Two types of relays meeting the above requirements were used in the laboratory tests of the linear-coupler scheme. One is a conventional plunger-type relay capable of operating down to about 1500 amperes internal fault current in a six-circuit bus. The other is a polarized-type relay of even greater sensitivity, operating on a 500-ampere fault. The polarized relay operates on direct current from a built-in rectifier. Exhaustive tests proved both relays adequate for the job.

Limitations, Advantages, Possibilities

The application limits of a bus-differential scheme can be conveniently expressed as a ratio of the maximum through fault current to the minimum internal fault current, for which it can be safely used. Theoretically there should be no differential current or voltage when the fault occurs outside the protected bus. Actually, when the through fault is large the inequalities present would cause tripping unless the relay were given a sufficiently high differential current setting so that it can not operate on the false differential currents flowing under such conditions.

As mentioned earlier, linear couplers are manufactured at present to commercial tolerance of ±1.5 per cent. Using such couplers, the maximum possible false differential current is 3 per cent. Hence if the relay setting is not under 6 per cent of the maximum through fault, a 2:1 safety factor is assured for the worst possible conditions. Such conditions are unlikely to prevail on an actual system. It would be necessary for the linear coupler on all incoming circuits to have a maximum possible plus error, and for the linear coupler on the faulted circuit to have the maximum possible minus error, or vice versa.

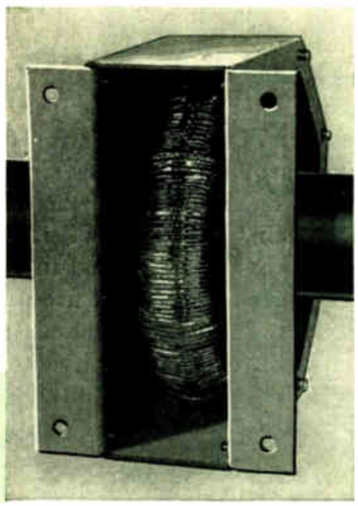
The 6 per cent setting corresponds to a 17:1 ratio of maximum through fault to minimum internal fault (for which relay operation is expected). Thus couplers of ±1.5 per cent accuracy are applicable safely on a system having a fault-current ratio of as large as 17:1 or requiring a relay setting not less than 6 per cent of the maximum calculated through fault.

The lower limit of 6 per cent on relay setting makes the present form of the linear-coupler scheme suitable for buses on low-impedance-grounded systems—about one-half of the buses in the country. Systems grounded solidly or through low impedance usually have fault ratios lower than 15:1, while high-impedance grounding sometimes involves ratios over 100:1. Using current transformers with the best differential relays available, it is possible to obtain correct relay operation for fault ratios over 100:1. This requires a variable-percentage relay with restraint elements. At present, the major limitation to the application of linear couplers is that they can be used only in systems with through-fault ratios less than 17:1.

The advantages of the linear-coupler scheme are many, the major ones being greater speed and accuracy. The relay closes within one cycle after the start of the internal fault. This high speed is made possible by the absence of saturation and by the freedom from the effects of the d-c transient component, because in the linear-coupler scheme it is unnecessary to delay operation of the relay while the current transformers become unsaturated. It is also possible to test the complete installation at steady-state conditions, knowing that correct operation is thereby assured for actual fault conditions. This is because of the absence of saturation and almost complete freedom from the effect of the d-c transient. While the d-c transient can cause the secondary current of a current transformer to become offset by as much as 100 per cent, in practical cases the maximum deviation from symmetry (known as "overshoot") that can be obtained in the secondary current flowing in a linear coupler is only about 5 per cent.

The inherent simplicity of the series circuit means that the connections are less complicated and that the continuity of the wiring can be readily supervised.

The linear-coupler scheme has been put through its paces in an elaborate series of high-power laboratory tests. Each of the essential characteristics has been critically checked and the relay has been found to operate in all cases as predicted by the simple calculations. The tests have included circuits with both short and long d-c time constants and have been made on coupler designs suitable for use in the bushings of circuit breakers as well as for separate mounting. As a result, this novel bus-differential scheme merits careful consideration for protection of buses that fall within its practical range of application, that is, where the ratio of the maximum through fault to the minimum internal fault is less than about 17:1, or where the relay setting is approximately 6 per cent.



The winding in a linear coupler is toroidal, or helically wound over a doughnut-like form.

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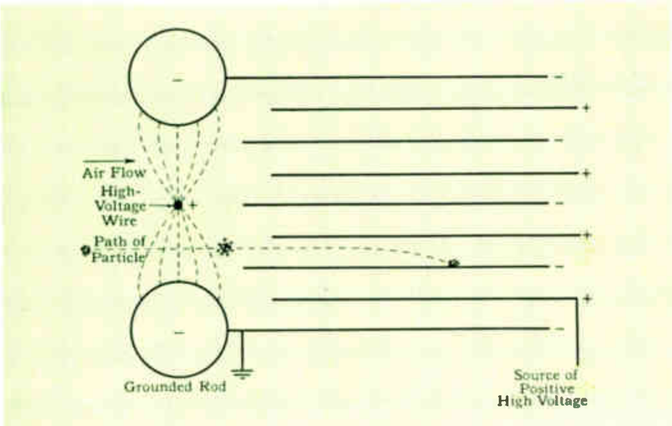
Trapping Dust Electrically

Dissatisfaction with air is growing. With electricity air is processed in many ways to suit man's convenience. Electricity cools it, sometimes heats it, controls its humidity, kills bacteria in it, and now rids it of dust. The electrical cleaner, by planting on each particle an ion, and moving it past a charged plate, draws dust from the air—for cleaner homes and factories, longer life for electrical machines, relief to hay-fever sufferers, and sterile blood plasma for emergencies.

To the two things in this world we cannot escape, death and taxes, can be added "dust." It is everywhere. Even the air over the ocean contains several hundred dust particles per cubic inch—mostly salt. Counts of dust at 10 000 feet above the earth show the thin air to be dust laden—even including the hay-fever pollens. But the really serious dust is man made, and occurs in cities and industrial areas. Typical counts in large cities like New York and Chicago run from one to three million particles per cubic foot, or roughly five to fifteen times as much as in rural areas. In Pittsburgh, for example, a blanket of dust 1950 tons per square mile gradually settles each month throughout the heating season.

Dust is an essential part of the earth's mechanism; each rain drop requires a dust particle as a nucleus about which to form. But we are concerned with the reasons for removing dust from ventilating air. Of these there are many. The effect on the health of the individual has been difficult to ascertain, but certainly it is considerable. How could it be otherwise? Consider that in a day a person breathes about 34 pounds of air—over five times as much as the combined weight of food and water consumed daily. In breathing that much air the average city dweller takes into his lungs each week a teaspoonful of dirt.

There is some correlation between dusty air and deaths from lung disorders. In 1929, in Illinois, the death rate from pneumonia was 93 per 100 000. In the country and villages, only 63. Chicago itself, 99. The evils of rock dust, as silicosis, are well known. The hay-fever season brings to millions the effect of dust in a painful manner.



In the electric air cleaner a particle is positively charged so that in the collector it is drawn from the air by negatively charged plates.

Smoke, the greatest offender in dust, causes an enormous economic loss annually. Many attempts have been made to evaluate it in specific cases, the results giving only a hint as to the magnitude of the loss. Merchants in Pittsburgh have estimated one day's loss caused by smog—extra cleaning, soiled merchandise, etc.—as $40 000. Two comparable stores in Scranton, Pa., one in the smoky area, one outside, report a difference of $8000 annual operating costs traceable to air-borne dirt. St. Louis, before effecting its smoke abatement program, estimated its excess laundry bills, dry cleaning, painting, renewing of sheet-metal work, cleaning and renewing wall paper, curtains, extra artificial light, and loss to merchants, as nearly $20 000 000 yearly.

Considering the total magnitude of the problem, relatively little has been done about the cleaning of air used for ventilation. One reason, perhaps, is that we are dealing with the invisible. Dust particles don't make themselves felt except by their mass effect. Some dust particles are big enough to see, but for each visible one there are tens of thousands below the limits of visibility, i.e., below about 10 microns in diameter. (A micron is a thousandth of a millimeter or roughly one twenty-five thousandth of an inch.) The lower extent of their size is unknown because even with the ultra-microscope particles less than 0.001 micron cannot be counted with trustworthy results. It is in fact this tremendous range in size—ratios of the order of millions to one—that makes of air cleaning a difficult procedure. As shown in the table opposite, if dust particles were multiplied 25 000 times in size, the relative range in sizes of objects that air cleaners must handle extends from particles no larger than the diameter of a human hair to a ball over 300 feet in diameter, in which could be placed a 30-story building. Particles smaller than 0.3 micron, including cigarette smoke, never settle out by gravity alone. Except as they are removed by rain, air currents, etc., they remain permanently suspended particles, invisible to the eye but important to the health of man and to the size of his cleaning bill.

The Principle of Electrostatic Air Cleaning

If a floating dust particle is electrically charged by depositing on it a negative or positive ion, the particle will be attracted to a surface oppositely charged. This simple principle of electrical precipitation of dust was noticed by Hohlfield of Germany in 1824 as he watched the behavior of an electrical discharge on smoke. Nothing came of his observation until 1884 when Sir Oliver Lodge successfully applied the principle in a lead smelter. Electrical precipitation of dust did not become widely practical until 1906 when Dr. Cottrell, who had worked with Lodge, brought out the precipitator that bears his name.

In the Cottrell system alternating current is stepped up to between 50 000 and 100 000 volts and rectified by a rotating machine. The negative terminal of the rectifier is connected to a heavy wire between vertical metal plates spaced ten or twelve inches apart and of positive polarity. The concentration of voltage on the small surface of the wire causes a corona discharge around it. In other words, electrons leave the wire and start to drift toward the positive plate surfaces, following the electrostatic lines of flux and, by bombardment of the gas molecules, create ions. A dust particle arriving on this scene picks up ions and becomes negatively charged. It is now strongly attracted by the positive plates where it gives up its charge and remains on the plates by mechanical and electrostatic adhesion.

The Cottrell precipitator has been widely used to collect industrial dusts and to precipitate smoke from the chimneys of power plants and factories. It has not come into use for ventilating systems, largely because at the high voltages used ozone is produced in such quantities that the air becomes too toxic for human consumption. Also the power to maintain a continuous discharge in the wide spacings between wires and grounded plates necessary with the high voltages used requires bulky and expensive transforming and mechanical rectification equipment.

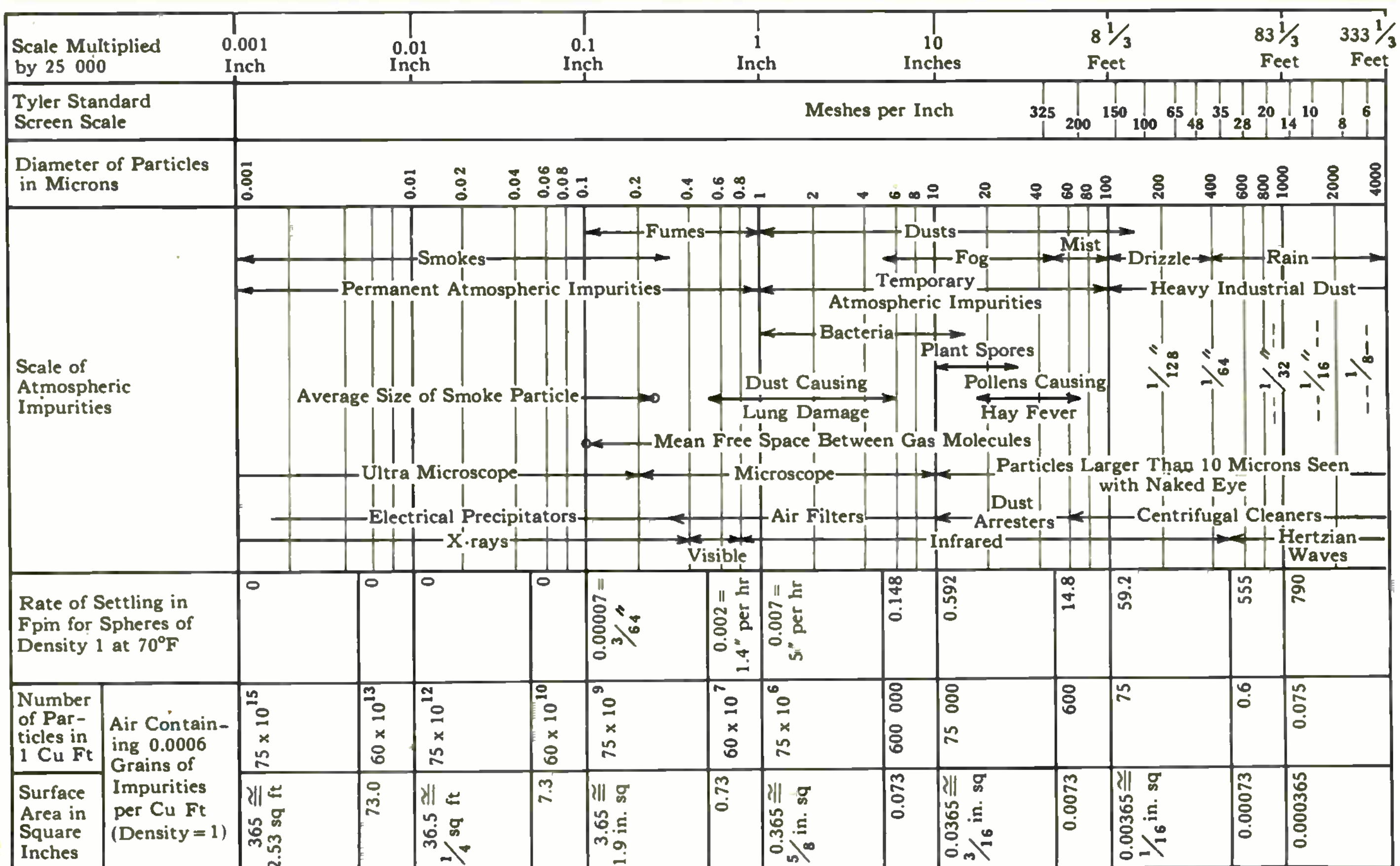
In 1937 a new type of electrical precipitator appeared, known as the Precipitron. Although the basic principle is the same as used in the Cottrell system, the Precipitron uses it differently. The Precipitron air cleaner is suited to ventilating systems.

