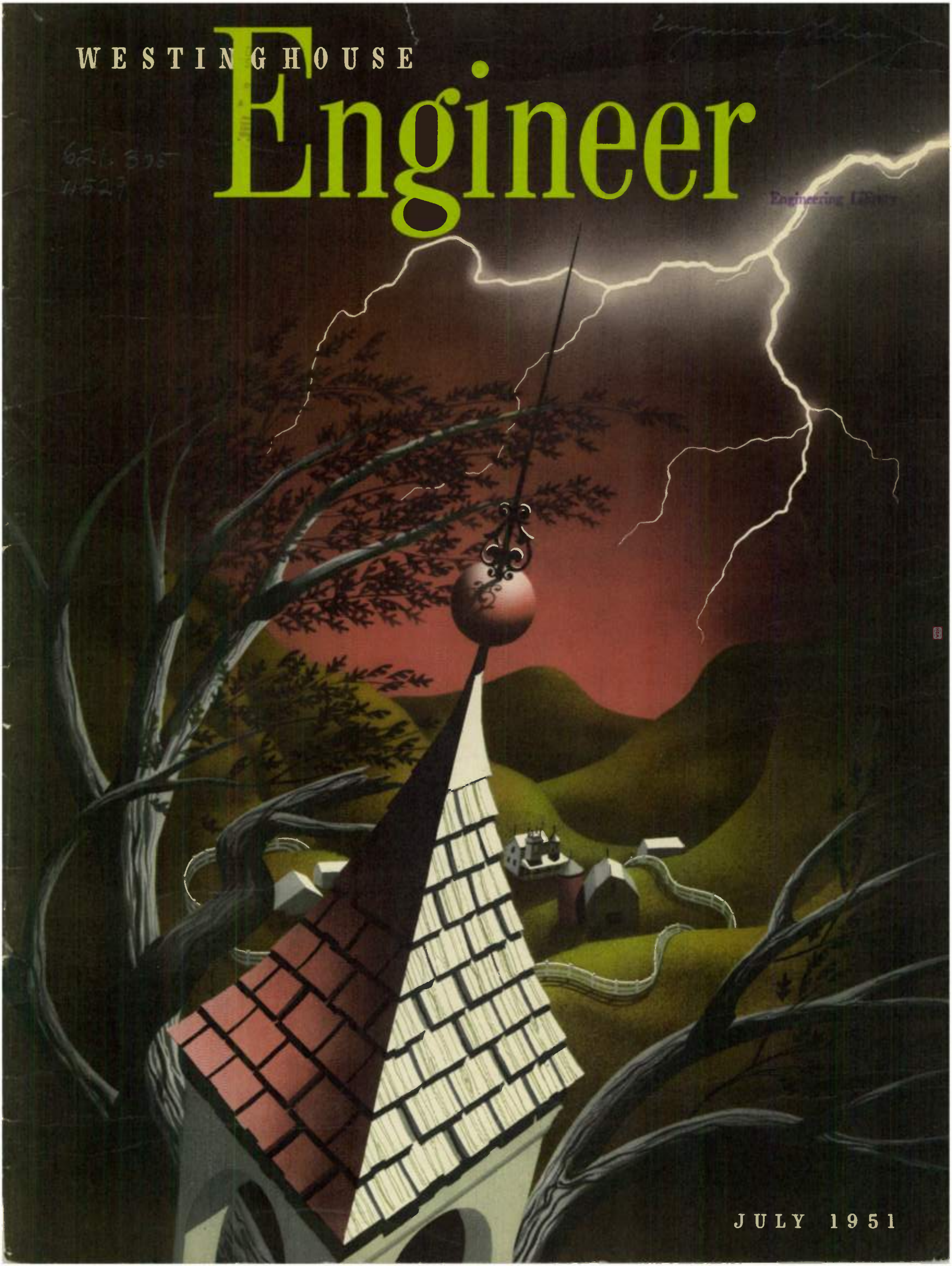
WESTINGHOUSE

Engineer



JULY 1951

LIGHTNING Protection ...and how it grew

The lightning arrester had its beginning a half century before the electric-power industry was born. The invention of the telegraph in 1844, by Samuel Morse, saw the installation of wire lines along railroad right of ways. The need for lightning protection was then born. The answer, in those early days, was various forms of saw-tooth air gaps, which were quite satisfactory because after a surge had been dissipated to ground the power supply (wet-cell batteries) was not sufficient to maintain the arc.

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But with the advent of electric-power systems, first the low-voltage Edison d-c system in the early 80's and the Westinghouse a-c system a few years later, matters changed. Power-follow capacities—miniscule by today's standards—were beginning to become large enough to exceed the arrester's ability to resume an insulating condition after discharge. Various types of gaps, some with series resistances, however, continued to be the only answer. These became progressively less satisfactory.

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One of the problems of gaps was the burning of the electrodes by the power-follow current. Some relief for this came when Wurts of Westinghouse in 1892 introduced his "Non-Arcing" lightning arrester. The "non-arcing" quality—quite definitely an overstatement—came from the use of brass contacts, which certainly did give less arcing than the contacts previously used.

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The first new protection principle came with the invention in Germany of the electrolytic arrester about 1905. When a voltage is impressed on an electrolyte contained in aluminum trays a film is formed on the metal. This film normally is an insulator but is punctured by a lightning surge. After the surge is passed, the film reforms, returning the arrester to an insulating condition.

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For many years the electrolytic served its purpose well. But it required frequent maintenance and charging to reform the film. It was outmoded by the oxide-film arrester that appeared in 1918. This arrester operated on a similar, film-breakdown principle, but employed no liquid and hence required much less servicing.

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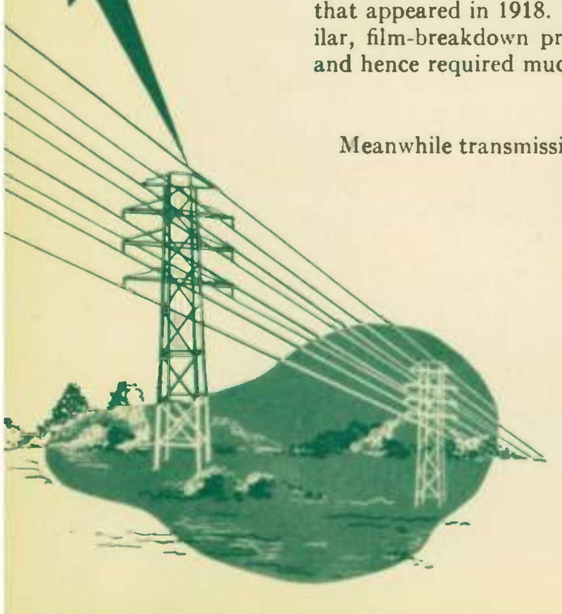
Meanwhile transmission voltages continued to rise and short-circuit capacities grew. In the early 20's Dr. Slepian began an active search for a new and better interrupting principle. He had studied Crookes-tube phenomena and had experimented with discharges in gases (which later resulted in his De-ion arc-interrupter inventions). From these he knew that if the surge could be forced through a multiplicity of narrow air passages he would have an arrester with the characteristics he wanted, i.e., low current density to provide a high arc voltage. His first device to achieve this was built up of many thin discs of resistance material in series. This was the beginning of the Autovalve arrester. This was followed by the porous clay block in which were embedded carborundum particles. In these blocks the arc was confined to a large number of small pores. Autovalve blocks have since been improved by greatly increasing the carborundum content, which increases the surge-current carrying capacity and decreases the voltage across the individual blocks during discharge.



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The Autovalve arrester now nearly 30 years old continues to be one of the two basic types used for protection of power apparatus. Many thousands are in satisfactory service. However, the exact mechanism of action during a surge is not understood. It is believed to involve some surface-contact phenomenon of the carbide crystals. This is one for further research to solve.

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The second basic type of lightning arrester in common power-system use employs the expulsion principle. This now appears in many varieties, but they all stem from the idea promulgated by J. J. Torok of Westinghouse in 1929 by which the air in a narrow passage between fiber walls is broken down by the surge voltage. The resulting arc vaporizes some of the cellulose material, creating a large volume of gas, which, in escaping, expels the ionized particles. This allows the gap to resume its insulating function at an early current zero after the surge is dissipated.

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Almost coincident with the introduction of the expulsion arrester came a new idea that gave a new concept of the job to be done by the arrester. Dr. C. L. Fortescue exploded the time-honored belief that arresters primarily are to protect against overvoltages induced by nearby strokes. Direct strokes, it had been felt, created surges of such severity that no protection could prevent damage. Fortescue showed that induced surges are unimportant and that direct stroke surges, while severe, are not inevitably destructive. In other words, the discharge current that arresters must deal with is much larger than had been suspected. Currents as high as 35 000 amperes have actually been measured through arresters in service. Doubtless even larger surge currents have occurred. In the laboratory currents of 100 000 amperes have been discharged through Autovalve arresters without damage. The more difficult arrester duty comes from smaller currents of longer duration.

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Lightning arresters have become a dependable single line of lightning defense. Their performance has made possible the coordination of insulation on all other classes of apparatus connected to high-voltage lines—such as transformers and circuit breakers. Thus instead of insulating each device so that it is self-protecting, reliance is placed on the arrester, with a consequent great reduction in the total insulation (and cost) required.

WESTINGHOUSE Engineer

VOLUME ELEVEN

JULY, 1951

NUMBER FOUR

On the Side

The Cover—Our cover artist periodically screams loud and long that, although an industrial artist, he likes to paint scenes too. So this month Dick Marsh uses a rural scene to illustrate lightning.

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Each new day brings with the routing slip another biggest, fastest, smallest, best something. As superlative is heaped upon superlative, they begin to lose meaning and no longer describe industrial progress.

The first 15 000-kw, 3600-rpm gas turbine generator for electric-power generation has been ordered by the Public Service Company of Oklahoma. The turbine, using natural gas for fuel, will drive a hydrogen-cooled generator. Intercoolers will lower the temperature of the air between compression stages; and to reduce fuel consumption, exhaust gas will be used to preheat the air.

The gas turbine notwithstanding, that old mossback, the steam turbine, still comes in for its share of headlines. Public Service Electric and Gas Company of New Jersey has ordered a 185 000-kw tandem-compound steam turbine. This single-shaft 3600-rpm machine will operate at 2350 psi, 1100 degrees F, with reheat to 1050 degrees F. The 25-inch turbine blades will be the longest ever used.

And four huge type—FOW transformers—each rated at 190 000 kva, three phase, 60 cycles—have been ordered by the Detroit Edison Company. They will step up 15 kv (generator voltage) to 138 kv.

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Did you get your copy of the 10-year cumulative index to the *Westinghouse* ENGINEER? This includes reference to everything we have published from 1941 to the end of 1950. Copies are available to you for the asking.

In This Issue

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The history of experience with lightning is proof that to know is to master. Only 25 years ago engineers were resigned to inevitable damage to power lines from direct strokes. Now circuits are designed for any desired economical degree of freedom from lightning damage.

Lightning Phenomena

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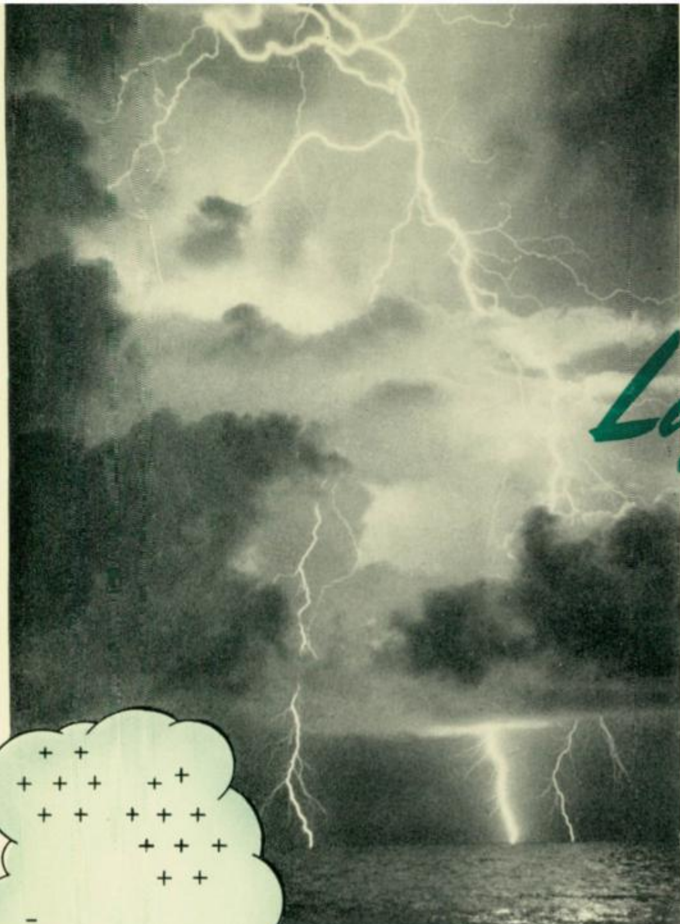
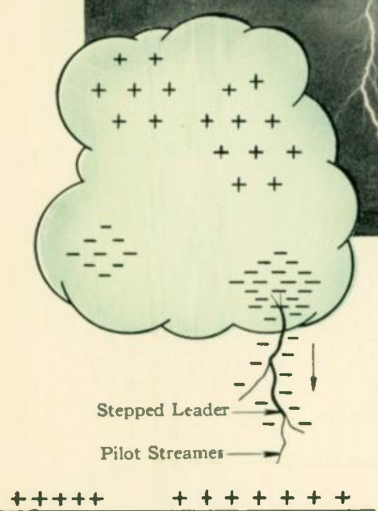


Photo of "Summer Flash," courtesy of Charles S. Watson and U.S. Weather Bureau.



← **Fig. 1(a)—This sketch shows the typical charge distribution in a thundercloud. When the voltage gradient to ground becomes great enough the pilot streamer starts toward the earth moving at less than 0.1 percent of the speed of light. It is followed to earth by a stepped leader of higher current density.**

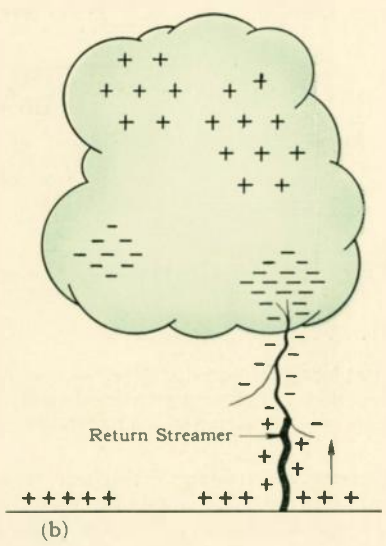


Fig. 1(b)—The bright, high-current return streamer is also surprisingly slow. It moves about one tenth as fast as light, but 100 times faster than the pilot streamer because the arc channel was partly ionized by the original streamer from the cloud.

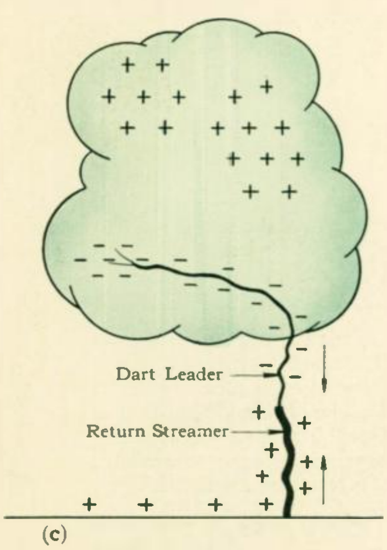


Fig. 1(c)—When a dart leader discharges a second charge center in a thundercloud, the arc is similar to a stepped leader. When this second discharge strikes the earth, another luminous, high-current return streamer travels up to the cloud from the earth.

Few people think of the simple causes of lightning: air, water, and low temperature. Although the elements are simple, the processes that act to build up an electrostatic charge in a cloud and establish an ionized path for the current—the conditions that lead to a lightning discharge—are most complicated. Studies of thunderstorm clouds indicate that electric-charge separation is caused by precipitation, rapidly rising air currents, and freezing water droplets. While water droplets are freezing and forming ice crystals, an electric potential exists between the water and the ice that charges the unfrozen water positively. In a thundercloud some of this charged water is separated and carried by vertical air currents to the upper part of the cloud where it forms a positive charge center. The heavier negatively charged ice crystals move downward in the cloud and form a concentration of negative charges nearer the earth. Usually, a small positive charge is found near the bottom of the cloud also, but the much larger negative charge induces a positive charge in the earth below, as shown in Fig. 1(a).

As the charge-separation process continues, the potential between cloud and earth increases; but because the earth is so large, the voltage gradient at earth seldom exceeds 100 volts per centimeter. However, the gradient in the cloud can become as high as 10 000 volts per centimeter and, as the critical breakdown voltage of air is exceeded, a small corona discharge called the *pilot streamer* moves earthward carrying negative charge from the cloud into the space below. The pilot streamer moves down, followed by a current arc called the *stepped leader*. The stepped leader is the first part of a lightning stroke that can be seen. It moves in spurts, or steps. See Fig. 1(a). These steps are about 150 feet long, and the ends, where one stops and the next one begins, are points of bright luminescence. When the pilot streamer strikes earth, an extremely bright, high-current *return streamer* travels from earth to cloud along the ionized path established by the first discharge from the cloud. This is the bright flash characteristic of lightning strokes, and is shown in Fig. 1(b).

The ionized path between cloud and ground established by a lightning discharge often causes adjacent charge centers in the same cloud to discharge to earth. When this happens, a *dart leader*, originating in the second charge center, propagates to ground along the original arc channel and causes another high-current return streamer to move up to the cloud, as shown in Fig. 1(c). Such lightning strokes made up of more than one discharge are called multiple or repetitive strokes, and each discharge is a component of the stroke. Most strokes have at least two components, but some having more than 40 separate components have been recorded. The time interval between components varies from thousandths to tenths of seconds. To the unaided eye repetitive strokes generally appear to be single flashes; but sometimes the separate components can be seen.

The lightning stroke represented in Fig. 1 is by definition a stroke of negative polarity; thus, a negative stroke is one that lowers negative charge to ground. About 90 percent of all strokes to ground are negative. Cloud-to-ground discharges are of prime importance in the art of lightning protection; however, discharges also occur between charge centers within a cloud, and between different clouds.

In lightning-protection work, stroke current is the most significant property of lightning. Consequently, the magnitude and wave shape of the stroke current are important considerations. Average lightning current and wave shape are illustrated in Fig. 2. The initial high-current peak neutralizes the charge in the stroke channel, and the moderate current of longer duration exhausts the charge remaining in the cloud.

The explosive and incendiary effects of lightning vary widely. A stroke that blows a tree apart, or extensively damages a masonry structure, may have little burning effect. But another, with little bursting power, may start a fire. The characteristic current wave shape of explosive strokes—"cold lightning"—is a high current of relatively short duration, Fig. 3. Strokes that start forest fires or ignite farm buildings—"hot lightning"—have long, continuing current of low magnitude, Fig. 3. High initial current may be followed by low current of long duration in a single discharge. These stroke properties and other properties significant in power system work are summarized in the table on page 108.

Lightning-Recording Instruments

A variety of special instruments has been developed to accumulate the large mass of lightning data on which our present understanding is based.

The *cathode-ray oscillograph*, when adapted to record lightning discharges, gives current magnitude and wave shape, and is particularly suited for recording wave fronts accurately. The oscillograph in Fig. 5 has a special tripping circuit, a time-sweep generator, and a photographic recording system. It is replacing the oscillograph using the Norinder relay, which for nearly 25 years provided the most accurate wave-shape records. The oscillograph records on film the current magnitude and wave shape by measuring the voltage drop across a non-inductive, resistance shunt. The voltage to be measured is passed through a delay line so that none of the record is lost. Thus, the surge pattern is "stored," or "remembered," long enough for the cathode-ray beam to start after the surge begins. Although the cathode-ray oscillograph records lightning currents accurately, its high cost restricts its use to only the more important recording stations.

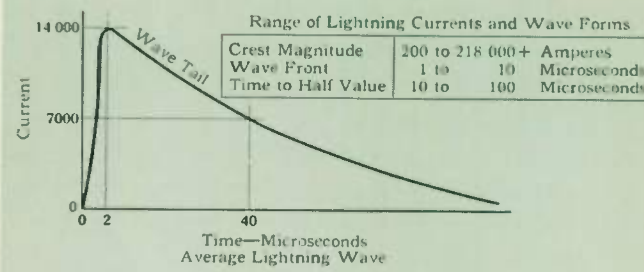


Fig. 2—This is a 2-40 microsecond wave. It reaches crest in 2 microseconds and decays by one half in 40 microseconds.

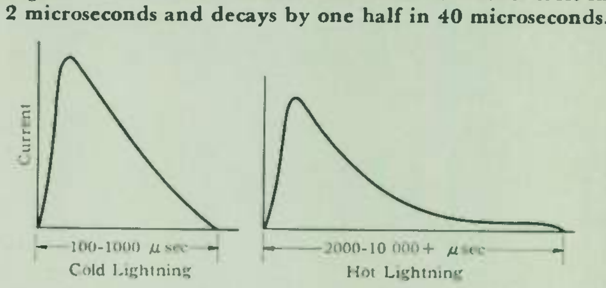


Fig. 3—High current that lasts only briefly, shown at left, frequently causes an explosion. The current at right, although smaller, lasts longer and often generates much heat.

Fig. 4—The ceraunometer is a stroke counter. Most lightning strokes within six miles of a given point result in positive field change and are indicated on the counter on the right side of the ceraunometer. Cloud-to-cloud discharges beyond six miles cause negative field change and register on the stroke counter at the left.

Fig. 5—J. M. Clayton inserts a film holder in an automatic cathode-ray oscillograph. The small electric motor turns the circular film so that separate components of multiple strokes can be recorded. The oscillograph is normally energized, but the electron beam of the cathode-ray tube is suppressed to keep from burning the screen and fogging the film. When lightning strikes, the surge trips the sweep generator and simultaneously intensifies the trace of the beam.

The *ceraunometer*,[1] Fig. 4, counts the number of lightning discharges occurring within a given area. It works on the principle that electrostatic field changes accompany all lightning strokes. These electrostatic field changes operate the two stroke counters of the ceraunometer through two independent electronic circuits. One circuit responds to positive field change and counts most strokes occurring within about six miles of the instrument. The second circuit responds to negative field change and counts just the cloud-to-cloud discharges occurring between six and twelve miles from the ceraunometer. The areas covered by the inner and outer zones can be controlled with reasonable accuracy by adjusting the sensitivities of the circuits. Thus, from the ceraunometer records—the total number of strokes in a given area, and the cloud-to-cloud discharges in an adjacent area—the number of strokes to ground per unit area can be found.

The *magnetic surge-crest ammeter* in Fig. 6(b), because of its simplicity, is used extensively to measure crest magnitude and polarity of lightning currents. A bundle of permanent-magnet steel is placed, unmagnetized, near the conductor carrying the lightning current. The magnetic field produced by the current magnetizes the steel *magnetic links* in proportion to the magnitude of the current. The residual magnetism in the links is then measured with a special instrument to determine the magnitude and polarity of the current. This instrument is used principally for measuring current in transmission line towers, overhead ground wires, and arrester ground leads. Its low cost makes it particularly useful where data must be obtained at many different locations.

The *fulchronograph*, Fig. 6(a), records wave shape as well as magnitude and polarity. The essential part of the instrument is a rotating aluminum wheel with 408 magnetic links mounted on its periphery. The links pass successively between coils that carry the current to be measured. Each link is magnetized by the instantaneous current in the coils at the time it passes between the coils. By measuring the residual magnetism in the links the wave shape of the lightning current can be plotted. Greater wave detail is obtained by placing in series a slow-speed (60-rpm) and a high-speed (3450-rpm) fulchronograph. The high-speed wheel with its resolving power of 43 microseconds (time interval between links) records the wave shape of most individual components; the slow-speed wheel, with a resolving power of 2450 microseconds, records components of very long duration and measures the time between components of multiple strokes.

