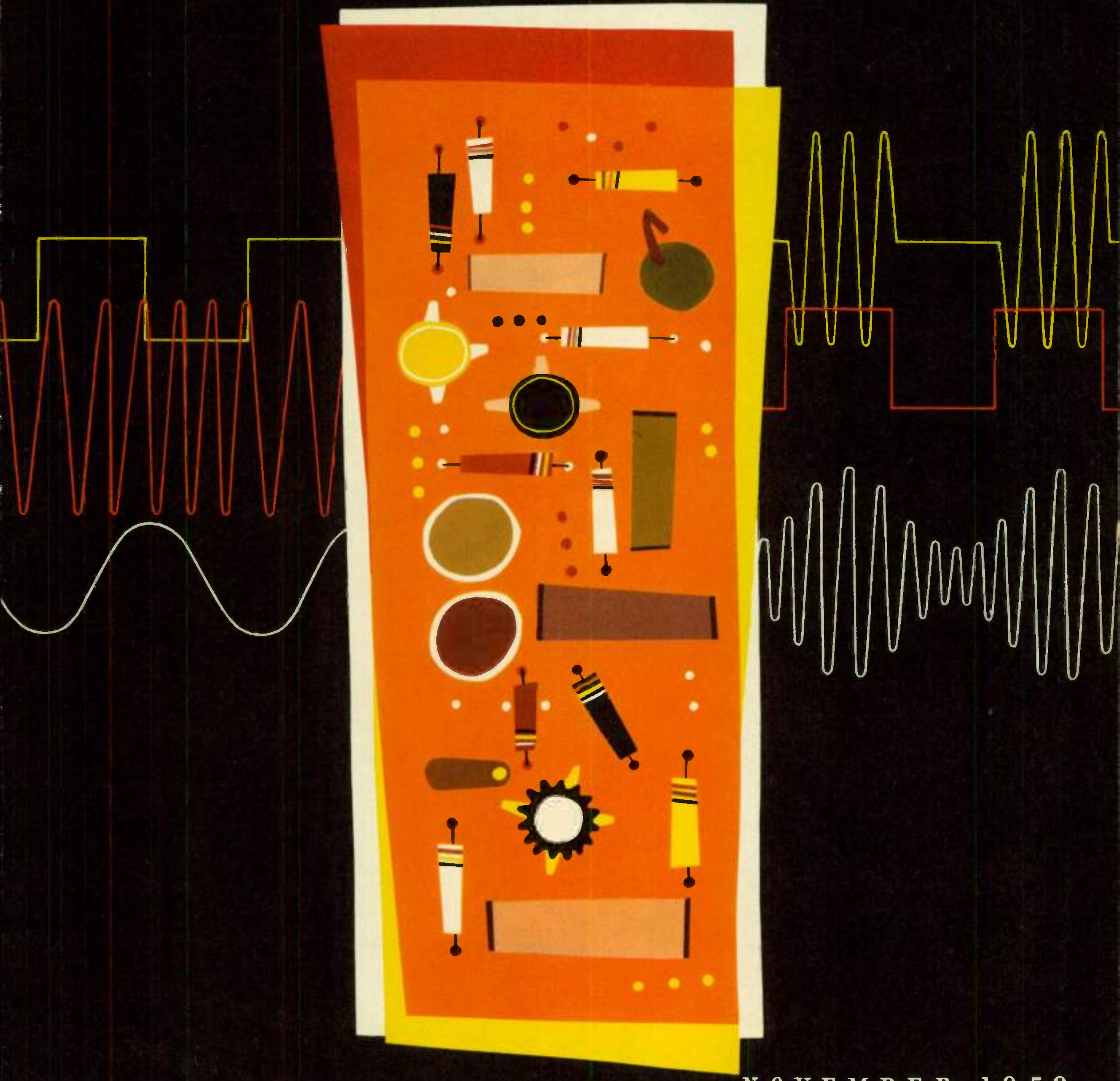
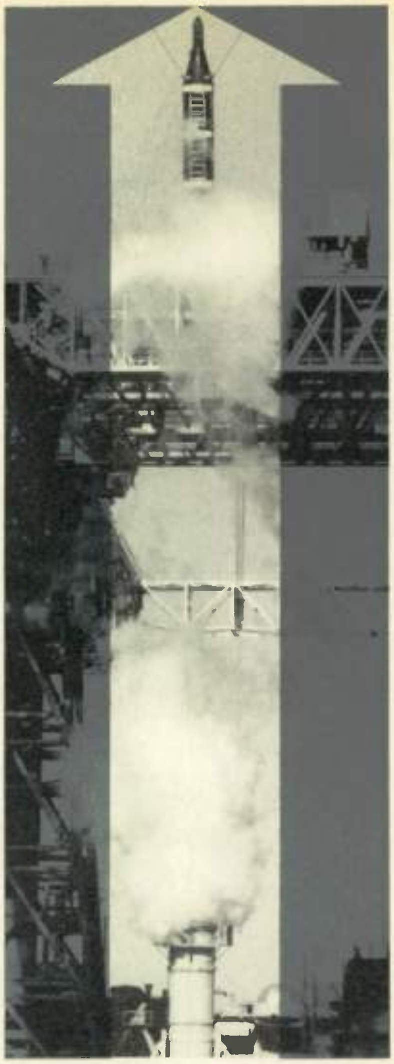
WESTINGHOUSE

Engineer



NOVEMBER 1959

Powerful blast sends the dummy *Polaris* missile skyward.



At top of its trajectory, missile is snubbed by modified carrier arresting gear.

Dummy *Polaris* is lowered gently toward the ground, for examination, removal of instrumentation, and preparation for next test.

"OPERATION SKYCATCH" is the newest phase of development of the launching system for the Navy *Polaris* fleet ballistic missile. In these sequence photographs taken of the launching of a dummy missile at San Francisco Naval Shipyard, a huge overhead assembly catches the multi-ton dummy in mid-air. In earlier testing there, the dummies were hurled out into San Francisco Bay and then retrieved. This new method simplifies the retrieval procedure and also permits accurate study of the effects of launch stresses on dummy missiles, which are structurally identical to live *Polaris* missiles. These tests are being conducted by engineers from Westinghouse Electric Corporation and Lockheed Missiles and Space Division, in conjunction with the U. S. Navy. Westinghouse is prime contractor for launching equipment, and Lockheed is *Polaris* missile system prime contractor and manager.

COVER DESIGN: Tone telegraph employs three basic techniques for signal transmission—continuous-wave on-off, frequency shift, and amplitude modulation. Cover artist Dick Marsh symbolizes the new transistorized tone equipment (p. 174) performing these functions.

