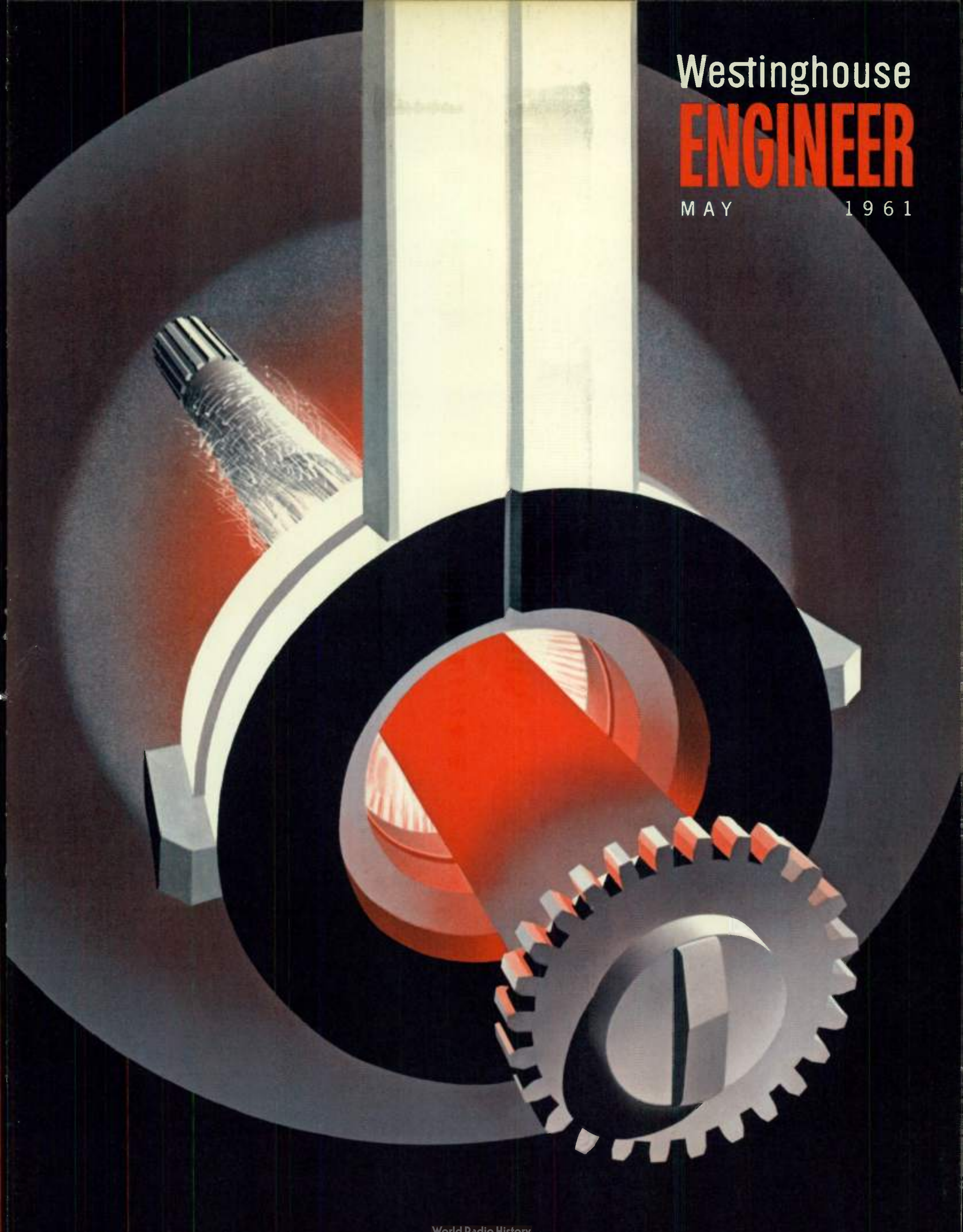
Westinghouse ENGINEER

MAY 1961



World Radio History

This new experimental Navy climatic suit is heated or cooled with a thermoelectric air-conditioning unit (Left). A temperature of about 80 degrees F is maintained inside the suit when outside temperatures are 40 degrees below zero (Center) or 135 degrees above (Right).

SARTORIAL THERMOELECTRICITY

A self-contained air-conditioned suit that can keep the wearer comfortable in outside temperatures ranging from 40 degrees F below zero to 135 degrees F above has been developed by scientists of Westinghouse and the U. S. Naval Supply Research and Development Facility.

Heating or cooling of the experimental garment is done thermoelectrically. More than 250 thermoelectric couples, each having a leg of p-type and a leg of n-type semiconductor materials (bismuth telluride), are the working elements in the thermoelectric unit. The couples are assembled between two circular heat exchangers about 18 inches in diameter and two inches thick.

During cooling, the flow of electricity through the elements causes one end of the thermoelectric couples to cool, thus lowering the temperature of the heat exchanger on the inside of the suit. The heat removed from the cool side flows through the thermoelectric elements to the hot-side heat exchanger, from which it is dumped into the atmosphere by a small fan. Another fan, mounted on the same shaft, circulates the cool air within the suit. During heating of the garment, the functions of the two heat exchangers are reversed. Heating or cooling is done automatically, depending upon the temperature inside the garment. Tests show that a temperature of about 80 degrees F is maintained inside the suit over the given outside temperature range.

The two small fans are the only moving parts in the suit's entire air-conditioning system. Batteries permit the suit to be independent of any other power source for one hour. For more restricted movement over extended periods, the suit can be plugged into a dc electrical outlet.

Completely air tight, the suit is made of an insulated aluminum-coated fabric. Air for breathing is supplied through a face mask connected to the side of the suit helmet, where incoming air is heated or cooled by a small heat exchanger.

Although thermoelectric refrigeration is presently less efficient than compressor systems, it does compete in small-scale applications and it performs cooling tasks that cannot be accomplished as effectively in any other way.

The unique thermoelectric air-conditioning unit was designed and built at the Westinghouse new products laboratories. Design and fabrication of the protective garment, installation of the air-conditioning system, and testing of the finished suit were done by the Clothing and Textile Division of the Navy Supply Facility.

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Cover Design Induction heating is serving industry today in a variety of ways. An outstanding example is the surface hardening of axles, shown symbolically on this month's cover by artist Dick Marsh. The heating and quenching cycle is shown against a background cross section of the hardened axle.

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LEADVILLE TEST PROJECT . . . EHV AT HIGH ALTITUDES

Construction and operation of extra-high-voltage transmission lines at high altitudes pose special problems. This test line was designed to provide information necessary for solutions.

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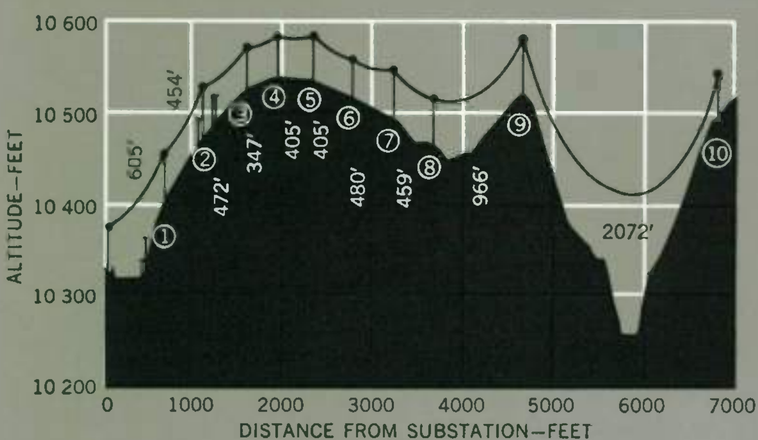
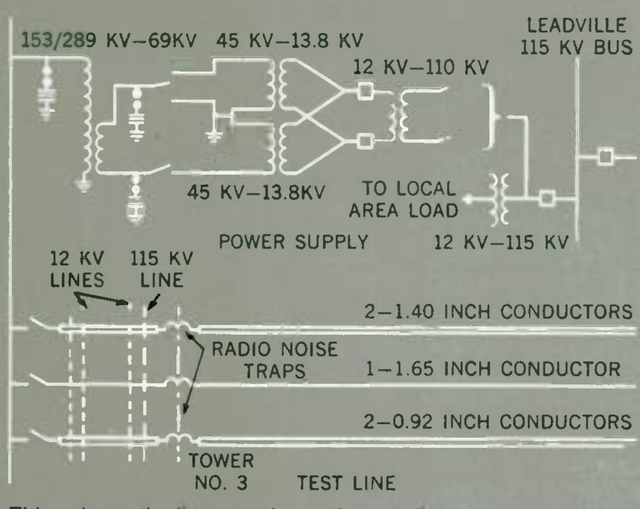
Test lines to explore the problems of extra high voltage transmission have been built in several parts of the world during the past 15 years, and have contributed a wealth of information. However, nearly all of these EHV test lines were built near sea level, and none of them offered experience at altitudes of 10 000 or 15 000 feet. The only guides to high-altitude performance were formulas based on laboratory or low-altitude tests. Since the operation of EHV lines at high altitudes involves considerations not



A profile of the Leadville EHV test line.



This schematic diagram shows the test line and power supply.

DESCRIPTION OF FACILITIES

The high-altitude test site is located near Leadville, Colorado, on a high plateau between two mountain ranges at an altitude of 10 300 feet. The line is erected near an existing 115-kv to 12-kv stepdown substation. A profile of the test line is shown at left.

The line itself consists of ten structures, eight of wood and two of steel. There are seven different types, all full-scale three-phase structures such as might be used on a 345-kv transmission line. Tests are conducted single phase, so different types and configurations of conductors were strung on each of the phase positions.

Conductors include both bundle and single conductor configurations. One conductor is a single 1.65-inch expanded ACSR, identical to one used in the Tidd low-altitude tests. A bundle of two 0.92-inch ACSR conductors at a spacing of 16 inches was strung in the second phase position; this was to enable comparison with a bundle of two 0.92-inch copper I beams installed in the Tidd low-altitude tests. This conductor was reduced to a three-conductor triangular configuration, to a two-conductor flat configuration, and eventually to single conductors as tests progressed.

As shown in the diagram at left, the route selected for the test line crosses both a 12-kv and 115-kv circuit; to avoid radio influence coupling, radio noise traps are installed in the test line.

Substation facilities include a single-phase transformer with an operating range of 100 to 300 kv line to ground, a 345-kv lightning arrester, and three 345-kv single-phase disconnect switches.

The instrumentation used at Leadville for measuring RI and corona losses is more accurate than that available in the Tidd low-altitude tests. In addition to the electrical instrumentation, full facilities are also included for measuring temperature, dew point, relative humidity, barometric pressure, precipitation, wind velocity and direction, and conductor temperature. Also, a 16-mm camera takes photographs of a sample conductor and insulator every 30 minutes, and is also used to observe general sky conditions.

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common to low altitudes, and since the economics of any high-altitude system depend heavily on these considerations, the Public Service Company of Colorado decided to build a high-voltage test line near Leadville, Colorado. With the cooperation of several equipment manufacturers, construction of this line was started in 1955 and test operations were begun in 1957. Since that time, much useful information has been developed, particularly about corona loss and radio interference, which will lead to better knowledge of these factors.

general background

Most of the Public Service Company's system is constructed at relatively high altitude—the city of Denver is located at an altitude of over 5000 feet, and much of the system is located west of Denver where lines must cross the Continental Divide at altitudes of 12 000 and 13 000 feet. Thus a transmission line must be situated in a relatively isolated and rugged mountain terrain, where weather conditions are severe. Obviously, construction, operation, and maintenance of such lines is difficult. Equipment should be light for ease of transportation, and simple to erect; on the other hand, it must be designed to withstand heavy snow, snow slides, and frequent lightning storms. These conditions also indicate the importance of using the minimum conductor size consistent with good corona and radio influence performance.

The Leadville EHV Test Project was undertaken to investigate design problems and potential savings. Two primary subjects of the investigation were corona and radio influence. Results so far indicate possibilities for substantial savings in future transmission systems.

test results—corona loss

Corona loss on a conductor is a function of the electric field gradient at the conductor surface, the condition of

In this photograph, all three conductors and both ground wires are in corona. Conductors are energized at about 275 kv to ground.

EFFECT OF ALTITUDE ON CORONA LOSS

The effects of altitude on corona loss, until now, have been determined by formulas developed by Peek and Peterson. For the most part, these formulas are based on laboratory experimentation, and the Leadville Project offered an excellent opportunity to check their accuracy.

Both Peek's and Peterson's formulas make use of the *air density factor*, δ, which can be calculated by the formula,

$$\delta = \frac{17.9\, b}{459 + t}$$

where b is the barometric pressure in inches of mercury, and t is the temperature in degrees F.

This formula can be expanded to include the effect of the partial pressure of water vapor, and is then known as the *absolute air density*. This formula is,

$$\delta = \frac{17.9\, b - 0.0073\, RH\, (t - 32)}{459 + t}$$

where RH is the relative humidity in per unit values.

In his formula, Peek found that the critical disruptive voltage for corona formation was expressed by the formula,

$$e_0 = K_1 \delta$$

where K_1 is a constant if all variables except δ are constant.

In later work, Peterson had different results, and found that the critical disruptive voltage varied as the $\frac{2}{3}$ power of the air density factor, or

$$e_0 = K_1 \delta^{2/3}$$

where K_1 is the same constant as used in the previous formula.

Because of the wide variation in results that these two formulas produce, the acquisition of further data and a better understanding of the factors involved became an important part of the Leadville Project.

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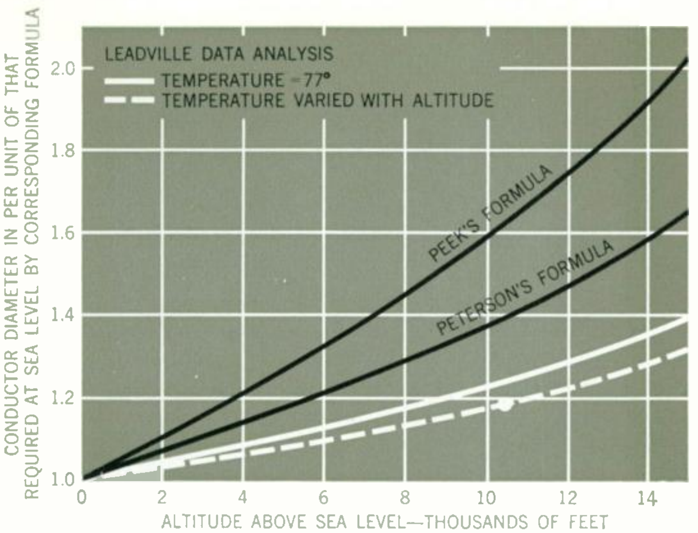

Fig. 1 A comparison of Leadville data analysis with curves of conductor diameter as a function of altitude to give a constant corona loss of 3 kw per three-phase mile on a 345 kv transmission circuit with an equilateral spacing of 28 feet.

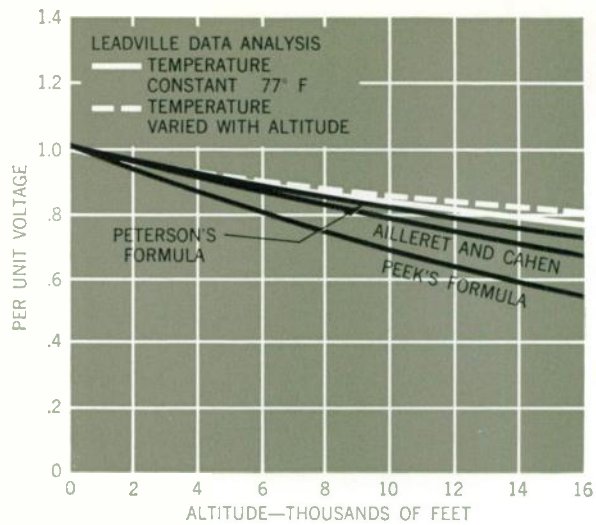

Fig. 2 A comparison of Leadville data with calculated curves of operating voltage as a function of altitude to maintain a constant corona loss of 3 kw per three-phase mile on a line designed for this loss at 345 kv operation at sea level.

the conductor surface, and the environment surrounding the conductor. When the voltage on a conductor is increased with respect to other conductors, ground wires, and ground plane, the voltage gradient at the conductor surface increases to a value that ionizes the surrounding atmosphere, producing a corona discharge accompanied by a power loss. Rain, snow, or ice on the conductors reduce the uniformity of the electric field and lower the critical voltage. Lower air density means that the air around the conductor ionizes more easily, and thus at high altitudes the critical disruptive voltage is lower than at sea level. However, lower air temperature at high altitudes tends to increase the critical disruptive voltage, and therefore has a compensating effect.

Conductor surface condition also affects the critical disruptive voltage. Dust or dirt particles, or nicks on the conductor surface create an uneven electric field; conductors in contaminated atmosphere also develop a black coating that affects the amount of corona loss.

Test facilities at Leadville were designed to obtain the maximum amount of corona loss information on different conductor configurations (see *Description of Facilities*). Any phase of the 1.3-mile, experimental transmission line can be energized from a single-phase test transformer, using the three single-phase motor-operated 345-kv disconnect switches. Taps and primary voltage changes give a testing range from 100-kv to 320-kv to ground, which produces conductor surface voltage gradients equivalent to three-phase operation from 150 kv to 500 kv.

During the tests, conductors were simultaneously energized for long periods to hasten the "aging" or long-time changes in corona loss. Although previous low-altitude tests produced blackening of conductor surfaces and a resultant decrease in corona loss, the conductors at Leadville are still bright; this is probably due to the dry atmosphere and the lack of air contamination. These results are also supported by the condition of 115-kv conductors that were installed at the same altitudes in 1949; even after 11 years of operation these 115-kv conductors show no signs of darkening.

Air Density Factor and Corona Loss—Theoretical relationships, based largely on laboratory experiments, indicate that the critical disruptive voltage (generally speaking, the voltage at which corona starts) is a function of a

Table 1 CONDUCTORS TESTED AT LEADVILLE, COLORADO

Conductor	Configuration	Period Conductor Was Available	Short-time Corona Loss Tests	
			Fair Weather	Foul Weather
4—1.4 inch Expanded ACSR	16 inch Box Spacing	Nov. 56—July 57	*	—
3—1.4 inch Expanded ACSR	16 inch Triangular Spacing	Aug. 57—Sept. 57	**	—
2—1.4 inch Expanded ACSR	16 inch Horizontal	Oct. 57—July 60	51	9
1—1.65 inch Expanded ACSR	Single	Nov. 56—Present	55	14
2—0.92 inch ACSR	16 inch Horizontal	Nov. 56—July 60	56	13

*Used for calibration of instruments.

**No results due to undetected instrument malfunction.

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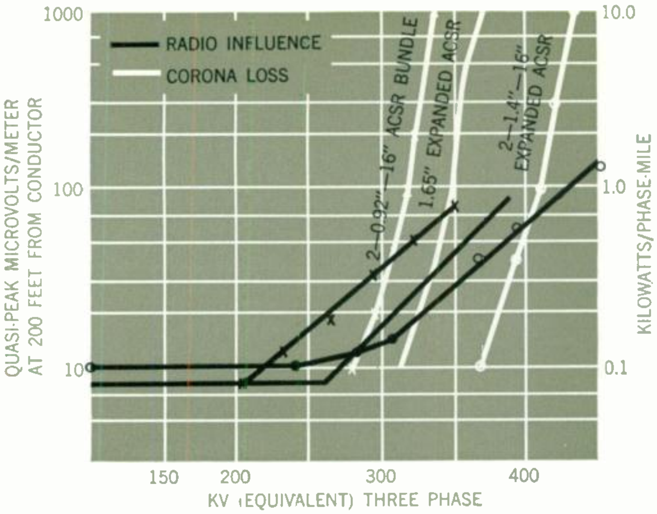


Fig. 3 Average curves of corona loss and radio influence level as a function of the equivalent three-phase voltage. These curves were developed with voltage on the test conductor, and the other two grounded at the substation.

factor called the ***air density factor*** (δ). The air density factor, in turn, is the ratio of the density of air at any given barometric pressure and temperature to that at 77 degrees F and 29.9 inches of mercury. This factor can also be expanded to include the effect of moisture, and is then known as the *absolute air density.* The various relationships are shown in the box, *Effect of Altitude on Corona Loss* (p. 67).

As indicated, the Peek formula shows that critical disruptive voltage varies with the first power of the air density factor, while Peterson's uses the 2/3 power of the air density factor. The use of these two exponents with corona loss data determined at sea level gives a wide range of conductor sizes required at high altitude, which again points up the importance of the Leadville Project tests.

Experiments on transmission circuits at Leadville indicate an exponent of from 1/3 to 1/2. For estimating purposes a value of 1/2 is indicated until further tests are made. Thus, the critical disruptive voltage becomes:

$$e_0 = K_3 \delta^{\frac{1}{2}}$$

where K_3 is a proportionality factor.

The smaller exponent resulting from the Leadville tests means, in effect, that the diameter of conductors can be smaller than that predicted previously. This is indicated by the curves of Fig. 1 and 2.

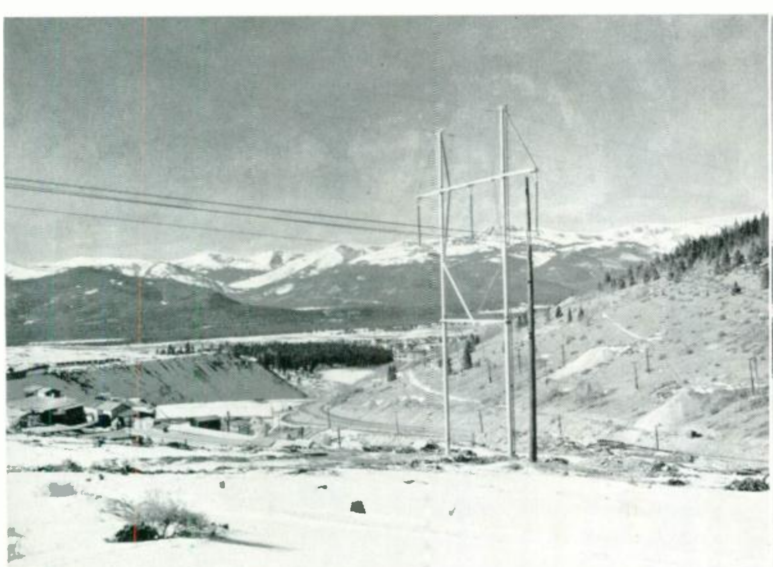
In the tests at Leadville, relative humidity had little effect on corona loss. Although previous investigations had indicated that humidity was an important consideration, in these tests it produced no measurable effect on the corona loss.

radio influence

Because some doubt existed about the ability of theoretical formulas to predict high-altitude radio-influence effects, investigation of this area was made an important part of the Leadville Project. Measurements were made to determine standing wave patterns, lateral attenuation, rf impedances, and fair and foul weather RI relationships.