With a resolving power of 43 microseconds the fulchronograph cannot measure wave fronts. The *magnetic surge-front recorder*, Fig. 6(c), is used for this purpose. A voltage pro-

TABLE I—SUMMARY OF NATURAL LIGHTNING DATA (Pertinent to System Protection)

I—VELOCITIES OF PROPAGATION

	Ft per Microsec Range	Ft per Microsec Avg	Percentage of Speed of Light
Downward pilot streamer	0.25–3.0	0.5	0.05%
Return streamer	40–500	100	10 %

II—APPARENT SURGE IMPEDANCE OF ARC CHANNEL 5000 ohms

III—STROKE CURRENTS TO TRANSMISSION LINES

1% over 111 000 amp*	20% over 33 000 amp
5% over 63 000 amp	50% over 14 000 amp
10% over 50 000 amp	70% over 9 000 amp

*Maximum recorded: 218 000 amp

IV—TOWER CURRENTS (600 to 1000 ft spans)

1% over 62 000 amp*	20% over 27 000 amp
5% over 42 000 amp	50% over 10 000 amp
10% over 33 000 amp	70% over 8 000 amp

*Maximum recorded: 135 000 amp

V—DISTRIBUTION-TYPE ARRESTER CURRENTS

1% over 21 000 amp	20% over 3000 amp
5% over 9 000 amp	50% over 1200 amp

VI—STATION-TYPE ARRESTER CURRENTS

1% over 9000 amp	20% over 1800 amp
5% over 4000 amp	50% over 800 amp

VII—WAVE FRONTS OF DIRECT STROKES

8% exceed 6 microsec	62% exceed 2 microsec
23% exceed 4 microsec	90% exceed 1 microsec

Recorded range from less than 0.5 to over 10 microsec
50% of strokes over 30 000 amp exceed 4 microsec

VIII—WAVE FRONTS OF ARRESTER DISCHARGE CURRENTS

10% exceed 6 microsec	50% exceed 2 microsec
17% exceed 4 microsec	70% exceed 1 microsec

Steepest high discharge current recorded: 5000 amp in 1 microsec

IX—RATE OF RISE OF DIRECT STROKE CURRENTS

5%* over 42 000 amp/microsec	20% over 17 000 amp/microsec
10% over 25 000 amp/microsec	50% over 8 000 amp/microsec

*Maximum recorded rate of rise: 45 000 amp/microsec.

X—TIME TO HALF VALUE OF HIGH-CURRENT COMPONENTS

	Direct Strokes	Distribution Arresters	Station Arresters
Over 20 microsec	96%	84%	65%
Over 40 microsec	57%	50%	20%
Over 60 microsec	14%	31%	7%
Over 80 microsec	5%	17%	4%
Avg. time microsec	43 ms	40 ms	27 ms

XI—DURATION OF INDIVIDUAL STROKE COMPONENTS

Duration of Current Exceeding 50 amp	Direct Strokes	Distribution Arresters	Station Arresters
Over 50 microsec	100%	98%	78%
Over 200 microsec	78%	73%	18%
Over 1000 microsec	23%	20%	3%
Over 10 000 microsec	10%*	3%	2%

*Longest direct-stroke components exceed 0.3 sec

XII—NUMBER OF COMPONENTS PER STROKE

Direct Strokes	Arrester Discharges
55% at least 2 comp	34% at least 2 comp
17% at least 6 comp	8% at least 6 comp
Average: 2.2 comp	Average: 1.5 comp
Most recorded: 40 comp	

XIII—POLARITY 90% of all lightning strokes are negative (those that lower negative charge to earth).

XIV—CHARGES IN DIRECT STROKES

5% exceed 130 coulombs*
20% exceed 63 coulombs
50% exceed 25 coulombs
*Maximum recorded: 160 coulombs
Charge through arrester rarely exceeds 1 coulomb.

XV—TOTAL DURATION OF COMPLETE STROKE

Direct Strokes	Arrester Discharges
89% over 0.001 sec	19% over 0.001 sec
45% over 0.1 sec	17% over 0.1 sec
10% over 0.5 sec*	6% over 0.5 sec

*Maximum recorded: over 1.5 sec

XVI—FREQUENCY OF STROKES (IKL=30)

To Transmission Lines....1 per mile per yr
To Small Substation......1 in 10 years
In Open Country..........10 per sq mile per yr
Higher isolated structures:

Height	No. Times Struck	Height	No. Times Struck
100 ft	0.4 per yr	800 ft	4.4 per yr
200 ft	0.8 per yr	1000 ft	10 per yr
400 ft	1.5 per yr	1200 ft	20 per yr

XVII—STROKE CURRENTS REQUIRED TO FLASH OVER TRANSMISSION LINES AND PROBABLE NUMBER OF OUTAGES PER YEAR

No. Insulators (or equiv.)	Midspan Separation	Stroke Current for Flashover*	Outages per 100 Mile/yr*
8	19 ft	80 000 amp	1.9
10	25 ft	97 000 amp	0.9
12	32 ft	116 000 amp	0.5
16	48 ft	150 000 amp	0.3

*Based on 1000 ft span, 10 ohms tower-footing resistance, ground wires, IKL=30, 0.1% shielding failures.

XVIII—SHIELDING ANGLE TO LIMIT STROKES TO PHASE WIRES TO 0.1% OF TOTAL

Height of Conductor	Height of Ground Wire	Shielding Angle*
25 ft	40 ft	40 deg
50 ft	65 ft	39 deg
100 ft	115 ft	28 deg

*Angle made with vertical by plane through ground wire and phase wire.

XIX—DISTANCE FROM TRANSFORMER TO LIGHTNING ARRESTER (TRANSFORMER CONNECTED TO OVERHEAD LINE)

System Voltage	Line Construction or Insulation Level	Maximum Distance*
69 kv	Wood	22 ft
69 kv	Steel	32 ft
138 kv	Wood	33 ft
138 kv	Steel	46 ft

*With full transformer insulation and 100% station-type arrester.

XX—MAXIMUM CABLE LENGTHS FOR CABLE-CONNECTED EQUIPMENT*

Equipment Basic Insulation Level	Lightning Arrester Rating**	Station-Type Arresters
60 kv	3 kv	NL
60 kv	6 kv	NL
95 kv	9 kv	NL
95 kv	12 kv	NL
95 kv	15 kv	80 ft
150 kv	20 kv	NL
150 kv	25 kv	90 ft

NL means no limit to cable length.
*Liquid-filled transformers, dry and compound-filled instrument transformers.
**Rating of arrester at junction between cable and overhead circuits.

Fig. 6(a)—The fulchronograph uses magnetic links to measure current. The rotating wheel adds time to the record so that wave shape and duration of the surge can be determined.

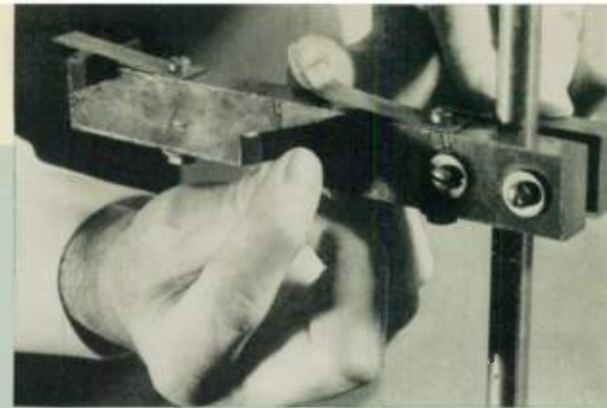


Fig. 6(b)—A magnetic surge-crest ammeter being prepared for use. Links spaced two and six inches from the lightning mast give a measuring range from 600 to 30 000 amperes. With links placed further from the conductor, lightning-surges of even higher current can be measured.

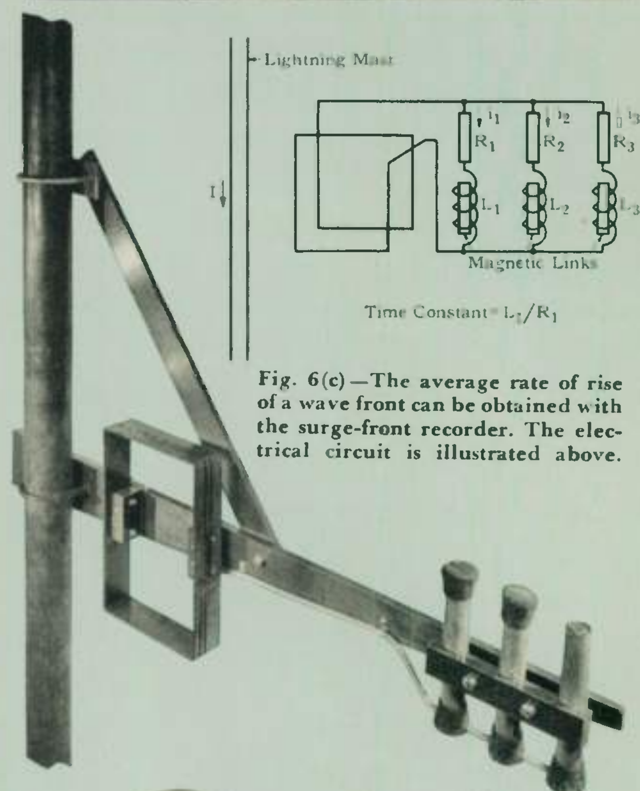


Fig. 6(c)—The average rate of rise of a wave front can be obtained with the surge-front recorder. The electrical circuit is illustrated above.

portional to the rate of rise of the surge current is induced in a loop inductively coupled to the current-carrying conductor. This voltage is applied to three parallel resistance-inductance circuits having time constants of 2, 5, and 10 microseconds. Magnetic links placed in the magnetic field of the inductors in these circuits record their maximum currents. From calibration curves the average rate of rise of the wave front and time to crest can be determined.

The *photographic recorder*, Fig. 6(d), is important because it registers currents ranging from the highest values down to less than one ampere; and its low cost permits installation in large numbers. The instrument photographs the luminescence produced by the surge current across a short air gap. A special aperture and set of barriers spread the light from the gap non-uniformly over moving film. The width and density of the image indicate the current magnitude. The film speed of one revolution per second permits measurement of time between components and on power lines shows the individual cycles of power-follow current.

Lightning Protection

Our knowledge of the lightning phenomena and the many complex recording instruments are only means to an end. What we're after is protection from the effects of lightning.

As the pilot streamer approaches the earth it tends to strike the highest point in the immediate vicinity. This gives rise to the concept of shielding—diverting lightning from vital wires or equipment by installing a grounded wire or mast above the equipment. Model tests and experience with actual lines and stations indicate that a grounded wire effectively shields a wedge of space below it at an angle of 40 degrees on either side of the vertical. This is shown in the sketch in Fig. 7. A shielding angle of 30 degrees is commonly assumed on important lines to provide a safety factor of 10 degrees to cover hillside effects and other irregularities.

Shielding, of course, does no good if the voltage drop in the shielding wire is so high that it causes a flashover to the equipment being protected. That's why trees are not good protection during thunderstorms. They are poor conductors, and the high-voltage drop developed across them often causes

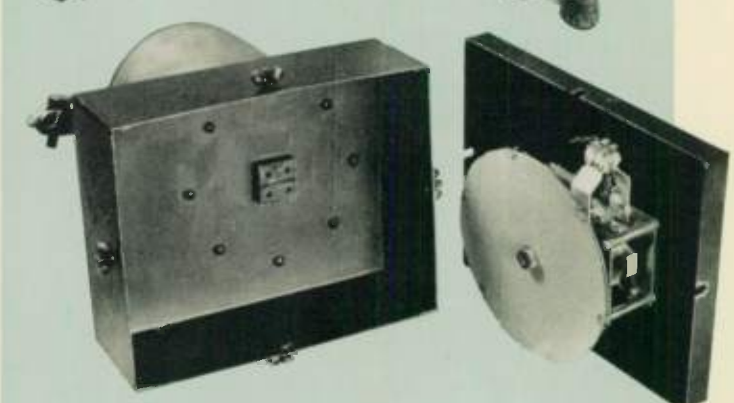
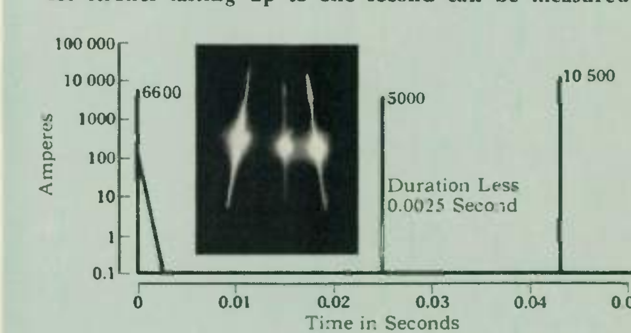


Fig. 6(d)—A photographic recorder with the cover removed is shown with a typical record. Currents from 0.1 to 150 000 amperes, and time intervals between components for strokes lasting up to one second can be measured.



flashover to objects nearby. To be effective, overhead static wires must be grounded through tower-footing resistance low enough to prevent flashover to phase wires on most strokes.

Protected Lines

Practically all lightning outages on high-voltage lines are caused by direct strokes and can be prevented by properly applied overhead ground wires. Such protection is installed on most lines of 66 kv and above. Use of overhead shielding is increasing even on 33-kv lines. With a shielding angle of 30 degrees or less (see part XVIII of table) a ground wire intercepts all but about 0.1 percent of the strokes. Since there are an average 100 strokes per 100 miles of line per year at an isokeraunic level of 30 (see Fig. 8), shielding failures account for only 0.1 flashover per 100 miles per year.

A stroke entering a ground wire near a tower passes to ground through the tower and footing resistance. It develops a voltage at the ground wire equal to the inductive drop in the tower plus the IR drop across the resistance. The phase wire voltage is also raised somewhat due to magnetic and capacitive coupling with the ground wire. So the insulators are exposed to a voltage equal to one minus the coupling factor times the ground-wire voltage. By lowering the footing resistance and properly insulating the line, flashovers can be kept to any desired probability. For strokes near mid-span, the spacing can be chosen to prevent flashover for all currents below certain magnitudes with a predetermined low probability of occurrence. With published curves[2] that give the footing resistance, the number of insulators, and the mid-span clearance required, a line can be designed for any desired probable number of flashovers per 100 miles per year.

Lightning performance obtainable with different numbers of insulators is indicated in part XVII of the table. Wood insulation is effective against lightning and often 33- and 66-kv wood-pole lines are equivalent to lines with 8 to 10 insulators, and have only one or two flashovers per 100 miles per year. There are still fewer tripouts because the wood reduces the ratio of outages to flashovers.

Unprotected Lines

For the lower voltage lines, 33 kv and below, shielding is frequently not justified economically, and a somewhat different technique must be used.

A power line in sections with an isokeraunic level (IKL) equal to 30 will be hit by lightning strokes of 2400 amperes or more, an average of once a year per mile of line. (Most power-line measurements have been made with instruments measuring tower currents of 2400 amperes or more.) A lightning stroke on one wire of a power line sees a surge impedance of 250 ohms (looking in both directions on the line). So a 2400-ampere stroke to a phase wire of an unprotected line builds up 600 000 volts (250 x 2400) through the surge impedance of the line. This is the flashover voltage of a 35-inch air gap, or six standard 10-inch-disk suspension insulators. Thus, most strokes cause flashover of lower voltage unprotected lines having insulation below this level, or unless arresters pass the surge.

Usually prevention of lightning power-arc damage on lower voltage lines depends on spacing that permits the arc to clear rather than preventing the lightning flashover. Lines in urban areas are exceptions. Arresters on distribution transformers prevent many lightning outages, and this improved performance is one of the justifications for their use.

At least one company[3] has correlated power-arc damage (requiring repairs) with wood spacing per kv of circuit voltage on 13.2- and 33-kv circuits. As the wood per kv is increased from 0.5 to 2 inches on 33-kv circuits, a 13 to 1 reduction in damage is achieved. Similar improvements result on 13.2-kv lines, where spacings up to 3.5 inches of wood per kv are beneficial.

However, these figures are variable. A similar line is likely to have twice as many outages in Tennessee (IKL = 60) as in New York (IKL = 30). (See isokeraunic map, Fig. 8.) And if grounding conditions make only 20-ohm tower footings possible, compared with say 10 ohms, the allowable

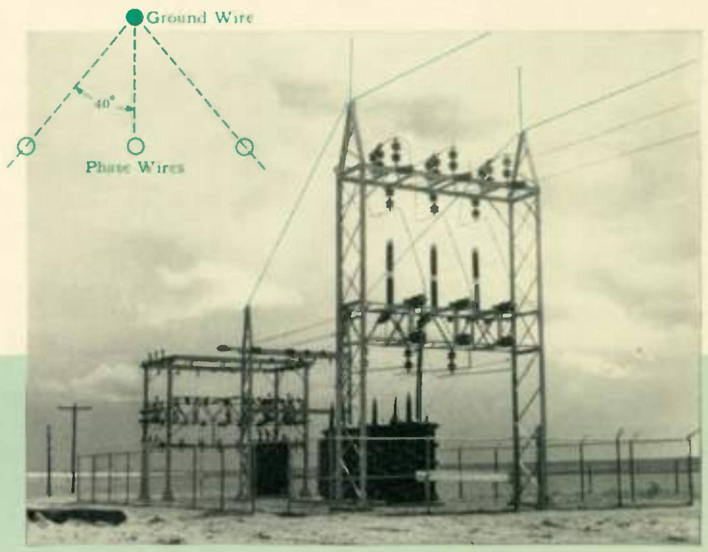


Fig. 7—The sketch and picture at the right illustrate typical shielding of a substation. The sketch shows how an overhead ground wire protects a transmission line. Shown in color in the photograph are the lightning masts atop the steel towers and the overhead ground wires that extend above the lines for about a mile from the substation. →

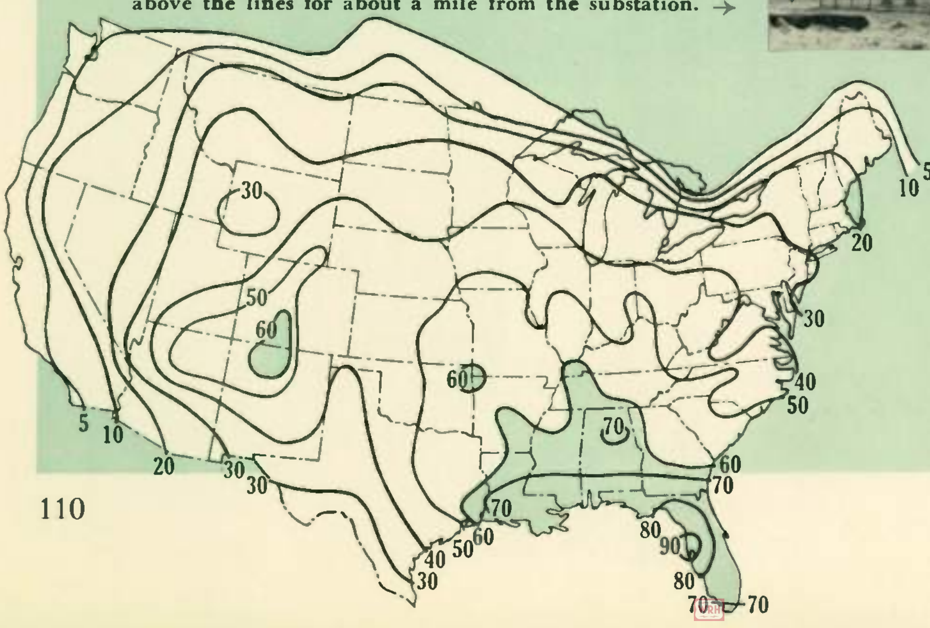


Fig. 8—The irregular lines on this isokeraunic map connect points with the same annual isokeraunic level (average number of thunderstorm days per year). East of the Rocky Mountains the overall average is 40 storm days per year, but two centers of much greater activity, shown in color, occur in New Mexico (60 storm days) and Florida (90 storm days). The quietest thunderstorm month is December; a peak is reached during July.

Storm disturbances on power systems follow this same trend, although they vary widely from year to year even in areas of the same isokeraunic level (IKL) because local topographic and meteorological conditions affect storm densities. Lightning probabilities on power systems are usually based on an isokeraunic level of 30.

lightning current on a protected line may be cut by one third because of the larger voltage drop developed. That one factor might increase flashovers four times. Part III of the table shows that strokes over 50 000 amperes are ten times more frequent than strokes over 111 000 amperes.

Protection of Substations

Shielding plays an essential role in the protection of substations also. Typical shielding, illustrated in Fig. 7, includes masts or wires to intercept direct strokes to the station and ground wires over the lines for about one mile out from the station. When this is done, protection can be based on strokes occurring a mile or more from the substation.

All recorded heavy-current arrester discharges at substations are caused by direct strokes within 500 to 1000 feet of the station. Depending on the IKL, such strokes would be expected about once or twice every ten years, as shown in part XVI of the table. This agrees with the number of observed arrester currents having steep fronts and crest currents over 5000 amperes.

The voltage at a transformer may rise considerably above that at an arrester 50 or 100 feet away from the transformer. With the acceptance of shielding to limit lightning current on phase wires, the relation between arrester and transformer voltage can be determined. Studies were made on the Anacom (electric analog computer) for two important cases, [4, 5] one corresponding to the use of cable, the other to the use of overhead lines or bus between the arrester and the transformer. Parts XIX and XX of the table show typical values from the recommendations resulting from these two studies.

The electric analog computer is a new, powerful tool for solving complex lightning-protection problems. In calculating transmission-line lightning-performance design curves and in determining the relation between arrester voltage and transformer voltage at a station, the lines and equipment are represented by equivalent electrical circuits (analogs) and the entire phenomenon is studied in miniature. The Anacom is used also to study the complete protection of specific substations, particularly larger ones too complex for accurate estimates by any other means. Studies have also been made of currents in arresters discharging high-voltage lines and cables, of traveling waves on lines with corona, and of the effect of mismatch where the overhead ground wire starts.

Fig. 9 — This is the direct-stroke lightning station on the roof of the Cathedral of Learning. Dr. E. L. Harder is placing the photographic recorder in its protective house. A high-speed and a slow-speed fulchronograph are evident on the table in the foreground. Surge-crest ammeters, a surge-front recorder and an automatic cathode-ray oscillograph (not shown in the picture) are also used at this station.

The computer is particularly useful in analyzing field records of natural lightning.

Lightning Field Investigations

Although present lightning-protection methods are on a sound engineering basis, field investigations continue. Direct-stroke lightning-recording stations are important because there the total lightning current can be measured. On electric power systems, only part of the total stroke current can be recorded because it passes to ground through a number of parallel paths. In a direct stroke station, a single mast receives the stroke and passes all current to the instruments.

A direct-stroke station is maintained by Westinghouse atop the University of Pittsburgh's 535-foot Cathedral of Learning. Some of the equipment there is shown in Fig. 9. The 50-foot steel mast (extending above the test board in the picture) has trapped strokes at an average of two to three per year for the past 12 years. The full current passes through five instruments that record complete details of current magnitude and wave shape.

Lightning arresters and other protective devices are also tested here under actual lightning conditions. There are four wires in series on the upper right corner of the test board. These four copper conductors, ranging in size from number 16 to number 10, are placed in the lightning current path to determine the largest size that can be melted by lightning current; number 18 is the largest melted thus far at this location, but there are authentic records of number 14 wire being fused by lightning current. And much larger wires have been severed on power lines.

A lightning stroke believed to be the largest ever measured was recorded at the Cathedral of Learning in 1947. A current of approximately 345 000 amperes was determined by measurement of the current in the mast and estimates of the amounts that flowed in parallel paths down the supporting guys. Normally the mast would carry the total current since the four guys are insulated from ground by four feet of wood, but this super stroke flashed over the wood insulators, completely shattering one and badly splintering two others.

A direct-stroke station is also maintained on a tall smoke stack at Great Falls, Montana in cooperation with the Anaconda Copper Mining Company.

A study of arrester-discharge currents is being conducted on several 25-kv substations of the West Penn Power Company. The arresters protecting the substation equipment discharge comparatively frequently because the substations are fed by unprotected, wood-pole lines.

Strokes to transmission lines of various designs are recorded on 33-kv wood-pole lines of the Public Service Company of Northern Illinois. The studies involve lines protected by overhead ground wires and De-ion protector tubes, as well as unprotected lines. The phenomenon of arc extinction is studied on the unprotected lines with photographic recorders that record the lightning and power-follow current.