In ventilating systems the amount of dust is small as compared to industrial dusts. Also corroding effects of the gases are virtually absent. Hence ruggedness, large-size wires, and wide plate spacings are not necessary for a cleaner of ventilating air. Smaller ionizing wire is extremely important because it permits a greatly reduced voltage and consequently closer spacings. The potential required for ionization is proportional to the diameter of the ionizing wire. The smaller the wire, the lower the d-c voltage needed to cause ionization and resulting charging of dust particles because the voltage stress is concentrated on a smaller surface.

The Precipitron uses a tungsten wire five mils in diameter, much smaller than the Cottrell ionizing wire. It requires an ionizing potential of about 12 000 volts, only one-fourth to one-tenth as much as in the Cottrell type. The lower voltage means smaller, less expensive equipment. Even more important, the amount of corona is such that virtually no ozone is formed.

Also contributing to extremely low ozone formation is the fact that in the Precipitron type of cleaner the ionizing wire is made positive instead of negative. This entails a slight sacrifice in ionizing efficiency but gains a large reduction—of the order of ten to one—in the production of ozone for a given voltage. With ionization by 12 000 volts

THE DUST SPECTRUM



Based, in part, on information from W. G. Frank and from *Chemical and Metallurgical Engineering*, Vol. 45, p. 133.

from a positive wire the ozone formed is only one part in a hundred million parts of air, or equivalent to that caused by sunlight in ordinary air.

In the Precipitron-type cleaner the dust-ionizing and dust-collection functions are separated. In the ionizing section ionizing wires are held between tubes oppositely charged. A dust particle as it passes between a wire and a tube is charged (in about 0.1 second) and is swept on into the collector section, which consists of parallel plates of opposite charge, 5000 volts to ground, as shown in Fig. 1. Here the strong field drives the charged particle out of its line of flight to the negative plate.

Separate ionization and collection are important. It is responsible in large measure for the great reduction in size and cost of the unit, making it economical for ventilating-air systems. These two functions of electrostatic air cleaning have different and somewhat conflicting requirements. A higher voltage is required for ionization than is needed for collection. Were the collection element insulated for the 12 000 volts found most satisfactory for ionization, the spacing of the plates would be more than doubled, greatly increasing the bulk. Furthermore, the charging process inherently requires a non-uniform field while for most efficient separation the field should be uniformly high. Separation of the ionizer and collector makes it possible to use the voltage and arrangement of parts best suited to each, with consequent minimum size.

The Precipitron-type electrostatic air cleaner is made in cell form, each 36 inches high by 8 inches wide, which includes an ionizing and a collecting chamber. Cells are stacked one on top of another and side by side as required to accommodate the amount of air circulated. Each cell has a rating of 600 cubic feet of air per minute for 90 per cent cleaning efficiency (by blackness test described on p. 50) or 750 cfm for 85 per cent efficiency. Energy is supplied by a power pack, which comprises a high-voltage transformer, vacuum-tube rectifier tubes, and capacitors to smooth out the pulsating d-c voltage.

One size of power pack can supply energy for twelve 36-inch cells. It has a total energy consumption of 110 watts when supplying its maximum load of twelve standard cells. A larger power pack can accommodate fifty cells, with a total energy consumption of power pack and cells of 380 watts, of which about one third is used in the power pack and two thirds by the cells. The power factor is about 75 or 80 per cent.

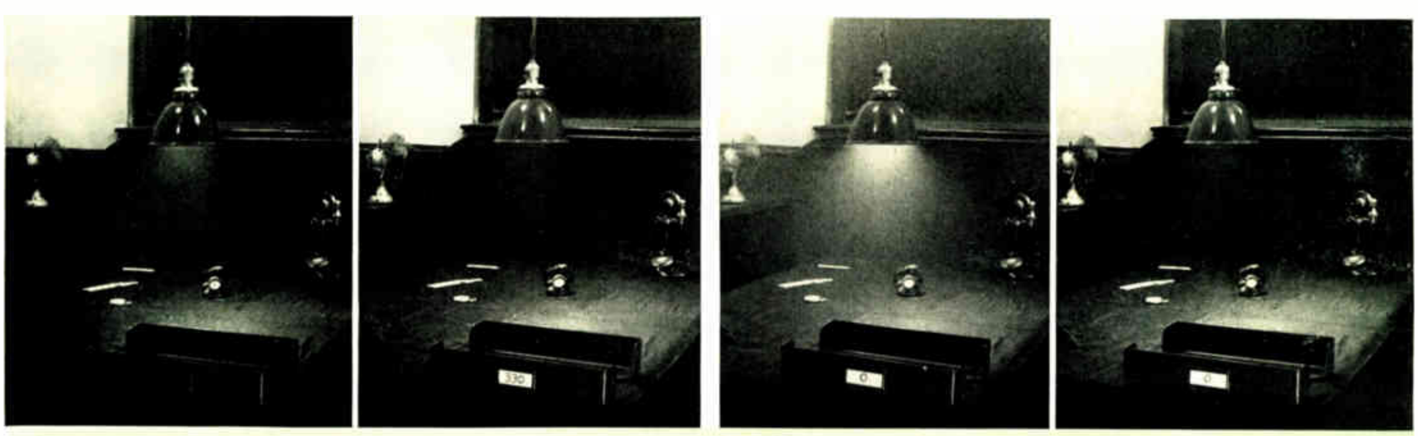
Advantages of Electrostatic Air Cleaning

Electrical precipitators show a great deal less partiality as to size of dust than do mechanical filters. With any type of filter the larger particles are more easily removed. However, the electrostatic precipitator has the widest range of all; particles from the smallest detectable with microscopes up to visible ones are removed by it.

The electrostatic air cleaner offers virtually no resistance to the air flow. The air path is wide and unrestricted. The air flows between parallel plates so no energy is lost in a multiplicity of changing directions. The pressure drop is almost immeasurable, so low in fact that to insure uniform distribution through many cells in parallel it is necessary to include artificial baffling. Even with resistance deliberately increased the pressure drop through a unit does not exceed 0.15 inch of water and varies only slightly with the dirt on the plates.

Electrostatic air cleaners require no replaceable elements (except vacuum tubes in the power pack, which have a rated life of 4000 hours, roughly six months). Ionizing wires usually last about two years unless the air is abnormally corrosive. The collector plates require periodic cleaning, which is usually accomplished by first washing down with a hose, drying, and re-oiling.

Electric air-cleaning units being assembled for removing dust from cooling air for steel-mill motors.



These views are from a laboratory experiment to determine the effectiveness of an electric cleaner in removing oil smoke—as in a machine shop. In each case oil smoke was created at a constant rate by dripping oil onto a hot plate. The pair of views at the left shows the amount of oil fog without and with the air cleaner for 330 cubic feet per minute fresh air intake; at the right, the same except with no fresh air intake.

Many Jobs for Electrical Air Cleaning

The first large-scale use of the Precipitron was for the removal of dust from the ventilating air of public buildings, such as offices, stores, restaurants. One of the first office buildings to use an electrostatic precipitator is the Field Building of Chicago. Seventeen groups of cells, cleaning 275 000 cubic feet of air per minute, were installed in 1937.

Retail establishments, such as jewelry stores, five-and-ten-cent stores, and department stores, are using the electric air cleaner largely because of the great waste incurred by soiled merchandise and because redecorating is needed less frequently. The interior of one store had been annually repainted at a cost of $4000. An electrostatic air cleaner was installed at a cost of $7000 and annual repainting became unnecessary. After four years the walls still have not been refinished and are still clean. One year ago a wall panel was removed for repairs and it was possible to repaint it from the original cans of paint with no noticeable difference from those adjacent to it.

Dust is as undesirable from the machinery as from the human point of view. Many manufacturing operations are so precise that even a microscopic film of dust impairs the product. Aircraft-engine factories are excellent examples. Many now electrically clean the air to rooms where the bearings are lapped and where the final inspection and assembly are done. In these large windowless factories, electrically filtering the air greatly reduces the fresh or make-up air required, with consequent reduction in the heating or cooling load.

Likewise in the grinding of optical glass atmospheric dust cannot be tolerated. The lens surfaces of the best binoculars, telescopes, and cameras must be true within a few wavelengths of light. A hard dust particle can ruin such a surface. Or a dust particle, too small to see, is magnified manyfold if trapped in an optical system, and may lead to visual error. For this reason laboratories where military optical systems are assembled or repaired are supplied with electrically cleaned air.

Heavy electrical machinery is also dust sensitive. Dirt, particularly electrically conducting dirt such as carbon dust from commutator brushes, is injurious to machine windings and may lead to premature failure. It decreases the ability of windings to dissipate heat. If the machines are in a dusty location it is necessary to stop the machines, open them, and remove the accumulated dirt. To reduce this maintenance expense and to lengthen the insulation life, electrostatic precipitators have been installed in the recirculating cooling-air ducts of some large synchronous condensers. Because of the large quantities of metallic dust about steel and aluminum mills, and because of the large numbers of heavy-current d-c machines present, many mills electrically clean the air for machine ventilation. In several such plants over 100 000 cubic feet of air per minute are thus cleaned, and in one large mill, a million.

The electrostatic air cleaner undoubtedly will have an important place in the ventilating system of the private home, although this use must be severely restricted until the termination of the war. Units specially adapted to installation in the ducts of forced-air heating and cooling systems have been installed. A representative unit is capable of cleaning 2250 cubic feet of air per minute, with a total power input of 80 watts. It is not unlikely that after the war room-type air conditioners will also include electrostatic air cleaning. Quite possibly domestic furnaces will have electric cleaners built into them.

The full extent of the elimination of dust on improvement of the health of the individual is not yet known. But there is ample sound medical evidence that the electrostatic air cleaner is able to remove air-borne pollen and brings relief to most hay-fever sufferers. Many hospitals use electric filtering in isolation rooms for hay-fever victims. Individuals with lighter cases have equipped their bedrooms with such a filter and find that by being able to sleep in pollen-free air they are either wholly or partially relieved of distress during their particular pollen season.*

Electrostatic air cleaning has still another function, the removal of bacteria and mold spores from the air. Some bacteria ride on dust particles through the air, others travel by themselves. In either case they are ionized and are removed from the air stream just as are dust particles. They are not killed in the process, but are held on the viscous surfaces of the collector plates for subsequent removal. A number of uses have already been made of this fact. Stores of blood plasma now so vital in wartime are dried in air made dust and bacteria free by electrostatic filters. Granulated sugar as it is being dried in low-humidity air for packaging makes an ideal bacteria culture bed, which has caused much loss, eliminated by bacteria-free air. Pharmaceutical houses package medical preparations in electrically filtered air.

Dust, whenever possible, should be prevented at its source. Much of this can be done, but there will always be a dust problem, the consequences of which on human comfort, convenience, and on machines we are increasingly aware. For the "cleanup" effort good tools are available. With well developed mechanical filters and the newer, more efficient electrical cleaners the air of ventilating systems can be rid of its burden of dust.

*The results of a survey of electrostatic air cleaning as it bears on hay fever is described in "Air Cleaning as an Aid in the Treatment of Hay Fever and Bronchial Asthma" by Drs. Criep and Green, *The Journal of Allergy*, Jan., 1936, p. 20.

MECHANICAL AIR FILTERS AND THEIR PERFORMANCE

Whereas all commercial electrical air filters have a single basic principle, among the many kinds of mechanical filters on the market at least four can be distinguished. They are (1) impingement, (2) straining, (3) inertia, (4) washing. The most common, especially in present-day domestic systems, is the *impingement filter*, which consists of a two-inch thick mat of fibers or shreds coated with oil or some other viscous substance. As the air works its way through the maze the dust particles strike the viscous surfaces and are trapped. Glass fiber, steel wool, animal hair, vegetable fiber, and cellulose batting are used as the filter material. Some impingement filters are meant to be thrown away after they are loaded with dirt. Others, more ruggedly constructed, can be washed, recoated, and used again.

The *straining type of filter* works on the principle of the household vacuum cleaner. Dust-laden air is forced through closely woven fabric, the dust particles being strained out. For domestic use cotton or cellulose wadding is used, corrugated to offer a larger surface to the air and to decrease the air velocity through it. Usually filters of this type are used but once and discarded.

The *inertia principle* appears in radically different forms. In one, which might be called static, the air is forced by vanes to make sharp changes in directions. The dust particles by their inertia are thrown against the coated vanes and adhere to them, later to be removed by a washing system.

Although seldom applied to ventilating systems, the cyclone filter is interesting because it employs the inertia principle. It is an active or dynamic device, air being forced into a specially shaped chamber in such a way that it rotates furiously. The dust particles of appreciable mass are thrown to the outer walls by centrifugal action.

Air washers are seldom used solely as a filtering device, but in connection with air-conditioning systems where they also serve to control temperature and humidity. The air is driven against a battery of heavy sprays of water. The fine spray catches the dirt and carries it out of the air stream. The process is effective for dust of large size that can be wetted but, of course, it requires the power for pumps, and equipment of considerable bulk. Air washers are inefficient collectors of soot particles of small size.

Mechanical Filters Catch the Big Particles

Mechanical filters are used with varying degrees of success, depending on the filtering job to be done. In their simplest form they are compact, and inexpensive in first cost. The cost of maintenance varies widely, being considerable for those requiring replacement. They have, on the other hand, two conspicuous disadvantages in common. Most serious is that they miss small particles and they have high and variable pressure drop. Most mechanical principles depend for the selective action on either the size or weight of the particle. Most well-constructed mechanical filters are relatively efficient on the basis of weight of dust collected—of the order of 75 to 95 per cent. This is easily possible with dusts containing some large particles. Assume, as an extreme case, one million particles composed of a single particle of 70 microns in diameter (which just passes a 200-mesh screen) and the remainder cigarette-smoke particles averaging 0.1 micron. Assuming equal density, the large particle weighs 343 times as much as all the others together. The mechanical filter thus has a cleaning efficiency by weight of 99.71 per cent, although it removes only a single particle of the million particles present.

Determining Filter Efficiency

This anomaly caused the National Bureau of Standards to devise an improved method of determining filter efficiency. It is a blackness test. The samples of the cleaned and dirty air are forced through white filter paper. A ratio of the volumes of cleaned and uncleaned air required to give spots of equal blackness is used as a measure of efficiency. By visual inspection, the method is accurate to three or four per cent. Using the more precise photo-electric comparison, the accuracy is one per cent or better.