RICHARD W. DODGE, *editor*
MATT MATTHEWS, *managing editor*
DANIEL E. UDELL, *assistant editor*
EDWARD X. REDINGS, *design and production*
J. A. HUTCHESON, J. H. JEWELL, DALE MCFEATTERS, *editorial advisors*

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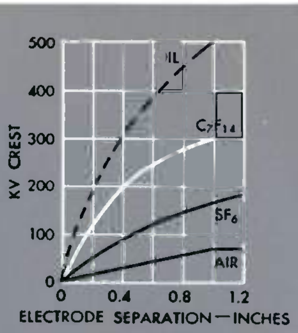


Fig. 1—Comparison of dielectric strengths of air, SF_6, oil, and vapor.

Vapor-Cooled Transformers . . . their development and present status

Vapor cooling of transformers has become a practical reality, as evidenced by the installation of a 500-kva network unit and a 7500-kva substation unit. The inherent safety of such units, however, suggests even more widespread use of the vapor-cooling principle.

PAUL NARBUT **G. A. MONITO**
Power Transformer Engineering
Westinghouse Electric Corporation
Sharon, Pennsylvania

Cooling by evaporation is a remarkably effective method, and as a result, its possibilities have long intrigued transformer engineers. However, despite the considerable amount of experimental work devoted to development of vapor-cooling, a suitable liquid was not found until the advent of the new fluorocarbons shortly after World War II. With liquids that satisfy the requirements for vapor-cooled transformers, work has progressed rapidly through the experimental stages to the point where commercial units have been installed.

The fluorocarbons themselves have amazing properties, and the potentialities for vapor-cooled and vapor-insulated transformers range far beyond the present transformers.

EARLY DEVELOPMENT SETS THE STAGE

While liquids are by far the most common dielectric and cooling media for transformers, gases of various types—including air—have also been used for many years in certain types of units. In fact, the first transformers built in the late 1800's were gas-filled. The gas was air; it was used to cool and to insulate these units.

Because of limited manufacturing techniques and the lack of suitable insulating materials, these original gas-filled transformers could not be expected to meet the power industry's requirements for higher voltages and larger kva ratings. With the advent of transformer oil, gas-filled transformers became very limited in commercial application and liquid-immersed transformers dominated the power equipment field. However, engineers never abandoned attempts to develop better gas-filled units.

As early as 1906, a Westinghouse engineer, Charles B. Gibson, experimented with carbon tetrachloride, acetone, and ether vapors in transformers. Among the papers in the Westinghouse archives is a "Digest of Reports on Self-Cooling Systems Using Volatile Liquids," dated May 8, 1907. Cooling systems investigating "transformer coils immersed directly in liquid and the vapor collected and carried through a condenser and back again" are described. One such temperature run indicates that small coils were operated at 680 watts per pound and 13 watts per square inch, which is many times the values used in liquid-immersed transformers even today. Unfortunately, the then insurmountable problems of sealing the tanks, the inflammability of the liquids and vapors, and the chemical attack on the insulation of that time held this development back.

At the same time, other investigators worked with air, bringing about the return of the commercial gas-filled power transformer in 1935. In that year Westinghouse an-

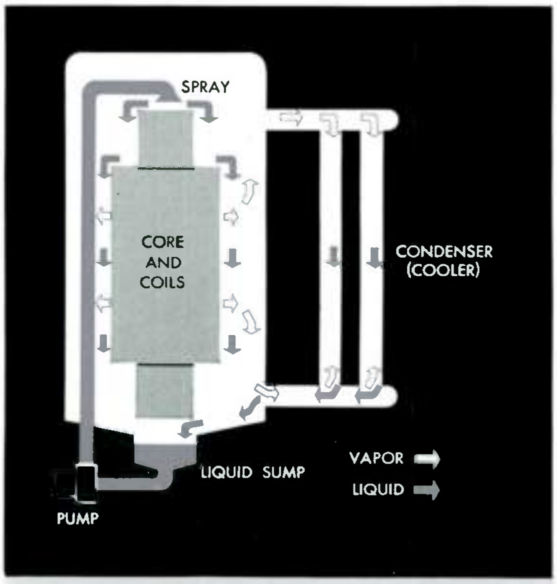


Fig. 2—How Vapor Cooling Works (In the absence of a noncondensable gas).

Although vapor cooling involves many unusual factors in a practical application, the principle itself is basically a simple one. A liquid fluorocarbon compound (indicated by solid color) is applied over the top of the core and coils of the transformer. The liquid flows down over all the surfaces. Sufficient liquid is flowed over the core and coils so that only a portion of it evaporates even under overload conditions.

The heat generated in the core and coils causes the evaporation of part of the liquid, and the vaporization process removes heat from the core and coils. The vapor (indicated by the outline arrows) then moves toward the cooler surfaces of the condenser and tank walls, where it condenses and gives up its latent heat. The liquid then flows to bottom of tank where it is collected in a sump, then recirculated by the pump.

nounced the development of the ventilated dry-type power transformer. The gas was still air, but with improved manufacturing processes and better insulation this unit was adaptable to voltage classes through 15 kv. However, its use was restricted to indoor applications where the condition of the gas, or air, could be controlled to some extent.

To overcome this restriction, development work on gaseous insulation continued and in 1941, a major step toward the present day gas-filled transformer was taken when the sealed dry-type power transformer was developed.

Without question, the sealed dry-type transformer provides a higher degree of operational safety than any power transformer ever built. It has the advantage of being non-explosive; it is virtually fireproof; it requires practically no maintenance. In addition, the dry nitrogen, which is used as the gaseous dielectric and coolant, can be lost without harm to the unit or to operating personnel. The only major drawbacks to widespread use of the nitrogen filled, sealed dry-type transformer are the limits imposed on voltage and kva by the gas. Nitrogen, at pressures up to one atmosphere, is not a sufficiently good dielectric or coolant to justify larger kva and higher voltage ratings because physical size and the cost of such units becomes prohibitive. Therefore, transformer manufacturers are attempting to extend the application of sealed dry-type transformers through the use of a better gas, which will provide the necessary dielectric strength and more efficient cooling while still retaining all the advantages of sealed dry-type transformers.