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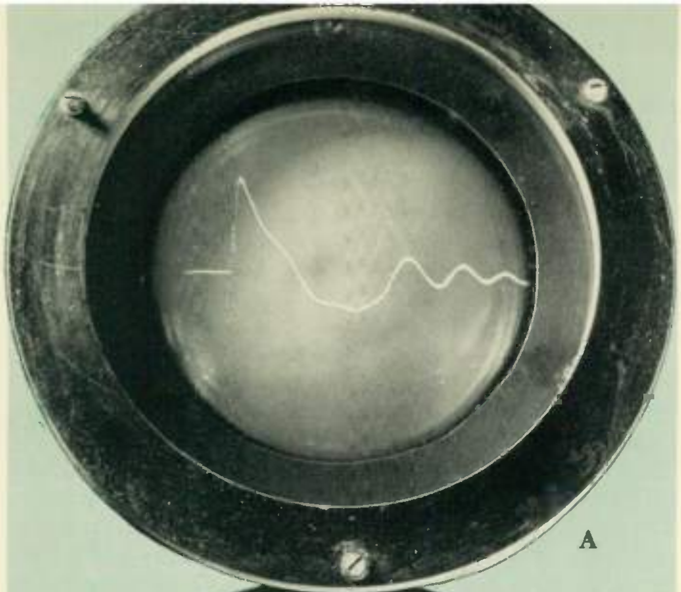

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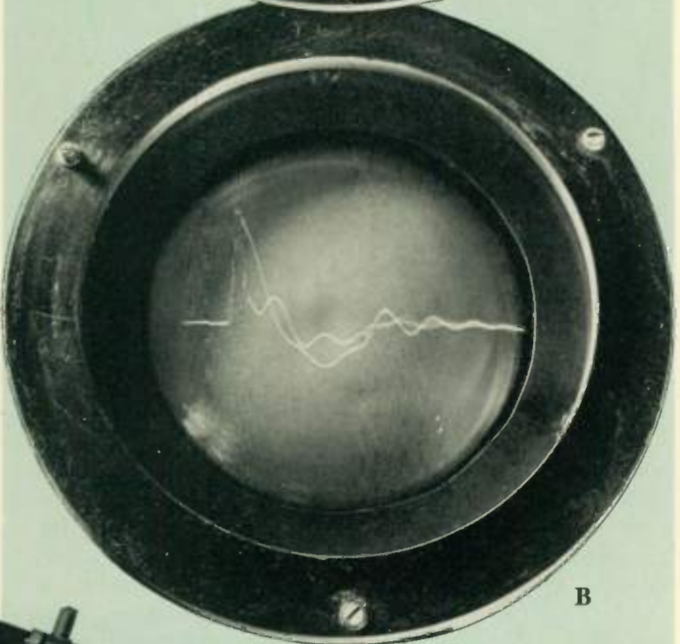

B

Testing Insulation with the *Surge Comparator*

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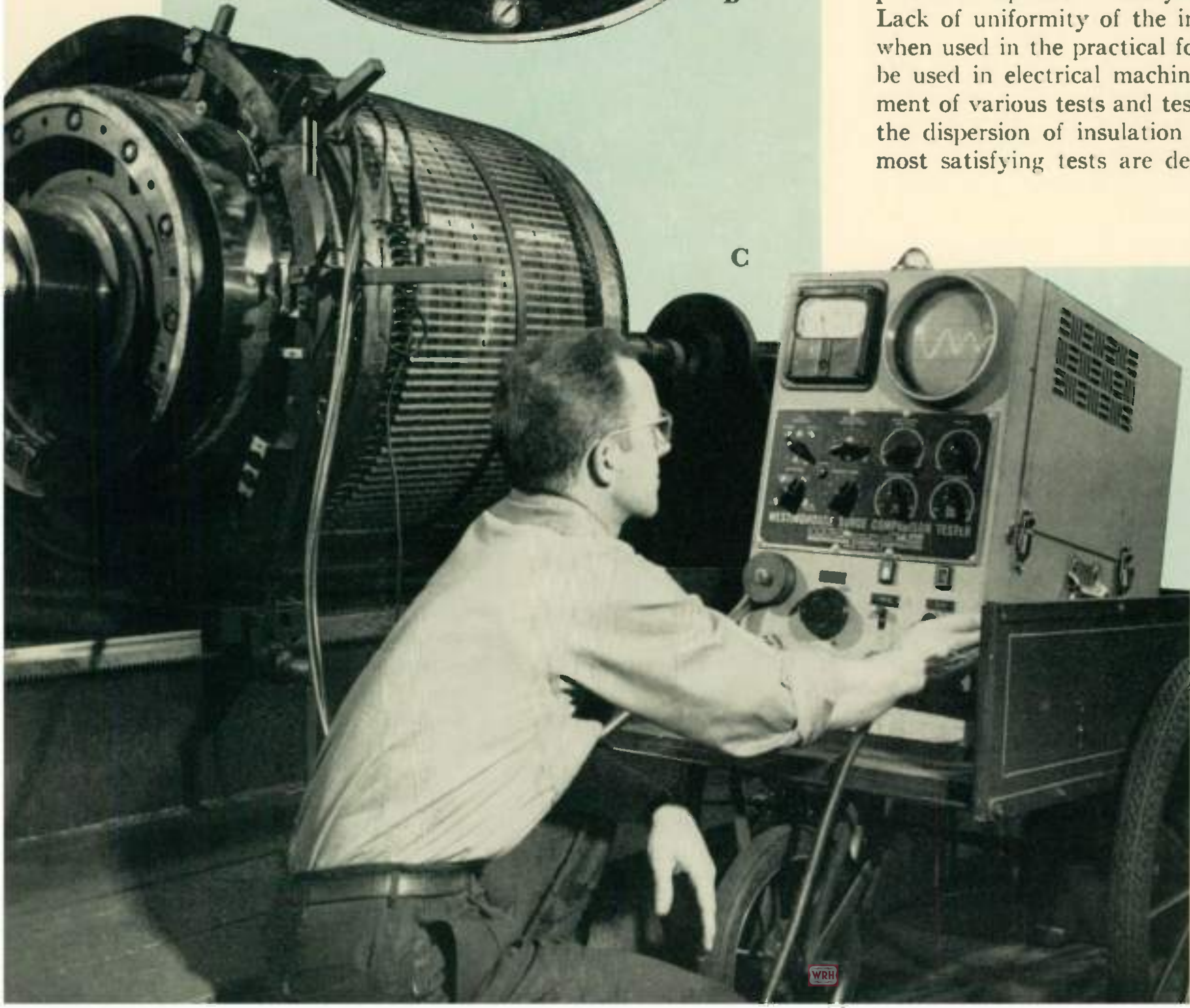
A small, repeating surge generator and a cathode-ray oscilloscope are teamed to provide a means of checking visually the soundness of insulation.

The insulation of electrical machinery is an art requiring shrewd selection of materials and processing. Just as no single theory of insulation failure will guide the machine designer, so no single test procedure can certify the length of life or all attributes of quality of the insulation of a machine. Sound, proved theories are used by the insulation designer to reduce to a minimum those areas of uncertainty where practical experience and judgment must perforce prevail. Lack of uniformity of the insulation strength of materials, when used in the practical forms and thicknesses that must be used in electrical machinery, has impelled the development of various tests and testing equipment. Unfortunately, the dispersion of insulation strengths is so great that the most satisfying tests are destructive. Each insulation test

C



When surges are alternately placed on two supposedly identical windings and the resulting traces coincide, as in *A*, the insulations of the two are alike; when two traces appear, *B*, the insulation of one is defective. The portable surge comparator is, in *C*, being used to check a large rotor. A side view of the portable unit is shown in *D*. Fig. 1—The essential circuit elements of the surge comparator applied to testing of direct-current armatures.

that can be successfully applied serves to reduce greatly the insulation failures in service. However, no single insulation test can be considered universally applicable.

The Surge Comparator

Established methods of dielectric testing of motor, generator, transformer, and other electrical apparatus windings have been to apply a high potential (about twice the rated voltage plus 1000 volts) between the winding terminals and the frame. However, failure often occurs between coils or between turns after the apparatus is placed in service. Obviously the ground-insulation test does not disclose weaknesses in turn insulation. This method of testing from conductor to ground is still employed, but it cannot conveniently be used to determine the value of the insulation between turns or coils, or as a means to detect short-circuited turns.

Adequacy of insulation for a given service is usually demonstrated by high-potential tests. Testing of insulation between turns, coils, layers, and phases is as important as the testing of ground insulation but it presents special problems and requires radically different tests. As early as 1926 Westinghouse engineers recognized the importance of this phase of testing and developed the Rylander high-frequency test set, which continues to find extremely useful application.

That there was a great need for a compact, portable machine that would produce a high voltage at relatively low currents with surge characteristics has been realized for some years. Surge generators as such are not entirely new, but those used for such work as transformer testing are cumbersome and expensive. To meet this need, the surge comparison tester was developed.

Surge-comparison testing of electric windings is a relatively new and useful tool for detecting and locating insulation faults. The application of a known and controlled voltage surge with visual comparison of the wave shapes through two similar electrical windings makes it possible to study insulation faults as well as to detect them. Because the energy of the surge is extremely limited the current through the faulty insulation is so small that no severe burning occurs at the point of weakness. The surge comparison tester opens the way to numerous possibilities for improving insulation testing equipment as well as insulation methods.

The surge tester is an electronic device arranged specifically to cover two functions: (1) to apply a voltage stress between turns of a coil, between phases, and from winding to ground, and (2) to detect short-circuited turns in windings under test. The turn and phase insulation is stressed by the application of a repetitive surge voltage to the winding in opposite directions. A mid-potential is displayed on a cathode-ray oscilloscope. If a short circuit occurs in one half that does not exist in the other, the difference in the impedance of the windings causes two traces to be observed on the oscilloscope, indicating a fault. If the winding is good, only one trace appears, making a simply interpreted indicator.

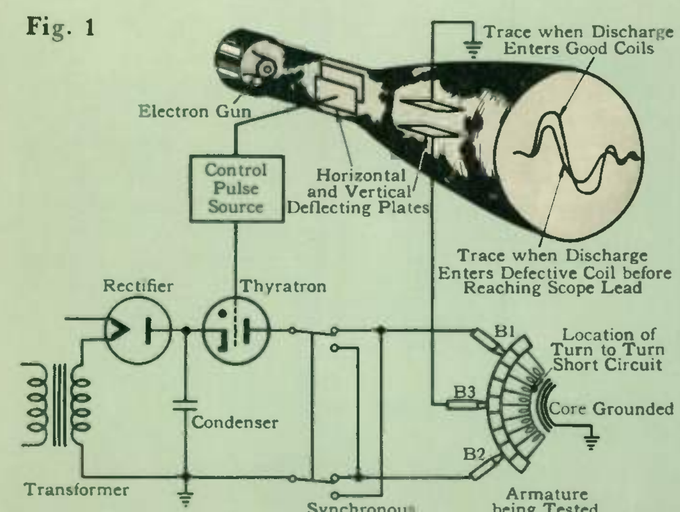
Two electrically similar windings are required to conduct the test. They can be either two presumably identical coils, one being a reference or standard, or a single coil can be tested if access can be had to the mid-point. The two windings are connected in series with a synchronous switch, which reverses surge and ground connections periodically. The mid-point connections of the two coils are connected to the oscilloscope plate terminal.

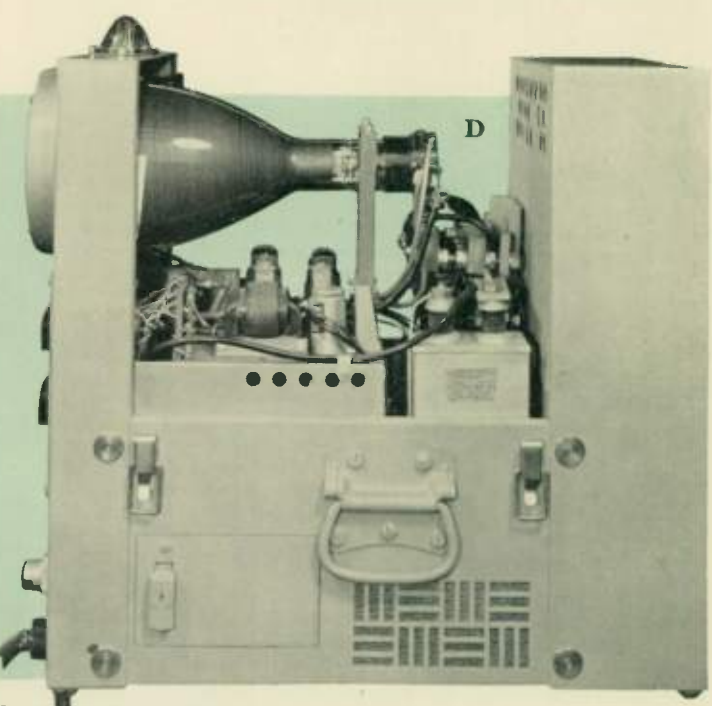
A condenser is discharged by a thyratron through a thyratron protective resistor into the winding under test. A Variac control and a meter permit adjustment of the voltage to which the condenser is charged. The applied test potential is effectively the charged voltage of the condenser when high-impedance windings are tested. When testing lower impedance windings, the voltage drop in the thyratron protective resistor should be allowed for. The surge is applied 60 times per second to the apparatus under test and lasts from about 10 to 450 microseconds.

A cathode-ray tube is used to indicate the surge potentials at the test mid-point. Owing to the short duration of the surges as a percentage of the total time (less than three percent) it is necessary to use a high-voltage cathode-ray tube to display the curves sufficiently brightly to see. A blanking circuit in the tester shuts off the cathode-ray tube except when the surge is displayed. This prolongs the life of the oscillograph.

The sensitivity to a fault varies in accord with the apparatus under test. Windings that have many turns all in inductive relation to each other, such as a field coil, permit an indication of faults corresponding to about one short-cir-

Fig. 1





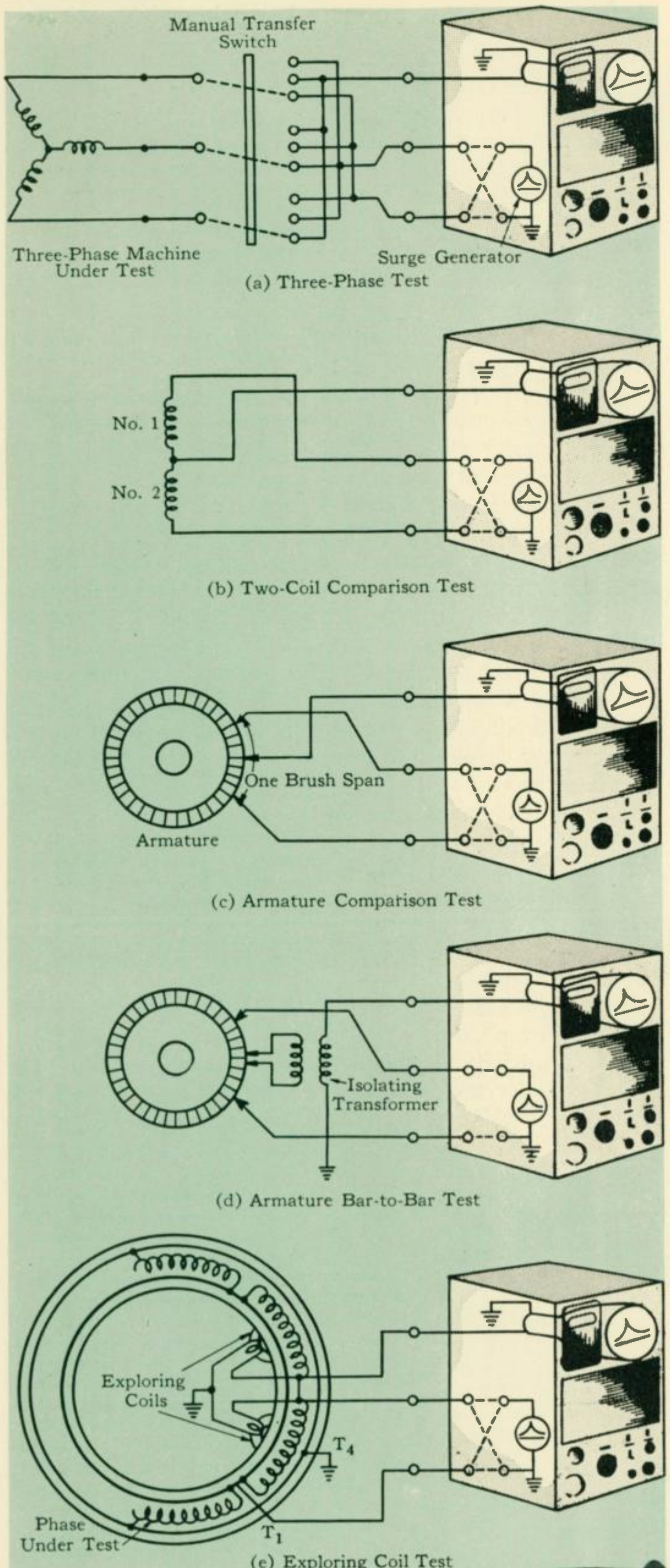


Fig. 2—Schematic diagrams and circuit arrangements of the surge-comparison test of various kinds of apparatus.

cuited turn in 400 or more turns. The sensitivity is less where the windings are distributed around a large motor stator, such as a 16-pole induction motor. Paths in parallel also reduce the sensitivity. More than four parallel paths generally result in loss of sensitivity to the point that the standard test method is no longer of value.

Connections are provided for the use of pick-up coils that can be applied in many cases to test windings with many parallel paths and to assist in locating the fault.

The comparator simultaneously tests the windings to ground, and indicates any fault to ground. However, it is not intended as a substitute for the standard 60-cycle ground insulation tests.

The power in the surge has a maximum heating value of 300 watts, which is low compared to that handled by most apparatus tested. Hence this test is essentially non-destructive and permits the easiest repair of defective insulation.

With proper accessories, this winding tester can be used for various motor windings up to and including many 2300-volt a-c motors, small relay coils, and d-c armatures up to about 750 hp.

In the case of some low-impedance armatures, the applied test potential may be lower than would be desired to cause breakdown of faulty insulation, but the indication is adequate to show a short-circuited turn that would be difficult to find by other methods.

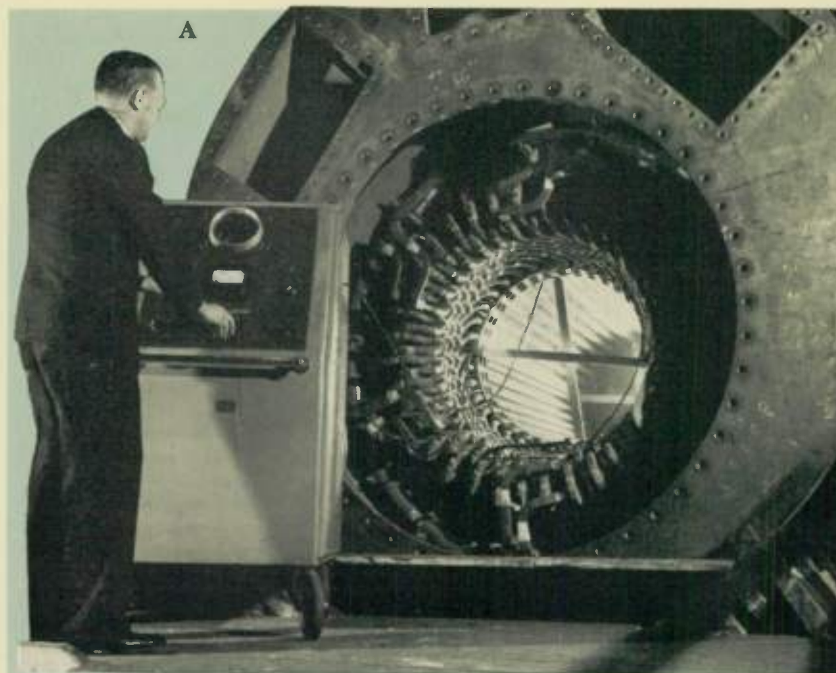
How the Comparator Is Used

In surge-testing small motors, stators, both standard and test, are placed on a test fixture. These fixtures provide clips for connecting the motor leads to the surge tester and a search coil, which is located in the bore of the stator. The fixture also insures that the stator is well grounded. For this application a number of relays have been added to the comparator. These relays are controlled by two-hand pushbuttons on the panelboard. By means of these pushbuttons the connections of both the test and standard stators are changed. The two-hand pushbutton requires both hands on the panel in order to reduce the risk of electrical shock to the operator from coming in contact with the test winding.

One of the most common windings to be tested is that used on dual-voltage, capacitor-start motors. The main windings are tested by connecting the two sections of a winding in series. This connection produces a voltage between the two sections and checks the insulation between the two sections. However, because the method of winding results in the sections being distributed differently in the slots for different motors, resulting in the variance in the induction coupling, this test does not provide a good comparison. Such windings while not faulty, cause a divergence of traces because the test stator is not identical to the standard stators. In order to provide a truer check for faults, each section is tested individually and an alternating-current voltage is placed between the sections as a separate test. The operator tests each individual winding for grounds, opens, short circuits, reversed coils, polarity and short circuits between windings by pressing a series of pushbuttons. This insures that the motor is connected correctly and the insulation is sufficient to withstand many times normal voltage before it is impregnated.

The surge tester is used to check control coils, alternators, and direct-current generators for aircraft application. Since space and weight are at a premium, a number of sharp bends are made in large-size wire for this type of apparatus. Such bends weaken insulation around the wire. The insulation must be as thin as practicable to obtain the greatest output from a given space and weight, and consequently it must be free from defects.

On a 300-ampere generator, for example, the shunt and interpole coils are checked after each stage of assembly. The coils are wound and tested as coils alone. These coils have relatively few turns—six to ten—in the interpole coils, and any breakdown of insulation shows up clearly on the comparator screen. By means of the surge tester a potential of 1600 volts is placed across 10 to 15 turns. The coils are placed on the poles and connected together and another check made with the surge tester and finally after all connections are made and the load bus brought out for external connections, another check is made. In case of faults in the final apparatus, a set of pick-up coils is used to locate the defective coil.



The second type of surge-comparison tester, possessing some additional features over the portable or table model, is shown here in service checking: (*A*) the stator insulation of a high-voltage generator, (*B*) a small-d-c armature, and (*C*) the stators of fractional-hp motors.

The comparator is being used to test the windings of large motors and generators, traction apparatus, transformers, and many types of coils during factory assembly and service-shop repair. It is used to test simultaneously the turn-to-turn, coil-to-coil, and coil-to-ground insulation. Qualitatively, resistance, impedance, turn balance, and high-potential tests are all made with one voltage application. The principal limitation of the tester is voltage. The voltage limit of present thyratron discharge tubes is 10 000 volts crest. Hence the device is unable to apply directly sufficient surge potential to the windings of high-voltage apparatus to locate slight insulation weaknesses.

In d-c machine testing, several methods are available for detecting a winding fault. The conventional test is to apply the surge across one brush span and observe the voltage at the middle of the span as the armature is rotated. Only one brush span need be checked to test the whole machine. This method is used in factory testing of small traction motors.

The conventional comparison method is inadequate for locating a short circuit or ground in cross-connected or wave-wound d-c armatures. To overcome this difficulty a bar-to-bar voltage near the middle of the span is observed on the oscilloscope. With this arrangement, as the armature is rotated dead, short circuited or grounded coils are exactly and quickly located in any of the armature types tested. This method has been successfully used on a cross-connected, 12-pole, 5000-hp d-c motor.

In three-phase machine windings of many parallel paths, detection as well as location of a short-circuited turn or coil is not possible with the conventional test at the machine terminals. Detecting and locating faults in these larger three-phase windings were first accomplished by using the comparison scheme to compare separate parallel circuits before connection to the paralleling rings. This method was generally satisfactory and made detection of a coil having a faulted single turn relatively easy. The testing of the winding after completion was also desired, and the use of exploring coils was ultimately devised. With this method of using the surge comparison tester, a unidirectional repeating surge is applied to a terminal of one phase of the winding, the other terminal being grounded. While one phase at a time is thus placed under test, two identical exploring coils are moved around one revolution in the bore of the machine. The exploring coils are so spaced as to be over two coils that are in identical electrical positions, but in adjacent parallel circuits of the phase being tested. Since the two coils in the winding must react alike to the surge voltage if no fault is present, they will induce identical voltages in the *two* exploring coils. The induced voltages are rapidly and repetitively compared by means of the oscilloscope and synchronous reversing switch. This method was extensively used in testing ship-propulsion motors during World War II.

A more recent application of the surge comparison tester has been the testing of turn insulation on completed high-voltage turbine-generator windings using multi-turn half-coils. The tester is used to apply the surge voltage to exploring coils laying in the bore of the machine, which induce a voltage in individual generator coils. With this method it is possible to apply materially more voltage turn-to-turn than when the surge is applied directly to the machine terminals. Two exploring or surge-inducing coils are used to create a voltage in two stator coils of the same phase in identical electrical positions. The conventional comparison scheme, wherein the two induced voltages are alternately placed on a cathode-ray oscilloscope, is used to detect faults. The surge voltage that can be induced in a coil is of sufficient magnitude to stress the turn insulation to several times that encountered in service. Surge-induction testing of turn insulation on completed half-coil windings is the only known method of stressing turn insulation above operating conditions and at the same time detecting and locating turn insulation faults.

This method can be conveniently used to test multi-turn coils in wound stators of many types of machines without removing coil insulation. All multi-turn turbine generators utilizing half-coil windings now have turn insulation tested before leaving the factory. Several stator windings have been tested in the field without removing the rotor.