On the basis of blackness tests mechanical filters in general have efficiencies between 15 and 35 per cent, the average being less than 25 per cent. Their efficiencies are widely scattered, depending on the distribution of particle size in the air cleaned and with the amount of dirt collected by the filter. Cleaning efficiency of some mechanical filters increases as dirt collects because the dirt itself acts as a filter, but this increased efficiency is obtained at the expense of sharply increased pressure drop which requires additional fan horsepower to overcome. Furthermore, the amount of restriction varies, depending on the extent the filter material is clogged. This makes it impossible to obtain balanced conditions in a ventilating system. The pressure drop through a two-inch mechanical filter is seldom less than 0.15 inch of water and may be anything higher than that, although it is common practice to clean the filter when the pressure drop exceeds about one-half inch. In fact, frequently a measure of pressure drop is used as the indication of when it is necessary to clean the filter.

Comparison of blackness spots of equal amounts of air: (left) uncleaned, (center) mechanically filtered, (right) electrically cleaned.

Rototrol—A Versatile Electrical Regulator

The Radio City elevators whisk passengers from the lobby to the Rainbow Room smoothly and uniformly because the Rototrol, a rotating d-c regulating machine, can take almost any quantity that can be translated into current or voltage—and few cannot—and either keep it constant or vary it in a predetermined fashion. Another outstanding application of the Rototrol is for the now-vital machine-tool industry, where it makes possible the design of machines with a speed range as wide as 120 to 1, and with excellent regulation at all speeds

W. H. FORMHALS*
Motor Engineer, Westinghouse Electric & Manufacturing Company

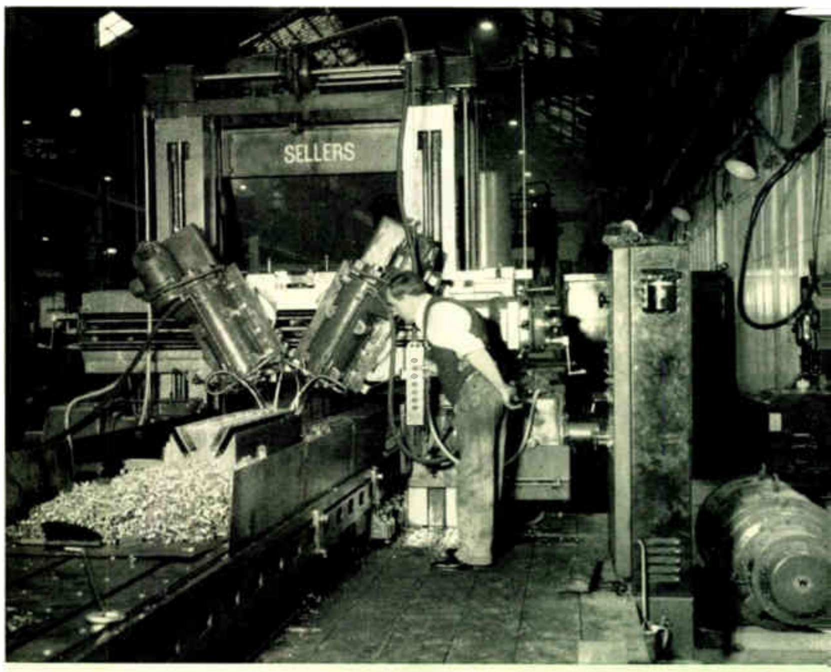
ELECTRICAL control has always been characterized by the ease with which small quantities, such as slight changes in current or in voltage, can be made to control the action of large devices—motors, generators, circuit breakers, etc. For example, to regulate the output of a simple d-c generator, it is merely necessary to vary the excitation, only about one per cent of the total generated power. Speed adjustment of motors is accomplished by regulating the relatively small field current. Many other physical quantities encountered in machinery, such as torque, tension, or acceleration, can be regulated by electrical means because the problem usually can be reduced to the task of keeping a small current or voltage constant, or vary it in a predetermined fashion.

By far the largest portion of regulated equipment centers around a control of speed of one or more rotating machines in the apparatus regulated, and many regulation problems are solved by devising means of changing the speed of some machine at will. The inherent speed control of any one machine, however, is limited. The ordinary d-c motor has a speed range by field control of about 6:1. By combining several machines, as in the adjustable-voltage drive, it is possible to go to about 20:1. A rotating regulator, known as the Rototrol, originally developed for elevator drive ten years ago, but since applied to a large variety of industrial control systems, extends the range even more. Speed controls as high as 120:1 can be obtained with it in adjustable-voltage drives.

In the successful operation of any regulating means it is necessary that the apparatus be capable of comparing the actual value of the quantity being controlled with the standard or calibration value desired. If there be any difference between the actual and desired quantities, the regulating device must supply power of the correct magnitude and direction to eliminate the difference. In other words, the regulating means must measure a certain quantity, compare it with a standard, and if the two are not equal, initiate some means for equalizing them.

Where extremely accurate regulation is required, the regulating device must be sensitive to small differences between the actual and desired quantities. A small change in the excitation of the Rototrol is sufficient to initiate the necessary corrective forces for satisfactory regulation of quantities with larger power consumption.

The Rototrol which is drawn at constant speed is essentially a small d-c machine similar in both construction and theory of operation to the standard d-c generator of equal size. The magnetic circuit is excited by a number of field windings. The Rototrol functions entirely through the interaction of these fields, without moving parts requiring delicate adjustment. After initial adjustments during installation, the Rototrol requires no further attention other than the routine maintenance associated with a d-c machine of similar size.



At the bottom right corner of the photograph is the motor-generator that supplies power to the large combination planer-milling machine at the left. The Rototrol is at the other end of the motor-generator.

The simplest form of Rototrol has three fields: a self-energizing field (generally in series with the armature), and two separately excited control fields. One of these control fields is commonly referred to as the pattern field and is excited with constant potential from a standard or calibration source. The other control field measures the quantity to be regulated, and is commonly referred to as the pilot field. Because this pilot field usually is connected so that its flux is in opposition to that of the pattern field, it has

*Mr. W. R. Harris, Industry Engineer of the Westinghouse Electric & Manufacturing Company, has furnished most of the information regarding the industrial applications of the Rototrol, and his help in the final preparation of the manuscript is acknowledged.

frequently been called a differential field. However, in some control schemes it is necessary for the pilot field to boost the pattern field, in which case the former is often called a cumulative field. In the following discussion, the pilot field will be identified as either differential or cumulative, so that its polarity with respect to the pattern field is readily identified. To explain how the Rototrol functions, it is best to follow step by step its operation in the regulation of a simple quantity such as speed.

Keeping Speed Constant

Assume that it is desired to maintain the speed of a direct-current motor constant irrespectively of load variations, temperature changes, or other factors that normally affect the characteristics of a motor. The circuit used for such

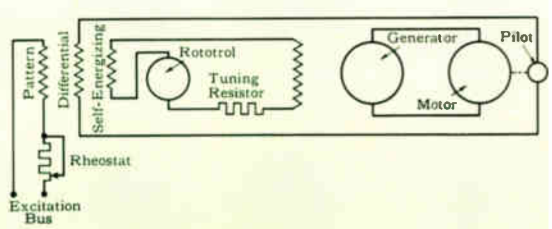


Fig. 1—*The speed of a motor is closely regulated with a Rototrol.*

a purpose is shown in Fig. 1. This is similar to a standard adjustable-voltage system except that a Rototrol driven at constant speed, and having three fields, is used instead of the usual generator exciter.

The Rototrol works by comparing a constant predetermined voltage with a voltage directly proportional to the speed of the driven motor. The comparison is effected by impressing each of these voltages on a separate Rototrol field. The standard of calibration voltage is impressed on the pattern field. The voltage proportional to the speed, obtained from a pilot exciter directly coupled to the motor (in effect, an electrical tachometer) is impressed on the differential field. The two fields are connected in opposition so that the net excitation in the Rototrol (neglecting the self-energizing field) is proportional to the difference between the ampere turns of the pattern field and those of the differential field.

Assume for a moment that the Rototrol had only these two fields, the self-energizing field being out of the circuit. Were the pattern field open under these circumstances, there would be nothing but residual voltage at the generator terminals. If now the pattern-field circuit is closed, the voltage of the generator builds up and causes the main motor to accelerate. The rotation of the pilot exciter energizes the differential field of the Rototrol, which acts to lower the voltage of the Rototrol, and thus that of the generator. A balance is reached when the difference between the ampere turns of the two fields is just enough to supply the necessary excitation to the generator field to maintain the generator voltage.

Now if the load on the motor increases, the speed tends to decrease just as in any separately excited motor. This decrease in motor speed, however, causes a decrease in the pilot-exciter voltage and therefore a decrease in strength of the differential field of the Rototrol. This results in an increase in its net field strength, since the pattern field is constant. This, in turn, increases the Rototrol voltage, generator field strength, generator voltage, and motor speed until a balance is again reached. However, because the net ampere turns required to effect this compensation must necessarily come from the differential field, the speed under the changed load conditions can never be precisely the same as it was originally, and full 100 per cent compensation is therefore impossible.

From this we can conclude that for complete accuracy in a regulating device, it is necessary that the pattern and differential fields control the Rototrol output without having to supply any of the power required to effect the regulation. This is the function of the self-energizing field on the Rototrol. In fact, the self-energizing field is the feature that makes the Rototrol so effective a regulating device. To clarify its operation, assume that the other two Rototrol fields are disconnected. We then have only the characteristics of a series generator to consider.

Rototrol Resistance Line Tangent to Saturation Curve

The saturation curve of a series generator is drawn in Fig. 2. As shown in any standard textbook, stable operation of a d-c series generator is possible only if the resistance of the field circuit is less than that of the line tangent to the saturation curve. If the resistance is higher, the generator voltage cannot build up. If it is less, the generator open-circuit voltage will be that determined by the intersection of the line with the saturation curve. If the resistance just equals the slope of the line, the generator can theoretically have an open-circuit voltage equal to the ordinate of any of the points of tangency.

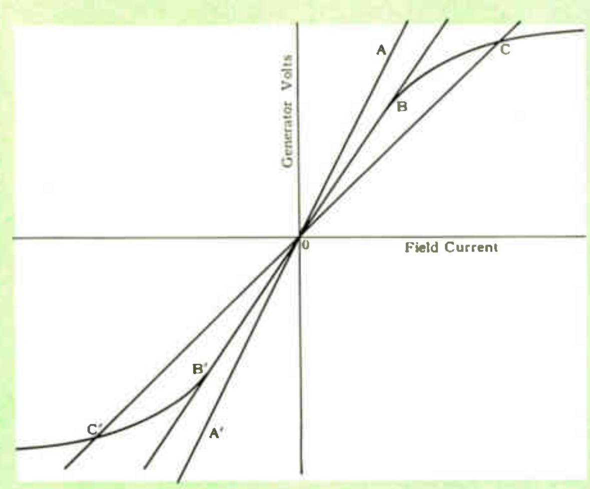


Fig. 2—*The field resistance line of the Rototrol (BB') is, unlike in a conventional d-c generator, tangent to the saturation curve.*

While this would be undesirable in a standard generator, it is an ideal characteristic for a Rototrol. Considering again the entire circuit shown in Fig. 1, the purpose of the two control fields (pattern and differential) becomes that of locating the proper operating point of a series generator consisting of the self-energizing field and an armature, keeping this operating point constant, and supplying the required amount of power to the generator field.

With the rheostat in the pattern field set at some position and the circuit closed, voltage in the Rototrol armature rises rapidly because the excitation of the pattern field is added to the effect of the self-energizing field. This voltage excites the generator field, causing a voltage across the differential field of the Rototrol, neutralizing the effect of the pattern field. When the differential field completely neutralizes the pattern field, the Rototrol reaches a steady point of operation because there is no more forcing of the field and the self-energizing field can just maintain this steady-state condition.

Consider an increase of load on the motor that causes its speed to drop. This decreases the differential field strength and because the pattern field is constant, the Rototrol voltage and thus the generator-field current and voltage increase. This increase in voltage continues until the differential field again neutralizes the pattern field and the self-energizing field again maintains this new condition. At this time the speed is exactly the same as before the load has changed, because the Rototrol can be at balance only if the pattern and the differential fields are equal. The differential field, which is the same as before, measures the speed of the motor and the speed, therefore, must be exactly the same in the two cases.

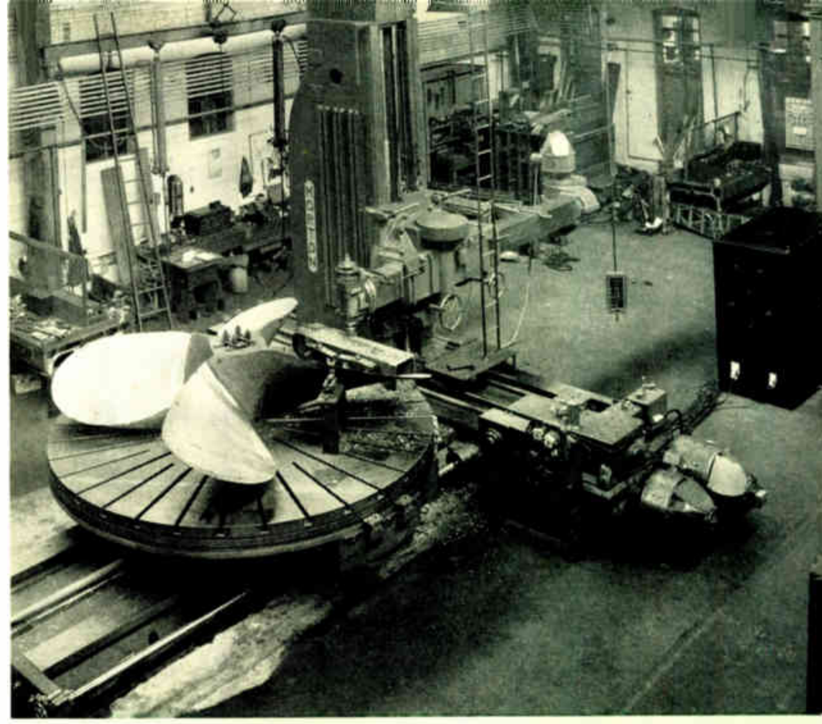
Obviously, if the speed of the motor were to rise for any reason, the differential field would become stronger than the pattern field and the excess ampere turns would cause the Rototrol to seek a lower operating point until balance was restored between the pattern and differential fields, or, in other words, until the speed was lowered to the former value.

Rototrol Serves Many Purposes

The principles described above in connection with regulation of speed can be modified for application to the regulation of many quantities other than speed. Some applications of the Rototrol and the functions obtained are listed in table I. Actually, the Rototrol can be made to regulate any quantity capable of being translated into a current or a voltage that can actuate a Rototrol field. For example, the speed of a motor may be translated into voltage by means of a small pilot generator driven from the motor; the torque of a separately excited d-c motor is proportional to its armature current; the horsepower of an adjustable-speed, constant-voltage d-c motor is proportional to its armature current; an accelerating force is proportional to the torque and thus to the current of a separately excited d-c motor.