Measured data taken at Leadville disagreed with calculated values based on theoretical considerations. Also, comparison with previous RI studies at low altitude is difficult. Radio influence appears to be a function of the size of dirt particles in the air, or the diameter of the individual corona source. If small radii surfaces on the conductor are the significant corona sources, altitude corrections based only on the ratio of relative air density and line conductor radius do not give accurate results.

Below, Left An experimental steel H-frame at the Leadville site. Note the type of terrain in which the line is located
Below, Right The fiber glass houses for RI measurements.



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To more fully evaluate the effect of small corona sources, tests were conducted both at the Westinghouse High Voltage Laboratory and at Leadville, using a smooth tube, small wires and fish line wound on a tube, and a tube with aluminum rivets. The tests indicated that the altitude corrections for corona critical voltage or gradient is less for small radius sources than for large radius sources. The test results also indicated that the critical voltages at Leadville were higher with respect to the High Voltage Laboratory values than the critical gradient formula (Peek's) indicates.

The information gained from these tests indicates that the effect of altitude can be approximated by the square root of the relative air density, rather than the first power as previously believed. For example, the 1.65 inch diameter conductor commonly used for 345 kv transmission at sea level generated an RI level of 15 microvolts per meter at 200 feet when energized at a gradient equivalent to 300 kv line to line. Based on previous investigations, the voltage would have had to be reduced to about 250 to 260 kv to achieve this low level, or a conductor larger than 1.65 inches would have been required for 300 kv.

These results at Leadville cannot be generalized as yet, since the effect of one important factor—environment—cannot be determined at this one site. Variations in air contamination, in the condition of the conductor surfaces, and from other causes require that a large number of tests must be conducted to explore the effect of environment. However, for conditions similar to Leadville—high altitude and clean air—the results of these tests should be adequate.

The RI levels and corona losses averaged over the many tests at Leadville are shown in Fig. 3. The results are plotted against their equivalent three-phase voltages. Note that for an RI level of 30 microvolts per meter 200 feet from the line, corona losses are below 400 watts per phase mile. This data indicates that the RI level is the determining factor in selecting conductor sizes for Leadville conditions.

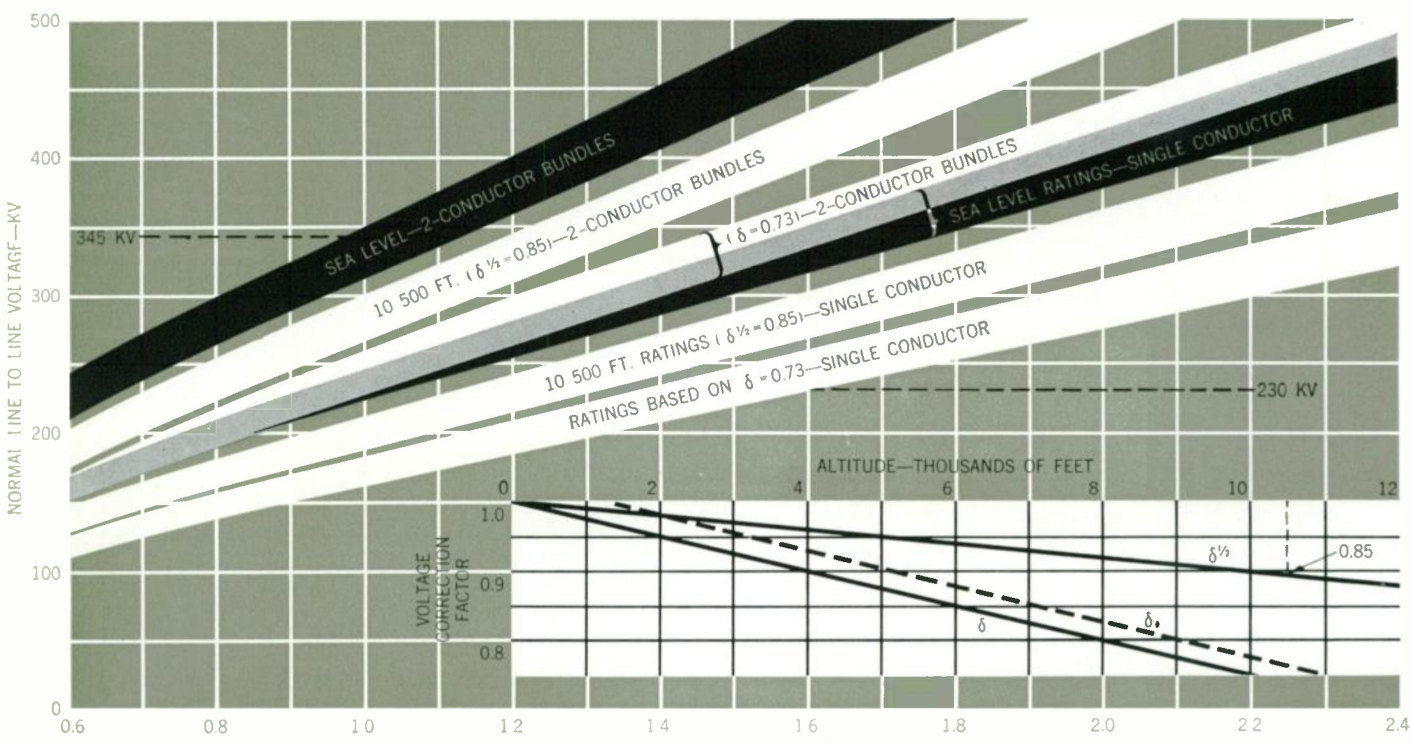
application of results

As mentioned, the Leadville tests indicate that for estimating the radio influence at these high altitudes, the critical gradient can be reduced by the square root of the relative air density corresponding to that altitude. The application curves shown in Fig. 4 give conductor sizes for operating voltages at sea level and for the conditions at Leadville.

The curves in Fig. 4 can be used for other altitudes, with some restrictions, and the curve of altitude correction is included for this purpose.

To use the altitude correction, a conductor is selected for a given voltage at sea level. This voltage is then multiplied by the correction factor for the particular altitude to give the voltage for which this conductor can be operated with results comparable to sea level operation. In this manner a curve of conductor size against voltage for the specific altitude can be constructed.

Several factors must be taken into account in applying these curves. They are based on average fair-weather results and gradients for a horizontal configuration with a height of 40 feet and no ground wires. Other configurations should be investigated to determine RI levels. Since foul weather can increase the RI generation from a conductor, this aspect should also be considered. For a given voltage and spacing, conductor sizes near the lower boundary are conservative; conductors near the upper boundary may have higher RI levels. The acceptability of a given RI



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level depends on ambient conditions and is a matter for individual consideration.

For areas with more contaminated air, such as industrial areas, conductors near the lower boundary of the curves should be chosen, i.e., the larger sizes; in clean atmospheres, such as at Leadville, conductors near the upper boundary give acceptable performance.

In some remote areas where radio influence is not a problem, corona loss can become the important consideration. Conductor sizes for these locations can be estimated from the curves of Fig. 5. These curves were developed from previous sea level research plus Leadville data, and were cross plotted using the air density relationships developed in the Leadville program.

future work

In the four years of testing at Leadville sufficient information has been obtained to permit substantial savings in future transmission system costs. At the same time, however, many new questions have arisen concerning corona loss and radio influence. Thus tests will continue at both Leadville and at the Westinghouse High Voltage Laboratory, in an effort to uncover more answers, since even greater savings may be possible.

One indication that greater savings may be possible is that laboratory tests of clean smooth conductors give critical gradients of 1.5 to 1.8 times greater than on conductors in service. This means that a conductor now used at 230 kv might be used at 330 kv from an RI and corona standpoint.

Two important factors affecting both RI and corona formation are the condition of conductor surfaces and environment. The most difficult effect to determine is that of environment since this includes atmospheric contamination, weather conditions, and altitude. The effects of individual conditions cannot be separated in the results from low altitude and high altitude experiments to date.

A new EHV test line at the High Voltage Laboratory, in conjunction with further work at Leadville, should help to segregate these effects. At the S.O. Laboratory, isolation traps in the line will enable two separate conductors to be tested simultaneously, thus assuring the same weather conditions.

Among the future tests will be one in which a clean conductor, a blackened conductor, and a conductor previously operated in a clean atmosphere will be tested under controlled atmospheric conditions both at the Laboratory and at Leadville. This should enable separation of the effects of surface condition, environment, and altitude.

Long time tests at Leadville will also be aimed at determining whether further changes occur in conductor surfaces now installed. Many other test programs are also being initiated to expand on the information already gained.

This article merely summarizes the corona and RI considerations, which is by no means the complete story of the project. Extensive tests were also performed in several other technical areas.

While a primary aim of this Leadville test program is to develop information necessary to build economical EHV lines at high altitudes on the Public Service Company of Colorado system, obviously many other benefits are accruing from the program. A better understanding of the basic causes of both corona and RI, and of their effects is bound to be derived from the test results and their correlation.

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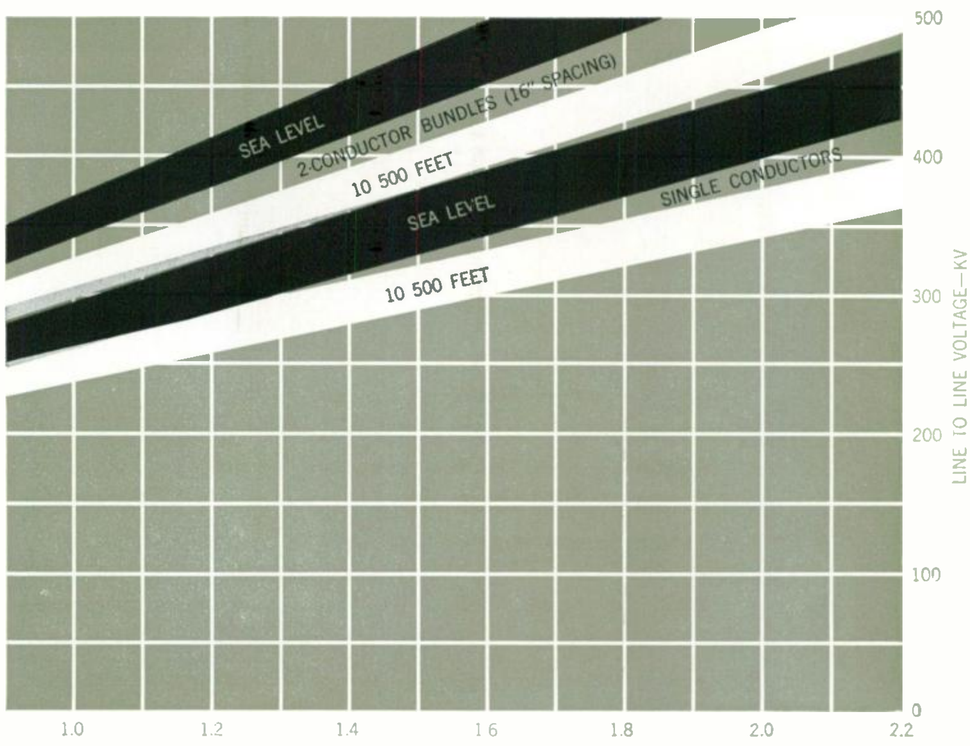
Fig. 4 (Left) Estimating curves for the radio influence comparison of sea level and altitude ratings of conductors. Dashed curve in inset is the relative air density factor from a report of the International Civil Aviation Organization.
Fig. 5 (Right) Estimating curve for corona loss levels of approximately 200 watts per phase mile using Leadville and previously published data for barometric pressure relationships.



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AC TO DC POWER CONVERSION WITH PACKAGED SILICON RECTIFIERS

Compact silicon power rectifiers in ratings up to 170 kw offer dependable and economical power conversion for a variety of applications.

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A recent survey showed that nearly 20 percent of the ac power generated in the United States for industrial use is converted to dc power. Conversion is accomplished by three basic types of equipment: rotating apparatus such as the motor-generator set; electronic equipment, such as the ignitron rectifier for large blocks of power and the glass-tube type for lighter conversion; and static units employing a semiconductor rectifying material.

Static rectifiers are the newest of these, and they are now used in a wide variety of ratings and types. This article describes the characteristics and capabilities of the versatile family of packaged static rectifiers with ratings up to 170 kw.

background

Selenium, germanium, and silicon are the semiconductor materials from which static rectifiers are made. Selenium has been used successfully for more than 20 years. Its inherent ability to absorb voltage surges still makes it useful for many applications, especially in lower ratings. Germanium is limited to low operating temperatures and lower peak inverse voltage ratings than silicon. However, it does have very low forward drop, and this gives it better efficiency than silicon for low-voltage power units such as those used in electroplating. Silicon, the latest arrival, has two distinct advantages over selenium and germanium for most power converting jobs: first, it can withstand higher operating temperatures; second, it is available in higher inverse voltage ratings.

Because of these advantages, the advent of silicon rectifiers has opened a new era in industrial power conversion. With proper external protection against voltage surges, silicon rectifiers are dependable and efficient converters.

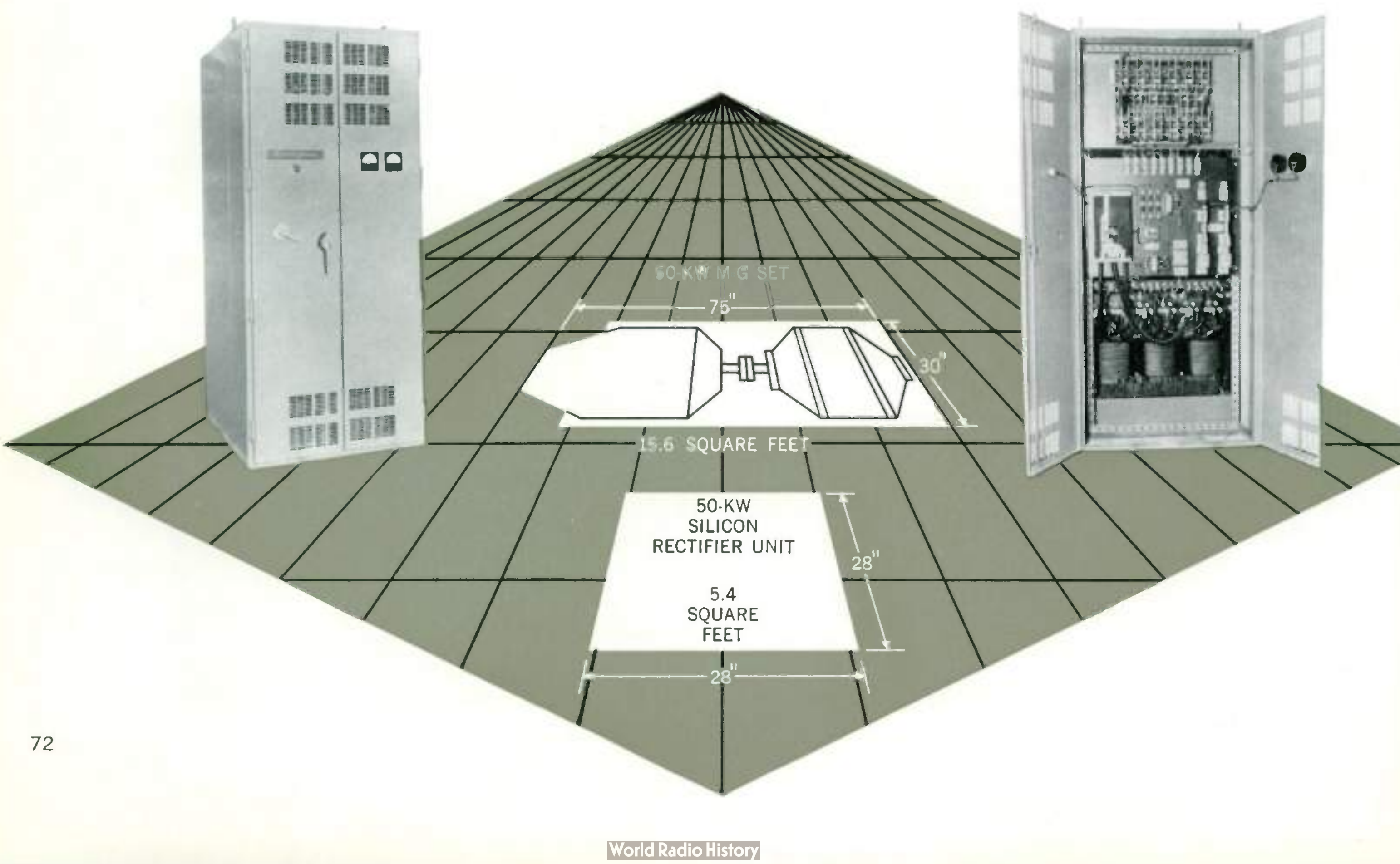

Fig. 1 (Left and Right) Packaged silicon power rectifier in 170-kw 250-volt rating. The transformer is the heaviest component, so it is located at the bottom of the unit.

Fig. 2 (Center) Typical floor-space comparison diagram shows that a silicon rectifier occupies about one-third as much floor space as an equivalent conventional m-g set.

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application

Practically all silicon rectifier power supplies of 170-kw rating and smaller are completely packaged types. They can be applied almost anywhere because of today's excellent ac power distribution systems. The power supply usually is installed at the load and connected to the ac line, making long dc runs unnecessary.

Some applications for these packaged silicon rectifiers are cranes and hoists, elevators, machine tools, printing presses, magnet cranes, magnetic chucks, constant-voltage wire-drawing drives, constant-horsepower drives, underground mining equipment, synchronous-motor field excitation, and general industrial dc service.

configuration

The silicon rectifier package includes a power transformer, rectifier stacks, ac primary control, and surge and current protection devices—all mounted and wired at the factory in a single ventilated enclosure. Separately mounted control is not required. Accessories such as a dc output breaker, indicating lights, air filters, and instruments are also available as part of the package.

For example, the 170-kw 250-volt packaged silicon supply shown in Fig. 1 includes, in addition to the transformer, the silicon rectifier assembly, the necessary primary control, a dc fused knife switch, and a red indicating light. An ammeter and voltmeter are included in most of the larger ratings above 25 kw. The silicon rectifier stacks, which are near the top center section of the cabinet, occupy less than three cubic feet of space.

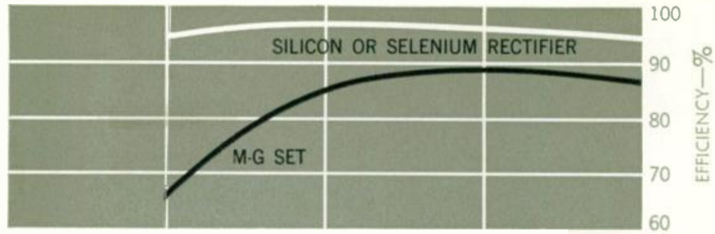
For cooling, a fan draws air into the unit through openings near the base of the front doors. The air is directed through the transformer air ducts, over the silicon stacks, and out into the room through the front openings near the top of the cabinet doors. The fan is driven by a three-phase totally enclosed industrial-type motor located behind the control panel near the center of the unit. The motor is mounted vertically, with the fan directly on the motor shaft. Larger ratings have two fan motors.

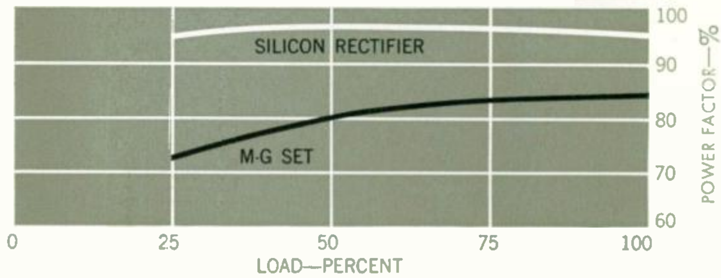
The unit illustrated in Fig. 1 is only 40 inches wide, 42 inches deep, and 90 inches high. It occupies less than 12 square feet of floor space and weighs approximately 3000 pounds complete.

Fan cooling is recommended on all the larger sizes unless the unit is to operate in an exceptionally dirty atmosphere or fan noise is objectionable. Fan cooling keeps the unit's size and cost at a minimum.

Smaller sizes (normally 15 kw and smaller) are convection cooled. Being completely static, with no motor-driven fan, such units are very quiet. Also, their no-load loss is less than that of fan-cooled units. The higher temperature ceiling and smaller size of silicon cells makes it possible to build larger convection-cooled rectifiers with them than is possible with selenium cells.

Convection-cooled rectifiers are usually desirable for elevators in public buildings because of their quiet operation. An incidental advantage of silicon rectifiers in these installations is that they are well suited to use in basements and other damp, poorly ventilated areas where elevator equipment often is installed. The rectifier cells are hermetically sealed for positive protection against adverse





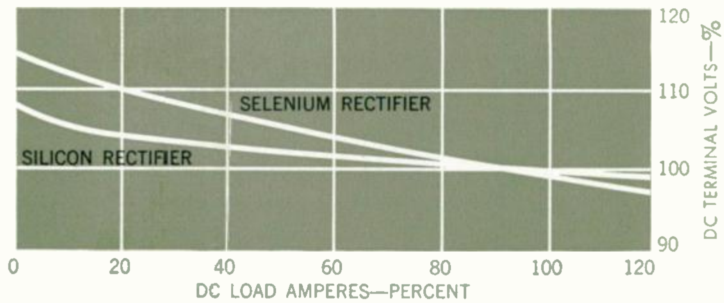


Fig. 3 Efficiency of a semiconductor rectifier compared with that of an m-g set (50-kw 250-volt dc, three-phase 60-cycle 440-volt ac).