FLUOROCARBONS OPEN NEW VISTAS

The new family of fluorocarbons, developed during World War II, offer nearly everything an engineer needs to extend the advantages and safety of sealed dry-type transformers to higher ratings. They are being investigated as dielectrics, as coolants, and as combined coolants and dielectrics, because of the remarkable properties they exhibit. They are probably the most inert and nonreactive compounds known. They are poor solvents for most materials, and they do not affect common insulating materials, or metals. Some insulating materials actually have a considerably lower aging rate in fluorocarbons than in air. They are nonflammable, and, in fact, have fire-extinguishing properties. The liquid used today is odorless and colorless, and resembles water. It can be handled as easily as pure water, and in fact, is less reactive. It is nontoxic. Other properties are shown in Table I.

electrical characteristics

Electrical properties of the fluorocarbons are equally unusual. Of specific importance, of course, is their dielectric strength. As a liquid, the fluorocarbon used has a dielectric strength of about 35 kv by standard tests, i.e., about the same as a clean, dry, transformer. More important to this application, however, is its strength in vapor form. The curves in Fig. 1 give a comparison of air, sulfur hexafluoride, transformer oil, and the vapors of a representative fluorocarbon. Note that for the same pressure and electrode configuration, the fluorovapors have nearly twice the dielectric strength of sulfur hexafluoride, and five times the strength of air. As pressure increases, the dielectric strength of the fluorocarbon increases, so that at 15 psig, its dielectric strength is comparable to that of transformer oil.

used as a coolant

Fluorocarbon liquids have certain physical properties that are especially valuable for vaporization cooling. They have extremely low viscosity and surface tension, which account for their ability to spread and readily wet coil surfaces and flow easily through minute crevices in the core. The high molecular weight of the liquid results in vapors of high density, an important aspect in vapor cooling.

TABLE I—PROPERTIES OF FC-75 FLUOROCARBON

Molecular weight	416
Boiling point (approx.)	101 degrees C
Freezing point	−113 degrees C
Density (liquid)	1.76 gm cm^3, at 25 degrees C
Density of vapor (101 degrees C)	0.87 lbs/cu. ft
Viscosity (liquid)	0.85 centistokes, at 25 degrees C
Surface tension	15.2 dynes/cm, at 25 degrees C
Coefficient of volume expansion	2.0 x 10^{-3} per degrees C at 40-80 degrees C
Heat of vaporization	21 cal/gm
Specific heat (liquid)	0.245 cal/gm at 25 degrees C
Dielectric strength	37 kv, (ASTM-D-877)
Dielectric constant	1.85
Power factor	0.0005
Volume resistivity	1014-1016 ohm-cm
Color	Clear
Odor	None

Using vaporizable fluorocarbon liquids, a relatively low rate of circulation is required to remove the heat generated in a transformer. The fluorocarbon liquids used in transformers are capable of removing about 10 kilowatts of heat for every gallon per minute of evaporation.

The outstanding feature of vaporization cooling is its remarkable effectiveness. Generally, temperature gradients required at the surface for cooling by vaporization and condensation are small, compared to other modes of heat transfer. Thus, to transfer heat at the rate of one watt per square inch by natural convection and radiation from an open tank surface, the temperature rise of that surface over the ambient air must be around 90 degrees C. For the same rate of heat transfer in oil by natural convection, the required temperature difference is about 15 degrees C. Compared to the above, in heat transfer by condensation of pure fluorocarbon vapor the required temperature difference, vapor-to-surface, is only about 3 degrees C; and by boiling of fluorocarbon liquid on the surfaces, the required difference is only ⅓ degree C. Thus, one result of the use of vaporization cooling is inherently low internal temperature gradients without the use of forced circulation of gas or vapor.

Still another interesting fact is that the maximum rate of heat transfer by boiling of a fluorocarbon coolant, before vapor locking will occur, may be in excess of 50 watts per square inch. Admittedly, this value is many times higher than could be permitted in a normal design of a vapor-cooled transformer. This indicates, however, that considerable nonuniformity in the wetting of the winding surfaces can be tolerated without ill effects.

cooling and insulation without a noncondensing gas

Because of these unusual properties as coolants and as dielectrics, the use of the same fluorocarbon liquid as a vaporization coolant and as a combined dielectric was suggested. This dual function would utilize the properties of the fluorocarbon to the best advantage and result in a fire and explosion-proof transformer, thus permitting the extension of the safety features of sealed dry-type transformers to units of higher voltages and indefinitely larger kva rating.

The essential physical components required for vaporization cooling of transformers are shown in Fig. 2. With pure fluorocarbon vapor in the gas space of a transformer, the gage pressure in the gas space would be equal to the vapor pressure of the coolant liquid. The temperature of the liquid would be substantially the same as that of the vapor and the liquid would be at its boiling point corresponding to the tank pressure. Any addition of heat to the liquid will be likely to cause its boiling and any removal of heat from the vapor will cause condensation.

Because of the high efficiency of heat transfer by condensation of pure vapor, all parts of the system in contact with the vapor tend to run at the same temperature; i.e., that of the vapor. The surface of the tank and the self-cooled coolers operate at approximately uniform temperature from top to bottom, and thus at the peak of their cooling performance.

With pure vapor in the gas space, there will be none of the familiar convection currents; the vapor will merely flow freely toward any part of the system from which heat is being removed (by external cooling), and will supply that heat by condensing back into a liquid. This method of heat transfer is especially suitable for remote installation of coolers, since only small pipe connections are required between tank and coolers.

Vapors of fluorocarbon coolants are an excellent insulating medium. However, to maintain their dielectric strength at the proper level, it is necessary to maintain their pressure, and therefore their temperature, at the proper level. Although this does not take place in a normal transformer because of the load and ambient temperature variation, some of the unique characteristics of condensing vapors permit the design of a cooling system with variable cooling characteristics. With proper design, such a system would automatically maintain transformer temperature within design limits in spite of the variable heat input, provided a certain minimum heat input is maintained, e.g., the iron losses alone.

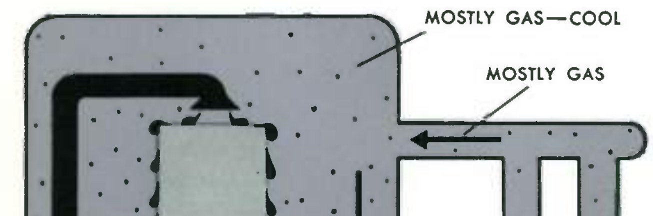


Fig. 3—Schematic diagram of vapor-cooled transformer, showing distribution of gas and vapor under operating conditions.

cooling and insulation with a noncondensable gas

While the use of fluorocarbon vapors alone as insulation has attractive possibilities, practical considerations have been a deterrent to such applications. In a commercial installation, such a transformer would have to be heated before it could be energized, to supply sufficient vapor for insulation purposes.

To overcome this difficulty, vapor-cooled units built thus far have been filled with sulfur hexafluoride gas at low pressure. When the transformer is cold, sulfur hexafluoride is the principal insulating medium, because the vapor pressure of the cooling liquid is low. As the temperature of the transformer increases, the vapor pressure of the cooling liquid increases, and at operating pressure, the major insulating medium becomes the fluorocarbon vapor.