TABLE I—ROTOTROL APPLICATION CHART

Application	Duty	Electrical Counterpart of Regulated Quantity
Elevators	Accurate landing speeds in either direction at all loadings.	Voltage and current
Planers	Wide speed range with close speed regulation, also rapid acceleration and deceleration.	Voltage and current
Feed Mechanisms for Machine Tools	Wide speed range, 120 to 1 with good regulation.	Voltage and current
Super-Calenders	Close threading speeds regardless of load with wide speed range of operation.	Voltage and current
Single Motor Paper Machine Drives	Speed maintained constant at any setting over entire speed range.	Voltage
Core-Type Reels	Tension of material maintained constant as a roll builds up. (Constant horsepower)	Current
Wet-End Auxiliaries for Paper Machines	Constant torque or driving effort regardless of speed.	Current
Skip Hoists	Constant landing or dumping speed regardless of load.	Voltage and current
Shovels	Control of current peaks reduces shock and maintenance of mechanical equipment.	Voltage and current
High Inertia Loads, such as Centrifuges	Constant or uniform acceleration.	Current
Drag Lines	Same as shovels.	Voltage and current



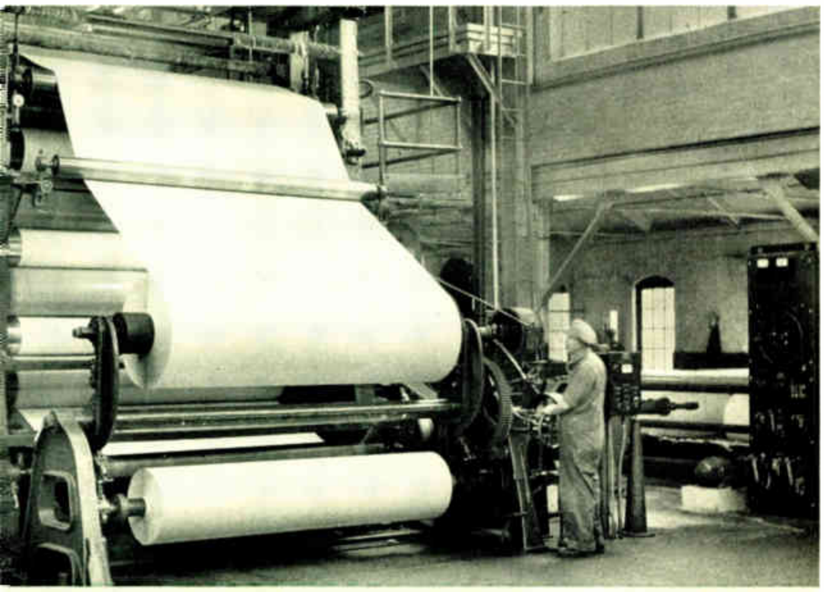
A ship's propeller is being machined on a large Morton planer equipped with a Rototrol-regulated adjustable-voltage drive.

In many regulator problems it becomes important to consider what is happening in various parts of the system. For such purposes the Rototrol is ideal because it can be equipped with additional field windings and thus receive more signals from diverse parts of the equipment under regulation than any other type of regulator element.

In addition to being able to receive the signals, the Rototrol also possesses the ability to integrate these signals, amplify the integrated result, and apply to the system corrective forces of the proper magnitude and direction. It is possible to proportion and polarize the fields so that each signal received can be given its correct importance. These fields and the armature of the Rototrol can be connected in any one of a variety of arrangements in additive or subtractive polarities depending on the application and the type of regulation desired.

Circuit Modifications

Bridge-Type Speed-Control Circuit—The "bridge-type" regulator circuit shown in Fig. 3 is widely used with the Rototrol. This simple circuit (modified slightly for individual conditions) has been used for the regulating circuits of elevators, planers, skip hoists, supercalenders, and machine-tool feed mechanisms, and can be used for many other similar regulating tasks.



In this supercalender of the West Virginia Pulp and Paper Company, a Rototrol keeps the threading speed constant regardless of the load.

This circuit makes possible good speed regulation at a wide range of speed—in some cases as much as 120:1. It differs from the scheme previously described in two important respects. Instead of being measured directly by an electric tachometer generator, the speed is obtained indirectly. The differential and series Rototrol fields measure the two factors (voltage and load current) that determine the speed of a motor. This method saves the necessity of an additional machine. The second and major point of difference is that instead of furnishing all the excitation, the Rototrol here furnishes only the regulating power required to maintain constant speed, while the normal excitation of the generator field is supplied from another source. Thus the Rototrol is confined to regulation alone, and a wide range of control and a more accurate performance are possible.

Torque or Current Regulation—The torque or current regulating circuit with adjustable-voltage control as shown in Fig. 4 has been applied to centrifugals for uniform acceleration, to paper-mill wet-end auxiliary drives for constant torque or driving effort regardless of speed, and to shovel or drag-line drives for controlled acceleration, deceleration and limitation of current peaks. The circuit is similar to the speed-regulating scheme discussed in detail above except that the regulator field fed by the pilot exciter is arranged to take a part of the main armature current. If the generator supplies power to a separately excited d-c motor, the armature current is directly proportional to the torque developed. Thus this scheme can be used for either torque or current regulation.

Horsepower or Current Regulation—The regulating circuit with constant voltage control as shown in Fig. 5 is used in paper-mill, core-type reel drives for maintaining constant sheet tension as the roll diameter increases. In a web moving at constant speed, constant tension results in constant horsepower. Consequently, with a constant voltage applied to the motor armature, constant current results in constant horsepower regardless of how the motor speed changes with increasing roll diameter. Such a circuit can be used for applications requiring constant horsepower.

The simple schematic circuits of Figs. 1, 3, 4, and 5 show how the Rototrol can be applied to a variety of drives. The Rototrol regulating scheme is rugged, simple, and involves only the well-known principles of rotating d-c machines. None of the component parts requires delicate mechanical adjustment to compensate for wear, and the entire equipment is therefore certain to maintain its accuracy throughout its life with little attention. Generally, the Rototrol system is applicable to practically any drive in which the quantity to be regulated can be expressed electrically. It is particularly suitable where simplicity of operation and low maintenance are desirable.

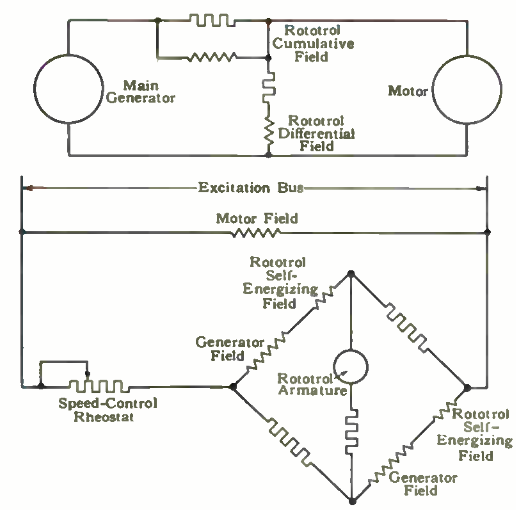


Fig. 3—*Bridge-type circuit permits wide range of speed regulation.*

Fig. 4—*Rototrol used to maintain constant torque.*

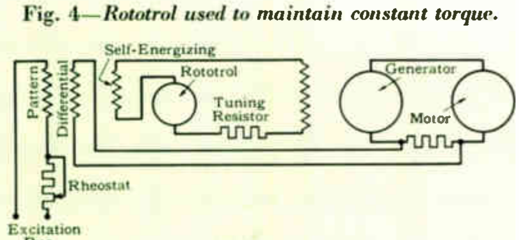
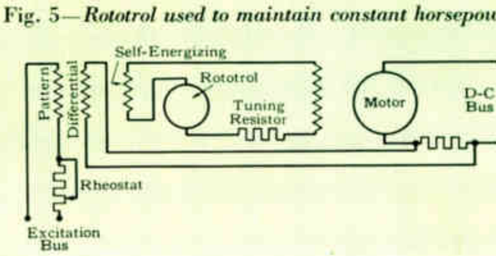


Fig. 5—*Rototrol used to maintain constant horsepower.*



Transformers Are Loud—Only If You Hear Them

Present-day requirement of transformers, and of almost all other machines, is that they, like children, be far more attractive to the eye than to the ear. Of the two tasks involved here, that of improving appearance and that of reducing sound level, the latter is far more complex, involving simultaneous solutions to problems in acoustics, mechanics, magnetics, and—often the deciding factor—economics. Essential to the general attack on all these problems is a clear understanding of the most important question: When and where is a particular transformer considered too loud?

H. FAHNOE
Consulting Engineer, Westinghouse Electric & Manufacturing Company

TRANSFORMER sound, or for that matter any noise, is relative to the noise of the surroundings. To classify a transformer as "noisy" or "quiet" it is necessary to take into account not only the sound energy produced within it, but the extent to which this sound is audible at the transformer location. The causes of transformer noise, the factors that aggravate it, and the various remedies for it, are known. In fact, if price is no consideration, it is possible to build a transformer of any desired sound level. But the general solution to the problem cannot be given by fixed standards, because installation conditions affecting the acceptable sound level vary over a wide range.

There should be two criteria of transformer sound. That of the manufacturer, as exemplified by the NEMA standards, table I, is based only on the voltage and kva rating of the transformer, and merely lists the lowest sound level possible to attain in a transformer without unduly increasing its cost. The yardstick of the application engineer, to which little attention has thus far been paid, should deal with the external factors affecting the audibility of transformer noise, such as the location of transformer, the general ambient sound level, the proximity to residential sections, or the presence of other structures that tend to reflect or amplify the sound initiated by the transformer.

Small distribution transformers, for example, have inherently low sound levels as compared with power transformers. Yet, mounted on a pole in a quiet suburban street, close to somebody's bedroom, it may give rise to more complaint than a much noisier trolley line a block away. Furthermore, what may be noisy in one street may be quiet in another, and a "loud" hum in a suburb may go unnoticed in a large city. From the point of view of the application engineer, the selection of the smaller, quieter transformer may therefore be just as important as one for a large outdoor substation, which may be located far enough from a residential area to be unobjectionable.

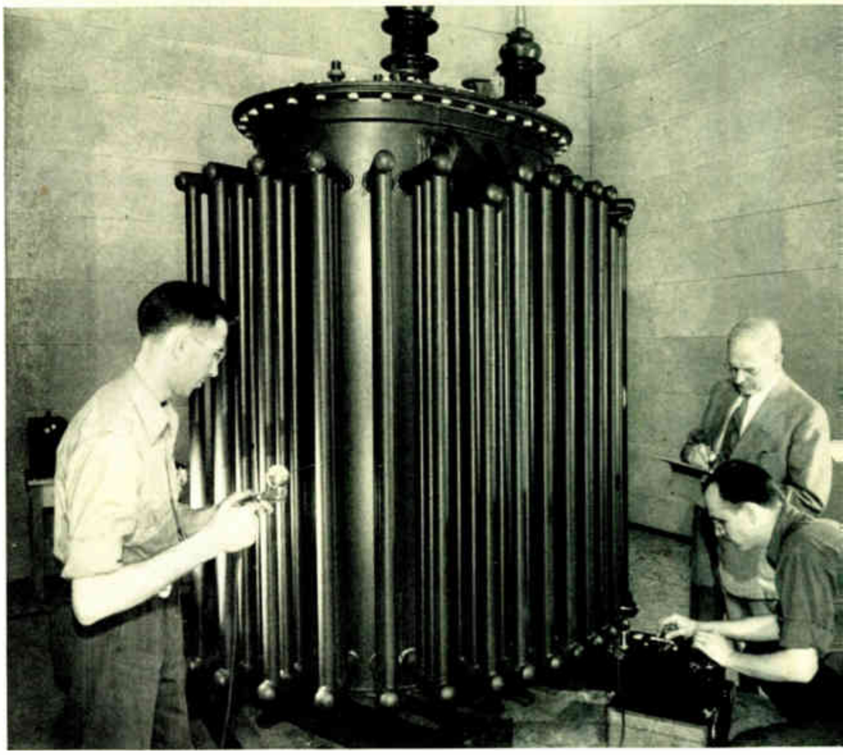
To cite another example, the NEMA acceptable sound level of a 500-kva transformer is 58 decibels (units of sound intensity). Such a transformer can be considered noiseless if located in an industrial plant, where the noise of the machinery is many times higher. But, placed in an office or apartment building as part of a city network system, the same transformer may be so noisy that the utility can not use it. It becomes necessary to select a transformer of different proportions, with structural parts that do not resonate, and with more iron—in brief, to get a quieter transformer it is necessary to make a more expensive one.

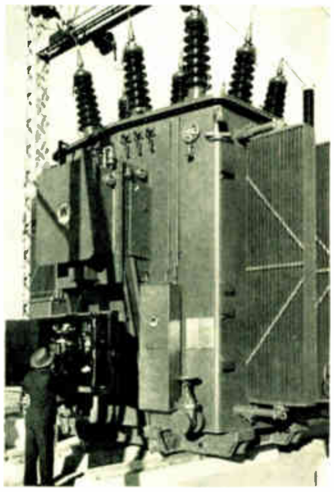
Another location where a transformer with an acceptable NEMA sound-level rating can prove too noisy is in large commercial structures where several substations are located on various floors of the building and can be heard in adjacent offices. It is necessary to mount the transformer on a sound-deadening support and thereby prevent its vibrations from being transmitted to the steel structure and to other parts of the building.

Transformer noise is troublesome in relatively few cases, but none lend themselves to a general solution. Each is an economic problem, to balance the additional cost of a quiet transformer against the cost of providing a suitable enclosure or locating the transformer far enough away for the noise not to be objectionable.

Transformer sound is one characteristic that must be designed for just like voltage ratio, current capacity, thermal rise, or regulation. Although it is not practical to calculate or measure sound levels with the same accuracy as, say, ther-

A sensitive microphone picks up the sound of the transformer. The amplified output of the microphone is read on a meter calibrated in decibels. This photograph was taken in a sound-proof laboratory (ambient level of 20 decibels) built solely to investigate transformer sound levels.





mal rise or regulation, sufficient experimental and analytical work has been done to enable the transformer designer to select his material and proportion the dimensions of his transformer that a selected sound level will not be exceeded.