Winding dissymmetries may cause differences in the voltage traces of supposedly identical coils or windings although no fault exists. Many windings and coils have inherent dissymmetries caused by differences in their varnish treatment, amount of fill, moisture present in the winding, or unknown causes. These effects of winding dissymmetries have sometimes caused uncertainty as to whether a fault is or is not present in the device under test. Nearly all examples of this uncertainty can readily be eliminated in a practical manner by placing the minimum possible fault, usually one short-circuited turn, in the winding and observing the effect. One short-circuited turn usually produces the greater and more unmistakable effect in most types of armatures, field, and magnet coils and in small machines with few parallel paths.

The tester has been tried on numerous samples of all common types of coils and windings. In general it is a satisfactory test for many insulation-testing applications.

The surge comparison tester possesses many advantages, which can be summarized as:

1. The test voltage can be readily preset to any desired value and held at that value during testing.
2. Control of the tester is simple and easy.
3. The surge tester is safe to operate because coils and the frame can be grounded.
4. The surge tester is flexible; large generators or small coils may be tested with no change in circuit constants or connections.
5. The tester is available in two forms. One is a relatively lightweight and compact unit, which can be easily moved. A model on wheels and a portable bench-type model are available.
6. The cathode-ray oscillograph gives the operator a view of the test voltage and its effect on the winding.
7. The surge voltage applied has a wavefront at least as steep as the wavefronts of most switching and lightning surges, which are the source of dangerous over-potentials in service.

The surge-comparison tester is effective in culling out windings that have defects of a type not readily discovered by other tests. On a-c stators that are rated at 4300 volts or more, the surge tester is not fully adequate without special test procedures, but with a little ingenuity of application of the tests the test becomes an aid in detecting poor quality products before they are placed in service as has been described. The surge comparison tester readily detects reversed coils or coil groups that sometimes do not have sufficient error in winding to show up on other tests.

For d-c armatures the range of ratings where the surge comparison tester is fully adequate is not as large as in the case of a-c stators. However, both large and small traction motors can be comparison tested. In many cases it detects coils too roughly handled or which have drops of solder on the commutator.

In general, other impulse tests are better for transformer insulation testing, however, it can be used for mass-production testing of the insulation of small radio transformers. The surge comparison tester is also of value in testing a-c wound rotors, contactor magnet coils, field coils, and armature coils before winding into a machine.

Surge comparison testing has passed from the first experimental stage to the investigative phase and then through the first trials in production lines. It has proven an invaluable tool for assuring a better product. It has aided cost reduction by detecting winding faults earlier since the product can be tested at several stages of production, as it is quickly used. The surge comparison tester benefits both the manufacturer and the user of electrical equipment.

A discussion of materials important to the electrical industry now in short supply began in the May issue with copper. It continues now with nickel and cobalt, two very different metals, but which have much in common. While demand now exceeds supply, the long-range prospects for both metals are good.

THE STORY OF NICKEL AND COBALT

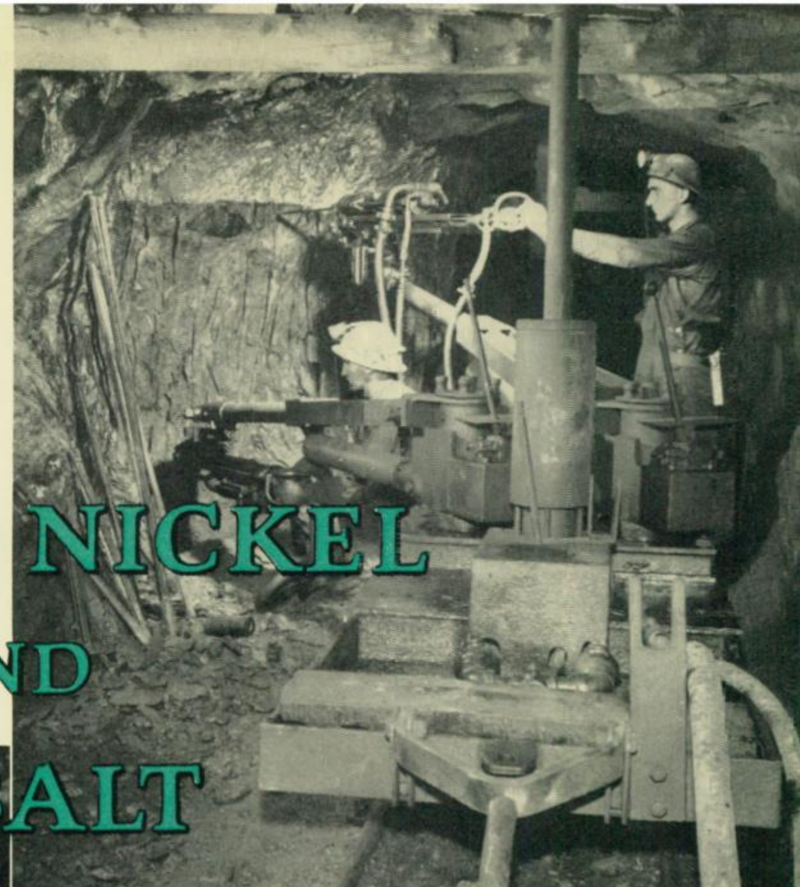


Photo courtesy International Nickel Co.

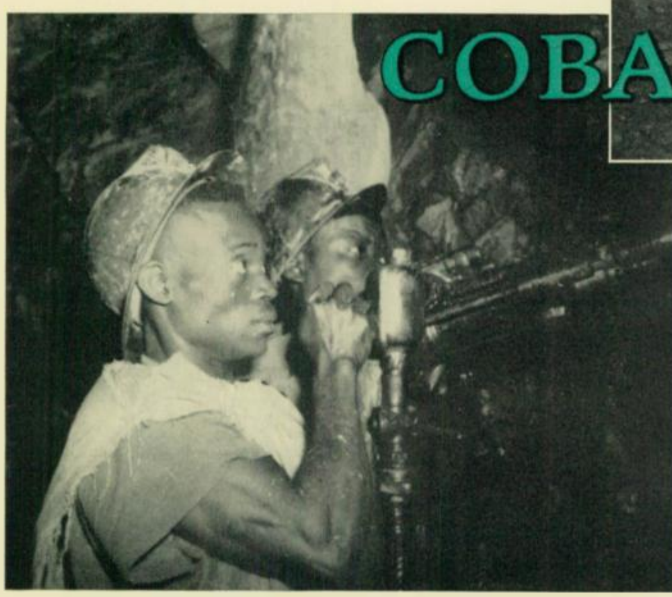


Photo courtesy Union Minière du Haut-Katanga.

NICKEL and cobalt have much in common. Both earned their names because they were nuisances. Nickel was Kupfer-Nickel (Old Nick's Copper) because it occurred with sought-after copper and played havoc with early methods of processing copper ore. Kobold—a mischievous spirit—was so named because ores containing it emitted troublesome and dangerous fumes, later proved to be associated arsenic. Now nickel and cobalt are earnestly sought. Both are growing in peacetime importance. In any defense program both are essential. They generally are found together in the mines. When one is mined, the other often comes along as a by-product. In fact, they are so much alike chemically that separation is difficult. While many of their uses are completely dissimilar, they often are teamed as alloying agents. And finally, production of each in the United States—the largest consuming country—is small. There are no known nickel deposits in the United States that could compete with the rich deposits of Canada and New Caledonia, but cobalt production in the United States has brighter prospects.

Prepared by Charles A. Scarlott from information provided by the U. S. Bureau of Mines, Howe Sound Company, International Nickel Company, and Westinghouse.

Nickel

Several times nickel has traversed a "rags-to-riches" cycle. Now it is enjoying the greatest success, use-wise, it has ever known. Further, the base of its industrial uses is so broad that it is not likely again to find itself going begging as it has when the industrial economy made sudden shifts from war to peace or prosperity to depression. Also—it is pleasant to learn—the world has copious quantities of nickel, although production facilities are being hard pressed to keep pace with the sharp rise in demand occasioned by the affair in Korea. World nickel production has averaged since World War II (1945–1949) 155 000 tons yearly. (All tonnages are given in terms of 2000 pounds.)

The story of nickel is primarily the story of The International Nickel Company. From its Sudbury mines in Northern Ontario come nearly three fourths of all the nickel produced in the world. Every other nickel-producing operation is small by comparison.

The nickel mines of the U.S.S.R. are important—important to the Soviets, that is. Estimates early in World War II indicated Russian nickel production as roughly seven percent of the world total, but it is believed that since the war this proportion has more than doubled.

After Canadian and Russian production comes—far behind—that of New Caledonia, which in the four postwar years, 1946–1949, averaged 4000 tons yearly or 2½ percent of the world output. The Union of South Africa and the United States in the same period produced roughly equal amounts, the two combined amounting to barely 1250 tons yearly. In both cases the nickel is a by-product of processing certain copper ores.

Small amounts of nickel have been obtained from Norway, Germany, Finland, Greece, Burma, India, and Japan. Cuba, Brazil, Venezuela, the Philippines, and the Dutch East Indies are known to possess large deposits of nickel-bearing ore, but difficult problems of production must be solved before they can be developed profitably.

Liquid nickel from converters is being poured (right) into large ladles. (All photos on this page are by courtesy of the International Nickel Company.)

This view of a large Sudbury, Ontario, open-pit copper-nickel operation will be historic in another year or two as the surface mines are about exhausted. Underground mining at Sudbury is increasing.

A concentrate from the copper-nickel ore is made by flotation.

Cuba's enormous deposits—three billion tons or more—of nickel-bearing iron ores also contain large amounts of chromium and cobalt. Financed by the United States Government, this deposit was worked during the war period, producing about 25 000 tons of nickel in the form of nickel oxide in 1945 and 1946 combined. Operation ceased in March, 1947 after a total cumulative production of about 32 000 tons of metal. However, mine and ore-processing plant are being rehabilitated by a private firm at the direction of and for the United States Government. Production will begin this fall and is expected to reach 15 000 tons of nickel annually or roughly 15 percent of 1946–1949 annual usage. The remodeled plant will be equipped for research, which may result in new production methods of separating cobalt from nickel, previously not done.

Cuban nickel-bearing ore is low grade, possibly averaging about 1.44 percent nickel. Also the nickel in the richest layer occurs as silicate minerals that cannot be initially concentrated or separated from the bulk of waste serpentine rock. The ore is mined selectively to obtain a plant feed containing about 1.44 percent nickel, all of which must be processed. An enormous quantity of material in relation to the actual nickel containing minerals must be put through the plant. The effect on cost is obvious.

Similar and very large nickel-iron ores occur in the Philippine Islands, Venezuela, the Celebes, and Borneo. Smaller, lower grades of this same kind appear in Japan, Greece, Madagascar, and Puerto Rico.

Brazil has a medium-size deposit of nickel ore of the silicate type, with important segregations of cobalt, composed of several score small bodies scattered over a number of square miles. These have been estimated as totaling 16 million tons of ore, containing one to three percent nickel. However, these occur in a region over 200 miles from the nearest railroad, far removed from a labor supply, and with neither coal nor, at present, water power for ore processing. A larger but lower grade deposit of this type is known in Venezuela where mining and transportation conditions are more favorable, but the low nickel content and the silicon present a difficult problem.

The only nickel ore within the United States that seems to offer major prospect at present is the Riddle deposit in Oregon. It is a silicate ore such as occurs in New Caledonia, but of lower grade. It has been roughly estimated at 40 million tons of one to two percent nickel. The M. A. Hanna Company, with encouragement and technical assistance from the U. S. Bureau of Mines, is studying the feasibility of its development. There are also some nickel-cobalt deposits in the vicinity of Fredericktown, Missouri.

Although copper ore was identified in the wilderness near the present town of Sudbury in 1856, it was not until 1883 that construction crews blasting a westward route for the Canadian Pacific Railway uncovered evidence of the enormous Sudbury ore body. Prospectors flocked in to stake "copper claims." Actual mining operations of the Canadian Copper Company, forerunner of the International Nickel Company, began in 1886. The presence of nickel was not suspected until the first ore reached the Bayonne, New Jersey refinery, whereupon it promptly manifested its presence in no uncertain terms. Just as the miners of Saxony a hundred years earlier had, in disgust, named the troublesome metal Old Nick's Copper, copper and nickel refused to separate, leaving a "worthless" metal, brittle and friable under the hammer. The Sudbury ores seemed doomed. Nickel in the Western World was born of discouragement.

But some Sudbury sponsors refused to give up, and out of

Cobalt-copper concentrate is reduced to liquid metals in electric furnaces like this in Africa. Photos courtesy Union Minière du Haut-Katanga.

Most of the Belgian Congo copper-cobalt ore comes from underground operations but Union Minière du Haut-Katanga does operate some large surface mines with modern equipment.

their labors came the discovery that the addition of sodium sulphate to the molten mixture caused the nickel sulphides to separate and settle by gravity from those of copper. Thus the riddle of the metallurgy of copper-nickel ores was solved by the Orford process, as it was called. The operators then had metallic nickel—too much of it. The problem became, what to do with it! By 1900, consumption—almost exclusively for coinage, electroplating, and german silver—totaled only 4000 tons per year. Sudbury ores alone could produce twice that much. More uses must be found for nickel if the Sudbury discovery was to mean anything.

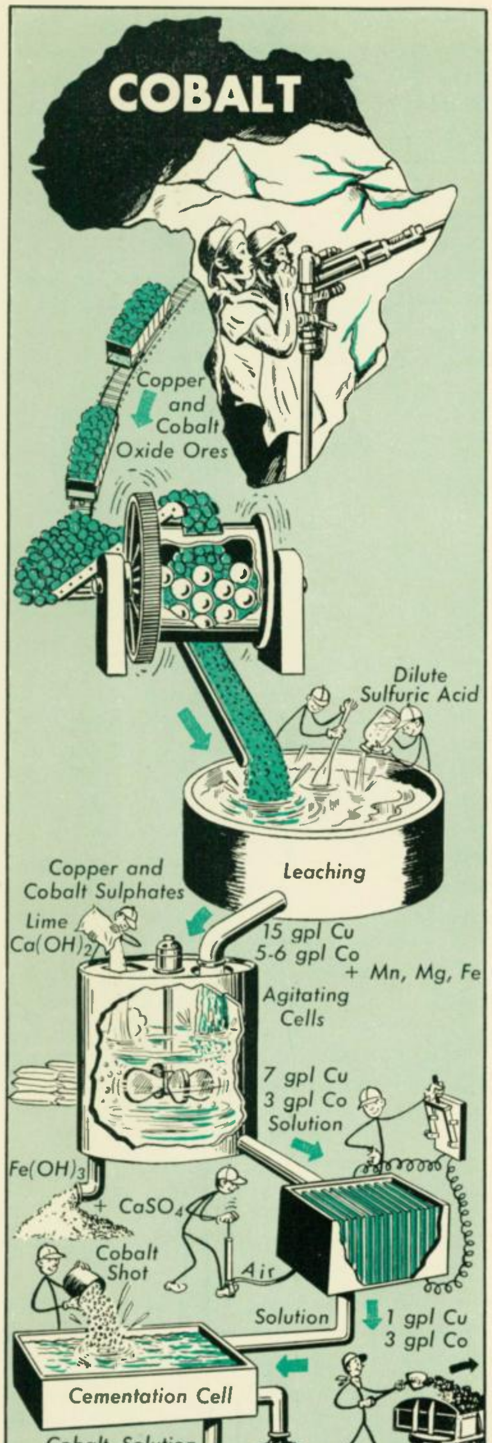
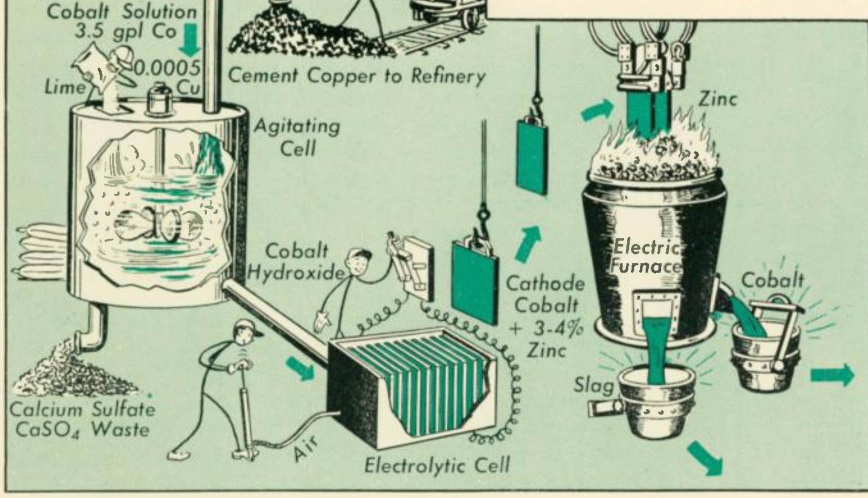
Word came of a French discovery that the addition of nickel to steel toughens it. Nickel producers, after trying without success to sell the idea to Krupp of Germany, induced the Secretary of the United States Navy to subject ordinary armor plate and nickel-steel armor to competitive test under the impact of six-inch shells. The superiority of nickel steel was clearly demonstrated with consequent placement of large orders for nickel—more, in fact, than the company was prepared immediately to provide. Feast or famine!

During the first two decades of this century demand for nickel developed rapidly, due principally to its use in armament. In 1900 total world production reached 10 000 tons (a third of it from Canada). In World War I, it had climbed to 50 000 tons in 1918 (and by then the 75-percent position of Sudbury nickel had become established). But with the war over and permanent world peace in prospect, nine tenths of the nickel market disappeared. Mines were closed. Production fell nearly to the 1900 level.

A fresh start had to be made; it became vitally necessary to explore the field of non-military production and develop new uses for nickel. Three things led to phenomenal success. Metallurgical experience during the war with nickel steels provided a great fund of knowledge about these materials. Also, the growing mechanization of industry was calling for heavier loads, higher speeds. Nickel alloying could help solve these more rigid demands on machinery. The automobile industry also had begun its rapid growth—and both manufacturers and customers were weary of cracked connecting rods and broken gear teeth. Further, public fancy was turning to brightly polished trim on its cars—a quality nickel could provide. As a consequence, nickel quickly recovered from its loss of armament markets. By 1929 it had reached a production peak of about 60 000 tons. This rise was interrupted only briefly by the depression of the 30's, so that by 1939 production had topped 130 000 tons. World War II skyrocketed nickel demand to 180 000 tons per year, which fell back to a world average of 155 000 tons in the 1946–1949 period. And now we have another rearmament period, with stock pile, military and civilian demand all together calling for more nickel than production facilities can

TABLE I—ANNUAL AVERAGE CONSUMPTION OF NICKEL IN THE UNITED STATES DURING 1946–1949 INCLUSIVE

	Short Tons	Percent
Ferrous		
Stainless steels	15 374	19.0
Other steels	17 058	21.0
Cast iron	3 638	4.5
Nonferrous	25 072	31.1
High-temperature and electrical-resistance alloys	5 538	6.9
Electroplating anodes	11 385	14.2
Electroplating solutions	570	0.7
Catalysts	451	0.6
Ceramics	180	0.2
Other	2 840	1.8
Total	80 687	100.00

comfortably produce. Hence the present need for rationing and limitation in use of nickel.

There is, however, no permanent nickel shortage. Extensive deposits, as mentioned, exist in many parts of the world, albeit many are fraught with various combinations of problems of grade, metallurgy, transportation, fuel, etc. The true extent of the great Sudbury deposit is still not known. The International Nickel Company stated to its stockholders in 1939 that its proved ore reserves at the end of 1938 were 212 million tons (6.8 million tons of nickel-copper content). The report for 1950 gives the figure as 253 million tons (with 7.7 million tons of contained nickel and copper), which shows that development has kept well ahead of production and, from all indications, will continue to do so for many years to come. In the interim some 1.4 million tons of nickel alone have been produced from the Sudbury deposit. (The International Nickel Company is the British Empire's largest producer of copper and even, in world competition, a major one. In 1950 it marketed 106 000 tons of copper, 80 percent as much as it did nickel.) In addition, International Nickel in 1950 delivered 267 000 ounces of metals in the platinum group, 37 000 ounces of gold, 957 000 ounces of silver, and important quantities of cobalt, selenium, and tellurium.

Efforts to find different, non-military uses for nickel have met with astonishing success. More than 3000 different alloys with other metals are commercially available so only major categories can be listed. Nickel alone, and in myriads of combinations with chromium, molybdenum, vanadium, and copper, is used for making alloy steels. The austenitic stainless steels, such as the familiar 18-8, are widely employed in the home, in architectural applications, and in food handling, chemical and petroleum processing equipment and in railroad passenger cars. More highly alloyed, sometimes complex types are used for heat-resisting applications in industrial furnaces, internal-combustion engines, gas turbines and jet engines, where strength and resistance to scaling and chemical attack at high temperatures are necessary. Nickel by itself and in combinations with chromium, vanadium, manganese, and molybdenum is used in steel castings. Foundries add nickel in making cast iron. Copper and brass mills and brass and bronze foundries alloy nickel with copper, tin, and zinc. (The United States coin, the "nickel," is curiously misnamed as it is but one fourth nickel, three fourths being copper.) Nickel-aluminum alloys are used in aircraft engine pistons and cylinder heads.

Nickel has great versatility in the electrical field. It is used for both magnetic and non-magnetic alloys, for permanent magnets, for controlled-expansion alloys, as the basis for the Edison alkaline storage battery, and for electrical-resistance elements.

Nickel and nickel salts are used as catalysts in the production of soap and edible oils, various chemicals and dyes, in gas purification and in the manufacture of high-octane motor fuel. The ceramic industry employs it in enamels and as a coloring agent. Large quantities of the metal are used for electroplating to obtain corrosion resistance and bright appearance, where it is generally employed as an undercoat to chromium on plated articles.

Monel has an interesting background. During the search after World War I for new uses, it occurred to Mr. Robert C. Stanley, of the International Nickel Company, to do what now

Cobalt—Electrolytic Method

Electrolytic Method—A comparatively recent technique produces cobalt by electrolysis from oxides of copper and cobalt. This essentially is a multi-step chemical and electrolytic process by increasing the proportion of cobalt to copper. The sulfates from the copper leaching plant contain about 15 grams per liter of copper and 5 to 6 of cobalt. By two sets of precipitation and electrolytic actions the copper and cobalt are separated, giving, as one product, cathodes of cobalt containing some zinc that can be driven off as a gas in an electric furnace. The final product is metallic cobalt shot.

appears to be an obvious thing. Instead of trying so hard to separate nickel from the copper, why not explore the natural combination of the two as an alloy worthwhile in itself! The result was Monel, now grown to several varieties and prized, among other things, for its ability to withstand corrosion. It is not affected by food and body acids. Hence its extensive use in kitchens, food-processing industries, and hospitals.

Nickel is one of the most versatile of metals. Although in short supply at present, its future stability has never been so bright.

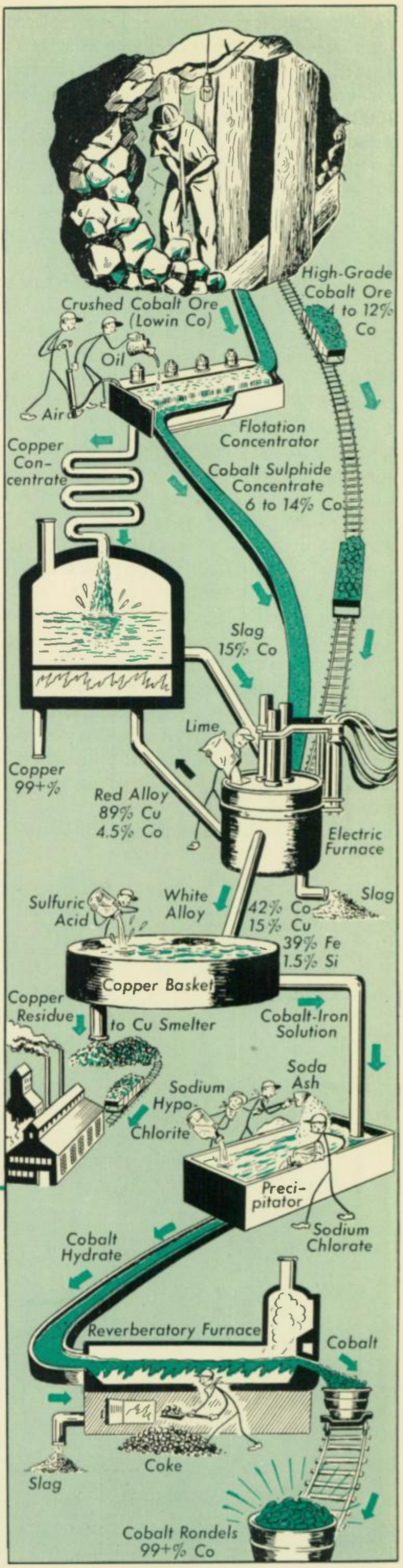
Cobalt

Cobalt was one of the first metals to climb aboard the list of strategically short materials after the Korean outbreak. But the story of cobalt differs from some of the others. In the first place, shortness of cobalt is not a matter of waning United States' reserves—for this country has never produced much of it. The scarcity is due, not to lessening availability (for the world has ample reserves of cobalt ore) but largely to skyrocketing demands for jet engines and electronic gear. Secondly, the picture of cobalt supplies will get brighter. Greatly increased amounts of cobalt, particularly from United States' sources, can be expected. So much so that by 1953, barring a full-scale conflict, cobalt will be in much greater supply for both defense and normal needs. The present world production of cobalt (1949) amounts to 6500 tons, with 5000 tons the annual average for the 1940–1949 decade. (United States' consumption in 1950 totaled 4120 tons.)