The use of SF_6 is a compromise. While it resolves the problem of the cold start, this noncondensable gas reduces the efficiency of heat transfer, particularly by the condensation process. The result is that larger internal temperature differences appear, and larger cooling surfaces are required than would be necessary in the absence of SF_6.

With a noncondensing gas added to the vapor, the mechanics of the vapor flow and the cooling characteristics are quite different (Fig. 3). As the coolant percolates through the windings, it forms hot and heavy vapors. These vapors mix to some extent with the SF_6 gas and generally flow downward because of the high density of this vapor rich mixture. The density of the mixture increases with temperature because of the high molecular weight of the fluorocarbon (416) compared to the SF_6 (146). Along the cooled surfaces, such as those of the cooler, condensation of the vapor takes place, and the mixture thus becomes richer in the SF_6 component, becomes much lighter, and floats upward. Thus a definite circulation pattern of the gas-vapor mixture is established; the mixture flows down near the windings in the tank, and up in the coolers. Because of

Fig. 4—The exterior of 7500-kva unit.

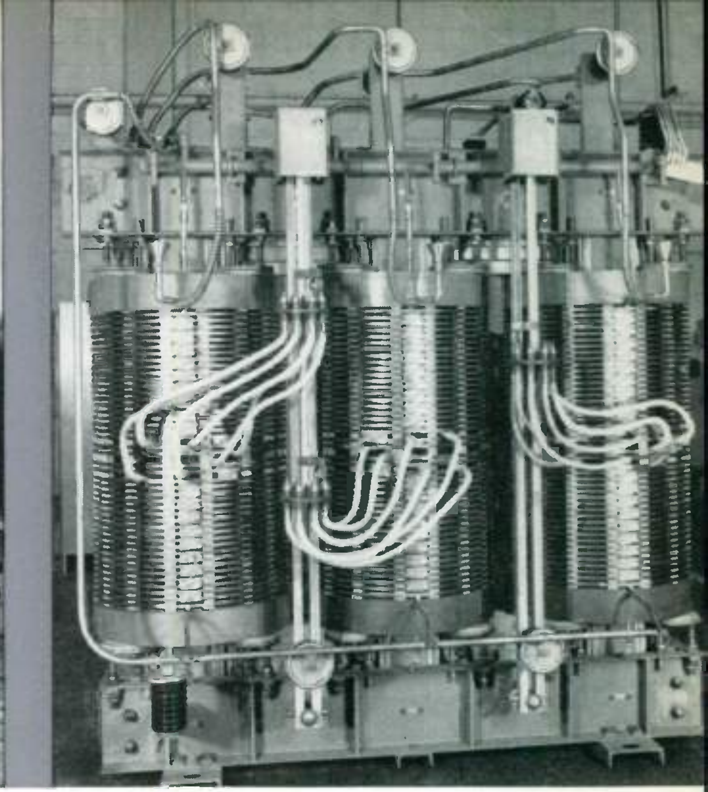


Fig. 5—The core and coils of 7500-kva unit.

the difference in densities, the circulating currents are vigorous; in fact, these natural circulating currents are sufficient to allow the use of standard self-cooled coolers for oil-immersed transformers with the 7500 kva unit. Without the vapor; i.e., with the SF_6 alone, normal convection through the coolers would be extremely poor, and the coolers would be practically useless.

The pattern of gas-vapor circulation is such that a peculiar situation exists with a vapor-cooled transformer—the lower parts of the tank and the lower parts of the cooler are the hottest, and the upper parts are the coolest.

VAPOR-COOLED TRANSFORMERS—FIELD EXPERIENCE

Aside from several experimental vapor-cooled transformers, two commercial units are in operation and others are under construction.

the 500 kva network transformer

The first of the two commercial units is a 500-kva, 15-kv, network transformer, first installed in the summer of 1957. The unit is compact in size, and has a high emergency overload capacity. Its performance was carefully checked during the first several months after installation, and the load, pressure, and temperature were monitored and found to agree with the performance curves furnished to the customer. A spot check after a total of 11 months of operation indicated a deviation from the performance curves, and a superficial inspection indicated that the pump was not operating. However, there was no interruption of service, and the unit continued to carry load satisfactorily. Since a factory inspection of this transformer was originally planned after about a year of operation, the unit was removed from service at a convenient time. Inspection indicated inadequacy of the pump bearings, which were replaced by a different type. The transformer itself, in spite of operating for some time under normal load without a pump, was found in excellent condition. It is now in service again.

the 7500-kva substation transformer

The second vapor-cooled transformer in service is a 7500-kva, 34.5-kv, residential substation transformer. In spite of the relatively low pressure of insulating gas used, this unit has a full 200-kv insulation level, normally associated only with oil-immersed transformers. With external fans, the capability of this transformer is 10 000 kva and maximum operating pressure is well under 15 psig. The unit was placed in operation in July 1958. After eight months of operation, pump bearings were inspected and found to be in excellent condition, indicating that pump servicing—the only item which may require periodic attention—needs to be done only at long intervals, possibly once in several years. Bearings used in these pumps are lubricated by the cooling liquid itself.

An exterior view of the 7500-kva transformer is shown in Fig. 4, and the core and coils are shown in Fig. 5. In this design, gas clearances, rather than solid insulation, are used wherever possible to provide the required insulation level. Where solid insulation is required for mechanical support, class B insulating materials are used throughout.

An inherent difference exists between gas and oil insulation. If the gas insulation is designed to be adequate to meet the full impulse requirement of an oil-immersed transformer, the 60-cycle withstand insulation level will be considerably greater than that required of the oil-immersed transformer. Therefore, a practical and economical approach would be to design to meet the required 60-cycle level, and permit a reduction in impulse strength consistent with the protection level afforded by the associated protective equipment. Thus, for example, on a 69-kv circuit protected by modern 60-kv arresters, a 250-kv full wave insulation level is entirely reasonable.

operating characteristics

The operating characteristics of a vapor-cooled transformer, considered below, are variation with load of the following: gas pressure, gas-vapor temperature, coolant temperature, and the temperature of the windings.

A series of heat runs with the 7500-kva transformer at different load levels provided the information contained in Table II and Fig. 6. Note the peculiarity of the temperature distributions, i.e., the hot bottom and cool top of the tank and coolers. This distribution suggests efficient forced cooling with bottom-mounted fans. The temperature distribution is also shown in Fig. 7. These and other tests indicate that the cooling performance of the vapor-cooled system improves with load more than would be expected with an oil-immersed cooling system.