Magnetostriction Causes Hum

Transformer hum is caused primarily by magnetostriction in the core laminations, a phenomenon first discovered by Joule in 1842. Magnetizing a steel lamination causes a minute change in its dimensions that disappears when the magnetizing field is removed. In a 60-cycle transformer core there is therefore a small deformation of each lamination every half cycle of magnetization, resulting in a 120-cycle vibration of the core surfaces. In addition to the fundamental frequency, there are also higher harmonics, due to characteristics of the steel that come into more prominent play at higher flux densities. A typical magnetostriction cycle for a representative sample of silicon steel is shown in Fig. 1.

Not all modes of vibration in which a transformer core can vibrate are attributable to magnetostriction alone. The core

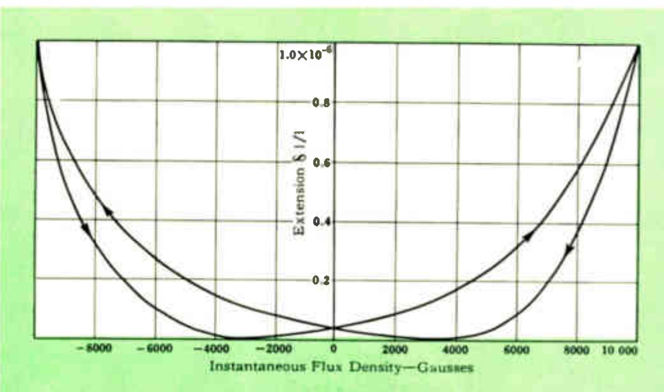
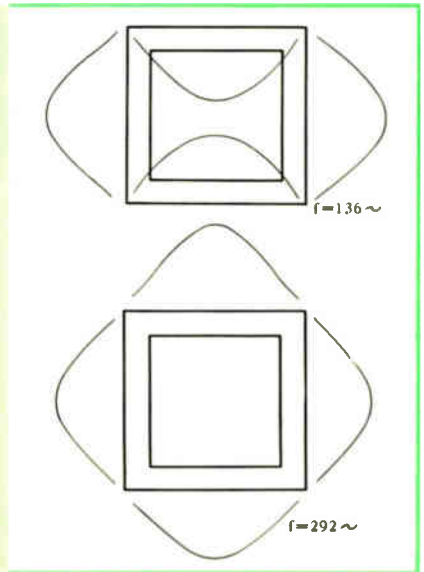


Fig. 1—Magnetostriction cycle of a silicon steel.

Magnetostriction depends not only on the absolute magnitude of the flux density in the iron, but also on whether the density has been increased or decreased prior to the measurement. Magnetostriction therefore resembles hysteresis, inasmuch as the cycle is not completely reversible, and energy proportional to the area bounded by the curve is dissipated as heat. The heat loss is increased by impurities in the iron.

is a mechanical structure that can have several natural frequencies and at each of these frequencies the core will vibrate in a particular manner or mode. In a rectangular core with rigid corners, the first or fundamental mode of vibration is in a plane parallel with the plane of the laminations, as in Fig. 2 (top). Two opposite sides bend outward at the instant the other two sides are deflected inward. The second mode is shown in Fig. 2 (bottom). Here all four sides are simultaneously deflecting first outward, then inward. At still higher frequencies, modes of vibration occur where one or more of the sides are vibrating in a variety of multiples of odd harmonics.

Fig. 2—Modes of vibration of rectangular cores. The phase relationship is measured on the core center line.



In more complicated core structures, combinations of these modes may occur. For example, the successive modes appearing in the core of a three-phase, shell-form transformer are shown in Fig. 3. The legs of an upright rectangular core, not clamped between heavy plates, are restrained from elongating in the direction of their length by the inertia of the yokes; they can therefore tend only to bow outward, as shown in Fig. 4.

If one or more of these natural core frequencies happens to equal the corresponding sound frequency caused by magnetostriction, resonance occurs and may raise the sound level considerably, depending upon the magnetostriction characteristics of the steel. With present-day transformer steel, the magnetostriction at fundamental vibrational frequency predominates. It is therefore important to ascertain that the natural frequency of the core be well removed from 120 cycles (for 60-cycle transformers).

Vibrations of the coils, caused by load currents, are principally of twice the applied frequency. If the coils are prop-

TABLE 1—NEMA STANDARD SOUND LEVELS OF TRANSFORMERS—DECIBELS

55° C Kva Rating	69 Kv and Below		92–115–138 Kv		161 Kv and Above	
	Without Fans	With Fans	Without Fans	With Fans	Without Fans	With Fans
0–300	56	70				
301–500	58	70				
501–700	60	70				
701–1 000	62	70	67	72		
1 001–1 500	63	70	68	73		
1 501–2 000	64	70	69	73		
2 001–3 000	65	71	70	74	72	76
3 001–4 000	66	71	71	75	73	76
4 001–5 000	67	72	72	76	74	77
5 001–6 000	68	73	72	76	74	77
6 001–7 500	69	73	73	76	75	78
7 501–10000	70	74	73	76	75	78
10001–12 500	71	75	74	77	76	79
12 501–15 000	72	76	75	78	77	80
15 001–20 000	74	77	76	79	78	81
20 001–25 000	75	78	77	80	79	82
25 001–30 000	76	79	78	81	80	83

These sound levels are based upon present-day transformer practice, and are derived from the physical dimensions of the core, the average flux density at which the core is normally worked, and the average magnetostriction characteristics of the steel.

erly clamped, the sound produced by these vibrations is negligible compared with that caused by vibrations originating in the transformer core.

When the core and coils are placed in a tank and submerged in oil, the vibrations produced in the core are transmitted to the tank by direct contact at the bottom and through the oil from the core sides to the tank walls. At the lower range of frequencies produced in the core, up to about 500 cycles, depending upon the dimensions of the oil column, the oil acts as an incompressible fluid, and is equivalent to a larger mass in the tank wall. Because of this damping action of the oil, the tank wall should vibrate at somewhat lower amplitude than the core by an amount depending on the size of the transformer, on the size of the tank, on the oil level, and on the density of the oil.

The tank of a modern power transformer is, however, a complex structure, and it is possible for the cover or for segments of the tank wall to vibrate at many different frequencies or modes. In such complicated structures it is not a simple matter to predetermine these frequencies with any degree of accuracy. Were these vibrations of the tank structure to resonate with any of the flux frequencies in the core, the sound would be amplified. By means of braces anchored at suitable points on the transformer tank, this undesirable condition is avoided.

What Is a Quiet Transformer?

The principal factors that determine the acceptability of a transformer of a given sound level are, (1) the lowest ambient or background sound level at the place where quietness is of importance, (2) the placement of the transformer and buildings, and (3) the physical dimensions of the transformer. Obviously the latter depends on the rating of the transformer, and on the voltage, which determines the size of the coils, the amount and class of insulation used, and the size and construction of the transformer tank.

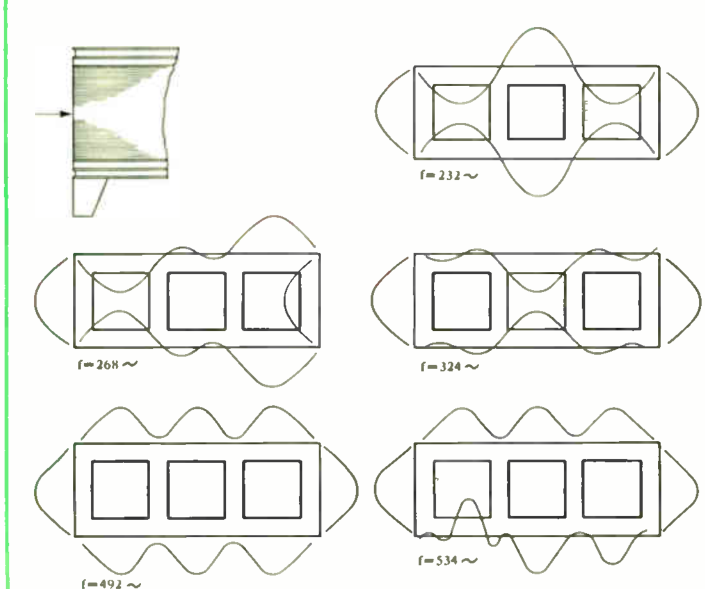
The simplest method for obtaining a quiet transformer would appear to be to use core material having low magnetostriction at flux densities that are economical for transformer operation. However, the magnetostriction of silicon steels heretofore available is roughly the same and the minor improvements that appear to be feasible by special processing seem hardly justifiable.

A new magnetic steel, known as Hipersil*, capable of carrying about one-third more flux than ordinary silicon steel, does have lower magnetostriction than ordinary silicon steels and its use at the same density as ordinary transformers would result in lower sound levels. Its economical application, however, dictates taking advantage of the high permeability of the new steel to reduce the quantity of material used rather than the sound level.

Although it is thus impractical to eliminate the noise originating in the core material, many precautions can be taken to limit its outward propagation, and particularly to prevent resonant vibrations in the core or in parts of the transformer tank. It is possible to calculate the resonance frequency of the core in advance and thereby avoid a natural frequency close enough to the magnetostriction frequency for resonance.

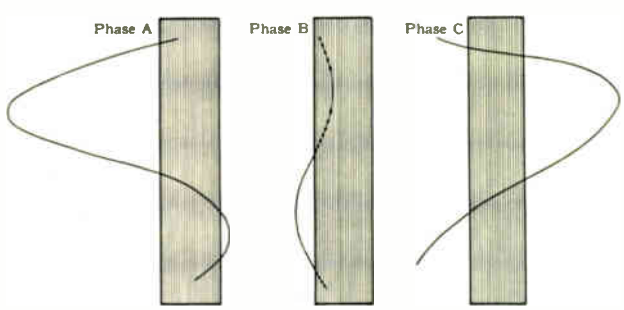
With reliable instruments for measuring sound level and an understanding of the fundamentals involved, the noise problem in transformers has resolved itself simply into one of engineering design or computation, modified, as in all engineering problems, by economic considerations.

*"Hipersil, a New Magnetic Steel and Its Use in Transformers," J. K. Hodnette and C. C. Horstmann, *Westinghouse ENGINEER*, v. 1, no. 2, Aug., 1941.

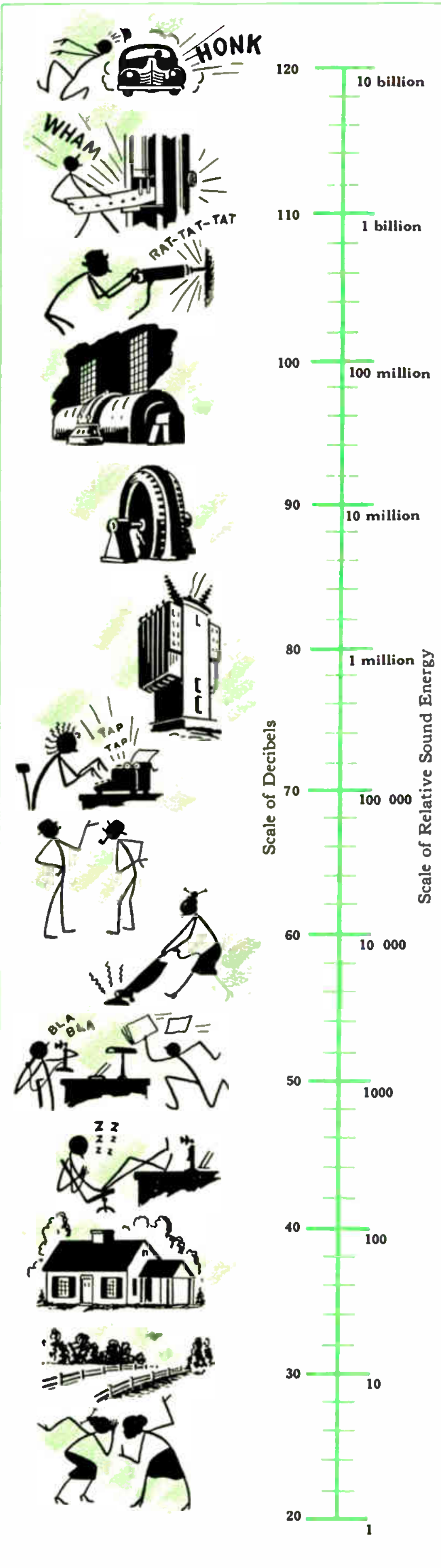


← *Fig. 3—Phase relationship of vibration measured on the center line of a three-phase, shell-type transformer.*

Fig. 4—Phase relationships of 116-cycle vibrations perpendicular to the plane of the laminations. All three legs of the core are excited from a three-phase supply. ↓



SOUND INTENSITY AND ITS MEASUREMENT



The unit of sound measurement, the decibel, is theoretically defined as ten times the logarithm of the ratio of energy between the sound measured and that of a standard sound level. Arbitrarily, the sound specified as the zero of the decibel scale is one requiring 10^{-16} watts/sq cm for its production. Lower sound intensities have negative decibel values; they are however seldom encountered on the earth. The ambient sound level in a polar region, if there is no wind, would probably be less than zero decibels, but an isolated observer located there would hear the sound of his heartbeat and his blood stream plainly. A "quiet" place, say a residential neighborhood at night, has a noise level of 25 to 30 db.

In practice, the decibel may be thought of as approximately the smallest change in sound intensity discernible by the human ear. Because it is necessary to increase the sound-producing energy approximately one-quarter before the ear can distinguish any change in the sound level, it is more convenient to use a logarithmic unit, such as a decibel, rather than a unit directly proportional to the energy. This is why the addition of one machine to, say, four or five similar machines in a room barely affects the overall noise level of that room.

Transformer sound-level tests are usually made in accordance with the AIEE test code*. There are many types of sound-measuring devices. In general a sound-level meter consists of a sensitive microphone, an amplifier, and an indicating meter. The microphone picks up the sound and transforms it into a current that is amplified and measured with the meter, which is calibrated directly in decibels.

The sound sensitivity of the human ear is not the same for all frequencies, being lowest for the extreme ranges of the sound spectrum (about 20 and 10 000 cycles) and highest for the middle range (3000–4000 cycles). To offset this inequality in perception, sound-level meters are generally provided with weighting networks, which amplify the middle frequencies more than the highs or lows, thereby making the response of the meter approximate that of the ear. Sound-level meters are most commonly provided with three weighting networks, one having a flat frequency response, and the other two showing gains of 40 and 70 decibels, respectively. This makes the accuracy of sound measurements independent of frequency, an important consideration because the frequencies of transformer hum vary with the design.

All sound-level measurements are made with the transformer excited at normal frequency and voltage, but at no load. Measurements are made one foot from the major sound-producing surface of the transformer and approximately uniformly spaced around it. If the individual sound levels do not differ by more than ten decibels, it is permissible to average the decibel readings without an appreciable error; otherwise it is necessary to convert the decibel readings to sound intensities and average the latter. Measurement locations are not more than eight feet apart and not less than eight are used. The major sound-producing surface is taken as that of the radiators, tubes, switching compartments, or potheads, etc., but minor projections such as valves and thermometers are neglected.