Fig. 4 Power factor comparison between a silicon rectifier and an m-g set (150-kw 250-volt dc, three-phase 60-cycle 440-volt ac).

Fig. 5 Typical voltage-regulation curves of fan-cooled selenium and s licon rectifiers (125- or 250-volt dc, three-phase 60-cycle ac).

atmospheric conditions. Overall protection for the unit can be assured by keeping the ac supply connected all the time; this takes very little power from the line but it generates enough heat within the unit to keep it dry.

characteristics

Space and Weight—The silicon rectifier has a great deal to offer in space and weight savings. Comparing a 50-kw conventional 1750-rpm m-g set and a silicon rectifier of the same rating reveals that the silicon rectifier takes up about one-third as much floor space as the equivalent conventional m-g set (Fig. 2). (However, the 3600-rpm unit-frame m-g sets are comparable in floor-space requirements to silicon rectifiers.) Most silicon rectifiers weigh about 40 percent of the equivalent size conventional m-g set. These space and weight comparisons do not include any of the m-g set control; they do include the silicon-rectifier control equipment, which is mounted and wired with the rectifier to make a complete package.

Efficiency—Since the introduction of the silicon rectifier, efficiency has become a more important factor in selecting the proper dc power supply. The silicon unit has an efficiency of 94 to 96 percent from one-quarter load to full load. The efficiencies of a semiconductor rectifier and an

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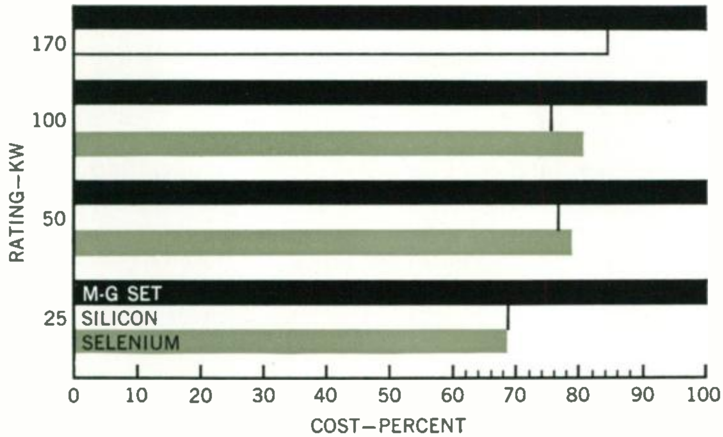
m-g set of the same rating are compared in Fig. 3. Semiconductor-rectifier efficiency remains nearly the same regardless of rating, but the efficiency of the m-g set is better in larger ratings than in smaller sizes.

In applications such as cranes and elevators, the power supply operates at no load or light loads most of the time. In a normal eight-hour shift, for example, a crane takes power from the line about 25 percent of the time. The rest of the time the converter is running at no load. The 150-kw silicon rectifier has approximately 1100 watts loss running at no load with the fans operating and the alternating current at rated voltage. The 150-kw m-g set, on the other hand, has nearly 12 000 watts loss at no load—more than 10 times the loss of the silicon rectifier operating under the same conditions. A rule of thumb often used with silicon packaged power supplies is that the no-load losses average one percent of the kw rating. (For 50 kw and below, especially in fan-cooled units, it is slightly higher; for larger ratings it is less.)

Power Factor—Most industrial m-g sets have induction motors with relatively poor power factor at light loads. On the other hand, the power factor of a silicon rectifier is approximately 95 to 96 percent from one-quarter load to full load (Fig. 4). Even at no load the power factor is 50 percent or better, and, because of the light no-load losses, the input kva is very small compared with that of the corresponding size m-g set. For example, a conventional 150-kw induction-motor m-g set has approximately 15 times the kva input at no load of the corresponding size silicon power supply.

Voltage Regulation—Typical regulation curves of selenium and silicon rectifiers are compared in Fig. 5. They were drawn from actual tests with a 50-kw power supply. As shown, the silicon rectifier has about eight percent regulation from no load to full load. However, from about 10 percent load to full load there is five percent or less actual change in output voltage. On overloads, there are no sudden dips in dc voltage; it follows the straight part of the curve right out to its maximum peak-load capacity. This is excellent regulation, but it is dependent on a "stiff" ac supply. If there are wide fluctuations in the ac line feeding

Fig. 6 Original-cost comparisons of silicon and selenium rectifiers and m-g sets. The comparisons are based on 250-volt two-wire dc and 460-volt three-phase 60-cycle ac. M-g set prices are for 1750-rpm machines and are shown as 100 percent in each comparison.



the rectifier, there will be corresponding fluctuations on the dc side of the rectifier.

An automatic voltage regulator can be used to compensate for ac line voltage variations or to obtain better overall voltage regulation. All of the packaged designs are available with voltage regulators. However, silicon's inherent voltage regulation is so good that most industrial applications do not require a regulated power supply.

Overload Capacity—The normal practice in selecting a silicon power supply is to provide one kw for each horsepower of continuous load. Standard ratings are designed to handle 150 percent of rated load amperes for one minute, following 100-percent continuous load. All designs will handle 200 percent of rated load amperes for 10 seconds. Ratings of 100 kw and larger will handle 125-percent load for two hours.

Designs are available for special applications where higher overloads prevail, such as in the mill motors used on many steel-mill cranes that commutate high intermittent current. The peak current on these applications should be determined before selecting the rectifier rating. It may be necessary to increase the continuous rating to handle the peak conditions. If several machines are operated from one power supply, the problem of peak load is usually taken care of automatically by having a larger unit to begin with.

Line Disturbance When Connected to AC System—When a semiconductor rectifier is energized from the ac line, the inrush current does not cause any ac line disturbance. Consequently, reduced-voltage starting is not required. Starting the rectifier is no different from connecting a dry-type conventional transformer to the ac line. On the other hand, many large m-g sets require reduced-voltage starting to minimize ac line inrush.

Change in Output from Cold to Normal Operating Temperature—Another desirable feature of silicon rectifiers is their inverse temperature characteristic. When the device temperature rises, its resistance decreases. This lowers forward drop in the silicon cells and increases dc voltage correspondingly.

Conversely, the resistance of the transformer windings increases with temperature rise. Although the two effects do not completely compensate for each other, they come close enough so that there is very little dc voltage change between cold starting and operation at the rated-load temperature.

DC Voltage Adjustment—The standard packaged power supply is designed for fixed-voltage applications. Primary taps are provided to adjust for plus or minus five percent of rated ac line volts. Once a unit is set for the load and line conditions, no further adjustments are necessary. Where units operate in parallel, some additional vernier adjustment is sometimes necessary to set the dc voltage of all paralleled power supplies at the same value.

Parallel Operation—Operation of two or more power supplies in parallel is relatively simple because cross-current compensation is not required for division of load. A fault occurring in one unit is easily isolated without interrupting the complete dc service, and this adds to the reliability of the installation. Units of the same rating should be used together for best results because their regulation curves match closely enough to assure proper load division between paralleled units.

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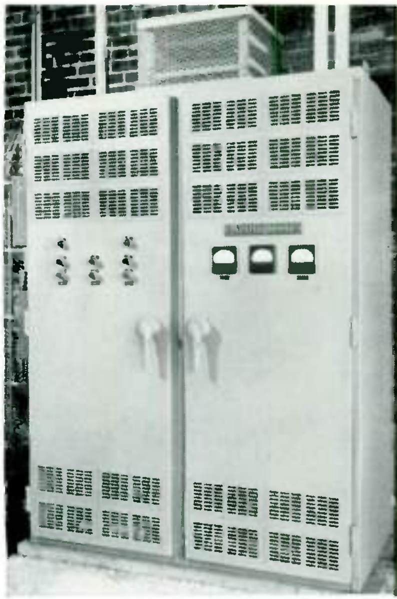

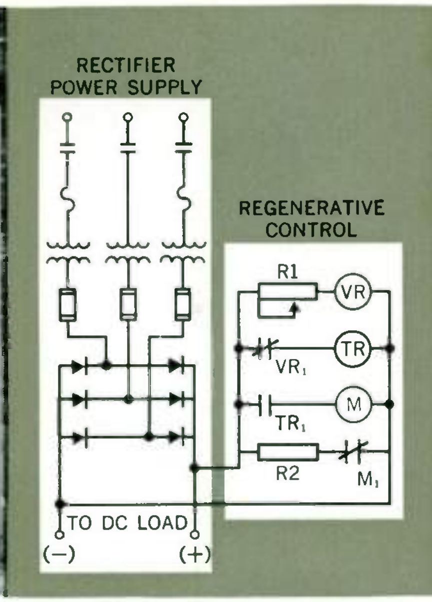

LEGEND

T = Timer

VR=Voltage-sensitive relay

R1=Tapped resistor for setting relay

TR=Pneumatic timing relay

M =DC contactor

R2=Ballast resistor for absorbing regenerated power

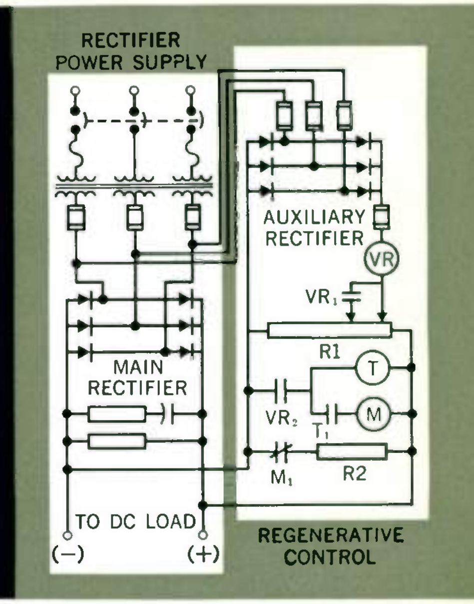

Fig. 7 (Left) This 100-kw packaged silicon rectifier includes a system for absorbing regenerated power. The resistors are in the enclosure on top of the cabinet.
Fig. 8 (Center) Typical circuit for controlling regenerated power in industrial applications.
Fig. 9 (Right) Typical circuit for controlling regenerated power in elevator applications.

Transformer taps permit setting the voltage of each rectifier at the same value. Once adjusted, the dc sides of the rectifiers can be connected together. Then any unit can be switched on or off from the ac side, leaving the dc sides tied together through their respective dc breakers or disconnect switches. The silicon cells are designed to withstand the dc voltage even though the ac side of a unit is disconnected. Because of the low leakage current in silicon cells, practically no loss occurs on an idle unit when operated in this manner.

Power supplies operated in parallel must have a dc breaker or dc disconnect switch. When a dc knife switch is used, current-limiting fuses are also recommended in the main dc line. These fuses are then coordinated with the fuses in the rectifier cell circuits so external faults are cleared by the main-line fuses without damaging the fuses in the silicon-cell circuits.

This provides sufficient interrupting capacity should an internal fault develop on one unit, causing the other units in parallel to feed into the faulted unit. The dc switch or breaker also provides a means of isolating the faulted unit so the others may continue in operation.

Installation—All packaged rectifier units are set at the factory for the nameplate voltage rating. Each unit is complete with its own control mounted and wired, so installation consists of connecting three ac leads to the line-starter or incoming line breaker and connecting dc leads to the output terminals. No special foundation is required.

Maintenance—Probably the most important single factor in favor of silicon rectifiers is that maintenance is practically eliminated. There are no moving parts whatever in the smaller sizes because no cooling fans are required. Reliable fan cooling is provided in the larger sizes by totally enclosed industrial motors that are essentially trouble-free.

If the units are used in dirty atmospheres, it is well to blow them out periodically with an air hose. Filters are available as an optional accessory to keep dirt out. They must be cleaned at shorter intervals to make sure there is unrestricted air flow into the power supply. The silicon cells are hermetically sealed, so there is no chance of contamination in the heart of the rectifier.

There is no aging with silicon, and experience with semiconductor rectifiers has been that low aging indicates long life. Although it is a little early to predict lifetimes of silicon rectifiers, experience to date has been excellent—the failure rate is less than one percent. The units operate at full output year after year without attention or adjustment, other than routine cleaning.

Original Cost—An original-cost comparison of 1750-rpm m-g sets, silicon rectifiers, and selenium rectifiers is presented graphically in Fig. 6. For easy representation, the cost of the m-g set is shown as 100 percent and the rectifier costs are shown as percentages of this. The cost of a silicon rectifier is as low as 69 percent of the m-g price. In this comparison, the price of the bare m-g set without any control is compared with the price of packaged silicon and selenium rectifiers that include the necessary basic control. If the control were added to the m-g set, the percentage difference in price would be considerably greater than that shown in the chart. On larger m-g sets, where reduced-voltage starting is often required, the price gap widens still more when control is added.

Regenerative Control (*Dynamic Braking*)—Some means must be provided for absorbing regenerated power from motors on overhauling load. This power cannot flow back through the rectifier because of the rectifier blocking action. If there is a continuous basic load on the rectifier of at least 10 percent of the kw rating, the load itself will absorb most of the power that is regenerated, making it unnecessary to provide a special regenerative control system. If this continuous basic load does not exist or is inadequate, a control system is required.

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A control designed for this purpose connects a resistor bank across the load automatically when any regeneration occurs. As soon as the motors require power from the rectifier again, the resistor bank is automatically disconnected. The control usually is separately mounted, but it can be built into the rectifier unit if desired (Fig. 7). Usually, seven to ten percent of the rectifier kw rating in regenerative control provides adequate rectifier protection.

A typical circuit for this regenerative control is diagrammed in Fig. 8. When the rectifier is energized from the ac line, normal dc voltage appears across the regenerative control circuit. This voltage immediately picks up timing relay *TR*. The relay in turn energizes the spring-closed contactor *M*, removing ballast resistor R_2 from the line for normal operation of the power supply.

When regeneration occurs from the load to the rectifier, the voltage must rise at least 10 percent above the no-load dc voltage of the rectifier before any change takes place. A 10 percent rise above no-load dc voltage energizes the temperature-compensated voltage-sensitive relay *VR*, which de-energizes timing relay *TR*. This immediately releases contactor *M*, which is spring closed to connect resistor R_2 across the line to absorb the regenerated power.

When regeneration stops and dc voltage returns to normal, voltage-sensitive relay *VR* drops out to close the circuit through timing relay *TR*. Since this is a pneumatic timing relay, its contacts TR_1 do not close for one or two seconds until it is safe to disconnect the resistor. The timing-out interval also allows the voltage to return to normal so that chattering does not occur in going through the pull-in and drop-out points of the relay.

Most dc crane motors are series type, so they do not regenerate power into the line under normal operating conditions. The hoist motor is usually connected shunt on lowering and is equipped with its own dynamic braking control. However, some regeneration occurs when lowering the load, so regenerative control is a good insurance policy against rectifier damage.

The regeneration problem often arises when adjustable-speed motors with speed ranges greater than two to one are used and speed change is accomplished manually by field rheostat. The chances of regeneration are greater here because the operator tends to turn the rheostat too rapidly.

To guard against this hazard, an inexpensive decelerating relay can be added to the rectifier unit with provision for connecting it into the motor field circuit. Regenerative control also can be added to provide dynamic braking when slowing adjustable-speed motors by rheostat adjustment. The control is simple, and the amount of resistance required can be tailored to the load. The resistor bank is seldom on the line; when it is, it is on only momentarily.

Magnet cranes, used mostly for handling steel scrap, present another special problem. Many of these use dc control for reversing the magnet polarity (often called plugging the magnet). Plugging the magnet imposes a high-voltage surge across the rectifier, and the normal regenerative control does not connect the resistor soon enough to protect the rectifier. The only protection known to date is using a permanent resistor across the rectifier of sufficient size to absorb the surge or applying control that connects a shunt resistor before the magnet-coil current is reversed. If there is a continuous shunt load equal to 20 percent or more of the magnet load, a ballast resistor is not required.

Power is regenerated in many elevator systems when the elevator is descending and its weight exceeds that of the counterweights. The regenerative control for this application is much different from that for industrial loads. It must be fail-safe so the resistor bank will be connected immediately through a spring-closed contactor during overhauling loads or when the unit malfunctions.

A typical regenerative control system for a rheostatic type elevator is diagrammed in Fig. 9. The main purpose of feeding the auxiliary rectifier from the transformer secondary is to match the main rectifier's output voltage to that of the auxiliary rectifier. Then if the ac line voltage changes, the reference at relay *VR* remains unchanged. This permits setting its dropout point just a few volts above the no-load voltage of the rectifier.

When regeneration occurs, the voltage rises across the main rectifier. This reduces the voltage differential across relay *VR* to the point where it drops out. This releases contactor *M*, which is spring closed to give positive closing on ballast resistor R_2 to absorb the regenerated power. As regeneration subsides, the voltage returns to normal and energizes relay *VR*. Relay *VR* pulls in and energizes timer *T*, which is preset for one or two seconds to allow time for the voltage to reach its normal value before contactor *M* is energized to disconnect the resistor from the line.

This control system should not be applied to dc-to-dc elevator m-g sets. Elevators using such sets are variable-voltage types, and when regeneration occurs it tends to overspeed the m-g set until its overspeed device operates and shuts the set down. It is recommended that the user replace the m-g set with an ac-to-dc set, since a rectifier is not yet available for variable-voltage elevator service. There is a regenerative control for dc-to-dc elevator sets for the user who does not have ac power at the m-g set, but it requires a signal connection at the generator. The elevator manufacturer should be consulted before attempting to apply rectifiers and their control to dc-to-dc elevator m-g sets.

synchronous motor excitation

When a synchronous motor is started, the field is shorted through a discharge resistor. The field control in the starter disconnects the discharge resistor as the dc voltage is applied to the field. During this transfer, a high ac voltage appears across the dc terminals of the rectifier the instant the field contactor closes. This often reaches 1000 volts, so certain protective features must be provided when silicon rectifiers are used as synchronous motor exciters.

The silicon rectifier must be coordinated with the protective scheme to provide a path for the induced current in the field to flow in either direction so the pull-in torque is not affected. The ac voltage produced must be held well below the PIV rating of the silicon cells so that the rectifier is not damaged in any way. Once the motor pulls into step, direct current flows normally in the field coils.

Two or more silicon cells are always used in series in each leg of the bridge for this application. Each silicon cell is shunted with a small resistor to provide added protection and balance the inverse voltage on the cells.

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IMPROVEMENTS IN SEARCH RADAR SYSTEMS Radar technology has had to improve by leaps and bounds to keep pace with developments in aircraft and missiles.

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Electronics Division
Westinghouse Electric Corporation
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Any modern defense system can only be as effective as its method for obtaining advance notice of attack; and since 1938, when the first long-range surveillance radar went into operation on the east coast of England, radar has been a basic element in the warning system. However, the radar systems in use today are a far cry from the first practical early-warning radar systems employed in World War II. The improvements have been forced by the increasing speed of aircraft and the development of missiles, making it necessary to pick up enemy aircraft at a much longer range. This situation was further complicated by the fact that the newer planes and missiles present a much smaller radar target. Furthermore, the information demands on the system become more complex, and data obtained by radar must be assembled and processed into useful information as quickly as possible. Tremendous strides have been made on all of these fronts since World War II.

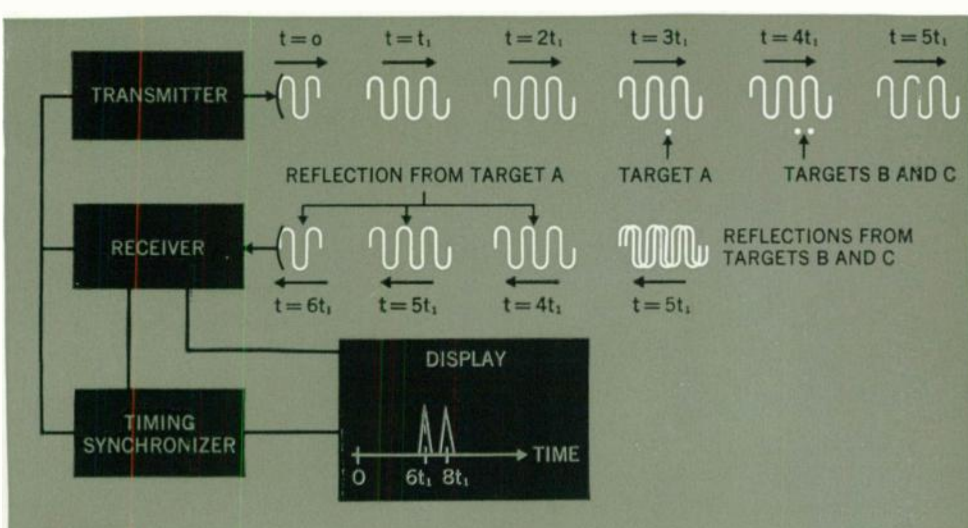
pulse radar and range

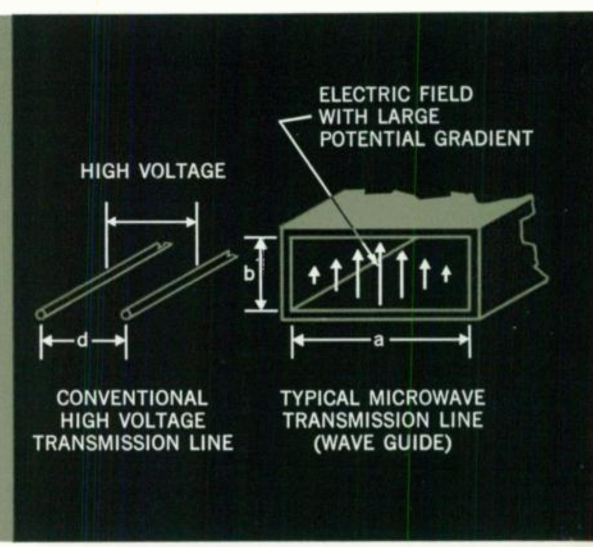
The range of radar is proportional to the fourth root of the *average* radiated power. However, because of the very nature of pulse radar, the type most commonly employed today, an increase in *average* power is particularly difficult to come by, even though modern radar transmitters can generate peak signals in the megawatt range.

The difficulties of obtaining high average power can best be appreciated by considering the characteristics of pulse radar, shown in Fig. 1. Inspection of the figure reveals two criteria for any radar system: (1) if the radar is to be able to resolve targets effectively, each pulse must be short; and (2) sufficient time must be allowed between pulses to enable the pulse to travel to the target, and be reflected to the receiver. This obviously means that in any sensitive, long-range pulsed radar system, the transmitter will be radiating only a small fraction of the time—typically, from one to five percent.