Cobalt occurs in many mineral forms and in many places. R. S. Young in his book, "Cobalt," lists 59 cobalt minerals, many of very complex chemical structure and of unmanageable names. Cobalt minerals rarely occur by themselves. In fact cobalt is seldom mined for itself alone. It is associated in a wide range of proportions and combinations with ores of iron, nickel, copper, silver, bismuth, antimony, manganese, lead, zinc, and others. The mineral itself is generally of three forms: in chemical combination with arsenic it is often mixed with ores of nickel, silver, and gold; with sulfur it is found with lead, zinc, and copper; and in oxide form it is generally accompanied by copper. Traces of cobalt are found in soil, vegetation, animal life, sea water, the sun and stars. We even get some from out of this world; meteorites are about one percent nickel.

Many nations have been and still are producers of cobalt. Ancient Babylonians and Egyptians used its oxides in pottery. Cobalt oxides also were responsible for the wonderful blues that characterize the famous ceramics of the Ming and Manchu dynasties. In the 17th century when intrigue made invisible inks popular, cobalt salts were among those used.

Since the beginning of the 19th century leadership in production of cobalt has swung from Norway, Sweden, and Saxony, first to New Caledonia, and then, in 1903, to Canada, and finally, in 1924 to the Belgian Congo where it still resides. Lately the Congo has been accounting for three fourths of the world total. All Congo cobalt is produced by Union Minière du Haut-Katanga, which has been increasing output almost consistently for the last 15 years. Northern Rhodesia is now a poor second with about seven percent of the total, although at one time it ranked with the Congo. Rhodesian output has fallen off steadily for the last dozen years. However, when a



Electric-Furnace Method

Electric-Furnace Method—Three types of cobalt-bearing materials are supplied to the electric furnace. Some cobalt ore is of sufficient high grade to go directly. Copper-ore low in cobalt is processed by flotation, the cobalt concentrate going to the furnace. Also the slag from the copper refinery contains sufficient cobalt to warrant electric-furnace treatment. The pour from the electric furnace separates by gravity into a white alloy, high in cobalt, low in copper, and a red alloy low in cobalt, high in copper. The white alloy is treated with sulfuric acid in copper baskets. Here, because cobalt and iron go into solution while the copper does not, a further cobalt-copper separation is effected. In a succession of precipitation steps a cobalt hydrate is formed from the solution. The reverberatory furnace completes the reduction.

Both the electric-furnace and electrolysis methods of cobalt and copper ore processing are employed by Union Minière du Haut-Katanga. In general the electric-furnace method is used for the highest grade of cobalt ores.

new electrolytic cobalt refinery is completed in late 1951, production is expected to increase to 1500 tons annually. Canada, United States, and French Morocco produce roughly similar amounts or, combined, not quite 15 percent of the world total. The remaining five percent is scattered in traces from Australia, Bolivia, Burma, Chile, Finland, Italy, Japan, and Sweden. Russian production was quoted in 1939 as amounting to 550 short tons or about 10 percent of world production at that time. It is believed that, by expanding old operations and with new discoveries, the U.S.S.R. is self-sufficient for military uses, cobalt-wise.

The only recent United States' production of commercial cobalt has been a by-product of the Bethlehem Steel Company's magnetic-iron-ore operation at Cornwall, Pennsylvania. Here cobalt occurs in a sulphide form. The iron ore, containing a little less than one pound of cobalt per ton, is magnetically separated from the cobalt-bearing minerals, and a concentrate averaging about 1.3 percent cobalt is produced and sent to the Pyrites Company of Wilmington, Delaware, for processing to metal and other cobalt products. The 1949 production was 256 tons of contained cobalt or about one tenth of United States' consumption that year (2350 tons). Production of cobalt from Cornwall ores is geared to iron recovery and is not likely to become much greater.

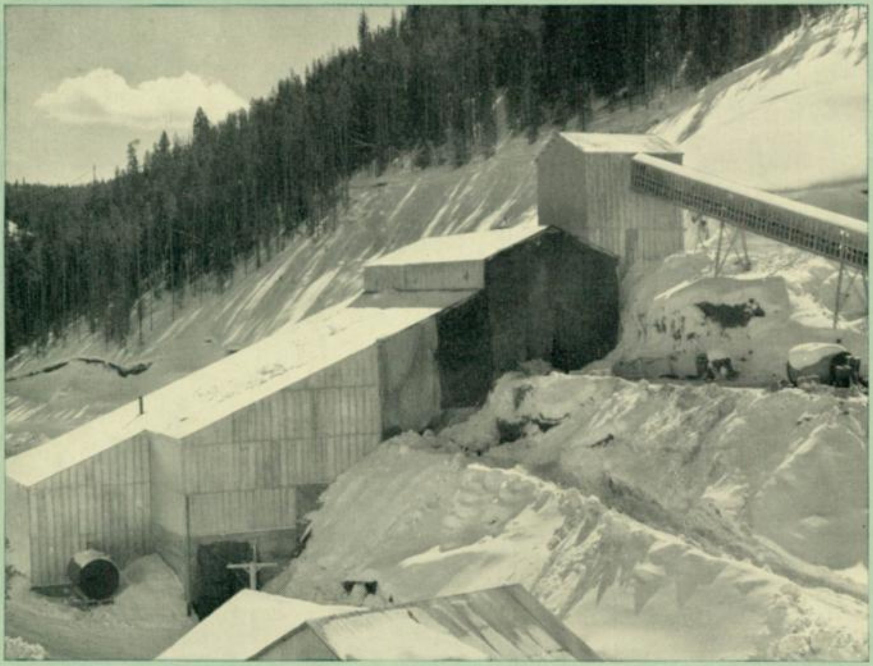
The United States, however, has other cobalt deposits. Sporadic attempts have been made to win cobalt from ore at Fredericktown, Missouri, where it and nickel occur with sulphides of lead, iron, and copper. But, complexities of the ore always introduced such serious difficulties in milling and smelting that efforts ceased in 1946. However, the Chemical Construction Company, a subsidiary of American Cyanamid, has recently developed a new process, not yet described, by which cobalt can be won from the Fredericktown ores. The process is expected to be in operation in 1951. According to estimates this will augment United States' cobalt supplies by about 400 tons annually or one tenth of 1950 consumption.

Trace amounts of cobalt ores have been obtained from Oregon, Nevada, and Arizona. Also a small amount has been produced as a by-product in the flotation of talc at Burlington, Vermont.

The great "white hope" for a significant increase of cobalt from within our own borders is at the Blackbird mines of the Calera Mining Company, near Forney, Idaho. This is an underground occurrence of cobalt and copper sulphides whose presence has long been known. The ore body is large, the percentage of cobalt running about 0.6 to 0.8 and twice that much copper. Separation of cobalt mineral from the rock and from the copper mineral, and final reduction to metallic cobalt, has presented stubborn technical difficulties. The Bureau of Mines has, since 1942, endeavored to develop a technique for processing Blackbird ores and has made considerable headway. The Howe Sound Company, parent of Calera Mining, became interested in 1943 and sponsored an extensive research program with such favorable results they are building facilities for large-scale operation, which is planned to begin late in 1951. Urged by the government, Howe Sound have expanded their original production plans and now expect to be able to produce a little more than 1500 tons of metallic cobalt per year (about two thirds of 1949 United States' consumption).

At the Blackbird mine two concentrates—one containing about 20 percent cobalt and the other about 25 percent copper—will be obtained by a remarkably sharp differential flotation.* Both concentrates will be shipped to Salt Lake City where the copper concentrate will be processed in the Garfield smelter of the American Smelting and Refining Company. Cobalt concentrate will be treated in a new plant being built by Calera Mining Company by a chemical proc-

*For description of flotation, see "Copper—The Problem and Prospects," Westinghouse ENGINEER, May, 1951, pp. 74–80.



Cobalt mining has begun at the Blackbird (Idaho) mine of the Calera Mining Co.

TABLE II—WORLD PRODUCTION OF COBALT—ANNUAL AVERAGE 1940–1949

Country	Short Tons	Percent of World Total
Belgian Congo	3 007	59.5
Northern Rhodesia	806	15.9
United States	317	6.3
French Morocco	222	4.4
Canada	213	4.2
World Total (Estimate)	5 071	100.0

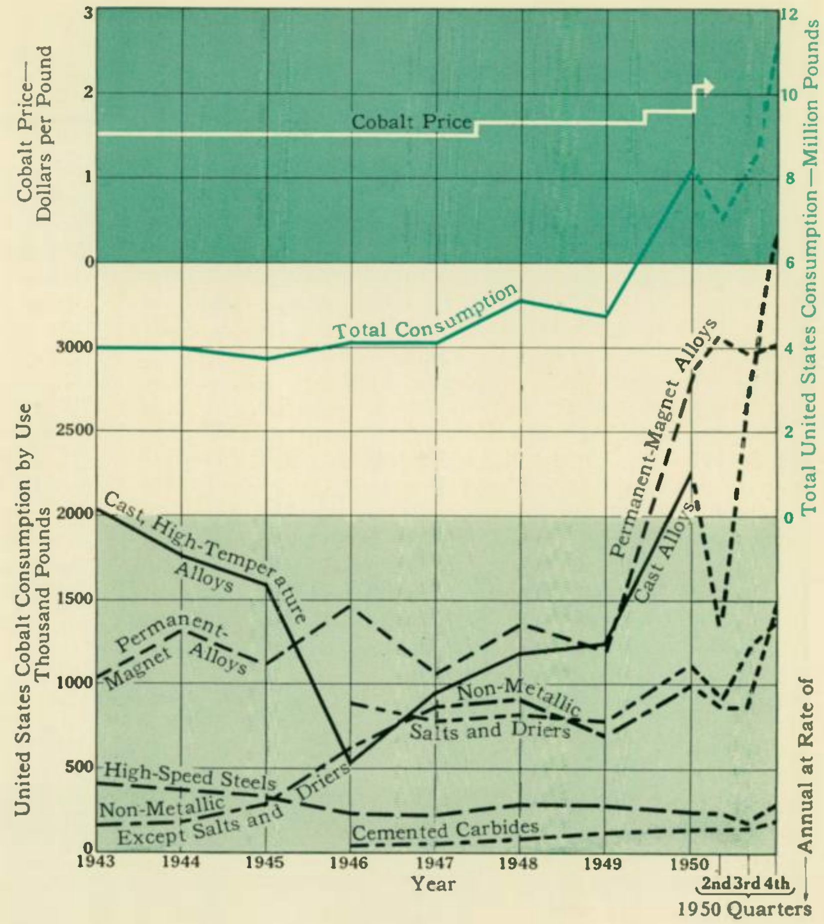
TABLE III—AVERAGE ANNUAL IMPORTS OF COBALT TO U.S.A. (INCLUDES STOCKPILE)

	Short Tons
1925–1929 Prosperity Period	376
1930–1934 Depression Period	327
1935–1939 Post-Depression Recovery	839
1940–1944 World War II	2223
1945–1949 Postwar Recovery	3255
1950	4140

ess that has not yet been publicly described.

It is anticipated that cobalt will be available to the United States in the following quantities annually: Belgian Congo, 3750 tons; Ontario, 375 tons; and French Morocco, 450 tons. These, with the expected quantities from Blackbird and Fredericktown, should bring supplies of cobalt by 1953 to about 6500 tons yearly, which compares with U.S. consumption of 4140 tons in 1950.

The principal uses of cobalt, the amounts, and trends are shown at the right. There are three general forms in which it is used: metallic, salts, and oxides. The metal is used as an alloying agent with iron and other metals, particularly for magnet alloys, high-temperature alloys, and high-speed cutting tools. In the postwar years, 1946–1949, this accounted for 65 percent of the total, but use of cobalt for magnetic and high-temperature alloys is rising steeply, as the figure shows, and in 1950 accounted for over 60 percent of the total. The proportion will be higher. The remainder is divided almost evenly between salts, mostly as driers for lacquers, varnishes, paints, inks, and the oxide forms, which generally are used as ground-coat frit to give better bond between steel and porcelain and for pigments. The appearance of defense needs and the resulting use-restricting orders disrupt this use pattern.



In the electrical industry the dominant use of cobalt is as the key constituent for permanent magnets. Ever since Honda of Japan in 1916 discovered the remarkable magnetic properties of steels containing high proportions of cobalt, the importance of this use has grown. There are now many different cobalt magnet alloys. The members of the Alnico family range in their cobalt content from 5 to 35 percent (aluminum, 12 to 6 percent; nickel, 28 to 14 percent; the remainder mostly iron). Some alloys such as Vicalloy and the Permendur group are one half cobalt. The Westinghouse electromagnetic steel, Hiperco, is 35 percent cobalt. For magnets of great magnetic energy for their size—such as are needed in loudspeakers, television sets, and particularly for airborne communication and other electronic equipment—cobalt-steel alloys have no near competitor. Compared with tungsten-steel magnets, which were generally used prior to Honda's discovery, the magnetic energy per unit weight runs from 5 to 17 times greater. Cobalt appears to have no substitute for this purpose.

Cobalt imparts to alloys unusual ability to carry heavy loads at high temperatures. This puts them in great demand for superchargers, gas turbines, and jet engines that call for parts to be severely stressed for long periods at 1300 to 1500 degrees F and for briefer times in the neighborhood of 1600 to 1700 degrees. For these alloys the percentage of cobalt varies from 13 to 66 percent. The Westinghouse alloys, Kovar, K-42-B, and Refractaloy, contain about 20 percent cobalt (remainder is various proportions of chromium, nickel, molybdenum, and iron). The cobalt content of stellites runs from 20 to 55 percent. Vitallium, about two thirds cobalt, was developed originally as a dental and surgical alloy but is now used for its high-temperature properties as well.

Cutting tools that run at high speed, and consequently quite hot at the cutting area, are greatly improved by the addition of cobalt. High-speed steels were developed about 40 years ago. These retain their cutting edge and hardness even at a dull red heat, which effects great savings in time and materials in machining operations. They have been very important in our industrial economy. High-speed steels generally contain from 5 to 12 percent cobalt, this use in the postwar period accounting for about one twentieth of the total.

Cemented carbides, in which cobalt forms the matrix or binder for the tungsten and other carbides, have an important place in high-speed machining of hard materials.

While these uses predominate in volume, cobalt has many other functions—some rather surprising. Until about 1935 the cause of serious malnutrition and deficiency diseases of cattle and sheep grazing in certain parts of Australia, New Zealand, Florida, and Wisconsin remained a mystery. The answer proved to be a deficiency of cobalt in the grasses. Almost immediate and permanent recovery was effected by adding minute traces of cobalt salts to the animals' feed.

Cobalt is an important catalytic agent in many chemical processes. In particular, the presence of cobalt in the Fischer-Tropsch synthesis of liquid hydrocarbons speeds up the reaction by several thousand times. The amount used is small.

Unlike prices of some metals, that of cobalt has not fluctuated wildly. Since 1939 when the price stood at $1.24 per pound it has risen at intervals and in May stood at $2.10.

The prospects for augmenting cobalt supplies with scrap are not good. Salvage of cobalt is difficult. In general, cobalt used once is gone forever. This is particularly true of its use in ceramics, paints, and porcelain enamels.

Nickel and cobalt have become fundamental metals. Both are growing in versatility, for peacetime as well as defense uses. Fortunately, although supplies are temporarily short, users of these two metals do not have to embark on long programs of substitution.

Stories of RESEARCH

A Better "Deep-Freeze" for Research

COLD CONTROL is becoming almost as important as heat control to science. In studies of the effects of low temperature on materials, a good supply of cold is essential. Liquid helium is an excellent refrigerant for extra low temperatures—it liquefies at about 269 degrees C below zero (only about 4 degrees above absolute zero)—but it's hard to keep the stuff cold for very long. And when it warms up, it evaporates. Until now it lasted just long enough to conduct an experiment. Shipping helium is another headache. There has been no good container in which to ship liquid helium. Usually, it is transported as a gas under great pressure and then liquefied when it is ready to be used. This requires heavy, metal containers to withstand the high pressures.

But now a better cold-retaining bottle has been developed for storing, and perhaps shipping liquid helium. Dr. Aaron Wexler, head of Westinghouse low-temperature studies, and Howard S. Jacket of the Hofman Laboratories, Inc., collaborated on the design. This new "vacuum" bottle can keep liquid helium at 269 degrees C below zero for 100 days. It consists of two concentric copper spheres with the helium contained in the inner sphere. The air space between the two spheres is evacuated, and then the entire unit is immersed in liquid nitrogen in a thermally jacketed container. The liquid nitrogen maintains the temperature around the double-walled helium container at −196 degrees C.

The resulting bottle is left uncorked, because liquid helium evaporates 840 times faster than water does at the boiling point, and the resulting pressure built up inside the bottle could cause an explosion if the bottle were stoppered. The main features of the design of the new container lie in the recognition of the importance of the refrigeration available in the gas resulting from the evaporation of the liquid, coupled with the relation between the transfer of heat by radiation and the heat conducted along the neck tube. In order to utilize the refrigeration in the vapor most efficiently, the neck tube is made very narrow—a little over half an inch in diameter. Radiation down the neck tube is absorbed by a black coating which prevents such radiation from reaching the liquid. Because of the efficient heat exchange between the vapor and the neck tube, the radiation heat transfer between the two spheres has relatively little effect on the evaporation rate. This results from the fact that an increased flow of vapor reduces by an appreciable amount the temperature gradient at the point of entry of the neck tube into the helium reservoir. Thus the effect of increased radiation heat transfer is almost offset by a concomitant decrease in the thermal conduction. Incidentally, the question of gas conduction in vacuum spaces surrounding liquid helium cooled surfaces almost never arises. The vapor pressure of air at these temperatures is lower than the pressure existing in the best vacuum systems.

The unprecedented efficiency of this container, which is more than 15 times better than containers previously described, resulted from a detailed analysis by Dr. Wexler of the factors involved in the flow of heat into liquid helium containing vessels. This analysis, made in connection with his studies of the relation between the optical properties of metals at low temperatures and their electrical conductivities, has been confirmed quantitatively by experiments at the Research Laboratories. The important thing is that design principles for equipment involving liquid helium are now well established. The present container holds ten liters (a little over 2 gallons); larger ones can be built that will maintain liquid helium for a year or more.

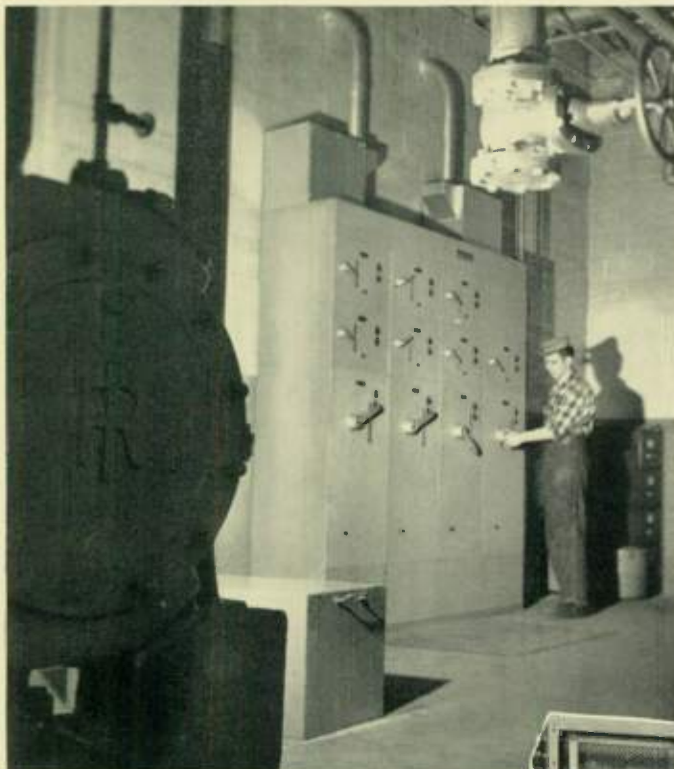
It is believed that the immediate effect of this work will be to expand research in the low-temperature field. Laboratories that cannot afford the relatively expensive helium-liquefaction equipment will not find it onerous to use a container of this type. Laboratories will now be in a position to have relatively large quantities of the liquid "on tap" at all times. The design principles will also affect the design of low-temperature apparatus in that they show that as an intermediate refrigerant liquid hydrogen is unnecessary in most cases. Finally, there is now the distinct possibility that helium can be shipped more economically as liquid in easily handled thin-wall containers at atmospheric pressure than as gas at high pressures.

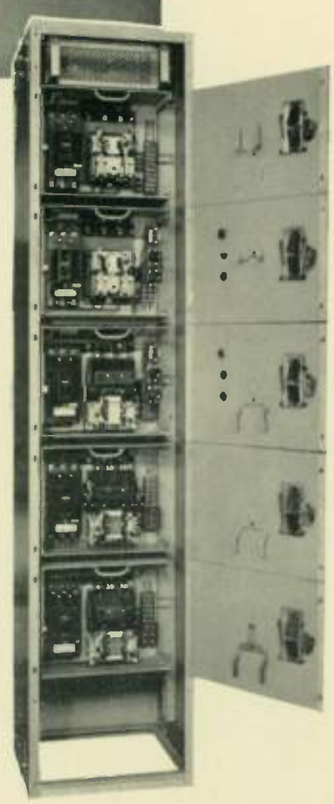
Dr. Wexler and his super vacuum bottle in which liquid helium can be maintained at atmospheric pressure for more than three months—fifteen times longer than previously.

The introduction of the motor control center is a boon both to the machine driven and to the control itself. When starters for several or many motors are centralized they can be given better surroundings and better attention. With only a pushbutton station required at the motor, more working space at the machine is available.

Centralized Motor Controls

E. G. Wise
Industrial Division
Westinghouse Electric Corporation
Chicago, Illinois





Control for several motors in the Pittsburgh plant of the Continental Can Company is conveniently centralized (above). At right is a single typical control center with door open.

Motor starters have generally been located near the motors they control, the power being fed from a distribution board. With this system the overload protection for the motor is supplied by the starter and short-circuit protection in most applications by the distribution board. This arrangement of control has several shortcomings. If the atmosphere around the motor is not clean, special enclosures are required. Also coordinated protection between the board and motor control is often lacking compared to the better overall protection obtained by mounting both in one enclosure. Finally, greater safety to plant personnel is provided by centralized control under authorized personnel.

About ten years ago Westinghouse introduced the unitized control center. This type of control combines the distribution board, which contains circuit protection, with the starter, which provides overload protection. At the same time provisions for entrance circuit breakers were included. All starter units were bolted to the buses but could be removed if necessary and units were basically designed with modular mounting spaces.

In the summer of 1949 the control center was further improved to provide additional safety features that appeared desirable as a result of industry experience. In this new control most of the devices in the electrical system such as motor starters, individual auxiliary feeder circuit breakers, distribution transformers, small lighting panelboards, relays, or in fact almost any electrical device can be mounted and wired into cell units of standardized, "building-block" dimensions.

Prior to the introduction of control centers, such devices were separately mounted and wired at the installation. Starters were located at the motor or racked together on a wall near the motors they controlled. In either case a control center, which is factory built, wired and tested, and requiring only connections to the line and load can be installed with less effort, in shorter time, and at less expense.

A control center can be described as "a placement of motor starters and auxiliaries for a single machine, a group of machines, or for an entire plant, which can be grouped or centralized into protective structures capable of being added to, rearranged or deducted from, to meet changing needs . . . but providing greater safety to personnel."

Use of a control center simplifies the layout of the plant electrical system. The control center itself is laid out like building blocks. Each structure is 20 inches wide and 20 inches deep. There are two basic structural heights, 90⅜ inches and, for low-head-room areas, 76⅜ inches. The 90⅜-inch height has five 14-inch modular spaces per side, five in front and five in back. The 76⅜-inch height has four on each side. Since all unit heights are multiples of the basic 14-inch modular space, the space required in a control center for any given number of starters or other devices can be easily determined. After motors are located on the floor area the centers of load are connected to the control centers. The space required for the control center is readily computed in advance because the space for each is the same. It is necessary, in planning the floor arrangement, only to know the number of units required.