The sound level of transformers less than eight feet high is measured at approximately one-half height. Units eight feet or taller are tested at one-half and one-third height. For a transformer to be inaudible to the average human ear, its sound level must in general be eight to twelve decibels below that of the background sound level. This decrease depends somewhat on the relative frequencies of the transformer sound and on the background noise.

Sound energy radiated from a small source follows the inverse-square law, and the sound level of such a source located in open space should decrease six decibels (corresponding to a one-quarter reduction in intensity) for every doubling of the distance from a transformer. (This theoretical reduction holds approximately for small distribution transformers; for larger units the sound level seldom decreases more than five decibels as the distance is doubled.) This relationship permits a rough prediction of the effect that a transformer of given sound level will have on a given remote location. It is necessary to measure the reference sound level at a distance not less than four feet from a small transformer, and not less than eight feet for a larger unit.

Where a bank of transformers is installed, the combined sound level is used as a base. Theoretically, in a bank made up of units having the same sound level, the combined sound level of two units is three decibels higher than that of one unit, and the combined sound level of three units is 4.7 decibels higher than that of one unit. Practically, the actual combined sound level is somewhat less because of the effect of spacing of the different units.

Figures obtained from such calculations must be modified when large reflecting surfaces are present. These can cause the sound level several hundred feet away to be as high as that at the transformer, yet be considerably less at intermediate points. Conditions like these must receive individual study, as no hard and fast rule can be given for their remedy. Relocating the transformers with respect to the sound-reflecting surfaces is frequently all that is necessary.

*Apparatus Noise Measurements (No. 520)

Stories of Research

The photomicrograph at the left is of a sample of fused-quartz glass exposed to high-temperature (900°F) steam for about twenty-four hours. The glass is part of a window used to observe the vibration of turbine blades under actual working conditions. After a few days' exposure to the live steam, the inner window surface became so corroded that it was necessary to interrupt the test in order to exchange and repolish the glass. To diagnose and cure this undesirable condition, Drs. E. B. Ashcraft and A. Langer have devised a miniature but severe "turkish bath" in which small samples of the quartz glass in question can be suspended and tested under carefully controlled conditions. The experiments in this "turkish bath" have disclosed a rather startling phenomenon. The fused-quartz glass panes are polished before installation, and mechanical strains that set in during the polishing operation make the surface susceptible to erosion by steam. Removal of these strains, either by annealing at 2500°F or by glazing the surface with an oxy-acetylene flame reduces the etching effect of the steam, as shown in the photomicrograph at the right, also taken after twenty-four hours' steam bath.*

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Exploring the Why's and How's of Arc Blow

Instead of passing from the electrode to the work in a straight line, electric welding arcs often deflect, as if blown by a wind. The cause is either a real wind, made by the flow of hot gases away from the arc, or an "electrical wind," caused by the attraction of the magnetic field created by the arc and surrounding it. In either case, the result is a deflection of the arc from the right path. This deflection is more than just annoying—it interferes with the speed and continuity of welding, and can result in a poorer weld.

Theoretically, it might be assumed that there should be no difference between a-c and d-c arcs, as far as arc blow is concerned. The force between the induced magnetic field and the arc is pointed the same way, regardless of the direction of the current. It has been known for a long time, however, that a-c arcs are less frequently disturbed by arc blow, and although various explanations have been suggested for this difference, none have been conclusive.

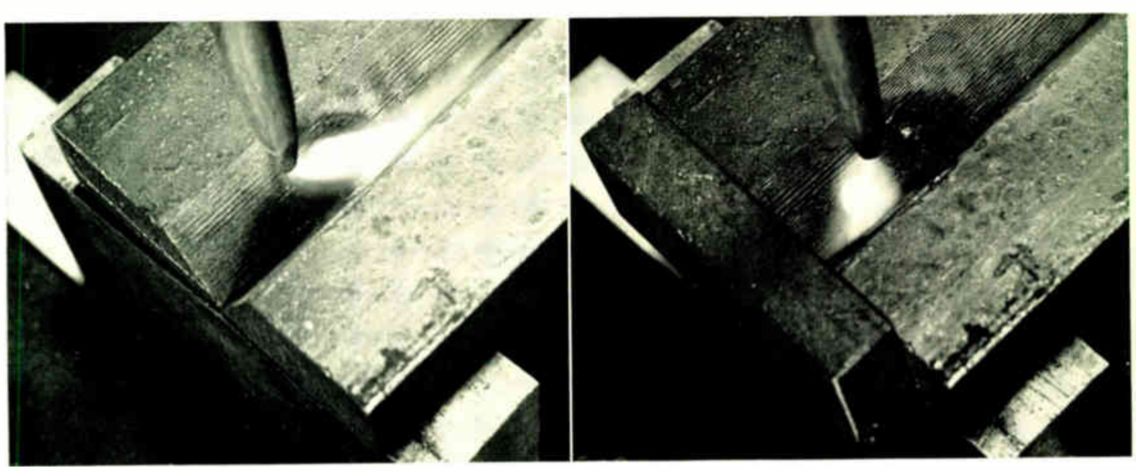
Convinced that a rational remedy to arc-blow troubles could be devised only after a full understanding of the principles involved, C. H. Jennings and A. B. White* developed a magnetic balance that explores the distribution of the flux lines in the arc and in the welded pieces, and thereby permits relative measurement of the forces between the arc and the magnetic field. The balance takes the place of an arc and of two pieces being welded, and in it the welded pieces are replaced by two bars of magnetic material and the arc is simulated by a copper rod. The rod is suspended between the work pieces and carries current equal to that drawn by an actual arc. This current produces a magnetic field, which is modified by the work pieces and deflects the rod in the same direction as it would a real arc. The rod normally blocks a beam of light but when it is deflected, light strikes a photo-electric tube. The output of the tube, read on a sensitive microammeter, is a measure of the force acting to deflect the rod or a real arc.

The findings of Jennings and White, although not yet sufficient to suggest a complete cure, have nevertheless contributed much valuable data on the nature of arc blow. The most important discovery was the effect of eddy currents on arc blow, and the resulting explanation of the difference between a-c and d-c arcs. The rapidly changing flux linking the alternating current in the arc causes eddy currents to flow in the work. These, in turn, produce a field of their own that partly neutralizes the field of the arc current. The intensity of the field acting on the arc, and the force tending to displace the arc, are therefore reduced. By using test pieces of insulated laminations, which greatly reduce the flow of eddy current, Jennings and White have proved conclusively that magnetic forces caused by eddy currents are responsible for the less frequent occurrence of blow in a-c arcs.

Another important factor in the production of arc blow is the arrangement of the work pieces and its effect on the symmetry of the magnetic paths surrounding the arc. If the magnetic reluctance is less on one side than on the other, the arc is attracted toward that side. Furthermore, if alternating current is used for welding, the unbalance in the eddy currents surrounding the arc produces a repulsive force away from the same path of lower reluctance and usually helps reduce a-c arc blow further.

Several practical methods of reducing arc blow have already been devised as a result of these findings. The greatest forces on the arc are caused by the variation in reluctance of the magnetic path surrounding it. Changing the magnetic paths around the arc, either by rearrangement of the work pieces or by providing additional magnetic material in the magnetic path, can equalize the reluctances surrounding the arc and thus reduce the cause of arc blow. The use of an external field, such as produced by a permanent magnet or electromagnet is also effective. It must be borne in mind, however, that the conditions affecting arc blow vary with each welding problem, and that no general recommendation can be made. The findings of Jennings and White, by providing a better understanding of the fundamental principles involved, make it possible to analyze the situation and devise means of improving welding conditions for each particular job.

*Westinghouse Research Laboratories.



Arc blow caused by asymmetric distribution of the magnetic circuit surrounding the arc (left) can be remedied by providing a magnetic shunt alongside the work pieces, as shown at the right.

Contacts That Do Not Bounce

WELTON V. JOHNSON
Relay Engineer,
Westinghouse Electric & Manufacturing Company

A STEEL ball dropped on a hard surface rebounds, but a bag of sand does not. This simple principle, centered around the absorption of kinetic energy by particle friction in the sand, has been put to use in relay contacts and enables them to close firmly without bouncing. Tungsten powder, placed in hollow contacts, makes a most effective damper that forestalls the natural tendency of contacts to bounce when they strike. As a result carrier-current relays, for instance, can establish a perfect circuit in the shortest possible time without the slightest chattering. Other mechanisms, too, can be made to operate positively utilizing a similar damper.

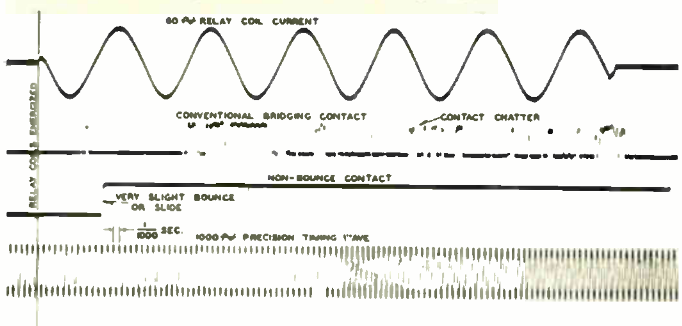
Contact Bouncing Troublesome at Low Currents

In conventional contacts no means is provided for the absorption of the kinetic energy of the moving contacts. Bouncing is therefore inevitable. Whether or not the current controlled is completely interrupted, its magnitude is always reduced by the bouncing.

If the current is large enough, the arc established during the first rebound provides a path for the current even while the contacts continue to separate. Thus in slow-speed induction relays the effect of bouncing is negligible. Circuit-breaker trip circuits in most relays are controlled through seal-in contact arrangements (in which an auxiliary pair of contacts operated by a series coil permits the tripping current to pass through the relay element and "seal" it shut for the duration of the tripping operation) and are therefore not affected by the bouncing of the contacts.

In high-speed carrier-current relays, on the other hand, the current in some elements is so small that it cannot form an arc, and even a slight separation of the contact surfaces interrupts the current momentarily. Yet for satisfactory carrier-current operation the relays must work as fast as possible and either remain positively closed or fully open. No "indecision" can be tolerated—contact action must be complete in one or two cycles.

Fig. 1—This oscillogram shows that the chatter of conventional contacts prevents them from closing completely, whereas non-bounce contacts pass current uninterruptedly after they close.



The higher the speed of a relay mechanism, the greater the necessity for chatterless operation. Operating times must be cut to an absolute minimum, especially in carrier-current relays, and it is not permissible to use contacts that delay the establishment of the protective circuit by bouncing.

Tungsten Powder Absorbs Energy

Contact chatter can be reduced by applying some damping force to the contact arm, either through friction or through a strong restoring spring. Neither of these remedies, however, is satisfactory. Some linkage between the moving contacts and the stationary parts is necessary, invariably adding to the size and weight of the contact assembly and calling for larger current consumption. This is always undesirable and frequently impossible. In the non-bounce contacts the damping tungsten powder occupies very little space because it is contained in the very part that strikes, where a small quantity of powder can absorb the most energy.

The moving contact consists of a hollow metal shell partially filled with small grains of tungsten. When the contact arm starts to move, inertia causes the tungsten powder to stay in the rear end of the shell or capsule. When the contact strikes the stationary element, the powder is thrown to the front end of the shell. In doing so the grains tumble and slide over each other, absorbing the kinetic energy released by the impact. The result is that the circuit is made without any tendency for the contact to separate. Oscillographic evidence of this is shown in Fig. 1.

The material for the powder is important. It must be as dense as possible, so that the particles have high inertia as they slide over each other. The individual grains must be rough, to create intergrain friction, and hard, to avoid wear. Tungsten meets these diverse requirements best. Of all the metallic elements only a few are heavier than tungsten, which has a specific gravity of 19.3. The smaller the grain size, the more the damping friction. However, the smaller the grain, the larger the bulk for a given mass of tungsten, which means a larger metal capsule and an undesirable reduction in ratio of powder weight to shell weight. A uniform mixture of grain sizes ranging from 150 to about 250 mesh is the best.

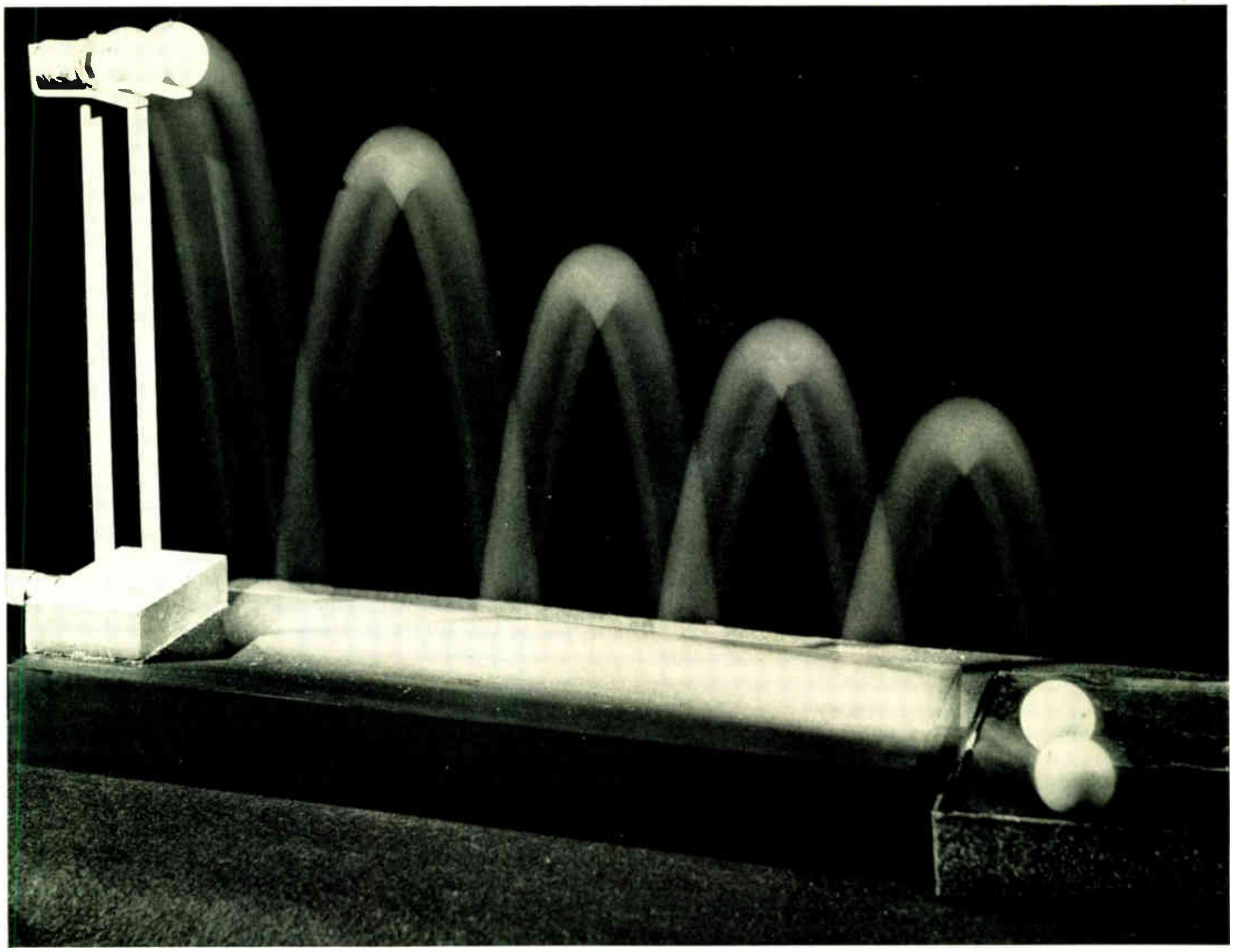
Specific Applications

At present tungsten-powder contacts are used with the second impedance element and directional element of some high-speed impedance relays, and on current and directional elements of high-speed directional ground relays for carrier-current control. Carrier-current relay elements demand the superior performance of the tungsten non-bounce contacts.