The obvious approach to improving range is to develop microwave oscillators or power amplifiers that will deliver any desired peak power level. However, even if this were possible, the difficulties of transferring power from the point of generation to the radiating antenna become insurmountable. Unlike the conventional 60-cycle high-voltage transmission line, microwave waveguides have critical dimension limits—the higher the frequency, the closer the dimension (Fig. 2). These limitations in waveguide geometry mean that peak power cannot exceed certain limitations, or arcing will occur. Although some improvement can be effected by pressurizing the wave guide, or filling it with some material that will increase the allowable poten-

Fig. 1 (Left) Operation of conventional pulsed radar.
Fig. 2 (Right) A comparison of power transmission at low and high frequencies.





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tial gradient before arcing occurs, the overall gain is minor.

pulse stretching

Obviously, the easiest way of increasing average power would be to increase the pulse length, keeping peak power fixed. But with conventional radar, this would degrade its ability to resolve targets. Fortunately, the answer to this problem has been at least partially answered by a relatively new development, called *pulse stretching*.

Key to the pulse-stretch radar system is an "all-pass" filter that has a nonlinear phase characteristic, so that all frequencies will pass through the filter but with a different group delay for each frequency. When a pulse, which theoretically consists of many frequencies, is fed into the filter the various frequencies in the pulse are shifted relative to one another in time with an overall effect of stretching the pulse (Fig. 3). Enormous amounts of phase distortion (normally to be avoided in communications equipment) have been deliberately introduced.

When the stretched pulse reflection enters the receiver, it is passed through the same type of all-pass filter, which recompresses the pulse to its original length. Hence, the long pulse radar can give the equivalent resolution of a short pulse.

There are many possible physical realizations of an all-pass filter. The types most commonly employed are identified as lattice and bridged-T filters (Fig. 4). Because of economy in the number of elements required and convenience in driving unbalanced networks, bridged-T type construction is generally employed.

Unfortunately, pulse-stretch techniques cannot fulfill the total needs for increased power. Even if the pulse is stretched to the point where the transmitter radiates 100 percent of the time at the power limit permitted by pressurized wave guides, the need for more radiated power will remain.

phased arrays

The next logical step in the search for more power will be the phased array. This, in principle, amounts to driving a number of transmitters in parallel and adding their outputs in space. The general principles of operation are shown in Fig. 5. As illustrated, an array of radiators are spaced by a half wave length and all excited with identical pulsed cw signals. At a distance that is large compared to the array size, the contributions of the individual radiators add at point P and cancel at point P_2. Thus, the phased array not only permits the addition of power contributions in space, but also has directive characteristics not unlike those obtained with the dish-type reflectors of present-day radars.

A final advantage of the phased array is the possibility it yields of controlling the direction of radiation electronically. Indeed, by varying the relative signal phase of the individual radiators the direction of radiation of power can be controlled. By using pulse stretch and phased array techniques simultaneously, the range of future radars will have no theoretical limitations, except perhaps as to whether space itself can withstand the potential gradients and stresses induced by such large amounts of radiated power.

the third dimension

The earliest pulse radars gave reasonable range information and, because of low frequencies and wide beamwidths,

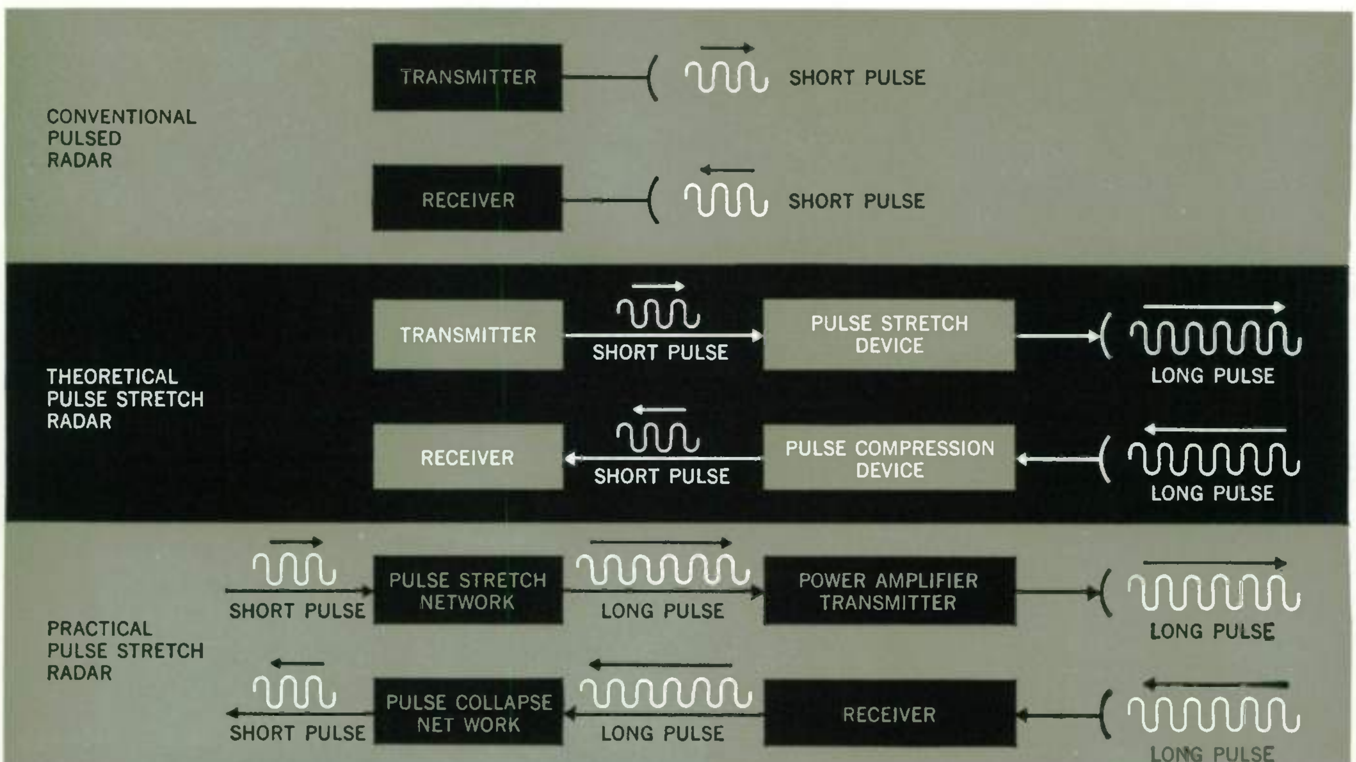

Fig. 3 Comparison of conventional and pulse-stretch radars.

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somewhat less accurate angular information. Since height can only be determined directly by measuring small elevation angles, the resultant accuracy was poor. Moreover, in an operational system, the most important information required is plan position, so that ground-based search radars naturally evolved towards two-dimensional systems.

With the development of higher frequency and hence narrower beamwidths and more accurate radars, target altitude could be determined with a separate radar as shown in Fig. 6. This radar, given the name "nodding beam height finder," is made to search in elevation on a certain azimuth indicated by the main search radar.

The primary limitation of the nodding-beam system is the low rate at which altitude information can be obtained. Even with high slewing rates and fast action by the operator, 10 to 20 seconds are required to determine target height. Thus, if height is required for N targets, the information gathering rate on height is at least N times slower than the information gathering rate on range and azimuth (assuming a 10 to 20 second data rate for the search radar). This slowness of operation is somewhat compensated for by the fact that the height of a target normally varies more slowly than its other coordinates. On the other hand, it might change radically at a critical moment so that the nodding beam height finding system can fail precisely when it is most needed.

In addition, there is a possibility of error of correlation between the target as seen on the PPI of the search radar and the target on the range height indicator (RHI), particularly if the target density is high. This is due at least in part to the inherent delays in the system and the fact that several operators are involved.

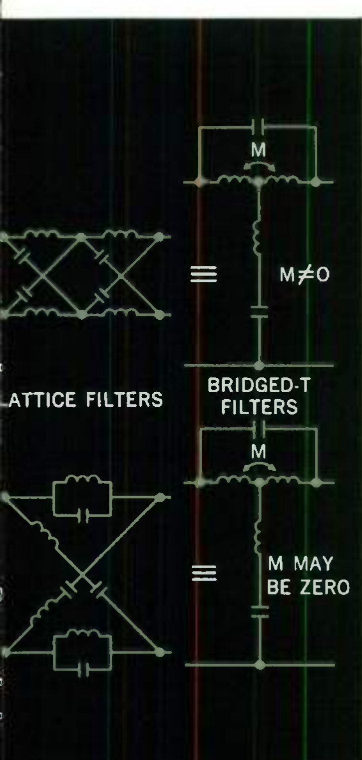
As aircraft performance improves with higher speeds, higher ceilings, and higher rates of climb, the interception problem becomes more and more difficult and the time available allows no errors. The position of all targets must be determined in three dimensions at the maximum rate possible by an integrated 3D radar.

The accuracy required is usually about ± 1000 feet at 100 miles, with search coverage out to 200 miles and up to at least 60 000 feet. This corresponds to an angular accuracy of ± 0.1 degree. With sufficient care, angular measurement with a radar can be made to roughly a tenth of a beamwidth. Hence, the ± 0.1 degree accuracy requirement calls for a one-degree beamwidth in both the vertical and the horizontal dimension.

data rate

The next basic problem is one of data rate. Despite the fact that the velocity of electromagnetic waves in air is greater than the velocity of any other useful phenomenon by many orders of magnitude, and can be considered as infinite in most practical applications, its measurement is fundamental to radar and its absolute value imposes a definite limitation in the design of a three-dimensional search radar.

If a pencil beam radar of one degree cross-section is required to search the hemisphere from the horizon up to 20 degrees in elevation, and out to 200 miles in range, it must look at $360 \times 20 = 7200$ elements separately, and for a time long enough to give reasonable data on each element. If six



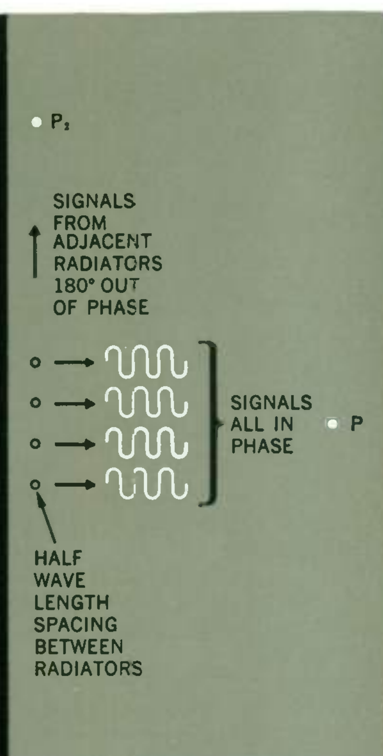


Fig. 4 (Left) Equivalent all-pass filter realizations.
Fig. 5 (Center) Principles of phased array transmission.
Fig. 6 (Right) Main search radar (right) and separate nodding beam height finder.

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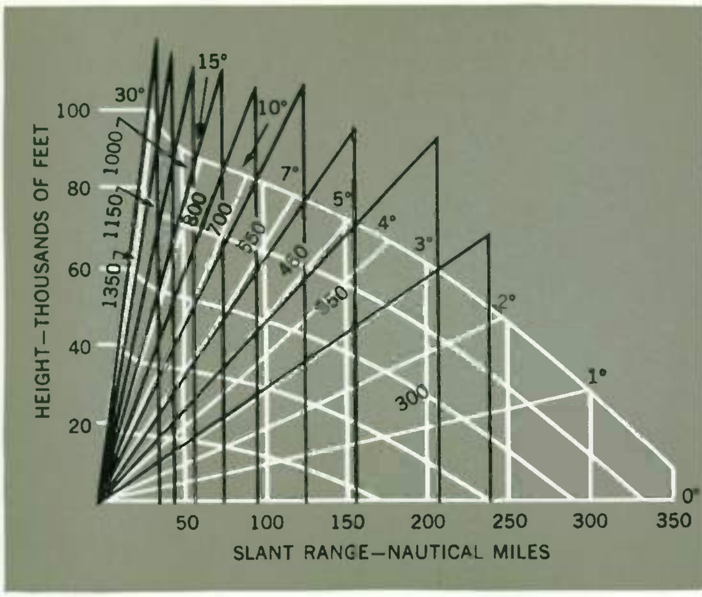

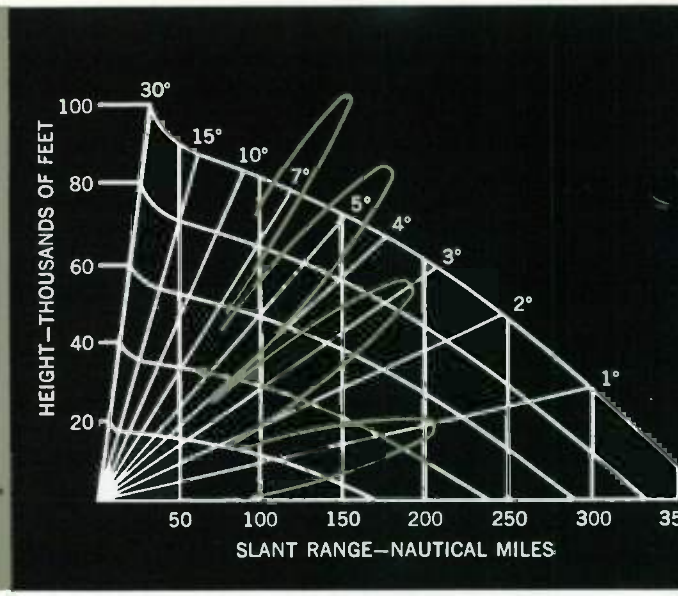

Fig. 7 (Left) Programming of pulse repetition frequency with elevation; 240 microseconds radar deadtime assumed.
Fig. 8 (Right) Typical vertical coverage of low-frequency radar; the fade zones for a 40 000-ft track are shown.

paints are required to provide the necessary integration for reasonable target detection, then the time spent on each element must be:

$$\frac{200 \textit{ nautical miles} \times 2 \times 6}{162\,000 \textit{ nautical miles/sec}} = 14.8 \textit{ milliseconds},$$

or about 18 milliseconds allowing for radar deadtime. Thus the complete hemispheric search will take

$$7200 \times 18 \times 10^{-3} = 130 \text{ seconds}.$$

This time leads to a completely unacceptable data rate. What, in fact, constitutes an acceptable data rate is a complete problem in itself. Many factors, such as possible aircraft maneuvers between paints and importance of raid penetration, must be taken into consideration. Suffice it to say that 12 seconds, which is the usual data rate for a conventional long range 2D radar, is considered to be the upper limit for any search radar today.

The 130 seconds figure can be improved upon by setting an upper limit to the altitude at which targets are likely to be found and programming the pulse repetition frequency (prf) accordingly (by adjusting the prf for the reduced slant range at higher elevations). It is also acceptable to increase the vertical beamwidth with elevation since the accuracy of angular measurement decreases with slant range for constant height accuracy. It may also be possible to reduce the number of "hits per target" and, of course, if the maximum range is reduced to 100 miles, the problem is proportionately reduced. A range-height coverage diagram showing how a pencil beam radar might have its prf programmed with elevation is shown in Fig. 7. In this particular example the time to search the hemisphere would be reduced by a factor of 2.3.

Though the hemisphere can be scanned in a number of ways, the usual method is for the beam to scan rapidly in elevation while the pedestal rotates at a slower rate. The high rate of vertical scanning requires the scanning to be carried out electronically.

In the early days of radar, long range three-dimensional information of a sort could be obtained with reasonable accuracy, at least at sea, by observing the fade pattern of the track of the target aircraft. This was only practicable with metric radars (with relatively long wavelengths) with reasonably large lobes as shown in Fig. 8. This lobing is due, of course, to the path difference between the direct-ray and the ray reflected off the surface of the sea. By noting the ranges at which fades occur, it is possible to

A SHORT HISTORY OF RADAR

The operating principle of modern radar was first demonstrated by Heinrick R. Hertz in the late 1800's. Hertz, who discovered the radio waves predicted by Maxwell in 1864, showed that they could be focused into a beam and be reflected from objects. In 1922, L. C. Young and A. H. Taylor of the Naval Research Laboratory detected reflections from a boat on the Potomac River. By 1930 Young and L. A. Hyland had observed reflections from an aircraft 50 miles distant. It was not until 1934, however, that the first pulse type radar was successfully developed by R. M. Page, another Navy scientist. None of these devices were practical from a military standpoint, however, because of their short detection ranges. The invention of the multicavity magnetron by British scientists in the middle 40's made radar a practical tool. The magnetron, for the first time, made possible the practical generation of large amounts of power in the microwave region of the spectrum. Radiated power, which was once measured in watts, is now measured in kilowatts and megawatts. Unfortunately, generation of power is not the only problem which confronts the radar design engineer. Some of the associated problems are described in this article.

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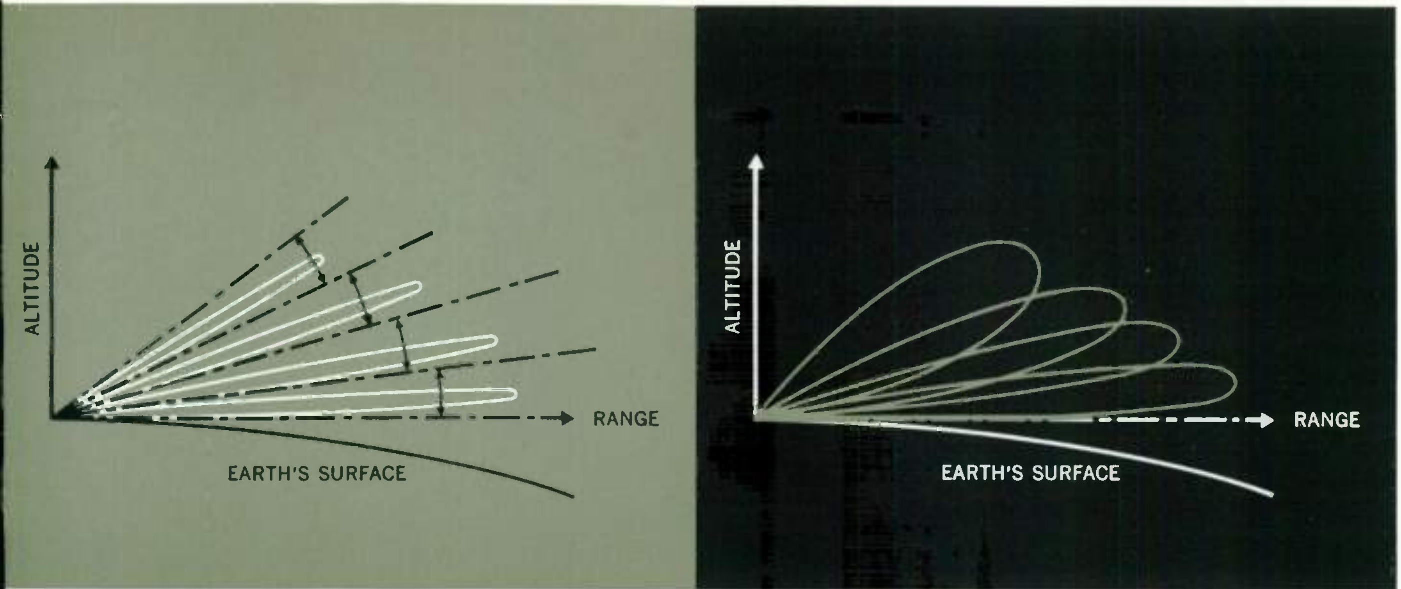

Fig. 9 (Left) Pencil beams, stacked in elevation, search through adjacent elevation sectors.
Fig. 10 (Right) Overlapping beams stacked in elevation.

estimate the height of the target but this process is slow and only suitable for aircraft flying at a more or less constant altitude.

stacked-beam radars

An early attempt at obtaining height information simultaneously with plan information led to the design of the "V beam" system. This system consists of two separate fan beam radars, one vertical and the other inclined at 45 degrees. Each target was therefore seen twice. The time interval between the appearance of a target on one radar and its appearance on the other depends obviously on the elevation angle. Suitable displays were designed to give the height information directly. The disadvantages of this system were size, difficulty in obtaining high coverage, and difficulty in correlating the two echoes at high elevations. In particular, it was wasteful of transmitter power since the maximum search range was in no way improved by the second transmitter.

Present-day long range 3D radars overcome the data rate problem by generating a number of separate pencil beams. These are usually stacked in elevation, all in the same vertical plane. Each beam has its own receiver channel and the video are combined to provide the plan picture corresponding to a conventional fan beam radar. The data rate is, therefore, the same as for a 2D radar and the elevation coverage depends solely on the number of pencil beams generated.

These stacked beam radars fall into two categories: the stacked scanning beam and the overlapping stacked beam. The stacked scanning beam (Fig. 9) is equivalent to a number of nodding-beam height finders, each searching over a relatively narrow sector in elevation at a suitable nod rate, while rotating at the conventional speed of 5 rpm. The sectors scanned are contiguous so that the total scanned angle gives the vertical coverage of the set. The principal problem associated with this system is how to achieve the scan. A mechanical scanning mechanism is normally bulky and, with a conventional reflector, the resultant shadowing would seriously impair the characteristics of the antenna. In one radar system, a lens is used instead of a reflector to overcome this problem. The lens consists of a large number of aluminum wave guide sections welded together, the longer lengths towards the outside of the lens speeding up the phase to produce a plane wavefront.

The second approach is the overlapping stacked beam radar where a number of independent overlapping beams in the vertical plane are used (Fig. 10). The beams are made broader and are of lower power as the elevation increases since, for a given height accuracy, the required elevation accuracy decreases with the slant range. Each beam has a separate receiver output, and elevation is measured by comparing amplitudes of signals in adjacent channels. This method does away with the cumbersome scanning mechanism of the previously described stacked scanning beam radar. The system, however, has difficulties of its own: the beams must be accurately shaped and have controlled overlap. The receivers must have accurately matched input/output characteristics. By generating beams with Gaussian shapes ($e^{-\theta^2}$) and by using logarithmic receivers, the difference between outputs of adjacent receivers gives a direct measurement of target elevation: the relationship between the difference in dbs of the outputs from adjacent channels and the elevation is linear.

future radars

The next generation of radars will no doubt employ phased arrays for electronically scanning the hemisphere by means of a number of high-powered beams. Automatic data processing will be used for extracting the information and performing such operations as threat evaluation and weapon guidance, which are generally carried out manually at present. Such automatic data processing will be necessary to meet the threat of small-section, high-speed, and high-approach-angle missiles.