An important parameter that may determine the load capability of a vapor-cooled transformer is the operating pressure in the transformer tank. The pressure situation is complicated by the fact that the mixture is composed of a noncondensable gas and a vapor component, whose pressure varies considerably with temperature; also, a continuous condensation process in the coolers and along the tank walls causes at least a partial segregation of the SF_6 in the upper part of the tank. Due to these complications, the total pressure in the transformer tank is largely an empirical function of the vapor-gas temperature for the specific cooling structure. The 7500-kva unit is designed for low-pressure operation. Thus, operating tests with this unit indicates that the tank pressure, even at 133 percent overload with fans operating and at 30 degrees C ambient temperature, will be less than 13 psig.

APPLICATIONS OF VAPOR-COOLED TRANSFORMERS

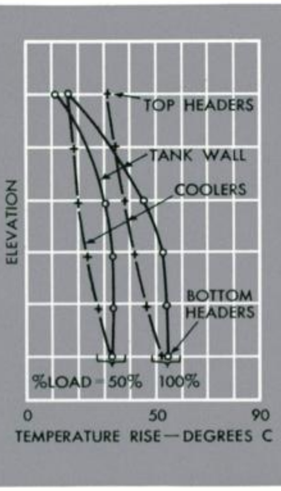
The outstanding characteristic of vapor-cooled transformers is their inherent safety, which is the key to their application. The absence of oil, and a minimum amount of organic insulating materials make them compare favorably with the sealed, dry-type transformer. With the prospect of eventual availability in all kv and kva ratings, they open a new dimension in transformer application in the area currently closed to the dry-type transformers because of their limitations. Where safety rules prohibit oil-immersed transformers, or where additional expense is involved in special construction for safety reasons, the vapor-cooled transformer has a natural area of application.

Particularly intriguing is the possibility of vapor-cooled and insulated transformers without the presence of noncondensable gas. Even at low pressures, such a transformer could be considerably smaller and lighter than the vapor-gas type. At the present stage of development, such a transformer would be limited to applications in which preheating of the transformer would be acceptable. One example of this is a central-station generator transformer. The safety of vapor cooling would permit the location of this type of unit in the immediate vicinity of the generator. Preheating of the transformer could take place simultaneously with the starting of the turbine and generator.

Thus, while the vaporization cooling of transformers has already proved practical, as evidenced by the commercial units built to date, the full potential of vapor cooling has yet to be reached. The inherent advantages of this type of unit may lead to much more widespread use of vapor cooling in the future. ■

TABLE II—TEMPERATURE RISE ON CONTINUOUS LOAD HEAT RUNS—DEGREES C

Cooling	Percent Load	Coolers		Tank		Vapor-Gas	Liquid
		Top	Bottom	Top	Bottom		
Self	50	15.5	32.8	11.2	33.8	42.8	41.8
Self	75	24.0	40.8	12.1	41.7	52.2	50.2
Self	100	31.3	53.5	15.9	53.7	63.7	61.5
Fans	100	11.8	27.9	7.5	38.4	53.3	50.5
Fans	133	18.2	41.2	10.1	51.6	66.7	61.5



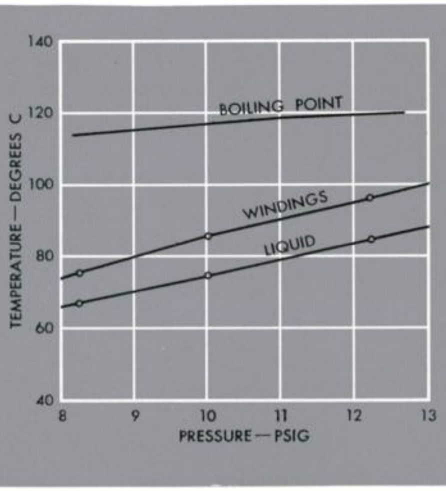


Fig. 6 (left)—Curves of temperature distribution in transformer.

Fig. 7 (right)—Pressure versus temperature—boiling point, windings, and liquid.

THE SILICON RECTIFIER . . . Principal source of d-c power for the 60's

In the three-year period since its introduction to ac-to-dc power conversion service, the silicon rectifier has assumed a dominating position as the d-c power supply for industry.

A. P. COLAIACO, Manager
Semiconductor Section

C. S. HAGUE, Manager
Power Conversion Engineering

Rectifier & Traction Equipment Dept.
Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania

Although practically all power in this country is generated as alternating current, a large percentage—estimates run as high as 20 percent—is used in the form of direct current for such tasks as aluminum production, electrolysis of salt to produce sodium and chlorine, metal refining, electroplating, and to power d-c motors. From 1940 to the present, over 8 million kilowatts of mercury-arc rectifier capacity has been built in the United States to satisfy this demand. Best estimates are that an additional 10 million kw of ac-to-dc conversion capacity will be built by 1970. However, the vast bulk of this new capacity will employ silicon rectifiers, not mercury.

silicon dominates the conversion field

The rapid advance in the use of silicon rectifiers in electrochemical service in the last three years is illustrated in Fig. 1. About 2½ years ago, silicon rectifiers were proposed for the first time on an installation of major size. Silicon was not accepted because of lack of experience. At that time the ignitron was dominant at voltages above 400 volts d-c, while the germanium semiconductor and the mechanical rectifier were used below 400 volts. A few plating applications at the low end of the scale were supplied by selenium or copper-oxide rectifiers. Today, the picture has changed. Silicon rectifiers are the principal source of d-c power over the entire voltage spectrum. Ignitrons are no longer considered below 750 volts. Germanium is considered only for applications below 35 volts. The mechanical rectifier is obsolescent. Selenium and copper-oxide rectifiers are still used to a limited extent at low voltages.

Silicon rectifiers are becoming the dominant constant-voltage d-c supply for mills and shops. Furthermore, engineers expect silicon rectifiers to supersede ignitrons in 600-volt transportation service; this has not yet happened in this country because there has been almost no activity in this field since silicon became commercially available.

However, there are two fields of application where the ignitron has not been replaced: as a power source for large variable-voltage mill drives, and as a pulsed-power supply for particle accelerators. The grid control on the mercury-arc device is essential for these applications and will remain so until large power transistors have proven their reliability for essential service in continuous application.

advantages over other rectifying devices

Why is silicon so completely dominating the field in such a short period of time? Silicon has made the mechanical rectifier obsolescent because the silicon rectifier has the advantage of being a static device, but with an efficiency equaling the mechanical device. Silicon has superseded germanium because it will withstand inverse voltages three times as high, and temperatures twice as high.