Tungsten-powder damping is obviously not restricted to contacts. Many mechanisms that are subject to shock or to excessive vibration can be equipped with dampers or shock absorbers filled with tungsten powder. Some single-phase generators, for example, are equipped with tungsten-powder dampers to eliminate vibration. Likewise, some moving armatures in relays, even though equipped with non-bounce contacts, must be made so heavy that the kinetic-energy absorption of the small contacts is not sufficient. A supplementary damper, in the form of a canister partially filled with tungsten powder, is mounted on the beam of the moving armature and absorbs the shock caused by the striking contacts.

The non-bounce contact must be operated by a positive mechanism and has its greatest advantage when used on high-speed mechanisms even with contact pressures as low as one-fiftieth of an ounce. Although it answers the need in high-speed carrier-current relays, it is somewhat limited in application to other forms of relays, because it is not as fast as the conventional contact. The actual increase in the contact-closing time is only a fraction of a cycle and of consequence only in high-speed relays containing two or more contacts that operate in a predetermined sequence where incorrect coordination in the sequence of the operation can result if this time lag is not accurately predetermined. While only a few applications are described here, it is obvious that the principle involved will also be found useful in many other fields where troublesome vibrations are to be remedied or eliminated, such as in high-speed turbines and other rotating machinery.

Drop a conventional hardened-steel ball on a hard steel plate and it rebounds in a succession of parabolic loops, diminishing in amplitude and increasing in frequency, as shown on the time-exposed photograph below. Drop simultaneously another ball, this one hollow but filled with grains of tungsten, and it merely rolls along the platform after falling, without bouncing. Both falling balls have identical weights, fall the same distance, and have exactly equal kinetic energies before they strike the same kind of surface, yet show a vastly different behavior after impact. This is no trick. The instant the tungsten-filled ball strikes the plate, friction in powder particles transforms most of the kinetic energy of the falling body into heat, and none is left for a rebound. Used in relay contacts, this energy transformation permits high-speed relays to make their circuits positively, and results in improved operation.



What's New!

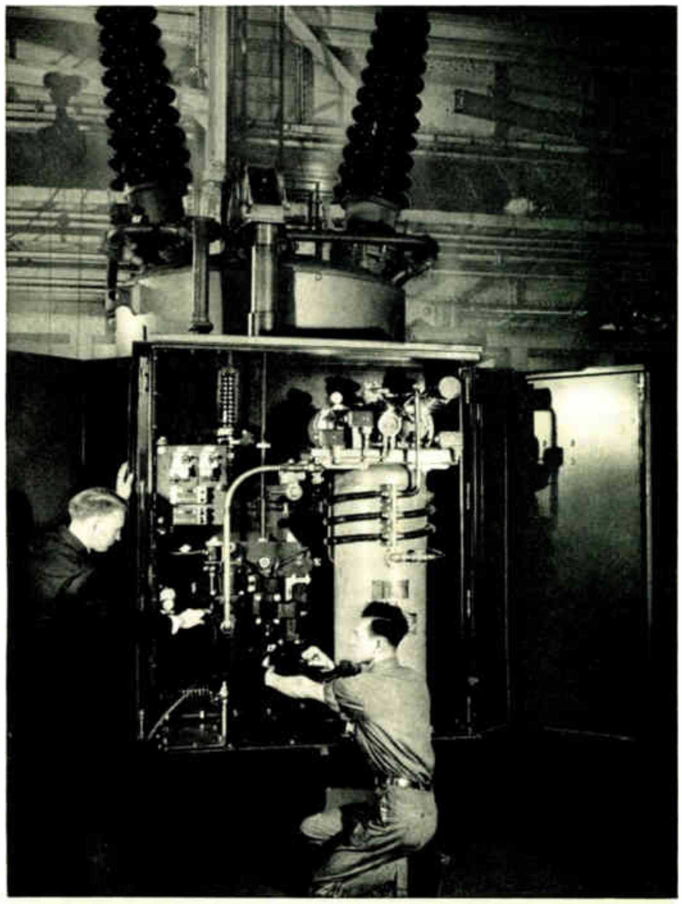
Compressed Air Operates Circuit Breakers

COMPRESSED air is becoming a handy tool for circuit interruption. It is used to supply a blast of air that extinguishes the arc of air circuit breakers by deionizing the arc path. The availability of compressed air readily suggested its use also for operating the circuit-breaker closing mechanism. Operation by compressed air has proved so successful that it has been extended to oil circuit breakers although it plays no part in current interruption.

The compressed-air operating mechanism has several advantages over other circuit-breaker operating devices. One is the reduction of closing time, making possible 20-cycle reclosing breakers and thereby raising the stability limit of the system. Another advantage is the reduced instantaneous drain on the station battery. The current requirement of a closing operation of the pneumatic mechanism is merely that drawn by the small coil that opens the pilot valve. In other words the energy for closing the contacts is stored in compressed air and does not all have to be drawn from the battery as it is used. This small current also means a smaller size cable from the battery to the breaker. The operating energy, released by the compressed air, is accumulated from the power supply at a slow rate, thus reducing the peak demand. One filling of the compressed-air reservoir is enough for several circuit-breaker closures without recharging.

The operating mechanism consists of a piston moving in an air cylinder, and actuated by electrically controlled air valves. A limited amount of air is allowed to enter the cylinder at the beginning of the stroke. At the time the piston just about completes its downward travel a mechanical throttle valve opens, permitting more air to enter the cylinder, providing maximum closing effort at the time the contacts touch. Large exhaust ports make the mechanism pneumatically trip free on opening.

Compressed air is supplied from a special assembly consisting of a motor-driven compressor, a storage tank, cooling and condensing coils, and the necessary automatic valves and other control equipment. The mechanism is tripped electrically by means of the conventional trip coil and latch.



Operating this oil circuit breaker with compressed air instead of with a motor or solenoid halves the reclosing time and reduces to one-fortieth the current drawn by the operating mechanism.

New 69-Kv Boric-Acid Fuse

BORIC-acid fuses have now been extended to 69-kv circuits, double the voltage for which these fuses have been heretofore practical. Thus an interrupting capacity of over a million kva, the highest of any known fuse, has been attained.

The fuse is a tube filled with boric acid that, upon short circuit, is dehydrated by the arc. Enough steam is generated by this process to extinguish the arc caused by the fusion of the current-carrying link. This link, too, is novel. Instead of extending throughout the tube of the fuse, it is made of two parts, one a stationary tube, the other a plunger opposed by a spring. Upon short circuit, this link does not drop out and hang from the fuse, as in other types; instead, it telescopes within the stationary tube. Thus there is less danger of secondary flashover. The new fuse is equipped with a delayed-action trip-out, so that after the arc is extinguished, the upper end is released permitting the tube to swing downward, leaving a readily visible air gap.

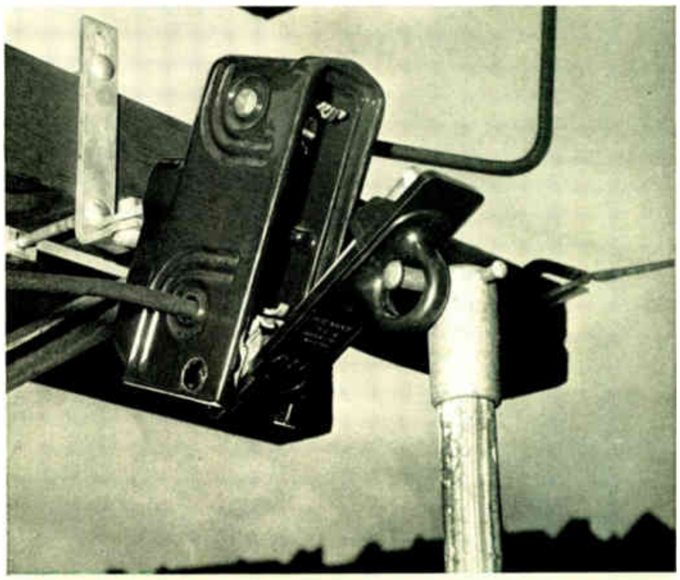
Mentioned briefly in an article on electromagnetic stored-energy welding (Westinghouse ENGINEER, May, 1941, page 8), Condens-O-Weld, a new resistance-welding control, employs special capacitors (instead of a transformer) to store welding energy. Thyratron-rectified current is drawn from the supply lines over a relatively long period, stored in the capacitors, and released suddenly through the materials to be joined.

Electrical Transmission and Distribution Reference Book

THE recognized reference book on transmission-line calculations has long been "Electrical Characteristics of Transmission Circuits," written by the late William Nesbit some twenty years ago. No greater tribute can be paid this truly classic work than to point out that, although written practically at the infancy of the transmission-line science as we know it now, it has remained one of the most frequently consulted handbooks on the subject. However, to consolidate the results of the past twenty years' advances, a new volume, "The Electrical Transmission and Distribution Reference Book," has been prepared by a group of Central Station engineers of the Westinghouse Electric and Manufacturing Company.

In the past two decades the growth of power transmission systems, both in size and in complexity, has been enormous. Operating voltages have increased from 154 to 287 kv. System interconnection, which just began in 1920, has become so extensive that now practically all the generating facilities east of the Mississippi are tied into one vast grid. This means that the problem of stability, which in 1920 was merely a theoretical consideration, is now recognized as a major factor in apparatus design. The one-second fault clearing has given way to three- and five-cycle operation. Protection against lightning was restricted to limiting the effect of induced strokes only—direct strokes, like acts of God, were to be endured helplessly. So useful an engineering tool as the method of symmetrical components was then treated as merely a mathematical novelty.

Such a variety of advances and new concepts is naturally the result of the cooperation of many men in the industry. Each author is well known in the central-station field and is recognized as an authority in his specialty. All are engaged daily in solving with the utilities the practical problems of electric-power production and distribution. The volume totals nearly 600 pages, and its format is large enough to permit reproduction of tables and curves for maximum legibility and for greater usefulness as a reference.



A blown fuse spells no climb to the top of this pole. The fuse in this new cutout is fastened to the door, and both can be inserted and removed with any hookstick, with complete safety to the lineman. The cutout is designed for use with fuses up to 50 amperes and for distribution circuits up to 12 500 volts (the unit illustrated is for 5000 volts), and its enclosure is made of Prestite, a newly developed moisture-proof porcelain of high dielectric strength.

Lamp Brightness Controlled with Polaroid

THE many indicator lamps of aircraft instrument panels must be adjustable in brightness. At night they must be dim enough not to blind the pilot as he shifts his eyes from the darkness outside to the panelboard inside. In bright daylight the light from the lamp must be sufficiently strong to enable the pilot to see whether the lamp is lit, or else the daylight reflected from the lens of the lamp may be much brighter than the light from the bulb inside. Thus some control of the brilliance of the lamp is imperative.

The method previously used—that of inserting a variable resistance in series with each lamp—has not been well suited to airplane switchboards, where space is crowded and weight is at a premium. The rheostat may be bulkier and heavier than the lamp itself. A new method of dimming the lights occupies no extra space and involves only negligible additional weight. Two polaroid films are placed between the bulb and the lens. One is fixed; the other can be rotated by turning a ring around the lens. When the two polaroid films are oriented in the same direction, most of the light is transmitted from the bulb to the lens. When the polaroid orientation is at right angles, almost all the light is blocked. Complete control of the light emitted by the lamp, from full brightness to almost total darkness, is therefore made possible by a mere twist of the ring.

The change in the relative position of two polaroid filters, readily performed by a quarter turn of the knurled ring, permits complete brightness control in this instrument-panel light.

Portable Test Kit for Network Protectors

TESTING network protectors in the field presents several problems not present in field checks of other equipment. A network protector is an electrically operated air circuit breaker controlled by relays that are sensitive to network conditions, and its principal duties are to safeguard the secondary network against faults occurring in the primary feeders or in the transformers, and to reclose automatically when voltage conditions are such that power will be fed into the network. The circuit breaker of a network protector closes only if potential on the side of circuit breaker nearest the transformer is slightly higher (by about one to five volts) than the network potential. For proper testing it is therefore necessary to have not only a source of voltage, but also some means of raising it slightly. Similarly, the circuit breaker trips only on reverse current, that is, when a fault occurs in the primary feeder or in the transformer, or when a feeder breaker is opened and causes power to flow from the network to the primary circuit instead of in the opposite direction, as it should be. It is therefore necessary to have some means of circulating current through the relays and in the circuit breaker, while at the same time maintaining full voltage at the protector terminals. In addition to these two main tests, the usual closing mechanism, shunt trip, and auxiliary relay must be put through a series of diversified tests.