World Radio History

A NEW LOW-VOLTAGE SF_6 POWER CIRCUIT BREAKER This new design adapts the features of high-voltage SF_6 breakers to a unit suitable for application at 34.5 to 69 kv.

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The unusual arc-interrupting properties of sulfurhexafluoride gas has led to a rapid evolution in circuit breaker design. Once the properties of the gas had been satisfactorily verified in prototype models, engineers were able to create rapidly a number of ratings of SF_6 power circuit breakers, on a parallel with existing oil and air breaker lines. Present SF_6 breaker voltage ratings range from 230 kv down to 34.5 kv. The rapid development of these breakers can be illustrated with installation dates. The first 230-kv power circuit breaker was installed in October 1960 on the Pennsylvania Power & Light Company's system; the most recent SF_6 design, a medium-power breaker with a rating of 46 kv, 500 mva, will be installed on the Georgia Power Company system in mid-1961. Also shipped recently are breakers rated at 138 kv, and soon to be shipped are breakers rated at 69 kv and 161 kv.

In the new low-voltage SF_6 design, engineers have continued the practice of combining a gas interrupter with proven features of air and oil breakers—dead-tank construction, provision for bushing-type current transformers, and mechanical interconnection of all contacts with the circuit breaker operating mechanism. Designers have retained also the inherent features possible with sulfur hexafluoride—quiet operation, freedom from fire hazard, light foundation requirements, and a minimum of auxiliary equipment requirements.

puffer interrupter

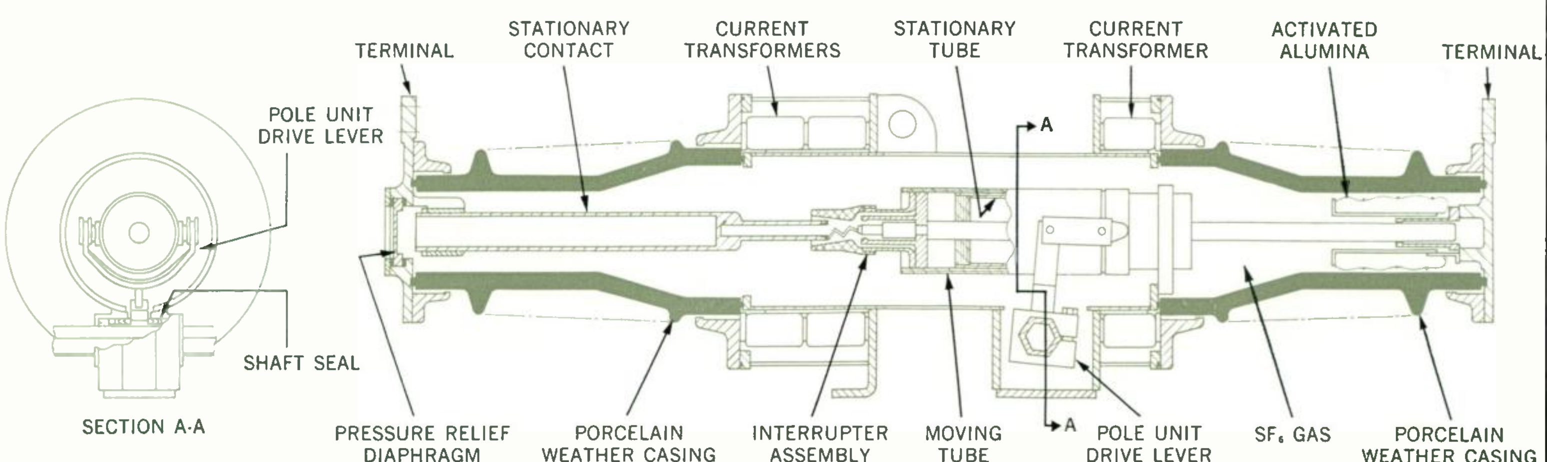
The puffer-type interrupter chosen for the new breaker is one of the most versatile, simple, and effective means of arc interruption in SF_6 gas. This interrupter can be used at moderate static pressures of about 50 psig. Gas flow is achieved by moving a piston in a cylinder simultaneously with the opening of a single break so that gas flows through the orifice when the contact opens. This forces gas into the arc stream to achieve arc extinction. The moving contact, orifice, and cylinder are fastened together so that they move as a unit when the breaker opens.

The puffer-type interrupter can be used for a wide range of currents and voltages, depending on the size puffer used, and the mechanical effort used to operate it. One of the early prototypes built and tested consisted of two 10-inch diameter puffer interrupters in series, which effectively interrupted faults at 138 kv as high as 10 000 mva. However, the mechanical effort required to operate these puffers effectively for a 10 000 mva fault was quite high, making this type of interrupter impractical for these higher ratings.

However, for a more moderate rating of 500 mva at 46 kv, typical of the new line SF_6 breakers, the puffer-type interrupter is ideal. Breaker voltage ratings will range from 34.5 to 69 kv.

A cross section view (Fig. 1) illustrates the construction simplicity possible with the puffer-type interrupter. The breaker consists essentially of a grounded steel tube that houses the interrupter, with current-carrying studs brought out of each end through porcelain weather casings. The entire unit including the porcelain is filled with gas at 45 psig. This pressure is sufficient for both insulation to ground and interrupting duty.

The puffer consists of a stationary insulating piston fastened to the grounded tank at the right end, over which slides a moving insulating cylinder. Attached to the left end of the moving tube are a set of contact fingers and a Teflon orifice. When the breaker opens, an accelerating spring on the operating linkage drives the puffer cylinder and contact fingers to the right. The arc drawn is transferred quickly to the arc-resistant tip which projects beyond the fingers. The movement of the puffer builds up the



World Radio History

gas pressure in the interrupting chamber until the orifice is pulled away from the end of the stationary contact. When this point is reached, the gas is forced out through the orifice, where it mixes with the arc to obtain interruption. When the breaker closes, the movement of the puffer is reversed to pull gas back into the cylinder.

The bag of activated alumina located in the right-hand porcelain is used to absorb the small amount of gaseous arc products that do not recombine into SF_6 to avoid possible corrosive action. The pressure relief diaphragm, which is shown on the left-hand terminal plate, is provided as a safety device to relieve any abnormal internal pressure that might develop.

other features of the new design

Space has been provided for two standard-accuracy current transformers mounted around the grounded steel tank at one end of the breaker, and one standard accuracy transformer at the other end. Since the transformer compartments are not in the gas chamber, special seals are not needed to bring out the secondary leads to the mechanism cabinet. The current transformers are separated to provide overlapping current transformer protection, which is desired by some users to detect an internal breaker fault with differential schemes.

A new approach in mounting frame design (Fig. 2) takes advantage of the space below the horizontally mounted pole units for the operating mechanism. This arrangement holds overall dimensions to a minimum and avoids interference between substation columns and mechanism cabinet doors, which can occur when the cabinet is mounted on the end of the frame. The pole units are tied together mechanically—closed by a single pneumatic mechanism and opened by a spring. This basic operating concept has been retained from oil breaker design for all SF_6 breakers.

laboratory tests

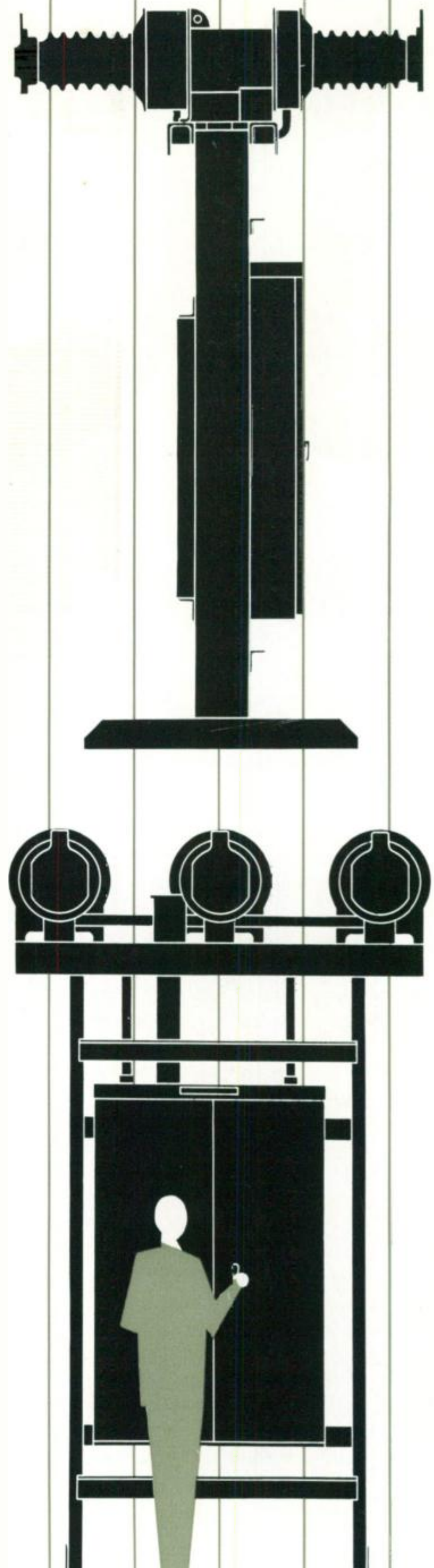
Full-scale interrupting tests can be conducted in the Westinghouse High Power Laboratory on this size breaker. A number of tests have been made up to and above the 500 mva rating with a high recovery voltage rate. The maximum interrupting time was 3.5 cycles, well within the 5-cycle time assigned to this rating. Contact erosion was moderate, and the contacts used throughout a test series, which included 25 tests near or above the 500-mva rating, were still good for further testing.

plans for the future

Switchgear engineers predict that SF_6 breakers will eventually be designed and built for most ratings now called for in A.S.A. Standards. In addition to the line of moderate-mva, low-voltage breakers discussed here, and the standard high-mva, high-voltage SF_6 circuit breakers already in service, designers are presently working on an intermediate line of medium-mva circuit breakers extending from 34.5 kv, 1500 mva up through 138 kv, 5000 mva.

Westinghouse ENGINEER May 1961

Fig. 1 (Left) Cross section view of the 46 kv pole unit.
Fig. 2 (Right) Outline of the 46-kv SF_6 breaker.



World Radio History

INDUCTION HEATING This form of metal heating is effective for applications where performance requirements are critical.

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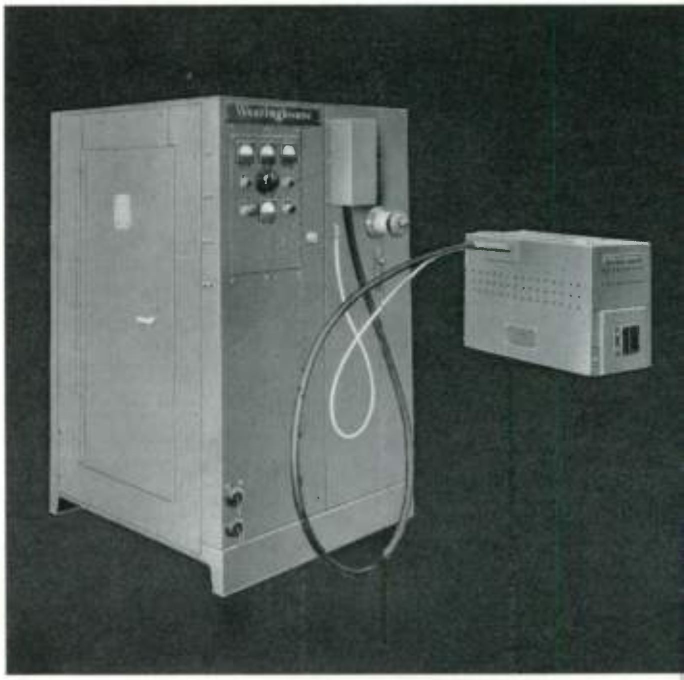
Induction heating, although a relatively new method of heating compared to furnace heating, has stabilized so considerably in the past decade that today it is the accepted method for many applications—axle hardening, crankshaft hardening, tool bit brazing, and stranded cable annealing, to name a few. The unique characteristics of induction heating frequently make it the choice over conventional heating methods, either because of economic advantages, or superior performance.

Induction heating has a number of basic and inherent advantages. Perhaps most important is its ability to heat selectively in area or depth with maximum sharpness of transition zone between hot and cold areas. Heat is generated only in the workpiece, so that heating is quick, with no thermal lag from the furnace. Heat-up and cool-down times are thus kept to a minimum. This makes high production rates possible. Quick heating times also help keep scale loss to a minimum. Water-cooled work coils remain essentially at room temperature, and therefore do not oxidize or crystallize from repeated heating and cooling. This means they cannot give off impurities, thereby eliminating contamination from the heating element.

Electrically induced heating is, by its very nature, susceptible to direct, fast, electrical control at the source of energy, the generator. This ease of control, along with the other conveniences of work-coil heating, makes possible the integration of the induction heating cycle directly into the tooling line, eliminating separate handling and transportation to and from the heat-treating department. Two further advantages are the small floor space required, and the fact that a minimum amount of work is committed to the induction furnace, thereby keeping inventory and scrap to a minimum during startup or shutdown.



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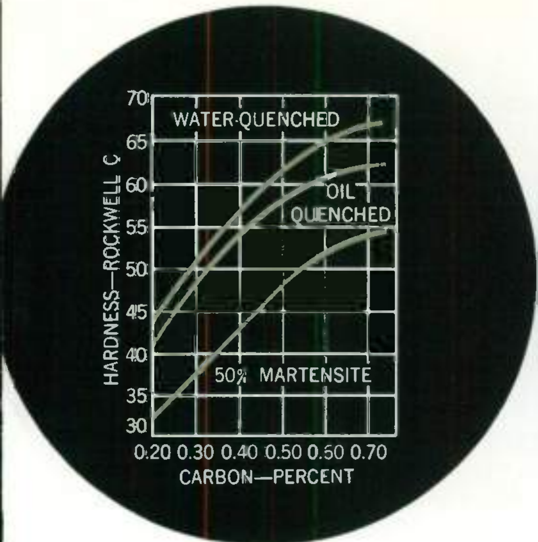

basic theory

Heat can be generated in a piece of metal or other current-conducting material by wrapping a coil around (or in the vicinity of) the piece, and applying an alternating current of suitable magnitude and frequency to the coil. A counter current is generated in the workpiece, and the resulting I^2R loss produces useful heating. The generated current density is highest at the surface of the workpiece, and drops off exponentially inside, as shown in Fig. 1. Heating in the workpiece due to this varying current density is equivalent to that produced by the same total integrated current distributed uniformly in a surface layer of thickness, δ. This depth, δ, is called the effective depth of current penetration, and is useful in selecting the optimum frequency for a particular heating job. The depth of penetration is expressed by the formula,

$$\delta = 2\sqrt{\frac{e}{\mu f}}$$

where δ is depth of penetration in inches, e is average re-

Fig. 1 (Top left, facing page) The principle of induction heating is shown for a nonmagnetic cylinder.
Fig. 2 (Top left) The hardness of quenched steel is a function of carbon content and method of quenching.
Fig. 3 (Top right) The relationship between hardness and strength is shown for three types of steel.

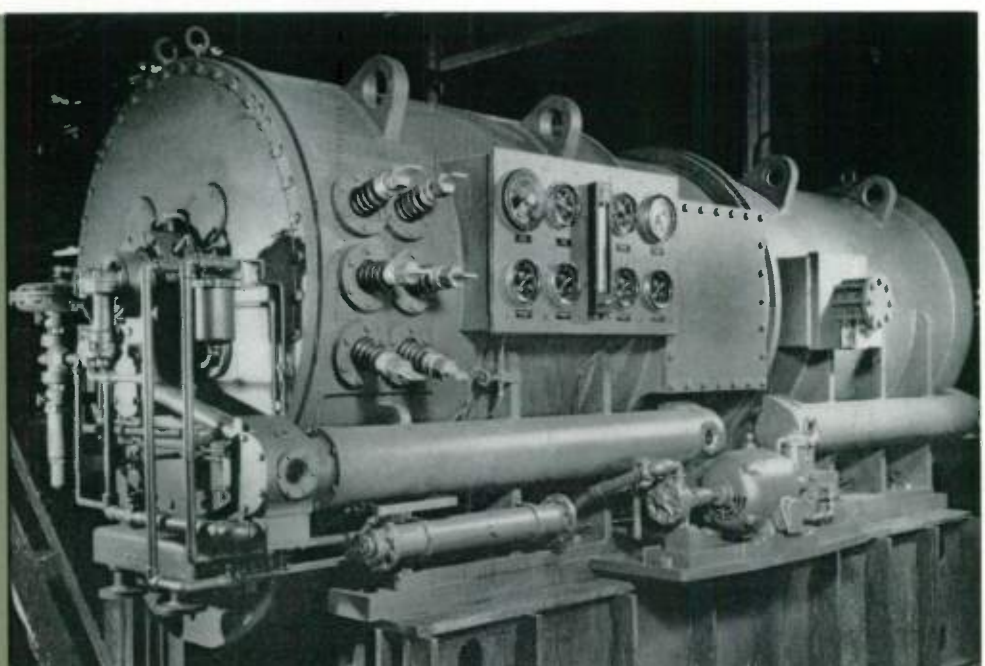

Fig. 4 (Left) This 10-kw r-f generator is dual frequency—4 megacycles and 450 kilocycles.
Fig. 5 (Right) This 1000-kw hydrogen-cooled m-g set is typical for generating frequencies for induction heating up to 10 000 cycles.

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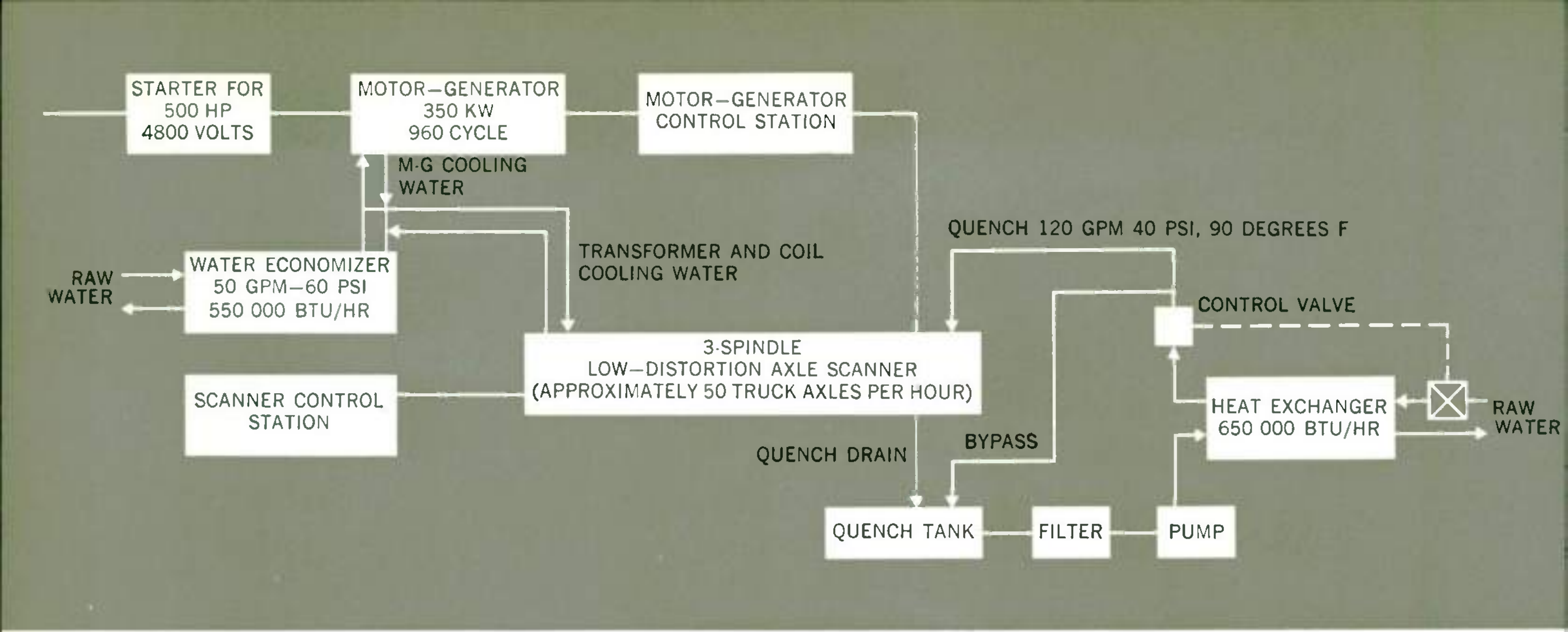


Fig. 6 Block diagram of a typical low-distortion axle hardening installation.

sistance of the workpiece in micro-ohm centimeters, μ is permeability, and f is frequency in cycles per second.

In the case of magnetic materials that are not heated above the Curie point (temperature above which a material loses its magnetization), permeability can vary greatly with power density, often making it necessary to call on prior experience or test results to accurately apply induction heating theory.

The first step in designing an induction heating application is the choice of a frequency that will give the desired heating depth. For example, hardening jobs utilize the advantages inherent in a thin, or "skin," heating depth obtained with high frequencies, whereas brazing and forging applications need the more uniform heating obtained with low frequencies.

The power required to accomplish heating of the workpiece can be estimated from the formula,

$$P_t = 17.5\ M\ C\ \Delta T \times 10^{-3}$$

where P_t is power in kilowatts, M is total mass to be heated in pounds per minute, C is specific heat (cal/gram/degree C), and ΔT is temperature rise in the heated material in degrees F. However, the two equations given provide only a starting point for the design of an induction heating application; some of the other complicating factors that must be considered are heat losses from the workpiece by radiation or conduction, efficient design of the heating coil, energy losses in other system components and the I^2R losses in the coil.