The five modular spaces, 14 inches each, or a total of 70 inches, for mounting of controller units front and rear, provide a wide flexibility. The multiple of 14 inches was carefully selected for maximum utilization of available space and changing requirements. There are borderline cases where motor sizes cannot be determined during the planning stage. Actual requirements may be subject to verification later, involving relocation in position of motor starters. In such cases it is a relatively simple matter to switch combination linestarter units. A single 14-inch space will handle motors up to 25 hp controlled by combination linestarters, NEMA sizes either No. 1 or 2. Two such starters can be exchanged for one NEMA size No. 3 designed for motor ratings up to 50 hp. NEMA size No. 4 combination linestarter units can be mounted in a space replacing three 14-inch units. Further flexibility is provided in 28-inch space when applications call for NEMA No. 2 reversing linestarters and four spaces of 14 inches can be utilized for 100-hp reduced voltage starters, NEMA size No. 4.

The interchange of various size NEMA starters in structures front and rear can be accomplished by the simple procedure of removing smaller units and replacing them with larger units without de-energizing the bus and making wiring changes, except to provide proper size motor leads and control wiring to the control center.

Further flexibility is provided by the fact that a control-center structure can be planned for incoming main feeder breaker, distribution feeder breakers, either two or three pole, multiple-circuit lighting panels, transformers for lighting and many other uses to meet diversified control purposes and changing requirements.

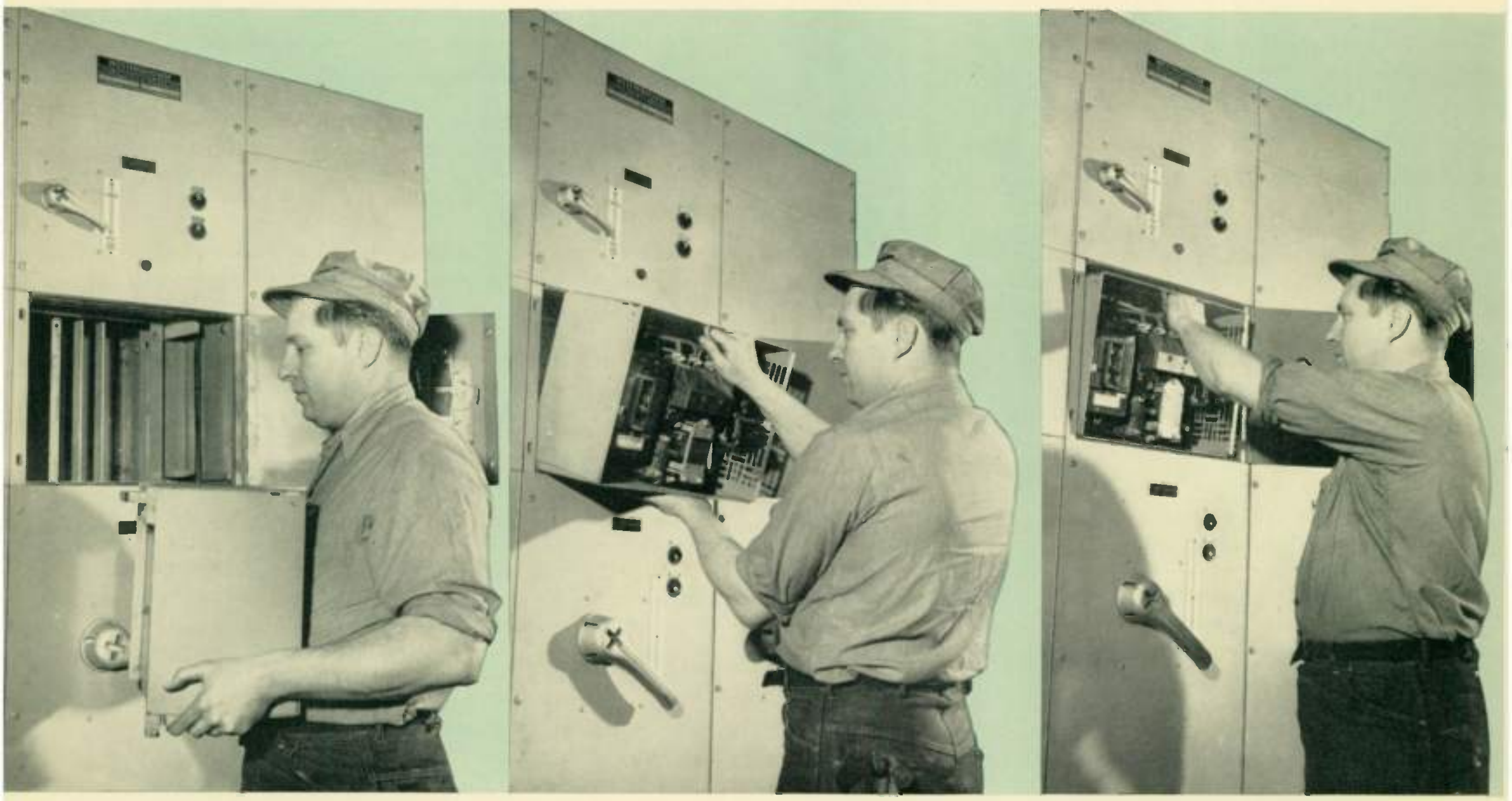
Use of control centers makes it possible to add new structures and starters to existing control centers as plant machine needs change. Structures or starters can be removed from the control center and relocated elsewhere should that become desirable. In fact any units can be removed or changed with complete safety and without de-energizing the bus. This is possible because each unit is provided with a Magnagrip line "plug-in" stab, which simply plugs into the vertical power bus provided in each structure. With this arrangement, after the starter has been set into position slightly tilted forward on the rails of its cubicle, the final act is to push it back, causing the terminals to establish contact and tightly grip the copper buses.

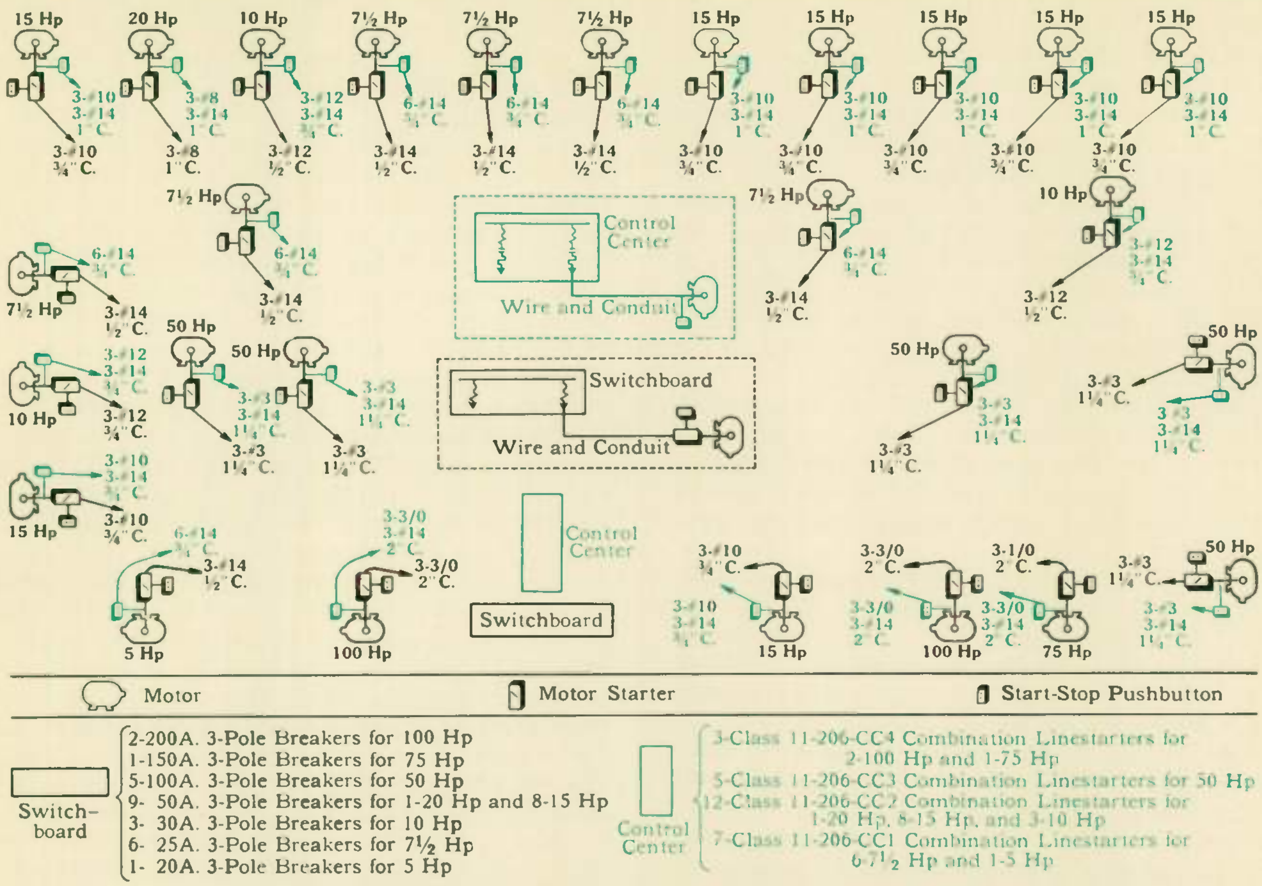
Each standard structure is free standing and self-supporting, requiring no auxiliary bracing. Each contains a 600-ampere main horizontal bus at the top and a 300-ampere vertical bus running the full structure height, into which the units plug. All structures have two horizontal full-width wiring troughs—one at the top and the other at the bottom, and two vertical full-length wiring troughs, one in front and the other in the back. Either front mounting only of the units (five modular spaces) or back-to-back mounting (a total of 10 modular spaces) is possible in every structure.

When starters are mounted only on one side, the control center can be located against a wall if desired to conserve floor space. This is possible because all units are wired and connected from the unit side and access to the rear of the cabinet is not necessary.

If starters are placed in both sides, that is, back to back, obviously the control center must be mounted away from the wall. This plan conserves floor space because twice as many starters can be installed in the same floor space as required for front mounting only. However, the front-mounted control center requires no openings for ventilation. It can be made dust tight. If starters are placed in both sides, louvers must be opened to permit circulation of air.

Obviously where several starters are grouped together the temperature will rise in the enclosure. To keep this rise to a safe value it is necessary either to provide louvers in the enclosure or keep each starter, in addition to the enclosure, relatively open. These methods offer adequate ventilation. It has therefore become a problem of basic design in a control





The floor plan of a typical industrial plant showing motor locations. The black shows the layout with traditional starter and pushbutton at each motor. Shown in color are the same motors but with starters located in control centers.

Insertion or removal of a motor-starter from its cubicle in the control center is shown in this sequence of views. The first view shows the cubicle with three vertical buses and the stabs on the back of the starter panel. In the next two the starter is shown being placed in position, still without making contact with the bus. Finally the door is closed and fastened in place with captive screws.

center to provide this adequate ventilation but—it has been discovered that instead of one problem there are actually two: adequate ventilation and adequate interrupting capacity. The two are related. If the units are designed with large openings or not totally enclosed the temperature rise within the structure may not be troublesome. However, if this is done and a short circuit occurs in any unit, the resulting ionized gases may travel to the next starter or to the bus, with consequent damage to the whole structure.

To avoid possibility of communicated faults each control center unit is totally enclosed so as to isolate any ionized gases and keep them from spreading outside of that unit. The right side of each unit has a removable grill that provides ventilation for the unit. At the same time the grill controls the hot ionized gases, which can be forced through it by the internal pressure. This provides a safety valve for the expanding gases, preventing possible damage to the equipment from this source. The deionizing effect of the grill makes the gas nonconducting.

If the control center has front-mounted starters, adequate ventilation is provided first by grills in each unit combined with the chimney action obtained in each structure by the open rear space. Heat from the units rises to the top of the structure, is cooled by the top rear plate and drops down the open rear space to return again up the front. This means the structure can be gasketed and still be self-cooling. This helps reduce maintenance by minimizing dust and dirt circulating in the control center. On the other hand, back-to-back mounting structures are provided with louvers at the top and bottom sides of the structure to obtain the necessary cooling of all units within the structure.

Each starter up to and including NEMA size No. 4 is the line plug-in type. The support for the starter is arranged so that a unit can be inserted or removed without de-energizing the bus and with complete safety to the workman. This is mainly due to the "tilt-out" feature. The unit is first set on the removable support and divider channel, and is not yet in contact with the live bus. The weight of the unit has then been transferred from the electrician's hands to the support channel. In other words, the workman does not juggle the unit into position after bus contact has been made. The unit is pushed back into the cell space and rides into position on permanent guide rails provided through the full height of each structure. The unit is now in the cell space but not yet engaged to the bus—it is in the tilt-out position.

In this position the safety lockout latch can be padlocked, thereby making it impossible either to remove or reclose the unit on the bus. It can be examined or worked on in complete safety. Unlocked, however, it is an easy matter to tilt and push the unit into closed position, engaging the plugs to the power bus.

Each unit is provided with the door as a part of the structure and separate from electrical units. This provides the additional safety feature of being able to close the cell opening over the live bus after a unit has been removed.

The doors have slam-proof interlocking safety handles. These give mechanical interlocking between the air circuit breaker and the door. The handle must be moved to "open cover" position before the door can be opened, thus preventing the opening of the door with the breaker in the "on" position. The door cannot be opened normally with the breaker in the "on" position but there is a screw head on the door, accessible only in the "on" position, by which the door can be opened by authorized persons.

In order that the least possible time will be required for the installation of wiring connections the doors open the full width of the structure. These are held closed by ¼-turn cam-locking screws. The horizontal support and divider channels are removable by slide-out action. The slide grill on the right side of each unit is removable and can be pulled out of each starter. This done, the entire structure is wide open from top to bottom so that the electrician can pull his wires to this structure from the conduits and simply lay them in place in the vertical wiring trough. Cable-tie supports to hold the cables in place for starter connections are provided in the vertical troughs. It is then necessary only to connect to the marked individual unit terminal blocks on the right side of each starter. No obstructions are in the way of wiring and it is not necessary to spend time "snaking" or "threading" the wires in. They are simply laid in place. After the wiring is completed the grills are slid back on the units—the support channels pushed into position and the doors closed.

Control centers are available in three NEMA types of construction: A, B, or C. These classifications have been set up by the industry to designate a type of interwiring within the control center.

Type A is the simplest form of control center. No terminal blocks are included—no wiring. The units are simply standard combination starters or circuit breakers, which are connected to the buses by line stabs. The motor and control wires must be connected direct to the starter terminals. Standard layout sketches and individual unit wiring diagrams are furnished—no connecting wires between starters are supplied.

Type B has clearly marked individual terminal blocks located on the right side of each starter or unit—accessible from the front. Individual terminal blocks make it easy to remove or install a unit as they are a part of the unit—not separately mounted—thereby helping to facilitate field wiring. Standard layout sketches and standard unit wiring diagrams are furnished—no connecting wires between starters are supplied.

Type C is completely factory wired and includes type B individual terminal blocks. It also includes wiring to master terminal blocks (which can be located at either the top or bottom of the structure). This construction may include any sequence or interlock wiring between starters. All terminal blocks are accessible from the front. Standard layout sketches and standard unit wiring diagrams are furnished as well as complete schematic and composite wiring diagrams.

The control center can be combined and connected to switchgear. Its 90⅜-inch height matches low-voltage switchgear as well as the bolt holes on the sides for holding the structures together. The control center can also be combined and connected to transformers to form power-center construction, or the control center can be combined with both the switchgear and transformer.

Control centers are now widely used in many industries. Power companies use control centers as a basic standard for the protection of station auxiliaries, coal-handling equipment, and other low-voltage circuits including the outdoor-type control center for cooling towers. Many installations have been made by manufacturers of metals, textiles, chemicals, rubber, paper, foods, meat packing, grain, lumber, machine tools. The control-center idea is attractive to mining, oil and gas companies because the motor control can be isolated from hazardous areas. Public works, such as water works, sewage-disposal plants, hospitals, schools, and hotels make extensive use of control centers.

Frequently it is advantageous to remove the control from the machine. In food plants, for sanitary reasons, it is desirable to keep the area around processing machines as free and open as possible. In other plants, for convenience, working efficiency, and even safety, the fewer objects located around the machines the better. The use of remotely located control centers with only a small pushbutton located at the motor fits well into this program.

The control center fits nicely into a distribution system. Because of its unit construction it simplifies the work of the consulting engineer when laying out a distribution system. Careful attention has been given to the matter of pleasing appearance. Less maintenance, greater safety, and simplified plant operation are obtained with centralized control—the control center. It has a bright future.

Personalities IN ENGINEERING — Dr. C. F. Wagner

The invention of the klydonograph by Peters of Westinghouse marked the beginning of organized attempts to understand lightning so as to create scientific defenses against it. That was just 30 years ago. That dramatic chapter in electrical engineering is summarized by Dr. Harder and Mr. Clayton in this issue. It is fitting that attention be drawn to one of the principals in this drama, a man who has been in it from the beginning and whose accomplishments in that and other phases of power engineering have won him world-wide recognition—Dr. C. F. Wagner.

Wagner arrived on the engineering scene at a propitious time as far as lightning research was concerned. Born and raised in Pittsburgh (his father owned and managed a very successful cigar-manufacturing business), he had completed his studies of electrical engineering at Carnegie Tech in 1917 and had added a year of study in physics at the University of Chicago. That brought him to Westinghouse in 1918 to work with Dr. L. W. Chubb and Dr. Joseph Slepian in Research Engineering. This assignment gave him five years of excellent engineering experience with a wide variety of problems in connection with heavy-current buses and conductors, a-c machines, and resistance welding as preparation for what was to come. By 1923 the campaign to do something about lightning was beginning to take shape and Wagner was recruited to the GHQ of the late Dr. C. L. Fortescue. Ever since, he has been intimately associated with the two phases of the problem—the studies of lightning, both natural and man-made, and the analysis of problems of power disturbance and loss of synchronism due to lightning. He made significant contributions to both. He helped plan the strategy of the lightning investigation stations established, in the middle 20's, in Tennessee, Arkansas, New Jersey, and elsewhere. He helped analyze the records that resulted. He was part of the team that, headed by Dr. Fortescue, refuted the notion that surges are induced by nearby strokes.

On the system-stability side of the problem, Wagner thoroughly investigated the theory and behavior of synchronous generators. He showed how the design of damper windings on synchronous machines influences the stability of generators and the associated system. He analyzed the behavior of synchronous machines under unbalanced conditions involving negative-sequence quantities. He predicted and provided the method of analysis of high voltages created when a synchronous machine is connected to capacitive loads under unsymmetrical short-circuit conditions. He developed a considerable part of the theory and methods of analysis of the performance of power systems under transient fault conditions. The papers published jointly with R. D. Evans, and those by Dr. Wagner alone, form an important part of the background for our present understanding of power-transmission stability.

Although much of his work is theoretical, many of his ideas take physical form. He has averaged a patent a year since beginning his professional career. He has invented several devices for use in studying lightning. Noteworthy is the fulchronograph (see page 109) developed by him and Dr. McCann. To help his associates and students obtain a physical concept of the phenomena of transmission-system stability, he built a model using the basic concept provided by S. B. Griscom. To show the behavior of traveling waves he invented a working model. Both continue to be used in engineering classrooms.

Many of his theoretical analyses have been aimed at apparatus —transmission circuits, rectifiers, inverters, regulators, waterwheel and steam-turbine generators, synchronous condensers, induction and synchronous motors, and protective devices. But some have been in the field of engineering mathematics. He, in collaboration with the late R. D. Evans, did more than anyone to make symmetrical components a useful tool. He and Evans reduced this new branch of mathematics to lay engineer understanding by a series of articles in the "Electric Journal" in 1928 and 1929 and followed with the book "Symmetrical Components."

Wagner had a great deal to do with another book—the "Electrical Transmission and Distribution Reference Book," which has become a best seller in its field. In addition to preparing the chapters on machine characteristics, wave propagation, and lightning phenomena, he largely supervised the planning and production of the original edition in 1940 and the recent one.

Another measure of an extremely fruitful career is the large number of scientific papers he has presented, mostly before the AIEE. He has averaged one every six months since 1918 and none can be classed as light, bedtime reading. The scope of his endeavors is indicated by his having served actively—often as chairman—of 11 AIEE national committees and four committees of other national engineering bodies. In 1945 he was sent by the U.S. Government as a member of the Technical Industrial Intelligence Committee, on the heels of the retreating Germans, to learn what important developments had taken place in the central-station field in Nazi-held lands during the war. He returned to Europe in 1949 as a member of the International Electrotechnical Commission, at its meeting in Stresa, Italy. As these words appear in print he is again in Europe, at another meeting of this same Commission, this time in Estoril, Portugal. When his committee work is finished he will be busy in Portugal, Spain, and Germany taking colored pictures—his prime avocation and one in which he is especially adept.

Much more could be said about this unusual career of achievement. For his contribution to the engineering profession, the Illinois Institute of Technology awarded him the degree of Doctor of Engineering in 1944. He was at that time head of the Westinghouse Central-Station Engineering Department. He has since (1949) graduated to the position of Consulting Engineer for Westinghouse, which frees him from administrative responsibilities and allows him to devote full time to problems of lightning, corona, insulation coordination, and similar matters that require varied experience and unusual ability for analysis.

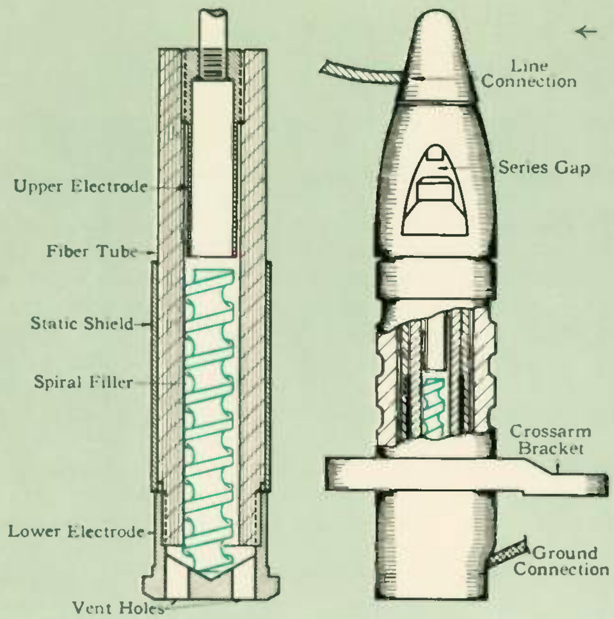
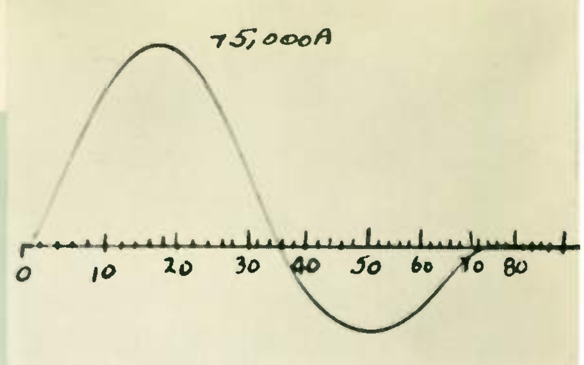


Fig. 1 — Basic construction of the LX De-ion lightning arrester. The initial surge creates a high field stress at the bottom of the upper electrode between the electrode and metal static shield. Since the resulting spark cannot get through the insulating fiber tube, it moves along the inside of the tube towards ground. If power current follows the first surge, the arc gases force the current to take a longer path along the spiral grooves of the filler.



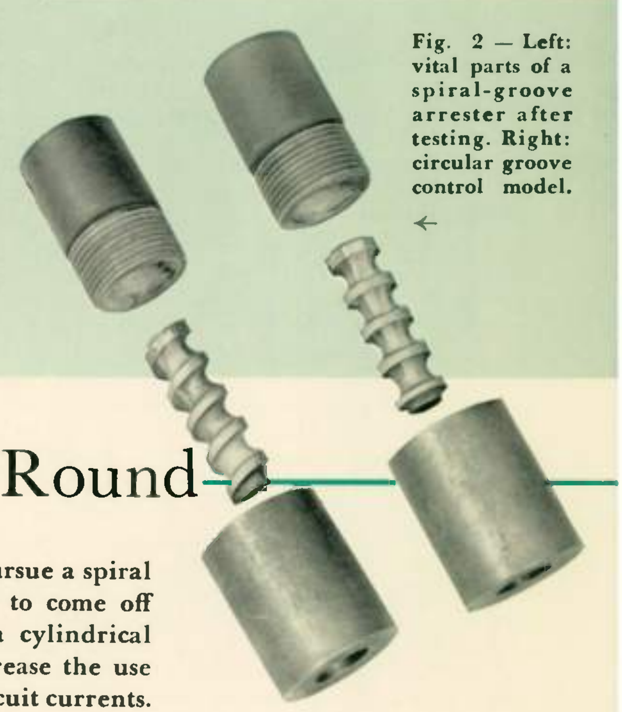


Fig. 2 — Left: vital parts of a spiral-groove arrester after testing. Right: circular groove control model.