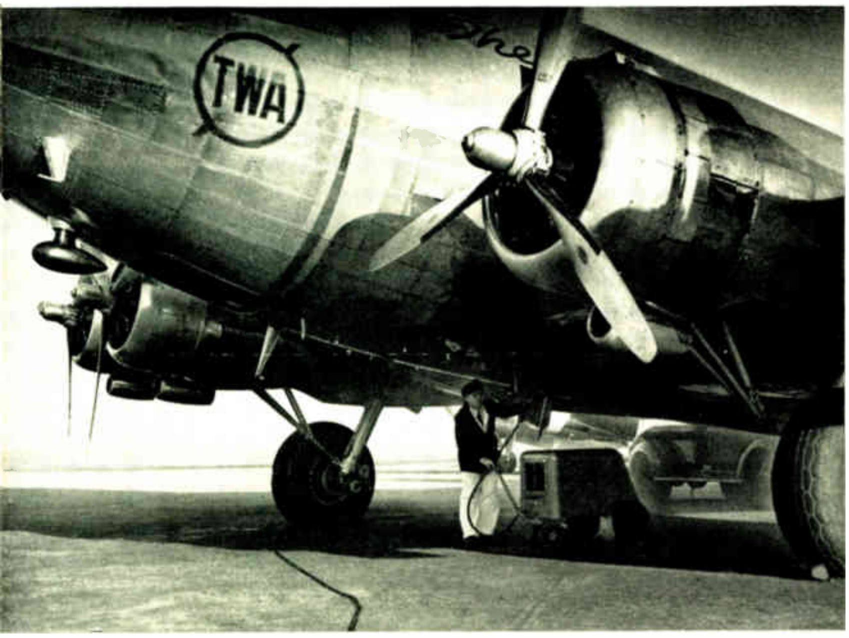
A new portable test kit developed for this purpose is suitable for the operating mechanisms as well as for the relays of most of the protectors thus far manufactured. With this set connected at the terminals of the network protector, all the circuits are tested exactly as they are connected in service, thereby reducing test errors to a minimum. Such important measurements as the minimum closing voltage, the reverse-current tripping value, the minimum shunt-tripping voltage, or the pickup voltage for the auxiliary relay are adjustable and are indicated on instruments by manipulating the various control switches. To get a complete check of the network protector, it is no longer necessary to remove it from the manhole or any other inaccessible location where it is usually placed and return it to a laboratory or to a factory.

A complete test kit is contained in a single case measuring about 15 by 11 by 26 inches and thus well suited for operation in crowded corners. Weighing but 75 pounds, it can be carried about and handled by one operator.

Rectox Unit Starts Airplane Motors

THERE is every reason for reducing airplane weight; the rating of airplane batteries is therefore just sufficient to supply the running current—that drawn by the lights, radio, defrosters, etc. The ground load and the starting current have heretofore been furnished by additional batteries located at the airport. These can now be replaced by new, truck-mounted Rectox units. This permits starting the engines directly from an a-c supply, without the necessity for batteries.

It takes a lot of current to start an airplane; about a thousand amperes are required just to turn the engine over. After the initial inrush of current, the engine starts to revolve and is smoothly accelerated until it reaches approximately 50 rpm, at which time the current has dropped to about 200 amperes and remains constant. For this type of duty cycle, a Rectox unit is more suitable than a battery, because of its inherently drooping voltage characteristics. The capacity of the rectifier is the product of its voltage and current. If it is possible for the voltage to drop, it is possible to draw a large current and maintain the output. If voltage regulation is constant, current drain is also limited.



The Rectox airplane starter is as sleek as the stratoliners it serves. At 12 volts, its instantaneous "break-away" current is 1000 amperes, and it can deliver 400 amperes in on-and-off cycles of two minutes each. The 24-volt unit also delivers 1000 amperes instantaneously, but (remembering that power is volts times amperes) its rating is 200 amperes thereafter. Power is supplied to the rectifier at 220 or 440 volts, three phase, 60 cycles. The efficiency—about 60 per cent—is approximately three-fold that of a battery.

In addition to the portable Rectox unit for airports, there are also stationary installations for engine starting and test purposes in airplane factories, where mobility is not essential.

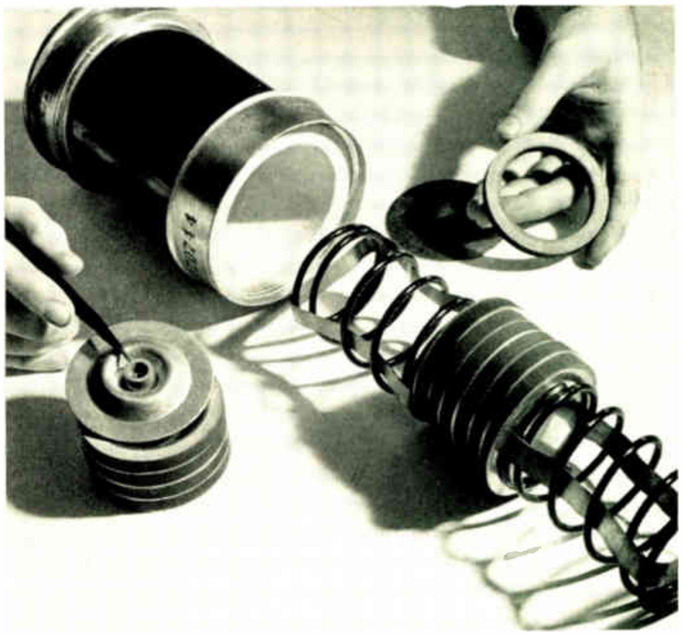
Lightning Arrester Ionizes Own Air Gap

THE air gap in a lightning arrester must perform a sudden about-face. Every time there is a surge on the system, the gap must change from an insulator into a conductor and back to an insulator after the surge has passed. Such a transition would always occur at the same voltage were the dielectric strength of air absolutely constant. But because of variation in the number of free ions in the air gap, the breakdown voltage is not the same for every surge. Now comes a new addition to the lightning arrester, a small button of rutile (titanium dioxide), with dielectric properties that enable it to "pre-ionize" the air gap for the surge, and thereby insure a uniform voltage response.

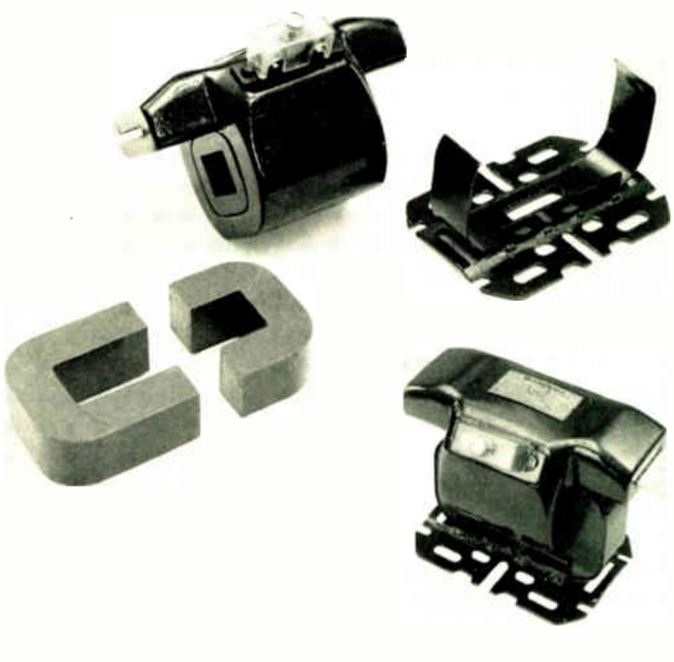
A lightning arrester protects against surges because its air gap, when ionized by the surge voltage, becomes sufficiently conducting to carry the surge current to ground before it has a chance to flow in the more valuable equipment. Air is normally a poor conductor, but becomes ionized at high voltage gradients. Free electrons in the air gap, which move at random if there is no electric field, become attracted to the positive electrode as soon as voltage is applied. As electrons accelerate, they collide with other atoms in the air and thereby liberate some more electrons, until eventually enough free electrons are present in the gap to make the air conductive. Obviously this process, known as ionization by collision, depends upon the number of free electrons originally in the gap, a number that is neither predictable nor constant, and the breakdown voltage of ordinary arresters varies with successive surges.

The rutile button insures an adequate supply of electrons when a surge occurs. Rutile has a very high dielectric constant (specific inductive capacity), about 80 times that of air. Thus, if there is high voltage across a gap consisting of rutile and air in series, the voltage divides so that there is a high gradient at the rutile surface adjacent to the air. As surge voltage begins to build up across the gap, the high gradient at the surface of the rutile causes corona, which in turn starts ionizing the air in the gap. By the time the surge voltage reaches a predetermined amount, enough ions have been created to permit the surge current to pass through the gap and be safely discharged to ground.

Rutile causes the arrester to discharge on lower voltages, but does not affect its ability to withstand overvoltages at power frequencies, or hinder in any way the extinction of the power-follow current. The arrester always discharges at the same voltage.

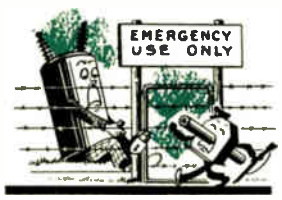


One good Hipersil development leads to another. Latest addition to the family is a current transformer having all the features and advantages of his larger brothers at reduced size and weight. It comes in current ratings up to 800 amperes and for voltages up to 15 000, and is designed to meet the dimensions and impulse-test specifications standardized by the Edison Electrical Institute.



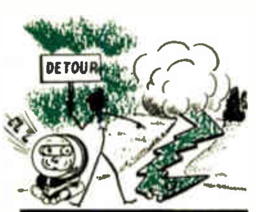
P E R S O N A L I T Y   P R O F I L E S

More than any engineer we know, *E. L. HARDER* can see a physical, practical significance in an abstract mathematical concept, and transform a set of complex equations into a relaying scheme, complete with the specifications for the relays. The whole idea of the simplified pilot-wire system that appeared about four years ago (commonly known as the HCB scheme) came to him as he was solving a group of problems in symmetrical components. Harder specializes in the intricate protective relaying that is part of every central-station job, but in his capacity as Central Station Engineer he must consult with various utility engineers on all their power generation and distribu-



tion problems. The extent of his proficiency can be judged by the 40-odd patents granted to him and by the similar number of technical papers that he has written or co-authored. All this was accomplished in the relatively brief span of 15 years he has spent with Westinghouse since his graduation from Cornell in 1926. And to confirm the adage that the busier a man is, the more time he has left for other activities, Harder has been finding time to teach relaying and system protection.

Asked about the interesting phases of his present occupation, *A. M. OPSAHL*'s comments were that "Something new is always turning up." We don't know whether he is referring to his work on lightning arresters or to lightning itself, which always seeks new places to strike. In either case, lots of new things have popped up since his graduation from Luther College, Decorah, Iowa, in 1924, considering that protection against lightning those days was limited to minimizing the effects of induced strokes only. He came to Westinghouse in 1925, after a year's teaching at his alma mater, and after a few years in the engineering laboratory, he was assigned to lightning arresters. Like all specialists, to paraphrase Shakespeare, the two things he could not avoid were patents and technical articles. When time permits, he finds distraction in photography and woodwork.

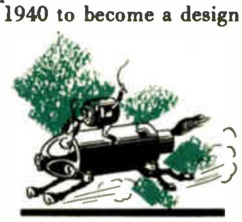


W. V. JOHNSON, who likes to make relay contacts keep still, does not put any damper to his own activities. He is really a hundred-per-cent engineer, meaning that when he is not busy on some relay design problem at the office, he amuses himself by developing or redesigning some home gadget in his basement workshop. This thirst for knowing the exact workings of things probably began at the age of five with a thorough analysis of the universal laws of motion as applied to alarm clocks. He is somewhat hazy about the findings, as well as about the details of his earlier development, but does admit holding a B.S.E.E. from Minnesota ('25), and joining the Westinghouse Company shortly afterwards. He has been with the Meter Division of Westinghouse ever since, and among his many contributions to protective relaying (in addition to the non-bounce contacts described in this issue) has been a flexible lead terminal now used on all new relays. His hobbies are gardening and hiking, neither a lazy man's task.

Keeping things noiseless must be a second nature with *H. FAHNOE*, an extremely quiet and modest fellow. His actions, however, are far from being speechless. Now Consulting Engineer for the Westinghouse Transformer Division, he keeps on tap a huge reservoir of practical experience acquired during his thirty-six years with the Company. A native of Denmark, he received his electrical engineering degree in Darmstadt (Germany) in 1905. He didn't get very far upon arrival to the United States the same year—the Westinghouse Meter Works in Newark is only a short distance from the New York harbor. Motor engineering came next, and in 1913 he transferred to the

Transformer Division. Touching on almost every phase of the art, his experience includes several trips abroad, many patents, and authorship of technical papers. In his spare time—which is severely rationed by the demands of war production—he reads voluminously, particularly history and biography. To quote Johnson, "There is no part of history so generally useful as relates to the successive advances of science."

W. H. FORMHALS, who now specializes in the Rototrol and its applications, started to become an engineer after he had already joined Westinghouse as a clerk in 1925. After several years of concurrent work and night study, he decided that school was a full-time job in itself, and went to the University of Illinois, from which he was graduated in 1930. A short spell with the Westinghouse student course preceded his going to Lehigh University. There he received his master's degree and taught electrical engineering, first as an instructor, then as assistant professor. He returned to Westinghouse in 1940 to become a design engineer



in the Motor Division. Regardless of his hobbies, his spare time these days is devoted to work.

Two prominent engineering names again figure in our passing show. *S. G. HIBBEN's* was the first article of the first issue (May, 1941). Much has been heard of him since December 7 because of his authority on defense lighting.

Another repeater is *RALPH WRIGHT*, who gave us the article in the August issue on steel-mill motor speed control. He maintained an active interest in dynamometers, even in the days when they were a matter of minor engineering concern, and can write about them expertly now that they have come of age.

One individual who has had much more to do with this and previous issues of *Westinghouse ENGINEER* than any whose name has appeared among "Personality Profiles" is *J. G. ADASHKO*. He joined the editorial staff as the Assistant Editor shortly before the *Westinghouse ENGINEER* made its public debut a year ago. Although he came here from Poland at the age of 17, Adashko has acquired the necessary skill with words while receiving his technical education, which includes a B.S. in E.E. (Purdue '33) and an M.S. (N. Y. U.), in this country. On his way to our office, he picked up his engineering experience with the Western Electric Co., in the naval architects' offices of Gibbs and Cox, and with the Public Service Co. of New Jersey, meanwhile developing his ear and hand for music. (Not content with being a patron of the opera, Adashko is becoming a skilled pianist.) At other odd moments he keeps his fingers busy at a portable typewriter of near-museum age, pecking out humorous articles on engineering and other subjects.

Air of a room where precision instruments are assembled is made to run this gauntlet of electrical air-cleaning cells, which snare all dust particles, large and small. A detailed discussion of air cleaning begins on page 46.