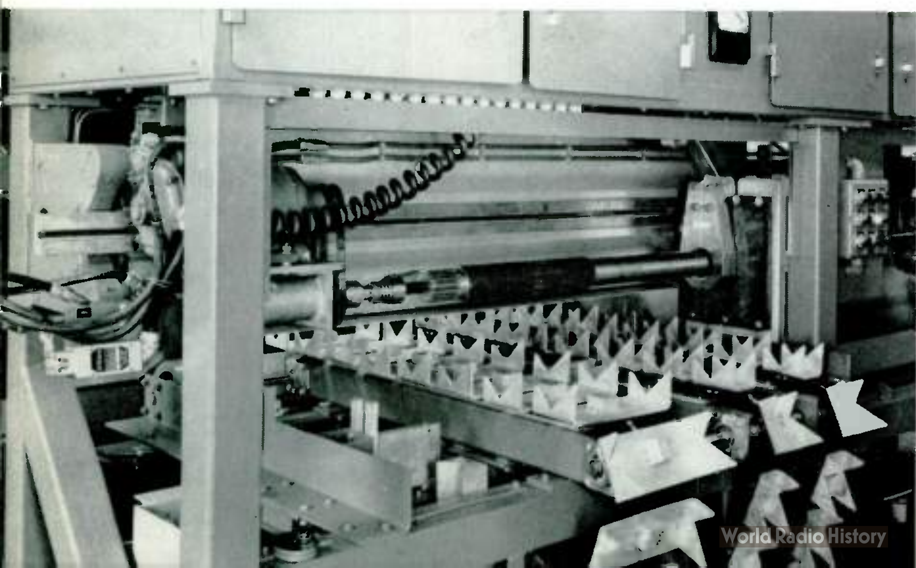
Few induction heating installations are exactly alike, so the above factors vary for each installation. Although these can be calculated for the same coil geometry, the final "fitting" of coil shape, voltage, and power requirements to a given workpiece configuration is often done by testing to insure maximum performance and efficiency.

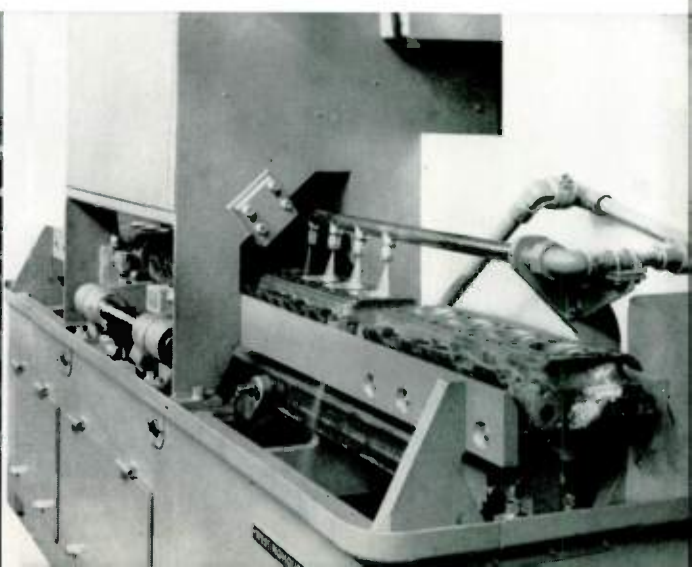
Induction heating applications can be divided into several categories: hardening, heat treating, forming, joining, strip heating, and melting.

hardening

Induction hardening is used today on automobile and tractor axles, transmission gears, bull gears, valve stems, crankshafts, rocker arm shafts, and a multitude of other parts for industry.

Fig. 7 (Left) This automatic induction hardening machine is used to process tractor axles.
Fig. 8 (Right) Induction hardening is used to eliminate the need for valve seat inserts in high-horsepower engines.





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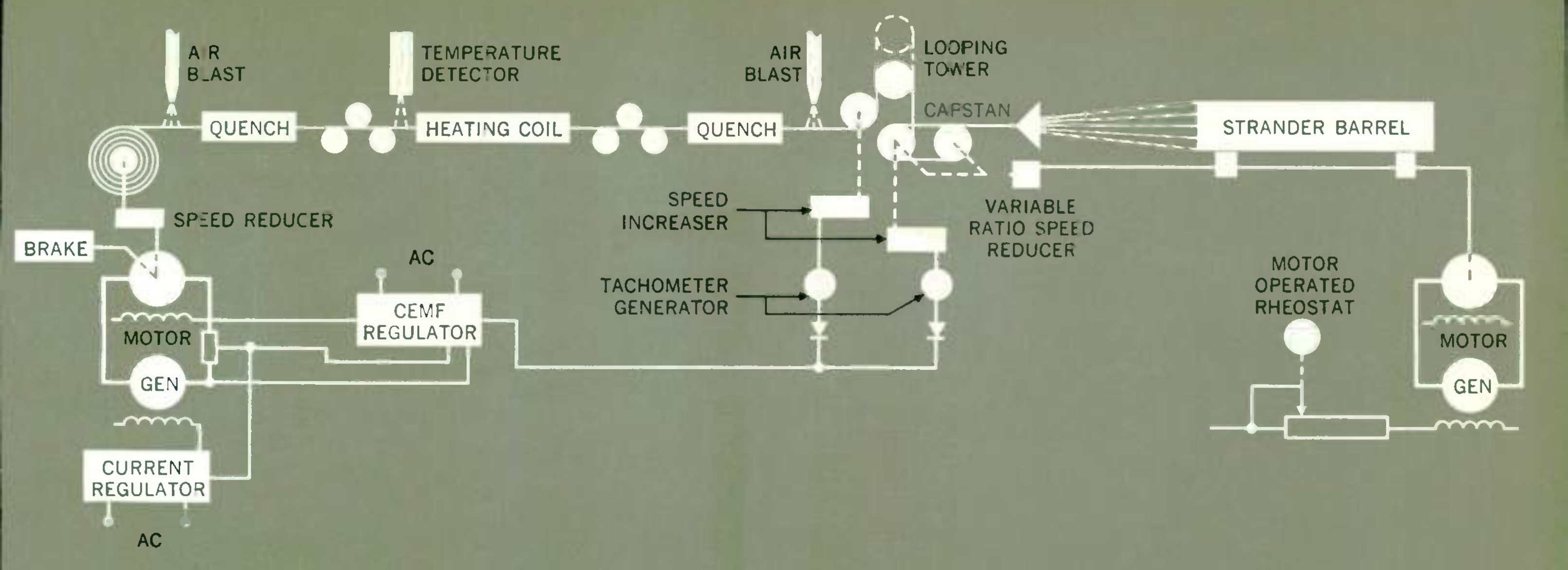


Fig. 9 Diagram of cable stress-relieving installation.

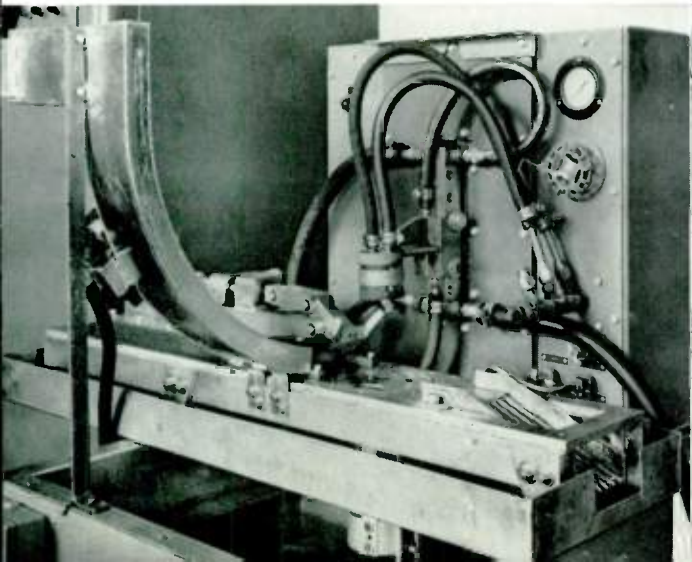
The control possible with induction heating makes it particularly suited to these applications. Heating coil shapes can be designed to cover a specific area, and frequency can be chosen to heat this area to the desired depth. The selected depth, when quenched, produces a strong, hard ring of high-tensile strength over a soft, unheated core. The hardened surface provides maximum strength and wear resistance, while the soft core insures resilience.

The energy required is only that necessary to heat the outer ring of the material. Short high-power-density coils (about 10 to 20 kw per square inch) are usually used for induction hardening applications. The coil is connected to a high-ratio transformer, which matches the work coil to a high-voltage, high-frequency power supply. Quenching is usually accomplished with a water spray from a quench ring, which is integral with or near the heating coil.

An area where considerable progress has been made in recent years with induction hardening techniques is in axle hardening. Greater material strength, resulting from a hard case and tough core, has minimized the need for larger axles and associated housing, bearing, gearing, etc. Furthermore, induction-hardened axles can be made of plain carbon steel (1041) instead of more costly special alloy steel, with a considerable material cost saving. Machining costs are also less with 1041 steel.

One of the latest developments in the induction hardening field is the low-distortion axle hardening machine shown in Fig. 7. In the past, the hardening process has produced distortion that required subsequent manual straightening. In this new type of hardening machine, a chucking device grips the axle flange rigidly during hardening; after the induction coil has passed over the axle, hydraulically operated steady rests support the shaft. These two mechanical devices provide the equivalent of jig quenching after heating. As a result, the axle is strong and straight, with no straightening strains locked in. Depending upon the manufacturing accuracy of the axle and the tolerance requirements, this method can often eliminate all cold straightening. This makes possible a maximum axle hardness—for example, with 1041 carbon steel, test samples have shown a Brinell hardness number of 550; tensile strength is 290 000 psi, as compared to 185 000 psi obtained with other hardening methods.

Fig. 10 (Left) This bearing race hardening equipment can process over 400 pieces per hour.
Fig. 11 (Right) Induction heating installation for stress relieving steel cable.



World Radio History

A good industry application is high-speed rocker-arm shaft hardening. An automatic horizontal rotating scanner feeds 18-inch rocker-arm shafts in a continuous line through an inductor coil and quench to the pickup for the next operation. The shafts are selectively hardened for 1⅙ inch length on each of the eight wear areas for the rocker arm; the power is keyed on and off by a rotating cam wheel so that soft areas exist between each hardened section. The induction process provides lower and better controlled distortion than was possible with the previous carburizing method, and the soft areas allow the shafts to be production-processed through a roll straightener without cracking. The production rate of one equipment powered by 25 kw r-f generator is 100 completed shafts per hour.

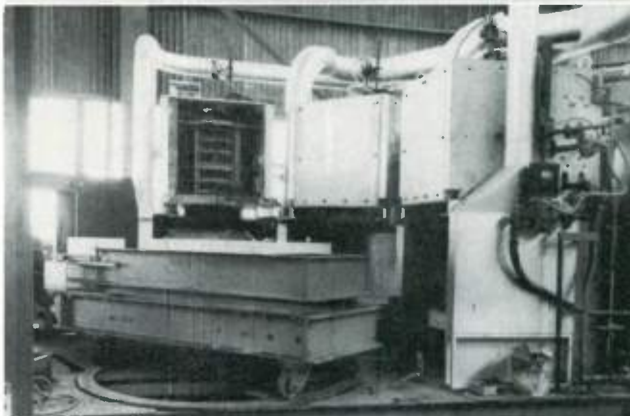
A typical induction hardening job, utilizing "one-shot" heating instead of scanning, is the inside hardening of bearing races for an automatic transmission. This is done in a semi-automatic machine that has an inclined chute feeding a rotating-lift cylinder mechanism (Fig. 10). The cylinder automatically moves the piece up around a single-turn "one-shot" integral inductor coil, rotates it while it is being heated and quenched, and then lowers it where it is stripped off and ejected down the outfeed chute; the cylinder then raises to the up position to receive another piece.

A unique feature of the unit is an outside clamping chuck that minimizes distortion by holding the piece rigidly during quenching. A 50-kw, 10-kc motor-generator produces a 0.090-inch case with a heating time of 3 seconds and a quench time of 3.5 seconds. Using a raise-lower load and unload cycle of two seconds, the production rate is 423 pieces per hour. With two units alternating on the generator, the production rate could be doubled.

heat treating

Some of the more recent uses for induction heating are annealing, stress relieving, and heating for shrink fitting.

The induction heating of stranded steel cable for stress relieving is an example of a high-speed production stress-relieving job (Fig. 11). After stranding, the cable has become cold worked, and its physical properties are markedly improved by heating to 600 degrees F prior to reeling on the drum for final shipment. A 36-inch long heating coil, fed by a 250-kw, 10-kc generator, is integrated with a strander and cable drum reel-up system. The strander, looping tower, induction coil, and take-up reel are in one continuous line with automatic power versus speed proportioning control to maintain 600 degrees F (± 30 degrees F) from 25 percent to full speed. A temperature vernier control cuts in at full speed to maintain running control at an indicated ± 10 degrees F. Speeds up to 275 fpm on ½-inch stranded cable are attained.



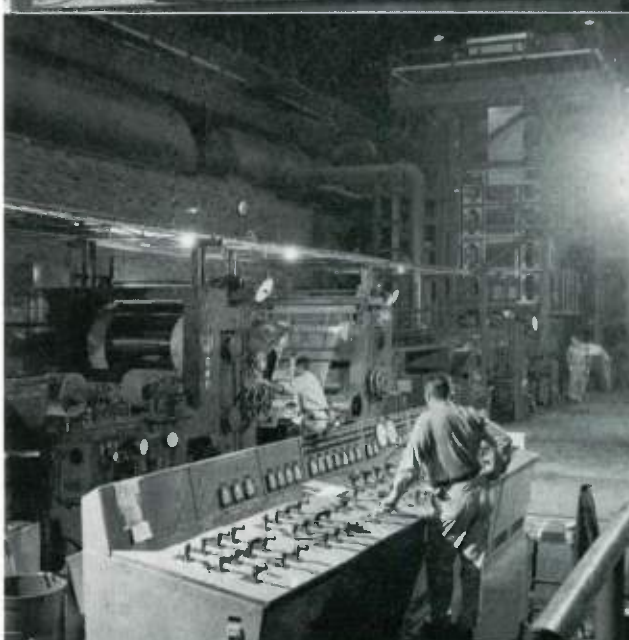


Fig. 12 This dual-frequency induction heating machine uses frequencies of 60 cycles for heating below Curie temperature, and 960 cycles above Curie to obtain efficient heating for a billet of 3-inch cross section.

Fig. 13 This 60-cycle vertical billet heater handles uranium billets 18 inches in diameter by 18 inches long.

Fig. 14 Photo of tin-reflow installation.

Fig. 15 This crystal-pulling furnace uses a 10-kw, 450-kc power supply. The furnace will produce up to ½ pound of single crystal silicon during each run.

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forming

The use of induction heating for forming is increasing because the basic advantages often outweigh the usual running cost increase over conventional furnaces. Billet heaters, for steel or nonferrous parts up to about 10 inches in diameter, are usually horizontal. Billets are pushed, one after the other, through a long helical coil that forms the heating tunnel. Because the heat is induced directly in the metal, the heating time is always shorter than for a conventional furnace, and induction equipments are usually automated right in the production line—often automatically feeding the forming press directly.

Induction heating is used widely for heating billets of varying diameter, for heating bars for hot nut forming, for heating bar ends for upsetting, and for heating aluminum, copper, and brass prior to extrusion.

A horizontal pusher type of forging unit is conventional for heating billets. The dual-frequency unit shown in Fig. 12 is used for heating 3⅛-inch diameter by 8-inch long billets to forging temperature. Sixty-cycle frequency is used below Curie temperature, and 960 cycles above Curie for efficient heating of a billet of this cross-section.

The machine shown features hydraulic feed, high and low temperature-controlled outfeed reject, and special rugged heating coils with independent hot rail suspension. This latter feature takes the billet weight off the heating coil itself and protects the coil and refractory from the horizontal thrust as the line is being pushed.

As billets get larger, up to 10–12 inches in diameter, and heavier, it becomes impractical to push them horizontally on coil liners and rails, so they are heated in a vertical position. Most vertical heaters now in use are designed for a specific job, like the three-position uranium billet heater shown in Fig. 13. For this installation, the low thermal conductivity of uranium and the close temperature uniformity required dictated a long heating time. In about one hour of heating time, the coils each heat 3000-pound billets (18 inches diameter by 18 inches long) to 2000 degrees F. The equipment consumes an average of 300 kw to produce about 4500 pounds per hour.

joining

Induction heating is used widely for brazing and soldering, particularly for high production runs. The compact induction coil arrangement lends itself to automation, and conveyorized fixtures are often placed in the production line with the other machine tools. A variety of coils are available so that each part can be conveyorized for maximum production rate and ease of mechanical handling.

strip heating

High frequency heating for reflowing of electrolytically coated tin, pioneered by Westinghouse, is now widely used (Fig. 14). Today, 0.010-inch steel strip, 36 inches wide, can be coated at rates up to 2400 fpm with superior quality because of the short alloying time between the steel and the tin. The induction-heating method, adopted almost universally today, provides the highest quality tinplate finish.

Another heating application with potential is transverse flux heating of aluminum and nonferrous materials in strip form. Transverse flux heating utilizes iron-cored coils for high efficiency. The magnetic flux is directed at right angles to the plane of the sheet being processed. Although this application is in its early stages in industry, two installations for aluminum heat treating are running, one in France and one in America. Transverse flux heating holds much promise for the future because of the high efficiency on thin strip, coupled with the basic control advantages of induction heating.

melting

Induction melting is also an established process today. It is essentially an extension of the billet-heating process—provision is made to hold the metal after melting. Frequencies of 960 and 3000 cycles are used for ferrous and nonferrous melting furnaces, which have capacities ranging from 50 pounds to 5000 pounds per hour. The fast startup time of induction melting and the strong stirring action make its use advantageous in many foundries and metalworking plants. Accurate, metallurgical control can be produced heat after heat.

semiconductor production

Two extremely critical heating applications are involved in the manufacture of new semiconductor materials; a crystal growing operation and, for the higher purity semiconductor materials, a zone-refining operation. The accurate and fast power response of r-f induction equipment has led to its almost universal use by semiconductor manufacturers.

Crystal pulling is the process of pulling a monocrystalline bar out of a molten pool of germanium or silicon, which is heated in a graphite crucible by a surrounding induction heating coil. Since semiconductors are not good conductors in the molten state, heat is generated in the graphite crucible, and conducted to the semiconductor material. The heating coil usually consists of a loosely coupled coil of water-cooled copper tubing.

Silicon must be heated to about 1450 degrees C, germanium to 950 degrees C. Temperature control can be maintained during the pulling period to within ± 0.1 degree C of the desired melt temperature.

Zone refining is the process of moving a molten zone along the workpiece in a continuous motion to sweep impurities out of the material. Horizontal zone refining is done in graphite boats, which move through a series of spaced inductor coils. The molten zones set up within the semiconductor material are swept along the length of the bar. Vertical zone refining, which is applied largely to silicon, is done in a gas or vacuum where a small inductor melts a narrow zone, and sweeps along the bar as the material is scanned.

Various refinements of these processes are being used today, and induction heating looks promising for zone refining, growing, and doping of other semiconductor materials and special metals as well, and for accurate temperature controlled heating in the pulling of dendritic semiconductor materials.

Induction heating has been found applicable to most metal-heating applications, but it is especially effective where performance requirements are critical. Here, the advantages of precise control and exact repeatability give induction heating a substantial advantage over other forms of heating.

World Radio History

POWER DRIVES FOR DECK MACHINERY Two modern drive systems widen the marine designer's choice.

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Motor and Gearing Department
H. L. LINDSTROM
Systems Control Department
Westinghouse Electric Corporation
Buffalo, New York

E. C. MERICAS
Marine, Transportation and Aviation
Facilities Engineering Department
Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania

The deck machinery of today's ship runs the gamut of applications and required operating characteristics. For discussion, it can be divided into two groups: machinery for handling the ship and machinery for handling cargo.

The ship-handling group includes anchor windlasses, mooring and towing winches, and capstans (see *Deck Machinery Terms*). The anchor windlass requires special hoisting and breakaway characteristics but seldom has to provide controlled lowering. Mooring and towing winches need unusually high accelerating rates and must provide, or be tied in with, some form of tension control. Simpler constant- or dual-speed control is usually sufficient for a capstan. Many of these drive requirements are fairly well

DECK MACHINERY TERMS

ANCHOR WINDLASS A windlass for lowering and raising an anchor.

MOORING WINCH A winch for handling lines used to tie up the ship.

TOWING WINCH A winch for handling tow lines.

CAPSTAN Much like a windlass but having the drum axis vertical instead of horizontal. Used for handling mooring lines and other lines.

CARGO WINCH A winch used with a ship's mast and boom in a derrick arrangement. An auxiliary *topping winch* positions the boom's free end vertically, and a *vang winch* positions it horizontally. Usually, two booms and cargo winches are used together in an operation called *burtoning*. One boom is positioned over a cargo hatch and the other over the dock, and lines from both are attached to the load to be moved. To unload the ship, for example, the first winch hoists a load out of the hold; it then pays out line while the second winch takes in line to draw the load toward the dock. The second winch eventually takes over the entire load and lowers it to the dock.

CARGO CRANE A ship-mounted crane that resembles a conventional land crane. It rotates to transfer cargo between the dock and the holds.

GANTRY CRANE A bridge structure with a crane trolley traveling on it. Used mainly on container ships for handling standard-size containers.

SIDE-PORT CRANE A telescoping crane for moving cargo through a port in the side of a ship.