The Surge Goes 'Round and 'Round

The dynamic spiral is as old as the earth. Vines, leaves, pine cones pursue a spiral path. But the spiral is new to lightning arresters. Just beginning to come off the production line is an improved expulsion arrester containing a cylindrical filler with spiral grooves cut into it. It promises to extend and increase the use of expulsion arresters on power systems with high attainable short-circuit currents.

OTTO ACKERMANN *and* E. J. DEVAL, *Lightning Arrester Design Section, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania*

IN EXPULSION arresters, gas pressure and consumption of gas generating material increase with the current; therefore, limitation of power-follow current is important to the operation and life of arresters installed at locations subjected to high available fault current. Power-follow current can be limited by increasing the arc voltage, and that can be accomplished by forcing the arc after the initial spark-over to take a longer path between electrodes.

This idea is not new, but because of the space restrictions imposed by arresters of economical size, the principle has so far not been put to effective use. A big step forward in this direction has been taken with the introduction of a fundamentally new technique of arc switching in the type LX De-ion lightning arrester. This arrester contains a cylindrical filler that has spiral grooves cut in it. The initial spark from one electrode to the other takes place in a more or less straight line in the space between the tube wall and the lands of the "threads," or ridges in the spiral filler (see Fig. 1). If power current follows the surge, the heat of the arc produces a considerable amount of gas, which, following the path of least resistance, flows toward the exhaust end of the device through the spiral groove of the filler. These high-velocity gases also switch the arc into the spiral groove, and effectively increase its length to about four times the straight-line distance between the electrodes. This raises the arc voltage and reduces the amplitude and duration of power-follow current to a relatively low value, and permits application of this arrester where very high short-circuit currents are possible.

Performance Tested

The essential parts of a spiral-groove expulsion arrester, which has undergone a series of tests, are shown in Fig. 2 at the left. It is to be noted that the discharge current from the upper electrode wore a conspicuous notch in the uppermost ridge of the spiral. Further down, no such notches are evident. Apparently, after the initial spark the gas in the groove quickly begins to travel crosswise to the original arc path and makes the arc current follow that same spiral channel.

That this is the actual process becomes even more evident when the performance of a spiral-groove arrester was compared with that of a control model whose core has circular rather than spiral grooves—as illustrated by the right-hand set of parts in Fig. 2. Obviously the gas pressure set up in such a device must be higher and this should cause higher arc voltage. Further additions in arc voltage might be expected from the restrictions and the gas turbulance created by the circular ridges. Despite these possibilities, the total arc voltage in the ring-groove model, as proven by tests, is lower than that in the spiral-groove arrester. The only explanation for this seems to be that in the spiral-groove arrester the arc is much longer than in the ring-groove model. Based on the physical dimensions of the spiral, the arc length is about four times longer in the spiral-groove arrester.

Although the spiral-groove arrester generates a high arc voltage, the voltage does not become so high that it defeats the purpose of the device. The magnitude of arc voltage around one turn of the spiral can never be higher than the

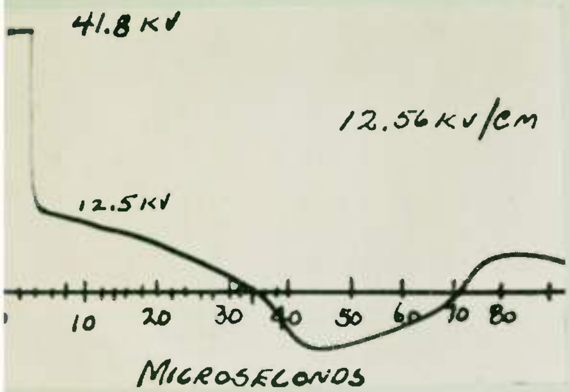


Fig. 3—A 75 000-ampere lightning-current wave (left above) and the voltage wave (directly above) are shown for a 9-kv arrester. After spark-over (41.8 kv) the arc voltage never rose above 12.5 kv, far below the insulation level of 9-kv equipment.

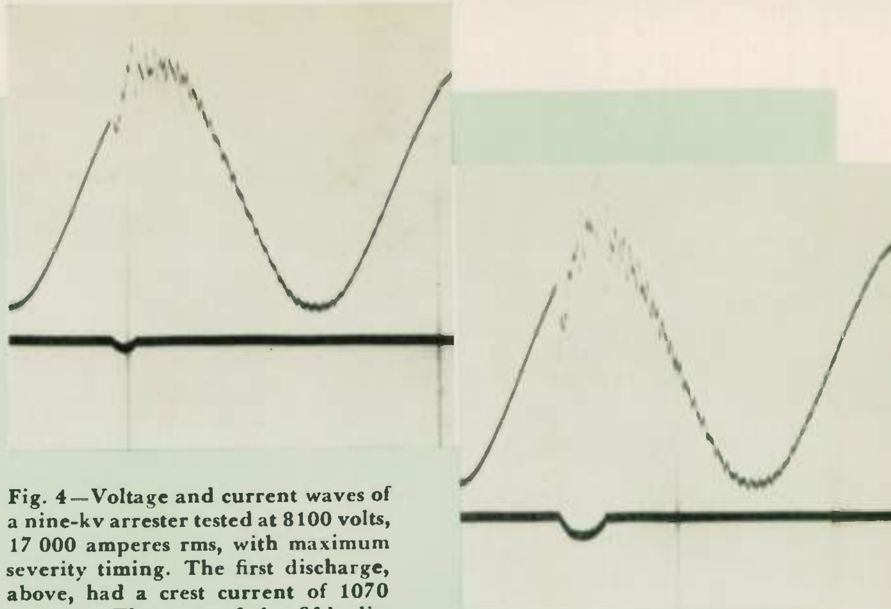


Fig. 4—Voltage and current waves of a nine-kv arrester tested at 8100 volts, 17 000 amperes rms, with maximum severity timing. The first discharge, above, had a crest current of 1070 amperes. The crest of the fifth discharge, right, was only 2140 amperes.

—and Out

voltage that will cause one of the spiral ridges to spark over. This limits arc voltage to about one third of the critical surge spark-over of the whole arrester because the space across the ridges is about one third of the total electrode distance. Even the currents of lightning surges, which exceed by far those drawn from power sources, do not produce unduly high arc voltages in the arrester. This is illustrated by Fig. 3.

Spiral-groove arresters have been thoroughly tested. Standard five-operation duty-cycle tests have been conducted successfully at currents much higher than the 10 000 amperes that are usually considered sufficient for a device suitable for unrestricted application (Fig. 4). In addition, power-follow tests have been extended to a much larger number of operations, with the timing of the discharges varied so as to simulate the random conditions of actual service (Fig. 5). The oscillograms (Figs. 4 and 5) show that the arc voltage rises quickly to values approaching and exceeding the generated voltage, while power-follow current is restricted to a small fraction of the available supply.

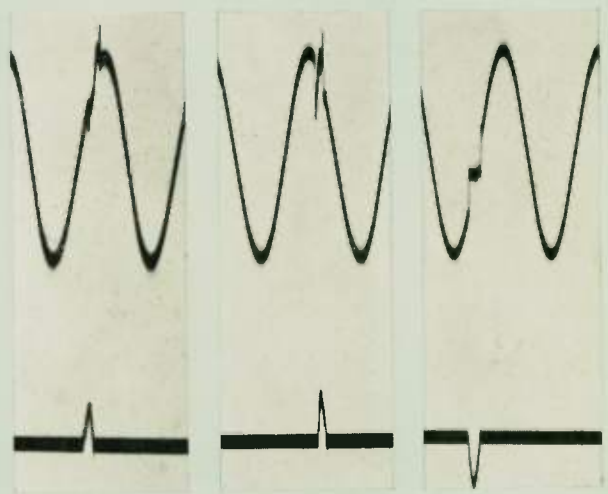


Fig. 5—Oscillograms of power-follow tests on a 3-kv arrester at 3 kv, 22 000 amperes rms. The crest current of the first discharge is 1700 amperes. The second discharge, timed to occur at a different point on the voltage cycle, has a crest of 2100 amperes. Crest current of the ninth discharge, right, also was 2100 amperes.

Advantages of the Spiral-Groove Arrester

The new design with its exceptional current-limiting characteristics appreciably widens the range of application of expulsion lightning arresters. In none of the tests has the power-follow current reached so much as ten percent of the available fault current. As a result, a very small amount of arc energy is dissipated in these arresters. This reduction insures long and dependable service life, even on systems with high attainable fault currents. Therefore, this arrester can be used on power systems having very large available short-circuit currents that until now were barriers to the use of expulsion lightning arresters.

High surge-current capacity also is essential to a lightning arrester. This depends primarily on the arresters' ability to provide adequate storage space for the gases created and heated by the stroke current, since no appreciable portion of them can be released through the vent during the short time of the lightning arc. The spiral groove in the new arrester offers an ideal storage space for the initial burst of arc gases by virtue of its uniform distribution throughout the length of the expulsion gap. The surge-current capacity of the new arrester, in fact, is far more than the 65 000 amperes called for in the present standards.

The new arrester also represents a marked advance toward satisfying the varied requirements of the power industry. The series gap is contained in a porcelain dome that has lateral openings. This prevents accidental contact of linemen with the electrodes, yet keeps the electrodes open for inspection; the openings let arc gases and electrode material vapors escape. The line terminal can be covered with an insulating cap. The cross-arm bracket may be left grounded or isolated, and even the ground terminal is porcelain protected to satisfy the requirements of various power-company installation codes.

This article is based on AIEE Technical Paper, "Spiral Arc Chokes Power in New Arresters," O. Ackermann and E. J. DeVal.

Ultrasonics in Industry

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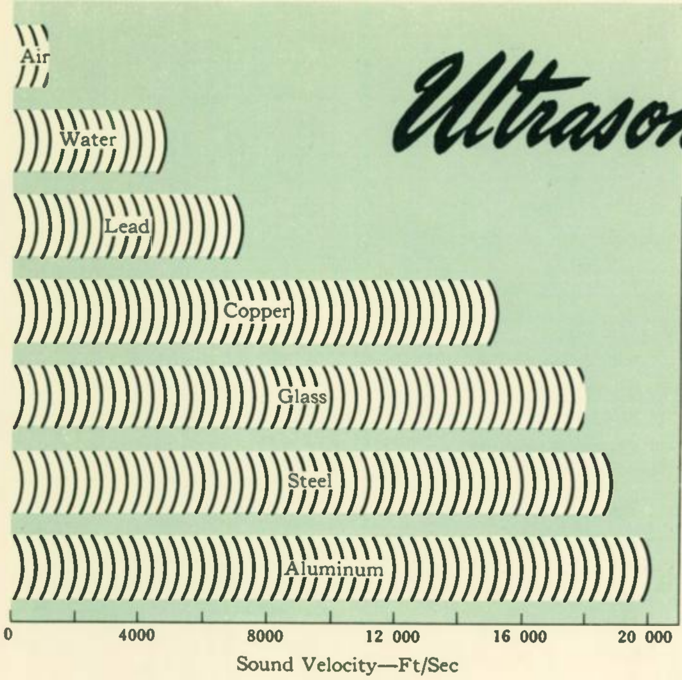
Newest frontier beyond the reach of man's five senses is the fascinating area of ultrasonics. Still little known, it is already evident that sounds beyond the range of the ear have many new and interesting industrial uses.



Speed of sound in air is roughly about 1100 feet per second but, as indicated here, it changes in various substances. It is nearly ten times faster in aluminum. The velocity of sound is proportional to the square root of the modulus of elasticity divided by the density.

The word "sound" means many things in the English language. To many people it is nothing more than a sensation, received by the ear and translated by the brain. To others it describes a physical phenomenon, a wave motion. And to a few it means only a bay, or inlet. No wonder the confusion, then, when the terms "supersonic," "subsonic," "hypersonic," and "ultrasonic" suddenly become common words in all walks of life. Ultrasonic, in particular, may well become as familiar a word as sound itself—it promises many unusual industrial applications.

In modern terminology, sound is usually considered to include the audible range of frequencies. Supersonics has, by common usage, become somewhat divorced from the study of sound; it is now more commonly applied to the study of air flows at a velocity greater than that of sound. Subsonics refers to frequencies lower than the audible range, and ultrasonics or hypersonics to those above the audible range.

In the years since the war, ultrasonic applications have been growing rapidly in number, and while most are still in the laboratory stages, the results thus far have been encouraging.

Physics of Sound and Ultrasonics

Since the word "ultrasonics" can be interpreted to mean "beyond sound," it might seem that this isolates the ultrasonic field from the study of sound. This is far from the case, in that the study of ultrasonics is the same as the study of sonics or sound, and almost all of the principles that govern the production and utilization of sound are equally valid in the production and utilization of ultrasonics.

Sound is a wave motion consisting of alternate compressions and rarefactions that can be propagated through any elastic medium, such as air, liquid, or solid. The individual molecules of the body through which the sound is propagated rush alternately from various areas of compression toward areas of rarefaction, back and forth, attaining considerable velocities and being subjected to considerable accelerations.

An area of compression moves through the medium with a velocity equal to the velocity of sound in the medium. It should be pointed out that the individual molecules do not move through the medium in this manner but only the area of compression. The velocity of propagation of this area of compression, or the velocity of sound, is approximately equal to the square root of the modulus of elasticity of the medium divided by its density.

The areas of compression do not travel through the medium without change but are slowly attenuated during their progress. In other words, the difference between the maximum pressure in an area of compression and the minimum pressure in an area of rarefaction becomes less and less as the distance from the source of the sound is increased, so that finally the presence of compression and rarefaction is indistinguishable. At this point the sound has been severely attenuated or "lost." The rate of attenuation through various media varies over a wide range, being fairly high for air and fairly low for most liquids and solids.

With this short review of sound, let us look briefly at the important differences between low-frequency or audible sound, and high-frequency or ultrasonic sound.

One of the first phenomena is the distinct relationship between wavelength and frequency in which the wavelength is equal to the velocity divided by the frequency. It is immediately apparent that as we go to higher and higher frequency, the sound wavelength, that is, the distance between two adjacent pressure peaks, becomes shorter and shorter.

As far as methods of generation are concerned, we find that many methods common in low-frequency sound are either useless or extremely inefficient in the generation of high-frequency sound. The loud speaker, for instance, must be replaced by a vibrating piezoelectric crystal or by a vibrating magnetostrictive rod. The use of whistles and sirens is permissible in the generation of ultrasonics provided that one does not require frequencies much beyond the audible range.

The beam emanating from a sound generator is more highly concentrated when the generator opening is many wavelengths in diameter. For this reason relatively small ultrasonic generators can be easily made to produce extremely sharp and narrow sound beams, while conventional sound generators must be many times as large to produce an equally great concentration of power. As far as applications and efficiency in utilization are concerned, this ability to concentrate power on a small area is a significant advantage to be obtained with ultrasonics.

The most serious difficulty that one encounters in proceeding from the production and utilization of sound to the production and utilization of ultra-sound is the severe increase in attenuation or loss when the frequency is raised. This attenuation increases for all sound approximately as the square of the frequency; thus a doubling of the frequency will cause a fourfold increase in the loss in sound power for a given distance of transmission.

Another problem is the increasing difficulty of generating sound at higher frequencies. In exchange for these difficulties, one gains through the ability to concentrate sound power into a small area, together with the increased velocity and acceleration of the molecules of the medium through which the sound is propagated. Moreover, the gain in human physical comfort is not negligible. Since speaking power is of the order of ten microwatts, a sound level of several watts would be quite uncomfortable physically if it were audible.

Some phenomena usually become more apparent at higher frequencies. Not all of these are peculiar to ultrasonics, but at ultrasonic frequencies they become of practical significance and lead to useful applications.

In addition to narrow bandwidths, the phenomena of most importance are those associated with high accelerations and cavitation, which become significant at increased frequencies. As compared to the conditions of sound, the velocities of molecules rushing from compression to rarefaction are very high. These molecules also develop accelerations of fantastic proportions. A handy reference for acceleration is that of a freely falling body, which is some 32 feet per second per second and is commonly called one "gravity." The acceleration developed by molecules subjected to the action of moderate power ultrasonics in the vicinity of 1000 kilocycles per second is in the neighborhood of one million g's. This can be considered as a very violent agitation. Small particles, of greater than molecular size, yet still quite small, when subjected to this sort of acceleration tend to break apart into even finer particles of a colloidal nature.

The other phenomenon of special interest, cavitation, is characterized by the formation of holes in a liquid traversed by ultrasonics and can be roughly described as the action of the molecules in rushing away so rapidly towards points of high pressure that they leave no liquid at all behind them. The forces exerted in this literal tearing apart of the liquid are tremendous and can be likened to those exerted in a water hammer when a faucet is suddenly closed. In the case of ultrasonic cavitation these forces are sufficient to erode metal and easily large enough to destroy small living organisms such as bacteria, insects, etc.

Applications of Ultrasonics

One of the earliest applications of high-frequency sound was made by Professor Langevin during World War I and used vigorously in the recent conflict. This application has come to be known as underwater echo-ranging and is comparable in effect to an underwater radar system. It is used both in locating submarines by their reflection of transmitted pulses, and also in determining the depth of the ocean by the time of travel of a pulse from the ship to the ocean floor and back. Obviously, if the velocity of sound is known and the times can be properly measured, the distance involved in either case can readily be determined. Such an application is not feasible for locating aircraft and other objects not beneath the water, because the losses of sound transmission through air are many times greater than those through water and the ranges that could be obtained are prohibitively low.

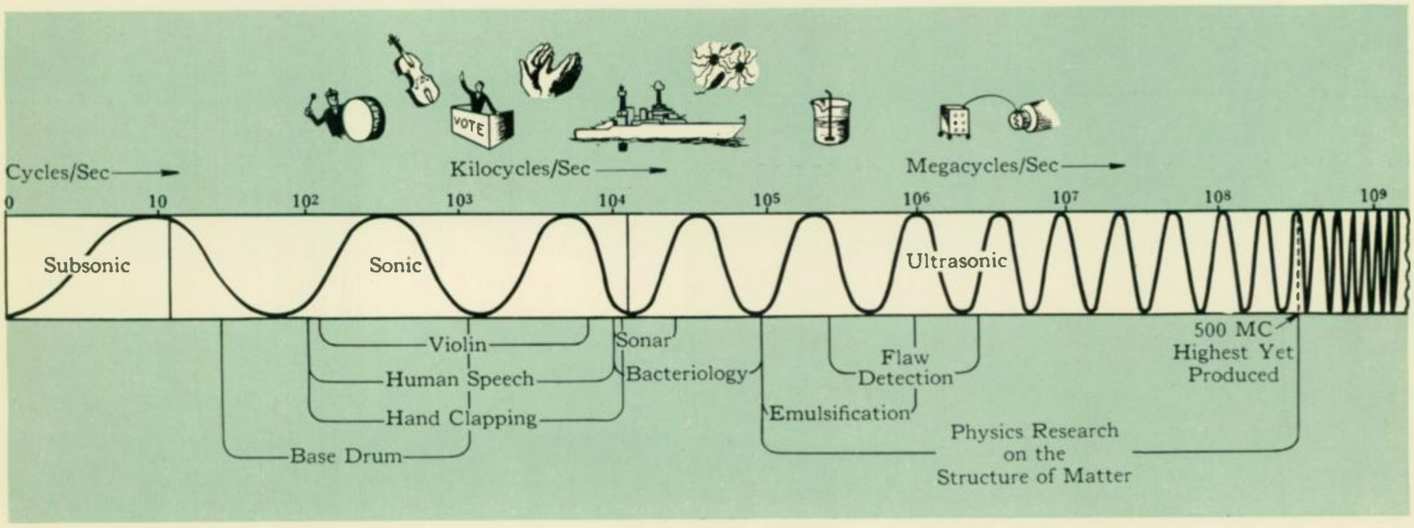
Another common application of ultrasonics that has grown in popularity is its use in material testing.* This field includes the testing of castings, concrete structures, forgings, etc., for hidden flaws by means of the different behavior of ultrasonics propagated through the main body under test and its propagation through a flaw or hole. In addition to testing for flaws it is possible to determine the elastic constants of materials to a high degree of accuracy by measuring the ultrasonic velocity through the material, which is proportional to the square root of the modulus of elasticity.

In addition to these two applications, which are only moderately new, there is a whole field of ultrasonic applications, so new that most are still in the experimental or pilot-plant stage. From these will probably come the most prolific results in the future.

Perhaps first among these is the use of ultrasonics in dispersion and agitation. When it is necessary to form an emulsion of two immiscible liquids such as oil and water, a high-intensity ultrasonic wave is unusually effective. Its

*See "Nondestructive Flaw Detection," by D. M. Kelman, *Westinghouse* ENGINEER, July, 1949, p. 115.

The frequency spectrum. Today, ultrasonic frequencies are performing a variety of important services for science and industry. And there are many applications still in the early stages of development.



frequency is not particularly critical provided that it is moderately high and that the power developed is great enough. This emulsification comes about through a combination of cavitation within the liquid and the extremely high accelerations, which actions tend to fling colloidal particles of one of the liquids into the other. An extreme example of this, the emulsification of mercury in water, can be demonstrated with laboratory apparatus. The emulsions so formed are more uniform and more highly stable than those formed in any other manner, while they require much shorter times. The process of dispersion is similar to that of emulsification and can be demonstrated by the dispersion of a pigment in a paint. The pigment so dispersed is more finely divided than that obtained by most conventional processes and requires appreciably less time. It has been estimated that such an ultrasonic method might be operated at a cost approximately the same as that of conventional means, with the advantages of a uniform high standard of dispersion and a considerable reduction in maintenance cost due to the replacement of moving parts necessary in conventional methods.

Another application of ultrasonics is in the laundering of clothes. The University of Pennsylvania has been carrying forward experiments in ultrasonic washing with a considerable degree of success. The process involved here is primarily one of cavitation combined with one of emulsification, in which the dirt or grease particles are completely surrounded by the detergent used while the cloth is violently agitated.

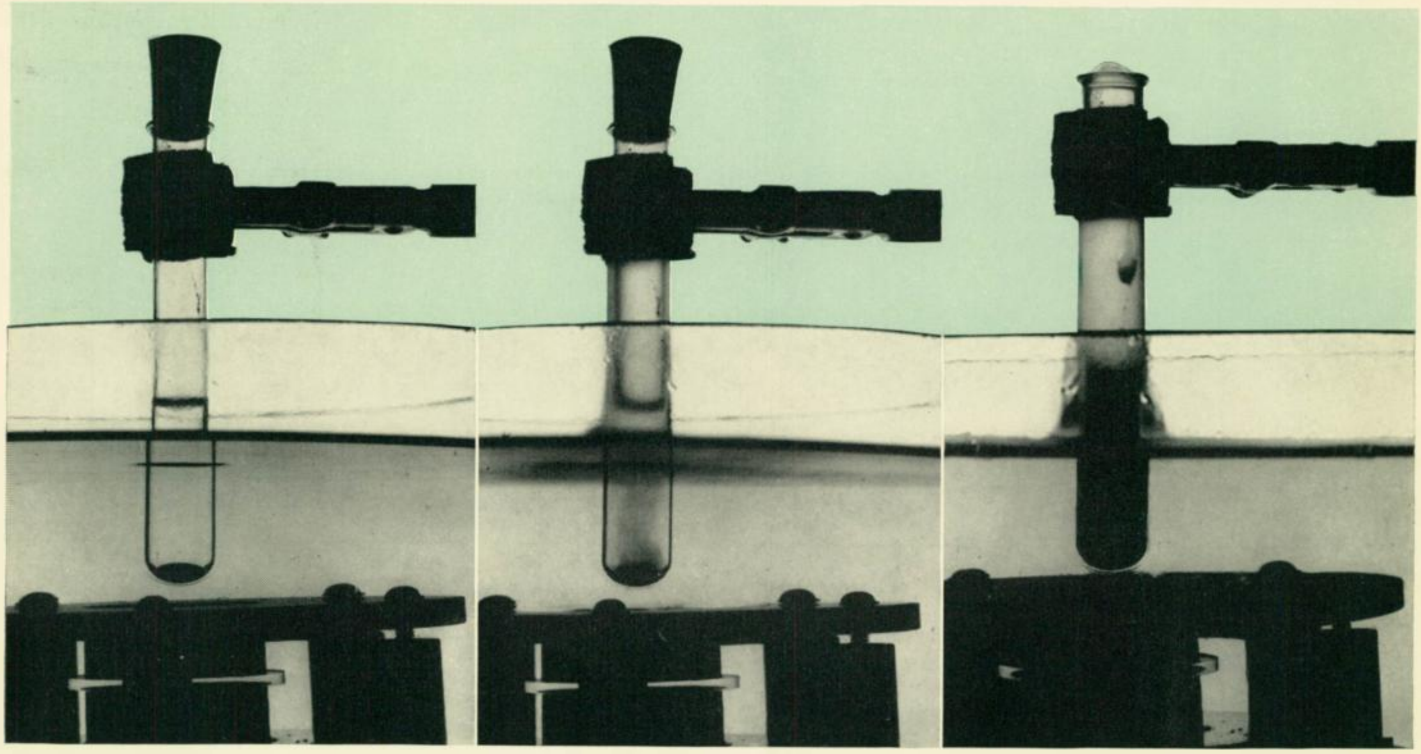
Curiously enough, ultrasonics can not only cause dispersion and emulsification, but if sufficient power is used, the reverse action can be observed. This is of particular interest in the coagulation of aerosols, which includes a subject of considerable interest today—smoke precipitation. Sufficiently powerful ultrasonic generators can precipitate smoke in industrial volumes and several installations of such precipitators have recently been made. The ultrasonic precipitator causes the smoke particles to collide with each other with sufficient intensity to adhere, and these clumped particles, when they grow sufficiently large, fall to the bottom of the stack. The necessity for cleaning this device does not exist because the precipitated particles do not adhere to the precipitator; it is only necessary to introduce the ultrasonic power in the stack at some convenient point and at some satisfactory intensity, so that the particles go to the bottom of the stack. Of considerable interest is the fact that the efficiency of an ultrasonic precipitator is increased with denser smoke over its efficiency with thin smoke. This can readily be seen from the fact that probability of collision between particles is highly improved if there are more particles present.