Silicon has replaced the ignitron for five reasons:

Efficiency—Silicon rectifiers have a decided efficiency advantage over the ignitron at low d-c voltages and are somewhat superior at voltages as high as 850 (Fig. 2). This efficiency becomes a potent economic factor. For example, consider an installation rated 300 volts, 100 000 amperes with a power rate of 7.5 mills. The annual savings in power costs for silicon over the ignitron is $80 000. At 850 volts,

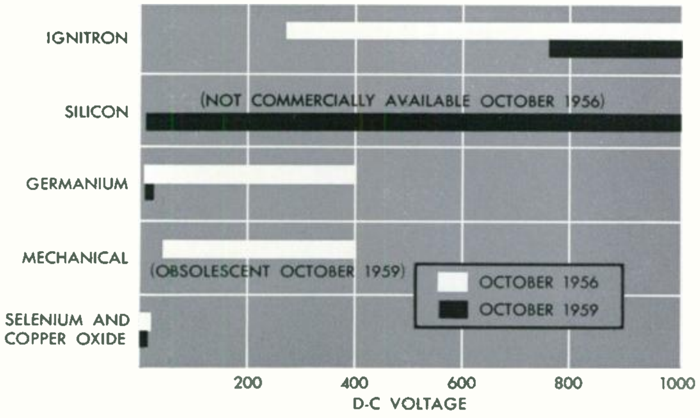


Fig. 1—Practical voltage spectrum of various rectifying devices for electrolytic applications.

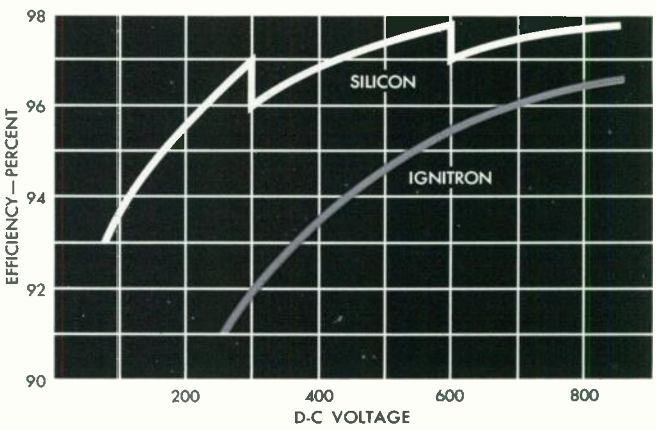
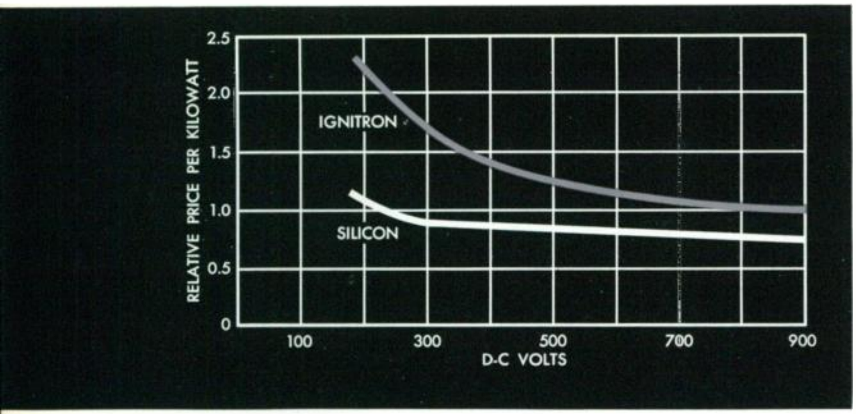


Fig. 2—Comparative typical overall efficiencies for 10 000-ampere rectifier units.



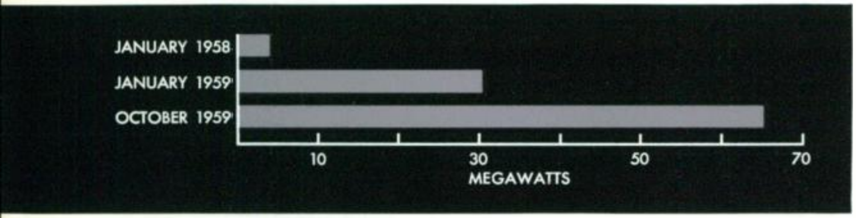


Fig. 3 (top)—First cost comparison for complete conversion equipment with ignitrons versus silicon rectifiers for large electrochemical applications. **Fig. 4 (bottom)**—Installed capacity of silicon rectifiers.

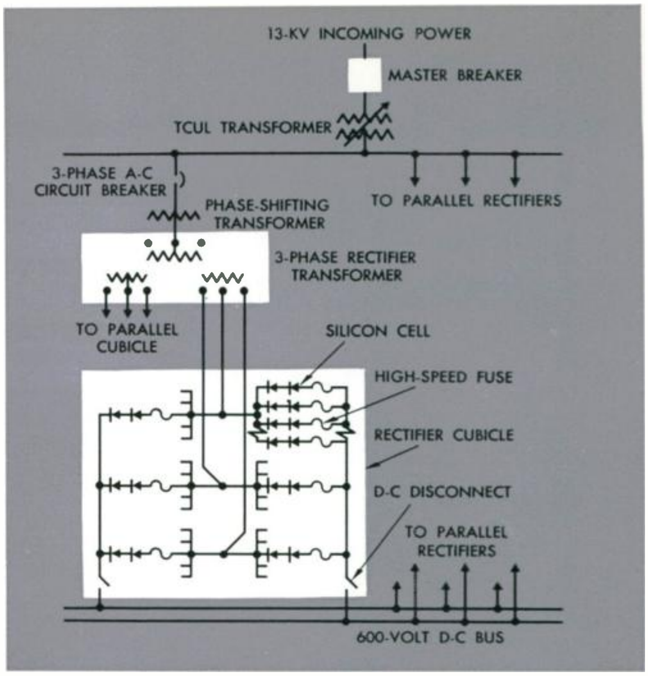


Fig. 5—Typical schematic diagram of d-c power supply with silicon rectifiers in electrochemical service.

90 000 amperes, and a power rate of only 5 mills, the saving amounts to almost $35 000 annually.

Space—The silicon unit requires much less space than a comparable ignitron unit. Although the ratio varies from installation to installation, it appears that for electrochemical application, the plan view square footage per kilowatt for silicon will be about 50 percent of that required for ignitrons.

Simplicity is another significant advantage of silicon. Water cooling is not necessary. Complex excitation circuits are not required, and vacuum problems do not exist. The silicon unit approaches the ultimate from the standpoint of maintenance attention.

First Cost—Perhaps the most important reason for the rapid gains of silicon is its relative cost. A comparison of the ignitron with silicon for large electrochemical installations is shown in Fig. 3. Note that the curve for silicon is much below the mercury-arc curve in the 200–400 volt range, and is somewhat below it even at 850 volts. In 250-volt industrial and 275-volt mining service, the complete silicon unit is also lower in first cost than the ignitron, but not by as great a margin as the curve indicates for electrochemical units at these same voltages.