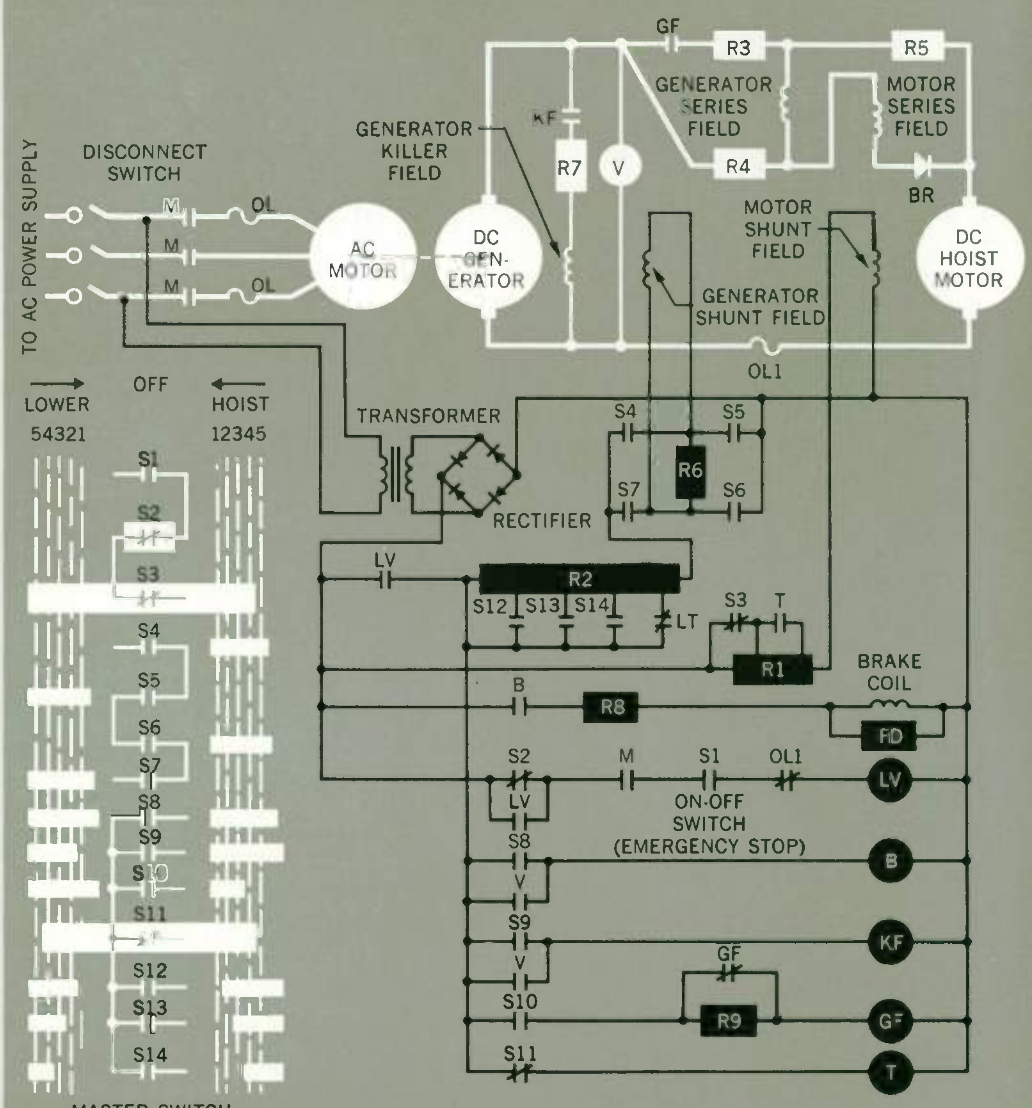

Fig. 1 Schematic diagram of an adjustable-voltage dc drive.

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stabilized, but, even so, they must be periodically reviewed to find out if the newer types of drives and regulators can improve their operation.

Cargo is usually handled with cargo winches, cargo cranes, gantry cranes, and side-port cranes (see *Deck Machinery Terms*). Cargo winches have traditionally required high light-line speeds, fast response, and maneuverability. Container-handling gantry cranes need constant speeds at all loads and very low landing speeds. Topping and vang winch drives have mostly been single speed, but some applications have required finer control. Some of these drives are well established, but again, the continued search for faster and lower-cost cargo handling repeatedly raises the question of what is the best drive for each application.

This article describes two modern drives—adjustable-voltage dc and reactor-controlled ac—that represent the latest developments in the field. The adjustable-voltage dc drive as a general type has been used for some time, but the improved version described here is of recent origin. The reactor-controlled ac drive is just coming into use for deck machinery and offers considerable promise.

adjustable-voltage dc drive

The new version of this drive retains the excellent characteristics that have made its predecessors popular for hoisting both ashore and on shipboard. In addition, it has been simplified and made more compact by incorporating most of the desired features into the inherent characteristics of the rotating machines and by using new circuit concepts. These features are reliability, high performance, safety, easy maintenance, and flexibility.

Operation—The drive's components are shown schematically in Fig. 1. They include a blocking rectifier that prevents reverse current flow through the motor series field and a generator killer field and resistor that help stop the drive. A special bridge circuit permits positive (cumulative) series ampere-turns in the first three hoisting positions and negative (differential) ampere-turns in the fourth and fifth positions for ideal shaping of the generator volt-

LEGEND

OL —Overload relay

M —Main contactor

R —Resistor

GF —Generator field contactor

KF —Killer field relay

V —Voltage relay

S —Master switch contact

LV —Low-voltage relay

B —Brake relay

FD —Field discharge resistor

BR —Blocking rectifier

T —Timing relay

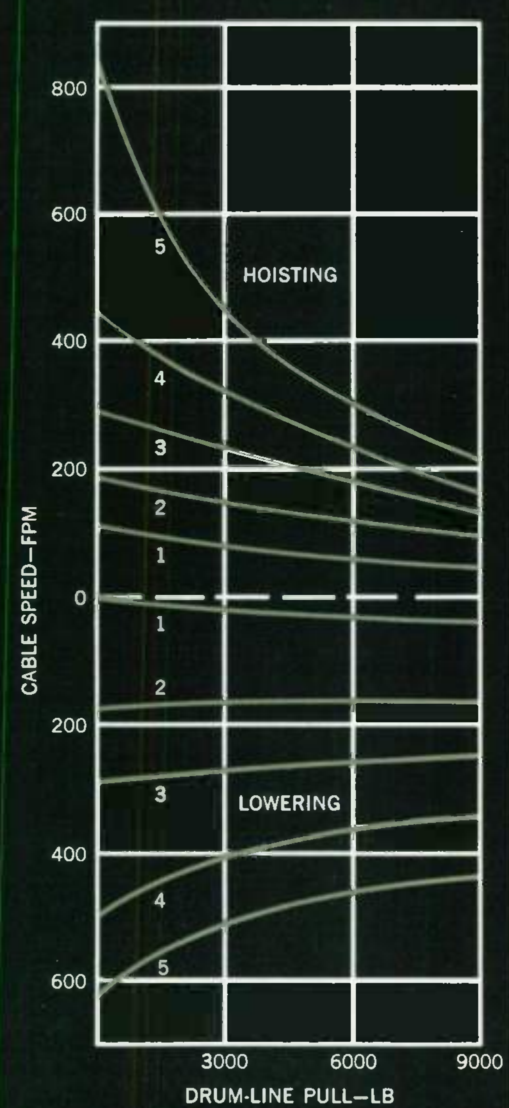

Fig. 2 Hoisting and lowering characteristics of the adjustable-voltage dc drive (50-horsepower 600-rpm dc motor).

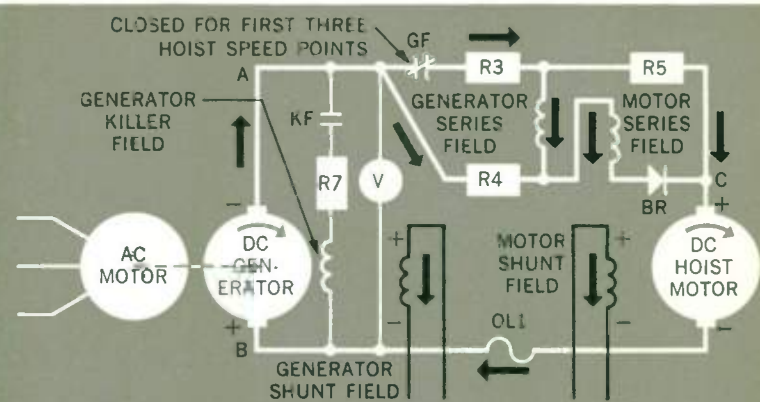

Fig. 3 Current flow in bridge circuit during hoisting.

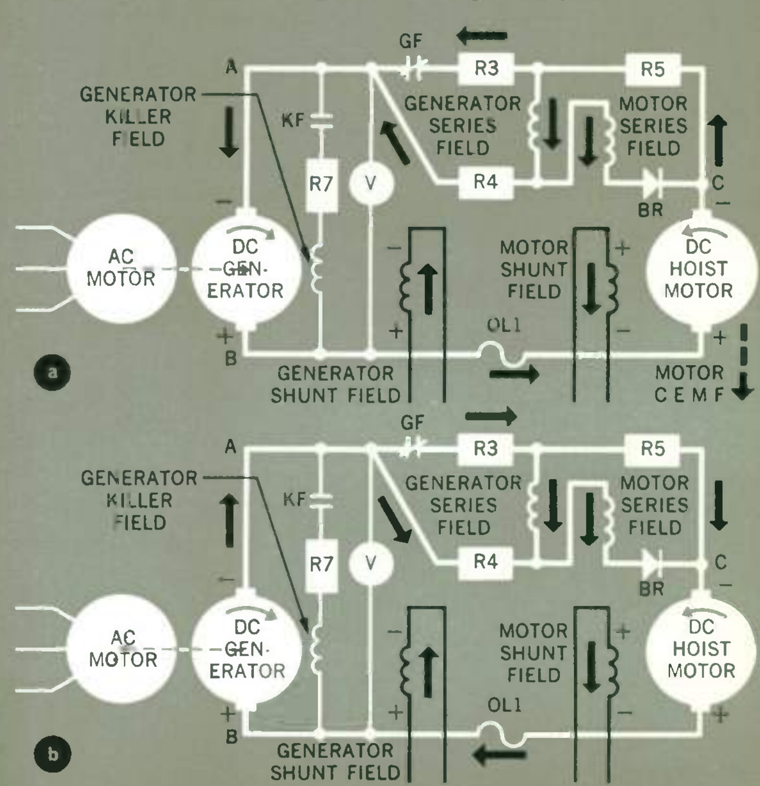

Fig. 4 Current flow in bridge circuit (a) during power lowering, (b) with overhauling load.

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ampere curves. The timing relay insures dynamic stability under any operation or load. The motor's low moment of inertia permits rapid acceleration and deceleration. The generator is designed for high speed and low field time constant to achieve fast response during rapid movement of the master switch handle and to provide the correct time constant for maximum operating stability under all conditions.

In *hoisting*, the combination of a heavily compounded motor powered by an adjustable-voltage generator produces the excellent set of curves shown in Fig. 2. The first three points are essentially speed points; that is, speed is relatively independent of load, and the drive does not stall if the load is heavy. Excessive strain on the winch is prevented by an overload relay that functions at 300 percent torque. When it trips, the killer field drives the generator voltage to zero and the brake sets.

These first three speed points are obtained by the closing of contactor *GF* (Fig. 3), which causes a small fraction of the load current to flow through the generator series field in the cumulative direction. This raises generator voltage and compensates for loop IR drop to prevent the motor from stalling.

The fourth and fifth hoisting points are obtained by opening contactor *GF*, which causes part of the load current to flow through the generator series field in the differential direction. The interaction of these ampere-turns and the shunt field ampere-turns shapes the generator volt-ampere curves in such a fashion that, together with the inherent regulation of the compound motor, hoisting curves 4 and 5 (Fig. 2) are produced. These basically inverse speed-torque curves, tending toward constant horsepower, are ideal for hoisting because they provide slow speeds for moving heavy loads and high light-line speeds (300 percent of rated load speed).

The main armature loop is never open, and closing or opening of contactor *GF* affects only part of the main armature current. This improves reliability and safety because energy levels handled by relays and contactors are low.

During power *lowering*, current flows from generator terminal *B* through the motor armature to point *C* (Fig. 4a). The blocking rectifier prevents reverse current from flowing through the motor series field. Thus, generator and motor act as shunt machines and provide high torque for quick acceleration.

The motor speed tends to increase when lowering a heavy load, and this increases the motor cemf until it becomes greater than the generator voltage. The current therefore reverses and flows from *A* to *C* (Fig. 4b). This causes current to flow through the motor series field, producing cumulative ampere-turns. The motor torque prevents further acceleration, and stable speed results.

Thus, the motor acts as a cumulatively compound generator sending power to the generator, which runs as a shunt motor and drives the ac motor as an induction generator. The greater the overhauling load, the higher the regenerated current, the higher the motor flux, and correspondingly, the higher the voltage.

For a given generator voltage, motor flux increases as load increases. This causes the motor voltage to match the generator voltage at a lower speed; i.e., heavier loads are lowered at lower speeds (Fig. 2).

This system provides lowering speeds varying inversely with load, and it matches hoisting and lowering speeds—all without load-measuring relays. The first-point lowering speed is 40 feet per minute (fpm) with a 100 percent load (equivalent to a free fall of 0.09 inch).

When the motor is being stopped, the blocking rectifier prevents reverse current flow in the motor series field, permitting the shunt field to maintain a substantial flux. This effect and the regenerative current in the armature loop produce a positive braking torque that, with the dynamic braking of the armature loop resistance, quickly slows the load without using the brake. The combination dynamic braking and killer generator field quickly reduces generator voltage to practically zero, which lowers the main-circuit current to a small value. The brake, therefore, is not required to absorb motor torque. It is basically a holding device, so there is little wear on it.

The various field time constants, the proportion of ampere-turns between fields, and the low moment of inertia of the motor and brake wheel produce smooth operation, even during plugging (moving the master switch handle rapidly from a hoisting to a lowering position). No severe torque pulses, with their accompanying mechanical strains, are encountered.

When the master switch is moved to *OFF*, the generator killer field and resistor are automatically applied after the voltage relay opens when generator voltage drops below 100 volts. This drives generator voltage to almost zero. The motor functions as a saturated generator (constant flux), and the current rises until it produces enough torque to lower the load at 30 to 40 fpm (equivalent to dropping it less than 0.1 inch). Thus, if the brake fails to set, any load is automatically and safely lowered. This also makes it possible to handle cargo without ever using the brake.

If ac power fails, the low-voltage relay applies the generator killer field and resistor, which drives the generator voltage to near zero. The regenerative (overhauling) current passes through the motor series field in a direction that increases flux with increasing current (load). This increases torque and slows the motor within 1½ seconds. The kinetic energy of the winch motor and load is mostly dissipated in circuit resistance, with little left for driving the m-g set. Therefore, the set does not overspeed, and the load is lowered at a steady 30 to 40 fpm.

Dynamic Performance—The static performance of a drive system is not the only consideration, for its dynamic or transient response often determines its suitability. In such an evaluation, the worth of this drive is evident. The system accelerates rapidly and smoothly whether the master switch is moved from *OFF* to any point or from a lower point to a higher point.

The time required to accelerate a 150-percent load from zero to full speed is about two seconds. It decelerates rapidly and with no equipment abuse. Practically all of the stored energy is absorbed by regeneration and dynamic braking, and the brake sets when only about 1/25 of the system energy is left. The time required to stop the load is about ½ second. When the master switch is manipulated at random, there are no undesired transients.

Mechanical Arrangement—The m-g set and control are assembled on a common bedplate and installed as a unit (Fig. 5). This minimizes weight and size and improves

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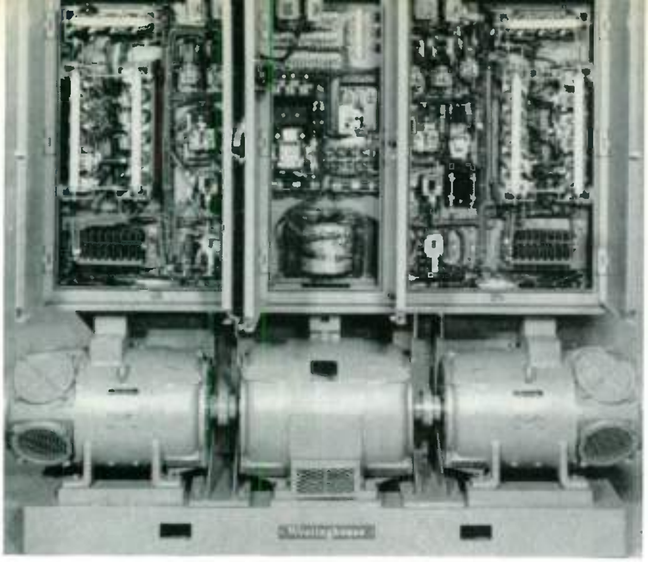


Fig. 5 The m-g set and control package for two dc cargo-winch drives.

accessibility. The control is compact and conveniently arranged, with all parts accessible from the front to permit easy maintenance and installation against a bulkhead.

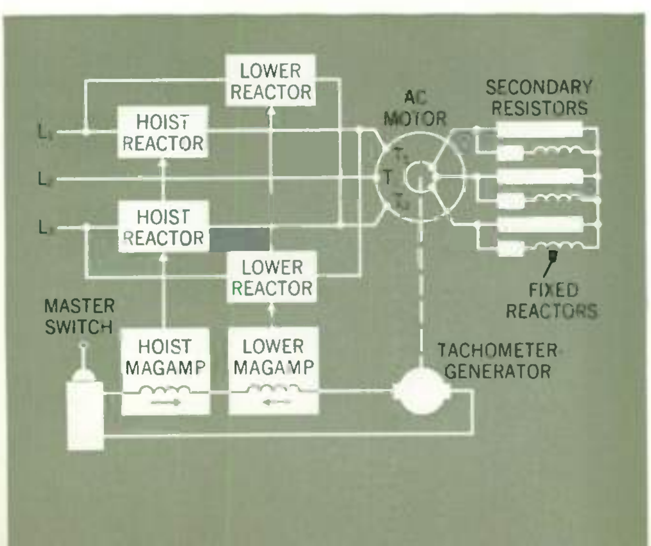
The ac driving motor is especially designed for high pullout torque and low magnetizing kva for low demand on the ship's service generator. The Life-Line H dc motor is designed for reliability, rapid response, and accessibility. The motor and brake wheel have a combined moment of inertia of 33 pound feet squared.

reactor-controlled ac drive

The advent of ac ship's service power plants in American dry-cargo vessels was delayed, no doubt, by reluctance to give up the inherently superior speed-control characteristics of dc drives. Cargo-handling gear, in particular, had speed-control requirements that precluded the use of early ac drives because of practical and economic considerations. However, the emergence of the Mariner class cargo ship heralded the marine industry's recognition and acceptance of the ac ship's service plant.

There is now strong industry interest in ac cargo-handling systems. The philosophy is that shipboard electric drives should, axiomatically, be powered directly from the ship's electric system. To this end, Westinghouse has developed a variable-speed ac system for deck machinery.

Fig. 6 Schematic diagram of a reactor-controlled ac drive.



The Load-O-Matic control system was developed 15 years ago to give ac cranes operating smoothness comparable to that of dc adjustable-voltage control. Many industrial crane users have employed Load-O-Matic control when fast speed-regulated control and excellent spotting characteristics were needed; with the advent of container ships and missile-handling ships, the marine industry can now apply it. Load-O-Matic operating characteristics have proved well suited to gantry cranes and consequently have gained general acceptance in them.

However, an ac motor has a flat speed-load curve, so its light-line speed is only a few percent higher than its full-load speed. An oversized motor and control would have to be used to give an ac cargo-winch drive a light-line speed significantly greater than its full-load speed. The maritime industry's light-line speed requirements for cargo winches (as high as 300 percent) thus impose economic restrictions on the ac drive. If these requirements can be modified, the Load-O-Matic system can be applied advantageously to cargo-winch drives.

Operation—The Load-O-Matic variable-speed drive employs a wound-rotor motor whose torque, and consequently speed, are controlled by varying its primary voltage. Speed and direction of rotation are controlled by magnetic amplifier (Magamp) controlled, saturable-core reactors. Functionally, the reactors are analogous to a set of main-line forward and reverse contactors.

The main components of the system are shown schematically in Fig. 6. They are two single-phase "hoist" saturable-core reactors, two single-phase "lower" saturable-core reactors, one wound-rotor motor, one set of secondary resistors with three reactors, one dc tachometer-generator, one master switch, and two Magamps.

A saturable-core reactor with no direct current in its control winding is like an open contactor; it is like a closed contactor when rated direct current flows in its control winding. To operate the motor in the hoist direction, direct current must flow to the hoist reactors and none to the lowering reactors (Fig. 6). Operating the master switch in the hoist direction causes the hoist Magamp to supply current to the hoist reactors, which then permit current to flow to the motor from L_1 to T_1, L_2 to T_2, and L_3 to T_3.

Reversing—To reverse the motor, the master switch is operated in the lowering direction. This changes the reference voltage polarity, which initiates and sustains an output from the lowering Magamp while the output of the hoist Magamp ceases. The lowering reactors, their control windings energized from the lowering Magamp, admit current to the motor from L_1 to T_3 and L_3 to T_1. Motor terminals T_1 and T_3 have thus been reversed by static devices. This simple reversing has proven itself in many shore cranes and is equally effective in marine drives.

Speed Control—The previous paragraph described how a standard wound motor is reversed by completely static devices. These devices, saturable-core reactors, also provide the means for motor speed control. The amount of direct current flowing to the reactors determines their degree of saturation and, hence, the voltage drop across their power windings and the line voltage to the motor. Since motor torque varies approximately as the square of the

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line voltage, torque (and consequently speed) control is attained by regulating the voltage drop across the reactor's power windings. Partial saturation and its attendant reduced line voltage reduces motor torque and speed; full saturation produces full motor torque and speed.

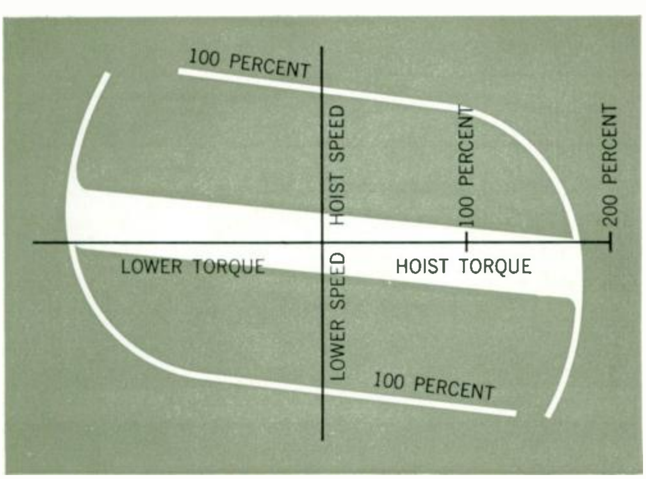
The system provides stepless control over the entire speed range (Fig. 7). The first speed-torque curve is obtained by moving the master switch to the appropriate position. This action releases a brake and sets up a reference voltage corresponding to the master switch speed position. The reference voltage initiates a flow of control current to the hoist Magamp, whose subsequent output to the hoist reactors provides about 185 percent motor torque. This torque causes the motor to accelerate. As it does, the direct-connected tachometer produces a countervoltage that, by acting against the reference voltage, reduces the Magamp output to a value consistent with the torque required for the speed called for by the master switch.