Other uses of coagulation are those involved in the recovery of a catalyst or other finely divided substance that is mixed in a solution, and which has served its useful purpose. This includes the emulsion of cutting oils in water. Although apparently industrial-scale applications of this phenomenon have not been made, it exists as an attractive possibility.

The biological effects of ultrasonics also have potential industrial applications. The cavitation and high acceleration available cause the destruction of bacteria, and at least one corporation is engaged in some full-scale work with the simultaneous pasteurization and homogenization of milk. Here the pasteurization is accomplished through the killing of bacteria and the homogenization is accomplished by the emulsification of the fat. Applications have been suggested for the sterilization of the contents of packaged containers through ultrasonic means. It should be especially noted that these effects are not due to heating but to the actual destruction of the living matter. As a corollary, it can be shown that ultrasonic vibration of sufficient intensity can be quite harmful to larger living organisms such as frogs.

It should be clear from these examples that the uses of ultrasonics in the chemical industry are attractive. In addi-

Ultrasonic waves can be used to emulsify liquids that usually resist mixing. The pictures below show three stages in the emulsification of mercury and water. In the first picture at the left the mercury is seen as the dark substance in the bottom of the test tube. It gradually intermingles with the water as the ultrasonic waves generated by the instrument below the test tube pass through the liquid.



tion to the mixing and emulsifying actions the application of intense ultrasonics to various chemical reactions has the effect of causing them to proceed at advanced rates. This may be the result of the intense stirring action or the increase in the surface areas of the reacting agents due to their being divided more finely by the ultrasonics. The preparation of colloidal suspension of matter within liquids by ultrasonics is of special interest. In the field of metallurgy, ultrasonics have been used, on a laboratory scale, to prepare mixtures of immiscible liquid materials in a manner similar to that used in emulsification. One particularly interesting application in the metallurgical field is the decreased grain size that can be produced by ultrasonic agitation of liquid metals during cooling. Another example is the use of ultrasonic frequencies in aluminum soldering. If ultrasonic vibrations are applied to the tip of the soldering iron, aluminum can be soldered without the use of flux. A similar application is that in which ultrasonics are applied to the cathode in an electrolytic plating solution to provide a very finely divided and uniform plate upon the anode. While speaking of grain size, it is worth mentioning that the use of ultrasonics in the preparation of photographic plates results in a smaller grain size and improved resolution over that obtained through conventional processes.

Although not exactly an industrial application, ultrasonics have been used in the Scophony system of television to replace the conventional cathode-ray tube by a light beam modulated with the varying densities present in a chamber traversed by ultrasonic waves in a direction perpendicular to that of the light beam. This system, in combination with rotating mirrors for the scan of the resulting ultrasonic modulated light beam, results in a projection television system of unlimited size.

Ultrasonics, though an old field, is still in experimental stages. Many other valuable applications seem possible, even likely, after the necessary laboratory development and testing.

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What's NEW! . . . . in Products

Reset Pole-Mounted CSP's from the Ground

If you are interested in saving an occasional pole climb just to reset a pole-mounted type CSP distribution transformer, there's a gadget out that will save you the trouble. It is especially useful in special applications, like sports lighting, where these transformers must be connected or disconnected at infrequent intervals. Because CSP transformers already have breakers it is not necessary to install one at the bottom of the pole. All that is needed is a method of controlling the breaker-reset handle from the ground.

The mechanism used is a simple one. Two cables are connected to a bracket mounted on the transformer breaker handle. These cables then drop down the pole in conduit to a control box mounted on the pole at average shoulder height. Handles marked "on" and "off" are attached to the ends of the cables in the control box.

To operate the transformer breaker, all you have to do is pull the proper handle until the breaker does what you want it to do—either open or close. The breaker can be reset after automatically tripping by pulling the "off" handle as far as it will go, and then pulling the "on" handle until the breaker closes.

The control comes in two styles: for CSP transformers rated from 3 through 25 kva, and for CSP transformers from 37½ through 100 kva. Parts supplied include all equipment necessary with the exception of the control cables, conduit, and padlock.

A Smaller 100-Watt Service Lamp

In these days of the big emphasis on fluorescent and mercury-vapor lighting, we're apt to forget about our old friend, the incandescent lamp. At best we tend to take it for granted. Not so with lamp engineers. They are constantly trying to improve it. The latest advance is a reduction in the size of 100-watt rough-service lamps—the kind used in shipyards, over factory work benches, on nighttime construction jobs, etc. The new lamp fits smaller size wire guards and holders, but gives the same light output as its predecessor. The diameter has been decreased a quarter of an inch, the overall length three quarters of an inch. It measures 2⅝ inches across, and is only 5 5/16 inches high, from the top of the bulb to the bottom of the base. The new lamp is sturdier, and furnishes more light with existing portable equipment. All 100-watt rough-service lamps are affected by the change, both frosted and clear, for both standard and high-voltage service.

By arranging the arrester elements spiral-fashion between three columns of insulators, great rigidity and a much reduced height are achieved. →

New Self-Supporting Lightning Arrester

The editors of the Westinghouse ENGINEER are going 'round in spirals this month. On page 130 we announce a new spiral filler that will increase the ratings of expulsion lightning arresters. And here is another spiral—this time a new structural arrangement for high-voltage lightning arresters that makes possible a self-supporting unit for 195/230 kv and higher. The new design is another forward step made possible by the experiments conducted in the high-voltage and the high-power testing laboratories.

The picture of a model of this self-supporting arrester shows how it's built. The arrester units, instead of being mounted in vertical stacks, are tilted and arranged in a spiral-like pattern around the inside of three supporting columns of standard apparatus insulators. This construction cuts the height of the installation almost in half—10 feet instead of 20: a substantial saving in head room, often a major consideration in substations. The low height also makes it possible to mount the arrester closer to the transformer, which makes for better protection; and inspection is quicker and easier, with less "outage" time required.

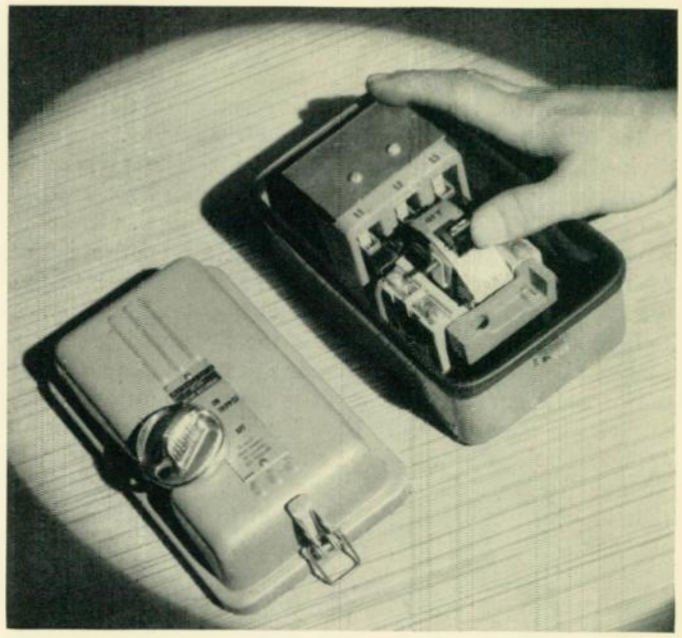
The big saving, though, is in installation costs. Large structural-steel supporting or bracing frames are no longer required, so time and expense are cut considerably. These arresters, mounted in groups of three, occupy little more ground space than previous models. The arrester is shipped disassembled for easy handling during shipment and installation.

Loom-Motor Starter

If you put a lid on a box, it keeps out a lot of stray foreign material. And if you clamp the lid to the box, still less material can enter. Add a gasket to the lid, then clamp it to the box, and foreign material is virtually excluded. That has been done on a new loom-motor starter.

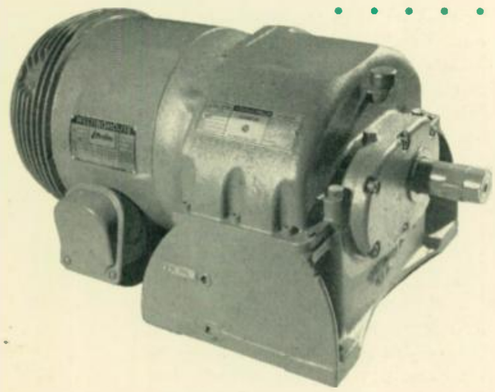
This starter was designed specifically to reduce the hazard of electrical fires in textile mills, although it can be used in many applications where there is a lot of foreign matter in the air. Lint and dust, so prevalent in textile mills, is kept from entering the starter case by a continuous Neoprene gasket. A pressure-type clamp maintains the seal. This starter, which meets the NEMA 1A specifications for gasketed enclosures, was designed in collaboration with the engineering division of the Associated Factory Mutual Fire Insurance Companies and leading textile manufacturers. Other protective features of the starter include a bimetallic snap-action disk-type overload relay and De-ion arc quenchers. The arc quenchers consist of grids that magnetically draw the arc away from the contacts when the circuit is opened. They extinguish the arc within half a cycle. A new rotary handle mechanism that can be locked in either the open or closed position prevents accidental operation.

The starter is arranged for straight-through wiring. Power wires enter through the top and motor wires through the bottom. It is also available with power terminals at the bottom and motor terminals at the top. A Micarta protective guard is placed over the power terminals to prevent possible accidents caused by workmen coming in contact with the power terminals while working on the starter. This new starter comes in ratings up to 600 volts, 7½ hp polyphase.



This new loom-motor starter has significant advantages in applications where lint and dust in the air are a fire hazard.

. . . . in Engineering



More Motor, Same Space

Motor and gear designers were recently given an opportunity to exercise their ingenuity to the fullest in creating and applying gearmotors for the shear tables in a new steel mill producing bars and special shapes. The duty cycle called for each of about 100 of these table-roll drives to start and stop 11 times per minute with a roll inertia of 42 lb-ft^2 while carrying a load of steel of 153 pounds. The largest motor that could be accommodated under the table apron was NEMA frame 225. But a totally enclosed, non-ventilated motor of that size is not normally of sufficient rating for this duty.

Several special construction features were adopted by engineers of Westinghouse and the Birdsboro Steel Foundry and Machine Company to solve the dilemma. The inertia of the motor armature was made less than standard by the use of special electrical parts. This reduced the energy to be dissipated during acceleration and deceleration. Also the braking losses were reduced two thirds by using d-c dynamic braking instead of the usual plugging method of braking. To provide better dissipation of the heat, ribbed front brackets were provided. Because of the high ambient temperature heat-stabilized bearings are used. A special gear housing of lower than normal height was also utilized due to the table-clearance conditions.

The result is a three-phase, non-ventilated gearmotor on a NEMA 225 frame with class B insulation that develops one half horsepower at 14 to 1 gear ratio without exceeding a 75-degree temperature rise in a severe acceleration and deceleration duty cycle.

Having and Eating the Trolley Coach Cake

A trolley-coach motor has two jobs to do. It must, of course, propel the vehicle. An equally important function is to act as a brake during deceleration. Without argument, the motor best suited to the propulsion job is the d-c series type. However, it is not as desirable in electric braking as one with a shunt winding because the voltage of a series generator changes more widely and more rapidly with change of current. A large number of notches is essential to smooth braking with a series generator. The performance characteristics of the shunt motor are not well suited to the propulsion of vehicles, especially in city-transit service. Also, its commutator has a tendency to flash excessively under the conditions met in that type of service.

The proper answer seems to be a series motor to provide acceleration and a shunt machine for braking. This is precisely what is being done. The new trolley-coach motor has a series winding and a shunt winding. During motoring only the series field is energized; during deceleration only the shunt field. While the addition of the shunt field to the otherwise conventional series motor adds about an inch to its girth, the control elements are reduced appreciably, and the control operations are cut almost in half. By these means, optimum performance is obtained both in motoring and braking.

What? An Unbroken Record!?

In 1928 a Nordberg coal hoist, using Westinghouse electrical equipment, raised 15 175 tons of coal in one 8-hour shift at West Frankfort, Illinois. After 22 years, this record still stands, and the equipment continues to give trouble-free service.

Any inquiries relating to specific products mentioned in this section should be addressed to the *Westinghouse* Engineer, 306 Fourth Avenue, P.O. Box 1017, Pittsburgh 30, Pa.

Personality Profiles

Certainly *D. J. Reynolds'* design career has had none of the aspects of a rut. He has worked on high-voltage x-ray tubes and power supplies, power control and switchgear, production facilities for d-c generators for military aircraft, the surge-comparison tester, work-handling equipment for radio-frequency heating, and power-absorption equipment for diesel test rigs. Reynolds liked his E.E. degree received from the University of Cincinnati in 1934 just fine, but he decided to leaven it with additional commercial and engineering courses that led to the degree of Commercial Engineer in 1938. He has followed this with night studies of security markets, corporate finance, and other business topics at Northwestern University's Graduate School.

R. J. Alke got a start on his engineering education with a year at the Montana School of Mines before a five-year hitch in the Air Force. The war won, he completed his work to an electrical engineering degree at the University of Washington in 1948. After a few months in the Graduate Student Training Program in 1948 he became a member of the Insulation Development Section of the Transportation and Generator Division.

L. W. Buchanan became an expert in the use of the surge comparator because it offered a means of studying defects in fractional a-c motors. Buchanan has been designing these motors since 1938—except for a four-year recess with the U. S. Army Signal Corps. He is largely responsible for the motors that are doing a particularly outstanding job in the unit-heater and hoist field. His alma mater is Purdue, class of '37. Degree, double E.

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If we were to select one word to describe *E. G. Wise*, it would be *intense*. Whatever he tackles is done with great persistence, vigor, and directness. On the personnel list of the Westinghouse office in Chicago, E. G. Wise is listed as a salesman. He is that all right. He has made scores of sales of control centers, his major concern. But he is more. To him there is no dividing line between selling and engineering. Frequently, to aid a potential user of a control center and to expedite his planning, Wise will take the problem home with him and draw up a floor layout, or contrive some modification of a switch or breaker in his own workshop.

Ernie has never had time to get everything done he wants to do. It was that way with his engineering education. He got in one year's work at Notre Dame in 1920. Another year and a half came by going to night school at Armour Institute in 1921 and 1922. He finally finished it with more night school work at Washington University in 1940.

He has been a lot of places while with Westinghouse, but almost always on controls, panelboards, and switchboards: first to Chicago in 1921 as panelboard engineer; this was followed by similar work at St. Louis; thence to East Pittsburgh; and finally in 1945 back to Chicago.

Right now Wise has gardening and landscaping projects in progress 72 miles from Chicago. Not content with just planting stuff and hoping it grows, he has been going in for soil analysis, scientific soil culture and planting, landscaping, and so on. Never have four acres had such a going over as his.

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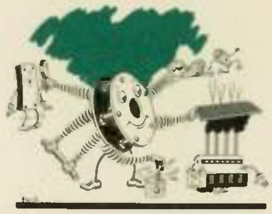
The physics of sound and horticulture seems like a rather amazing combination of interests. But, perhaps nothing should amaze when it concerns a Texan. *Dr. Patrick Conley* was born in Roby, Texas, went to Rice Institute for his B.S. in E.E. He found out that part of the world is outside Texas when he served in the U. S. Navy. He spent most of his service time



teaching at Harvard, but also spent 13 months in the Hawaiian area as radar observer, fire-control radar officer, and instructor. His interest in electronics took him to Harvard when he returned. Received a master's degree in communications from Harvard in 1946 and his Ph.D. in applied physics in 1948, when he came to Westinghouse.

Young Dr. Conley—he was but 27 then—came just in time to be placed in charge of a research group investigating underwater sound problems for the U. S. Navy. With one assistant he set up the laboratory and testing facilities at the Westinghouse Experimental Station in Key West, Florida. Now he is manager of the section and has 12 assistants.

Pat's hobby—raising orchids—is particularly pleasing to his wife. But he doesn't stop with raising the things. Also studies the physiology of orchids and many other plants. Plans to extend this hobby when he and his wife move into their new home in Fox Chapel.

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Otto Ackermann is a man of many interests. During the relatively long periods of inactivity while a member of the Bavarian field artillery in World War I he occupied himself with painting. He continues to pursue this hobby in serious fashion although it has to compete now with several others. He is also an accomplished violinist. Several years ago he became interested in butterflies. With characteristic thoroughness he quickly became dissatisfied with the traditional method of mounting the insects on pins. He devised a means of sealing them permanently in clear plastic. Originally intended for his own use, the word got around to other lepidopterists. In self defense he now makes for sale some 20 sizes of plastic mounts.

Ackermann received his technical training at the Munich Institute of Technology, but decided after World War I, with Europe in a chaotic state, to come to America. He went to work with Westinghouse in 1924 as a castings cleaner, but soon moved to motor engineering. About that time Westinghouse was beginning its field and laboratory studies of lightning. Ackermann heard a cathode-ray oscillograph expert was needed. He wasn't one but decided he could be, so he sought and obtained the post. He has since established an international reputation as designer of cathode-ray oscillographs and surge generators.

Ackermann has done a good job of helping tame lightning. Better in fact than he has done at taming nature's streams. Each summer for several years he has built a swimming pool on his 55 acres of woods in the Allegheny foothills. Each year, spring floods wash out his pool. Ackermann is not one to be easily thwarted. He has bigger and better plans for outwitting the streams this summer.

A lightning-arrester design section might seem a strange place for a mechanical engineer. But *E. J. DeVal* who graduated from M.I.T. in 1948 with the degree of B.S. in M.E. has already made a signal contribution in the field, although he has been associated with this apparatus less than three years. DeVal is given credit by his associates for the novel and basic idea that underlies this new type of lightning arrester. DeVal entered the Westinghouse Apprentice Course in 1942, studying tool and die making. This training sharpened an unusual mechanical facility. Like as not when he gets a new design-improvement idea, rather than wait for the model shop to produce it for him, he turns it out himself.

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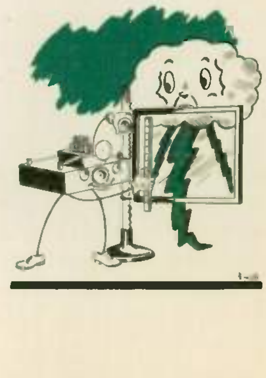
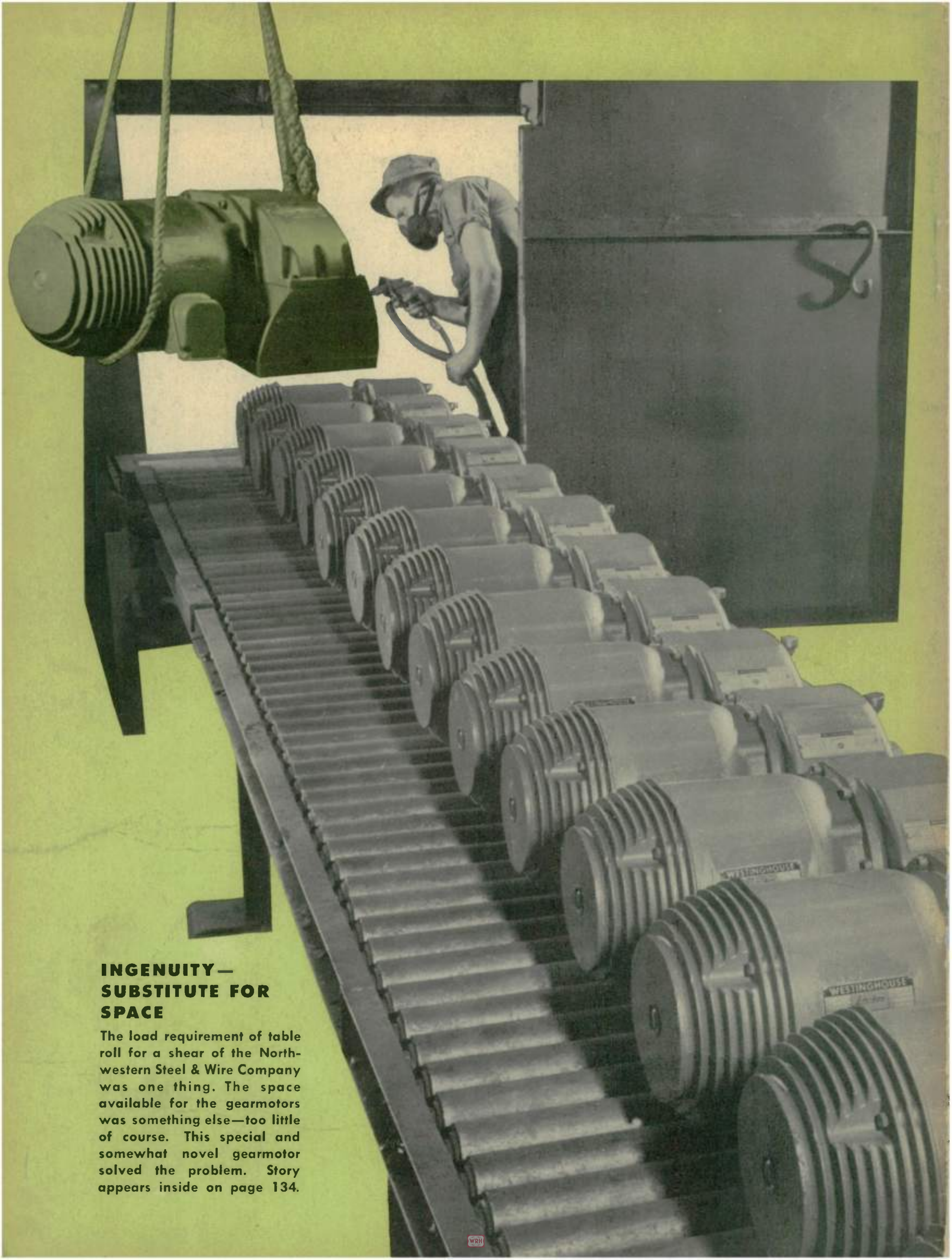
Collaborating is nothing new for *E. L. Harder* and *J. M. Clayton*. Since 1947 they have been studying lightning together.

Dr. Harder and Jim Clayton have co-authored two AIEE papers, but this is Clayton's first tour in the ENGINEER. Clayton's interest in lightning and thunderstorms materialized before he completed the Westinghouse Student Training Course. He came here from Alabama with two bachelors' degrees: one in E.E., the other in meteorology. He got a degree in meteorology at N.Y.U. where he studied while in the Army Air Force. Service as an Air Force weather forecaster in Georgia, where he was born, nurtured his budding interest in lightning. When he returned to civilian life in 1946, he completed his course in E.E. at the University of Alabama, then came to Westinghouse.





INGENUITY— SUBSTITUTE FOR SPACE

The load requirement of table roll for a shear of the Northwestern Steel & Wire Company was one thing. The space available for the gearmotors was something else—too little of course. This special and somewhat novel gearmotor solved the problem. **Story appears inside on page 134.**