Reliability—Two years of industry-wide operating experience with silicon rectifiers (Fig. 4) has shown them to have a device failure rate of less than one percent per year, and an unmatched record of continuity of power output; failure of an individual device does not disturb output power to the bus.

typical conversion unit

Although the silicon rectifying cell is the heart of the conversion apparatus, other components are essential for a functionally complete unit. Typical components for an electrochemical installation are illustrated in Fig. 5. The most important difference between the silicon rectifier and an ignitron installation is the use of double-way rectifier connection (bridge circuit) rather than the single-way circuit used with ignitrons. The bridge circuit uses the rectifier transformer more efficiently, since the secondaries conduct during both positive and negative portions of the sinusoidal a-c voltage wave. This makes possible a saving in transformer kva parts of approximately 25 percent.

Of equal importance, loss of blocking action by the silicon rectifying device constitutes a fault only on the transformer secondary—not on the d-c bus. Hence, the complement of d-c switchgear can be greatly reduced. Economical high-speed fuses replace expensive anode and cathode circuit breakers, which are required for ignitron installations. When loss of blocking action occurs in any parallel path of the bridge circuit, reverse current flows from *all* of the parallel paths in another leg of the bridge. In terms of current magnitude, a ratio of perhaps 10- or 20-to-1 exists between the parallel path that has lost blocking action and the paths that are feeding it. With this ratio, selective fuse coordination is easily obtained.

silicon cell

Silicon cell performance is to a great degree dependent upon its physical construction.

To protect the cell from environmental conditions, it is encapsulated in a hermetically sealed container. A cross-section of a basic silicon cell and its encapsulation into a practical working device is shown in Fig. 6.

The base of the cell is hard soldered to a copper mounting stud. Hard soldering is used because soft solders fatigue with thermal cycling and would eventually cause cell failure. The copper stud also serves as one electrical connection and provides a means for joining the cell to a heat sink to dissipate cell losses.

The other electrical connection is made with a flexible lead within the container. This internal flexible lead further ensures that thermal and mechanical stresses will not be transmitted to the cell. An external flexible lead completes the assembly and provides a convenient electrical connection. The assembly is evacuated to remove moisture, backfilled with a dry gas, and sealed off. A typical silicon cell is shown in Fig. 6, mounted on a heat sink. The cell shown is a Westinghouse type 339K, rated at 500 peak inverse volts.

Voltage Rating—Westinghouse silicon cells are classified by the maximum transient or recurrent peak inverse voltage (PIV) that may be applied to the cell, regardless of duration. This is the voltage at which cells are tested before they leave the factory. For example, the 339K cell is tested at a minimum of 500 PIV. However, this is not the voltage at which the cells should be applied. System voltage transients, caused by breaker opening and closing, lightning, or fuse operation must be considered in applying the cells in any given circuit.

The *operating* PIV of a cell is the recurrent reverse voltage that is applied to the cell by the circuit in which it is used, under steady-state conditions. NEMA standards call for a minimum ratio of 2.5 between the *rated* PIV and the *operating* PIV to provide sufficient margin for transient voltage conditions, when surge suppressors are used.

Thus, a 500 PIV cell should not be used at an operating voltage exceeding 200 PIV. Such a cell, employed in a 3-phase bridge circuit with 2 cells in series and 8-percent regulation, will provide a maximum output of 350 volts dc.

Current Rating—Though silicon cells can operate with junction temperatures as high as 190 degrees C, they are approaching failure at this point. For industrial applications, it is advisable to keep the junction temperature below 150 degrees C.

Where silicon cells are used in noncritical applications, or where only short operating life is required, they may be operated near their maximum current capability. The industrial rating selected for Westinghouse silicon cells is well below the maximum current that the cells can carry.

In selecting the number of cells for a given unit, allowance must be made for current unbalance between parallel cells and continued operation with the occasional cell failure. Silicon cells also have definite overload limitations due to their small thermal mass. For example, the 339 cell has a one-cycle overload rating of six times its industrial rating. For 10 cycles, it will carry 4 times its continuous rating. These are not values that can be applied to the cells repeatedly but are to be used only for coordination with protective equipment.

In many applications, such as mining, rapid transit, and general 250-volt industrial service, the system may experience severe d-c short circuits. In such cases, the number of silicon cells used in parallel for a given unit rating is determined by the short-circuit requirements rather than the continuous rating of the apparatus. For example, in mining rectifiers the 339 cell is applied at one-third of its industrial rating. In electrochemical applications, where the possibility of short circuit is too remote to be considered in rating the cells, the cells are operated at their full industrial rating.

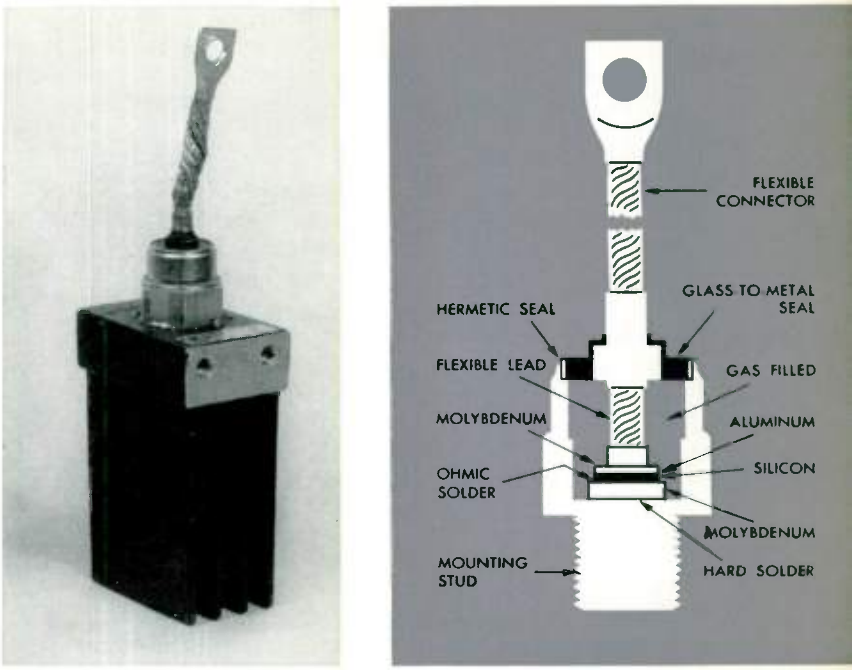


Fig. 6 (left)—Typical silicon cell for voltage ratings up to 500 peak inverse volts. **(Right)**—Cross sectional view of silicon rectifier assembly.

cooling

Silicon rectifier cooling is usually accomplished by one of three methods, listed in the order of desirability:

Straight Air Cooling—The diodes are mounted on heat sinks or fins, as shown in Fig. 6. This is the simplest and most reliable, a fan being the only moving part. Actually, a surprisingly small amount of air is required. A 10 000-ampere, 600-volt silicon rectifier requires only 5000 cfm even at 40 degrees C ambient, or 0.84 cfm per kilowatt. Air-cooled units are also surprisingly compact. This same 10 000-ampere unit requires a floor area of only 106 inches wide by 60 inches deep.