If motor speed falls below the master switch setting, the countervoltage diminishes and the Magamp output increases to the value corresponding to the master switch setting. As the master switch is advanced, the reference voltage increases steplessly and the drive speed increases steplessly. If the master switch is advanced rapidly, the motor does not exert more than about 185 percent of full-load torque.

To lower, the master switch is moved away from the operator; the speed-torque curve shown near zero speed is provided. As the switch is advanced, the drive provides a stepless family of curves parallel to the slow-speed curve. Acceleration or deceleration may be quick or slow, but mechanical parts are always protected by the torque limit.

To obtain the white area between the slow-speed hoist curve and the slow-speed lower curve, a thumb switch on the master switch is pressed to keep the brakes released in the region. The master switch reference voltage is continuous from hoist through zero to lower. Therefore, if the brake is kept released, the speed of the load can be reduced to creeping speed, stalled, or reversed without setting the brake. This eliminates the problem of the load bouncing.

Fig. 7 Hoisting and lowering characteristics of the reactor-controlled ac drive.



This drive relies on countertorque rather than on its mechanical friction brake to stop the load. The master switch, when moved from a running position to *OFF*, initiates an unbalance between the reference and tachometer-generator voltages. The former becomes zero while the latter gradually diminishes as the motor speed approaches zero. The unbalanced condition develops a motor countertorque that brings the load to a stop. With motor at zero speed (and hence tachometer-generator voltage at zero), no torque is developed in either direction. This is an effective brake system that ensures high reliability with minimum maintenance.

Advantages—The ability to operate a single wound-rotor motor directly from the ship's service electrical system is the most apparent and perhaps the most impressive feature of this ac drive system. Other important advantages are:

1. Absence of reversing primary contactors;
2. Use of standard wound-rotor motors;
3. Use of heavy-duty dc self-adjusting brakes;
4. Smooth acceleration and deceleration, comparable to that of an adjustable-voltage drive;
5. Reduced brake maintenance because the motor does 95 percent of all braking;
6. Nearly constant decelerating torque.

These features combine to reduce motor, brake, control, and mechanical maintenance. Motor maintenance is low because torque changes are smooth, though not sluggish. Minimum control maintenance results from the absence of reversing primary contactors, accelerating contactors, and relays. Extensive use of static components also minimizes maintenance, renders the equipment more reliable, and prolongs available service life. Low mechanical maintenance stems from smooth acceleration and deceleration.

conclusions

The two basic drives described in this article can be modified to obtain various degrees of regulation if the load characteristics demand it. Many different shapes of speed-load curves can be provided, and stepless speed adjustment is available where needed.

Other drive types that have been used for deck machinery include dc constant-voltage, other forms of adjustable-voltage, ac wound-rotor with secondary impedance control, single-and-multispeed squirrel-cage, and multimotor drives. It is extremely important to evaluate each kind of drive when choosing one.

For example, the dc variable-voltage drive described in this article is ideally suited to a burtoning cargo winch system. It has the wide speed range, speed-load characteristics, fast operating ability, low no-load power consumption, low maintenance, and other desired features.

On the other hand, the flat speed-load curves, extremely low landing speeds, low weight, stepless speed control, and low maintenance of the ac Load-O-Matic drive make it ideal for a container-handling gantry crane.

The engineer must evaluate each available drive, then, in terms of first cost, maintenance, performance, weight, space, power consumption, reliability, and other factors, with each factor properly weighted to suit the specific application. When he does this, he can give a reasonable answer to the question, "Which drive should I use?"

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WHAT'S NEW IN ENGINEERING

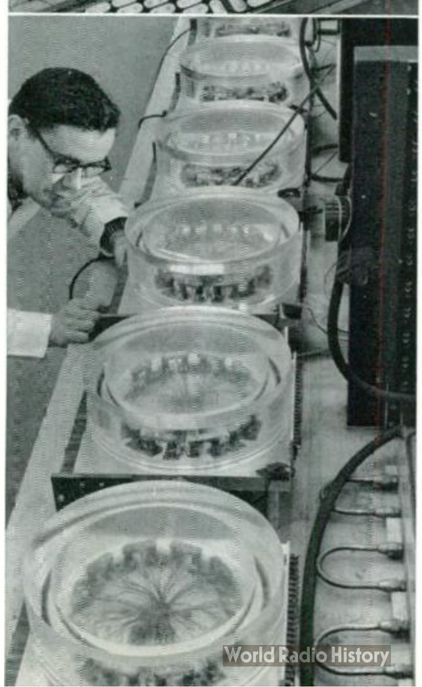
Thermoelectric Effects are Put to Work

Thermoelectric effects—those rather mysterious phenomena in which heat is converted directly to electric power or heat and cold are produced from electric current—are rapidly finding practical applications. Scarcely three years ago, their use was limited to such devices as thermocouples that produced weak currents for indicating temperature. Today, the combination of improved fabrication techniques and new materials with much better thermoelectric properties has changed the picture radically. A few recent developments are summarized here.

Four thermoelectric generator models, rated at 5, 10, 50, and 100 watts, are now in production at the Westinghouse Semiconductor Department. The department also is prepared to design and manufacture generators in many other ratings and configurations.

The generators are adaptable to many fuels and cooling media. Typical fuels are gasoline, propane, and natural gas; forced air, convection air, or water may be used for cooling. Operating temperatures, which depend on the application and the fuel used, range from 300 degrees to 600 degrees C. The generators are basically low-voltage high-current dc devices, but static inverters or converters easily provide the desired dc or ac output rating.

The thermoelectric generators are completely static, so they are well suited to use in remote locations where electric power is not available and to applications where a source of power independent of the local supply is desired. A 100-watt unit has been delivered to Northern Illinois Gas Company, Aurora, Illinois, to power a cathodic protection system for a pipeline and to charge batteries for a microwave communication system. Propane gas is burned at the base of the unit, and the hot combustion gases pass through a central chimney (see photo 1). A number of thermoelectric couples mounted around the chimney generate electric power as the heat is transferred to their "hot" sides. Heat is dissipated from their "cold" sides through anodized aluminum fins to the surrounding air.



The unit weighs about 75 pounds, and its output is 11 volts at 10 amperes. A static converter operating at about 88 percent efficiency changes this to 48 volts at 2.1 amperes for the pipeline installation. In addition to its basic applications, the unit will be used by the gas company in a research program to investigate other industrial uses for thermoelectric power generators.

In military applications, the reliability and noiseless operation of thermoelectric generators suit them to a number of special purposes. A 5000-watt generator developed for the Bureau of Ships, U. S. Navy, is the largest yet built. This unit was assembled by the Westinghouse New Products Laboratories to evaluate materials and fabrication techniques for large power generators. The couples are arranged in interchangeable modules (see photo 2). These modules line the inside walls of two 2500-watt sections that can be operated separately or together.

In another military application, radioactive isotopes are used as the heat source for a completely self-contained thermoelectric generator. This unit was developed by the New Products Laboratories for the U. S. Air Force to provide a reliable long-life power source for such devices as unmanned surface radio beacons and weather stations. It weighs less than

Photo 1 This 100-watt thermoelectric generator operates on propane gas. The meter at right indicates gas temperature inside the generator's chimney.

Photo 2 Final assembly and tests are performed on the thermoelectric couples for a 5000-watt power plant. The couples are arranged in interchangeable modules.

Photo 3 Long-term efficiency and reliability of thermoelectric materials are evaluated by life tests. Here, couples made from various materials are operated continuously and checked periodically for performance degradation.

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40 pounds, produces about 150 watts of power, and was designed for one year of continuous and unattended operation.

The thermoelectric cooling effect, produced when electric current flows through a junction of dissimilar materials, is applied in a new water cooler produced by the Westinghouse Major Appliance Division. This is the nation's first thermoelectric consumer appliance, although several earlier prototype appliances have been demonstrated. (These include a dehumidifier, a refrigerator, a baby bottle cooler-warmer, a mobile hostess cart with refrigeration and oven compartments, and electroluminescent panels that can heat, cool, and light a room.)

The water cooler resembles a standard compressor-operated cooler on the outside, but within the cabinet the cooling system occupies only about 25 percent of the volume required by the conventional type. The standard cabinet height was retained because it places the water tap at a convenient level. The first model is a bottled-water cooler for use primarily in areas where good drinking water is scarce. ■ ■ ■

In this demonstration of ultraviolet video transmission, input signals from TV camera (to left of subject) are impressed on the ultraviolet output of cathode ray tube in right foreground. The modulated ultraviolet light is directed to the tripod-mounted photometer (right rear), which changes it to a video signal that produces an image on the receiver screen (rear).

Communications System Uses Ultraviolet Radiation

Research in methods of communicating over great distances has produced a working system for transmitting images and other information over an ultraviolet carrier. The experimental system, developed by the Westinghouse Air Arm Division, employs a standard Westinghouse 5ZP16 cathode-ray tube as both a source and a modulator of ultraviolet light. A conventional ultraviolet-sensitive photomultiplier receives the transmission. Input signals are supplied by a standard television camera, and the output image is displayed by a television receiver.

The system's success indicates that it soon will be feasible to use cathodoluminescent devices as virtual point-source generators of ultraviolet radiation at the outputs and in the narrow bandwidths necessary for space communication.

The short-persistence phosphors of the 5ZP16 tube produce a radiated output of one watt of ultraviolet from a 0.011-inch spot when bombarded by a 30-kilovolt, 0.335-milliampere electron beam. Focused into a 0.033-degree conical beam by a one-meter optical reflector of 19-inch focal length, this power density of 10.3 kilowatts per square inch is sufficient to permit communication over a 10-cycle band at distances of about 15 000 000 miles. At ranges in the order of the moon's distance from earth, it is sufficient for video transmission.

Westinghouse research men are interested in ultraviolet space communications systems because they believe they will prove superior to infrared and radio frequency in several respects. Chief among these are the ability to beam the extremely short wavelengths by compact optical reflectors to achieve antenna gains of several million, and the relative freedom of ultraviolet systems from celestial and thermal noise. Deep space flights will make high antenna gain and high signal-to-noise ratio increasingly desirable in the future.

A research program has been initiated to develop new high-efficiency phosphors and the techniques necessary to prevent phosphors from being destroyed by the high-energy beams that stimulate ultraviolet emission. One technique under study is spinning the tube face so that the phosphor screen is spiralled under the point of impact of the stationary electron beam. ■ ■ ■

Radio Receiver Assembled from Functional Blocks

A radio receiver containing no tubes, transistors, or traditional electronic circuits has been built to test the feasibility of applying molecular electronics to complicated systems. Its main components are six silicon wafers about the diameter of a dime.

Each wafer is a functional electronic block that performs a complete function required for radio reception. Although the system is not directly comparable to conventional circuitry, it can be thought of as consisting of six stages: two radio-frequency amplifiers, a radio-frequency tuner, a buffer, a detector, and an audio-frequency amplifier. The receiver is tuned simply by changing the voltage on one of the functional blocks.

The receiver tunes in stations all across the standard broadcast band. A conventional set with similar capabilities requires about 50 individual components and about 150 soldered connections.

The receiver was developed by Westinghouse for the Electronics Technology Laboratory of the Wright Air Development Division, U. S. Air Force. It combines previously developed functional blocks in one of the most complex systems yet achieved with these units. The blocks are made by arranging the structure of a solid in such a way that phenomena occurring within or between domains of molecules perform electronic functions.

The functional block concept is the newest approach to development of small, reliable, and efficient electronic systems. The receiver thus represents progress toward the goal of molecular electronics, which is the integration, in a single block of material, of functions ordinarily performed by electronic circuits and even whole systems.

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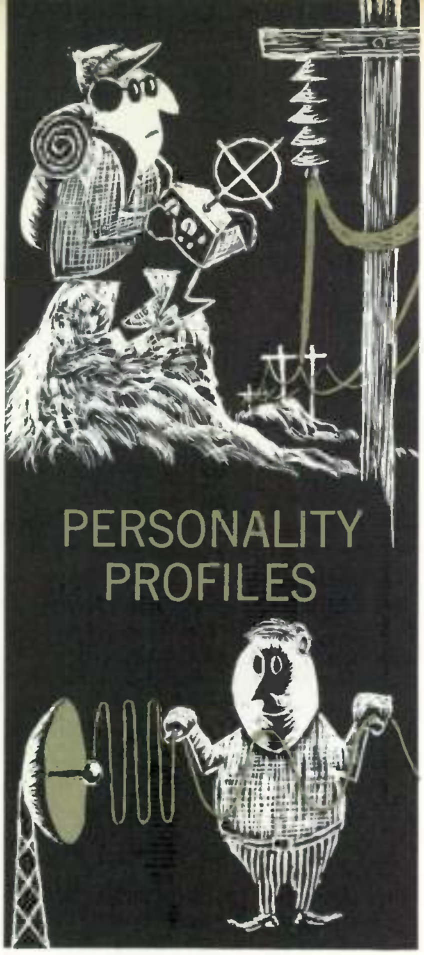

Compressing any engineering career into a few paragraphs on these pages inevitably means that only the high spots can be covered. This is the case with L. M. ROBERTSON, co-author with J. K. DILLARD of the Leadville Project article.

Robertson, Manager of Engineering for the Public Service Company of Colorado, earned his BS degree in electrical engineering from the University of Colorado in 1922. But this was only the start of his formal education. In 1927 he earned his EE degree from his alma mater. In 1930 he earned a law degree from Westminster Law School. In 1938 he earned his master's degree in electrical engineering from the University of Colorado. And more recently, in 1955; he gained a doctor of engineering degree from the same school.

Robertson started with the Public Service Company in the meter testing group, and since then has had a variety of positions in nearly every phase of electric utility engineering and construction. He became Chief Electrical Engineer in 1953, and attained his present position in 1959.

Robertson has been active in research work, particularly in studying transmission line phenomena at high altitudes. He has also been active in professional societies, civic affairs, teaching, and writing.

Regular readers will recall Dillard's recent appearances on these pages; in November 1958 he wrote of large turbine generator units; in September 1960, about utility system simulation. Dillard became manager of Electric Utility Engineering, his present position, in 1956.

E. J. LAUGHLIN has devoted a major portion of his time to power supplies and motors in his career with Westinghouse. He joined the company in 1929 immediately after his graduation in electrical engineering from Dunwoody Institute, Minneapolis, Minnesota. Laughlin rounded out his formal education in the Westinghouse student training course and then entered the Industrial Sales Department. From there he went to the Motor and Control Division, where his responsibilities included application engineering. He became manager of the generator section in 1946.

Laughlin moved to the General Purpose Control Department in 1951 as sales manager of the metallic rectifier apparatus section. He is responsible for battery chargers, selenium stacks, and the packaged power supplies that he describes in this issue.

DR. E. C. WATTERS and P. R. DAX join forces to describe recent developments in radar techniques.

Watters is a graduate of Notre Dame, with a BSEE in 1943, and an MS in Mathematics in 1946. He obtained his PhD in Mathematics from the University of Maryland in 1954, while working as an assistant professor of mathematics at the U. S. Naval Academy.

Watters joined the Electronics Division in 1957 as a Fellow Engineer in radar engineering. A year later he was promoted to supervisor in charge of the radar analysis group. In 1959, he was made an Advisory Engineer.

P. R. Dax graduated from London University in 1949 with an honors degree in Engineering. This culminated a period of undergraduate studies started in Paris, France in 1938 and interrupted by 6 years of active service in the Royal Navy.

Dax joined the Electronics Division in 1957 as a Fellow Engineer in the radar sub-division and worked for a time on the FPS-27 project. In 1960, he was promoted to his present position of Advisory Engineer in charge of the system development and analytical section in the radar sub-division.

A "native Hoosier" from Indianapolis, Indiana, G. J. EASLEY graduated from Purdue University in 1937. He came immediately on the Westinghouse Graduate Student Course, and soon started to work designing oil circuit breakers.

In 1956, Easley was made manager of the indoor and small outdoor oil circuit breaker engineering section. Three years later, he became manager of the compressed air and small SF_6 breaker development section.

J. M. EDWARDS graduated from Johns Hopkins University in 1939 with a degree in Electrical Engineering. From 1939 until 1942 he was a test group leader at the Westinghouse Radio Division. In 1942, he joined the U. S. Army Signal Corps, and served four years, leaving with the rank of Captain. He returned to Westinghouse at the Electronics Division, and was made an Engineering Section Manager in 1952. When the Industrial Electronics Department was formed in 1955, Edwards was appointed commercial engineering manager. In 1960, he was made engineering manager of Induction Heating and Static Conversion Equipment, his present position.

The team of J. J. CONOMOS, H. L. LINDSTROM, and E. C. MERICAS brings together an imposing array of knowledge in the field of power drive systems and their uses.

Conomos received his BS degree in electrical engineering from the University of Buffalo in 1951 and then joined the Westinghouse graduate student course. He is now a design engineer for dc motors and specialty drives in the Motor and Gearing Department. His primary interests are dc machine design, control circuitry for rotating electrical apparatus, and the application of mathematics to electrical engineering.

Lindstrom graduated from Purdue University in 1928 with a BSEE degree and he received the professional electrical engineering degree there in 1935. He joined Westinghouse on the graduate student course in 1928 and then worked on railway and industrial engineering projects in the General Engineering Department. Lindstrom left the fold in 1931 but returned to Westinghouse in 1941 as a consulting and application engineer. He went to the Buffalo Division in 1950 and is now manager of the application and project section in the Systems Control Department.

Mericas graduated from the U. S. Merchant Marine Academy in 1944 with a BS degree. He served as a commissioned officer in the Navy in World War II and then as a merchant marine officer from 1947 to 1951. He worked as a marine engineer with Creole Petroleum Corporation in Venezuela before joining Westinghouse in 1957 in the Marine, Transportation, and Aviation Facilities Engineering Department.

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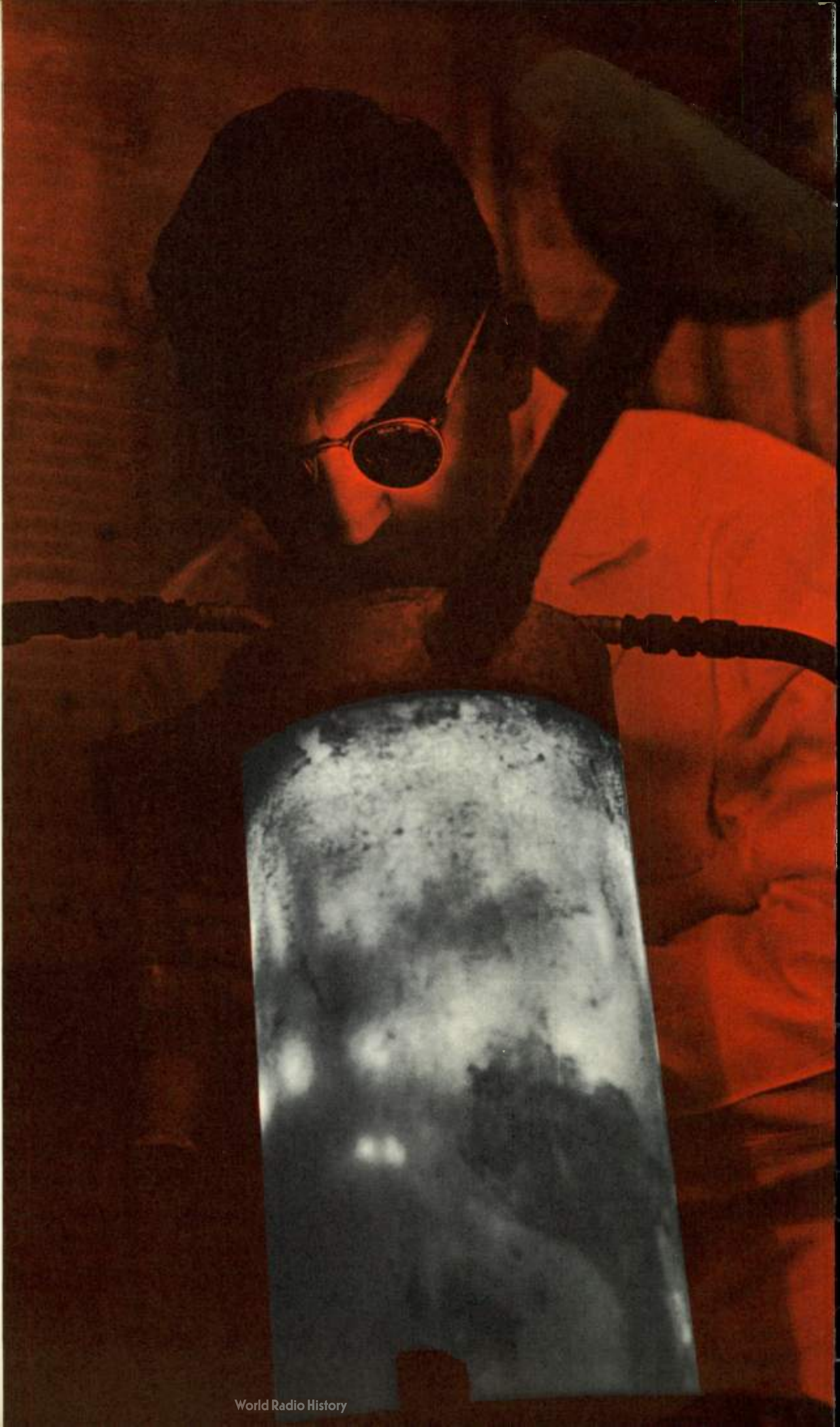

NEW THERMOELECTRIC MATERIALS PREPARED AT WHITE HEAT

This specially designed vacuum induction furnace, glowing white hot in the Westinghouse materials laboratories, is used to prepare a new thermoelectric material known as samarium sulfide. The new material is one of a family of ceramic-type, rare earth compounds that can convert heat directly into electricity at temperatures above the melting point of copper.

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