Recirculating Air with Air-To-Water Heat Exchanger—Where corrosive atmospheres are troublesome, the cubicle can be made air tight and the cells air cooled with recirculating air passing through an air-to-water heat exchanger. This system retains all the advantages of air cooling except that the cubicle is usually slightly larger. The water system can be grounded, and is physically and electrically separated from the electrical system.

Water Cooling—Here, practice is to bolt the diodes to a water-cooled bus. Water-cooled units have the disadvantage that the water system is in intimate contact with the electrical system and a large number of insulating rubber hoses are required, especially at higher voltages. Also, protection must be provided against electrolysis. At 150 volts, where a single-way circuit can be used, water-cooled units require only two insulating hoses, electrolysis is not critical, and direct water cooling is practical.

At voltages between 150 and 300, employing a bridge circuit, the use of direct water cooling is still feasible even though more insulating hoses are needed. However, above

300 volts, a minimum of 20 insulating hoses are required and the electrolysis problem becomes more severe. Therefore, above 300 volts, straight water cooling should be avoided if at all possible.

paralleling silicon cells

In high-power applications, a number of silicon diodes are used in parallel, as shown in Fig. 5. However, silicon cells vary in forward drop, and if paralleled indiscriminately, they will not divide current equally.

Several methods have been employed to obtain better paralleling of cells, such as matched cells or paralleling reactors. The latter method is generally preferred because it does not require matching cells.

One type of paralleling reactors, using "C" cores, is illustrated in Fig. 7. The same number of "C" cores as diodes is required. The lead from each diode passes through two "C" cores and each "C" core has two leads passing current in opposite directions. When the current between cells is balanced, the flux in the "C" cores is zero.

Should one cell carry more current than the adjacent cells, a resulting flux induces a voltage in the adjacent cell lead in a direction to balance the currents. Cores made of oriented Hipersil iron are ideal for this application, as they give a maximum balancing effect with minimum iron loss. With this arrangement, currents are balanced within 10 percent, even with 20 cells in parallel. Removal of one or more cells has little effect on the division of current between the remainder of the cells. Matching of cells is not required and cells can be paralleled indiscriminately, regardless of forward drop.

cells in series

Silicon cells also vary in back resistance by factors of ten to one, or more. Consequently, if two or more cells are connected in series, they will not divide voltage equally. Again, some external means is needed to force voltage division. A common method is shown in Fig. 8. Each cell is paralleled with a resistor, of a low enough value to minimize the difference in cell back resistance. Since cell back resistance is high, the value of resistors can usually be about 3000 ohms, with resultant low wattage loss. For a 10 000-ampere, 600-volt rectifier, the loss in the resistors is about 4 kilowatts. In terms of rectifier efficiency, this is a reduction of less than 0.1 percent.

reliability of silicon rectifiers

Silicon rectifiers can easily be designed to give essential service, where the rectifier must remain in operation even after failure of internal components, such as the silicon cells. This is accomplished by high-speed current-limiting fuses, designed specifically for use with semiconductor cells. As shown in Fig. 5, each parallel path, whether it has one or more silicon cells in series, is connected through a fuse. If the cells in one parallel path fail, this constitutes a short on the secondary of the power transformer through the cells in the other legs of the bridge. The fuse associated with the shorted cells will interrupt the fault current, isolating the failed cells. This is done with no disturbance to the rectifier output. Since in large power rectifiers the number of paths in parallel is usually 15 or 20, the increase in current in the remaining cells is small and does not affect performance.

detection of failed cells

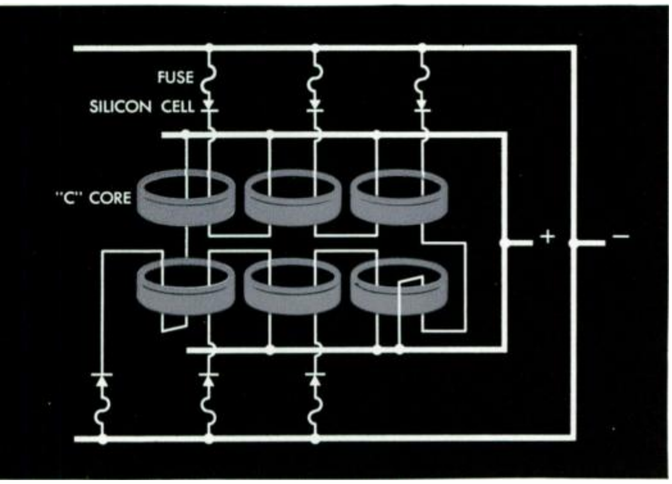
In early silicon-rectifier installations, both manufacturers and users were concerned about the possibility of cascading cell failures, which would have required excessive and expensive cell replacement. Complicated monitoring schemes were devised, which would give a remote alarm if any one cell failed in a group of parallel cells, and shut the rectifier down if two or more cells failed.

These schemes were of necessity complicated and expensive, and involved a large number of small components. Subsequent experience has shown that more trouble is experienced with the monitoring systems than with failed cells. Consequently, the trend is to substitute simple visual indication for complicated monitoring schemes. One such scheme, which is in successful operation and requires a minimum of additional equipment, is shown in Fig. 8.

application considerations

Several parameters serve as measuring sticks for rectifier unit performance, and must be taken into account when applying silicon equipment as a d-c power supply.

Efficiency—Note from Fig. 2 that efficiency increases slightly with increase in d-c output voltage rating. It is also



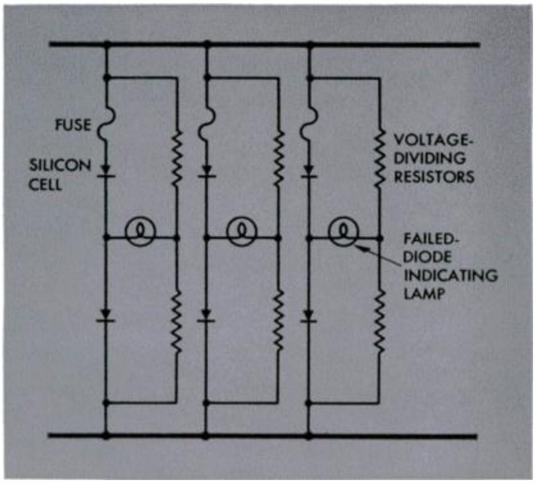
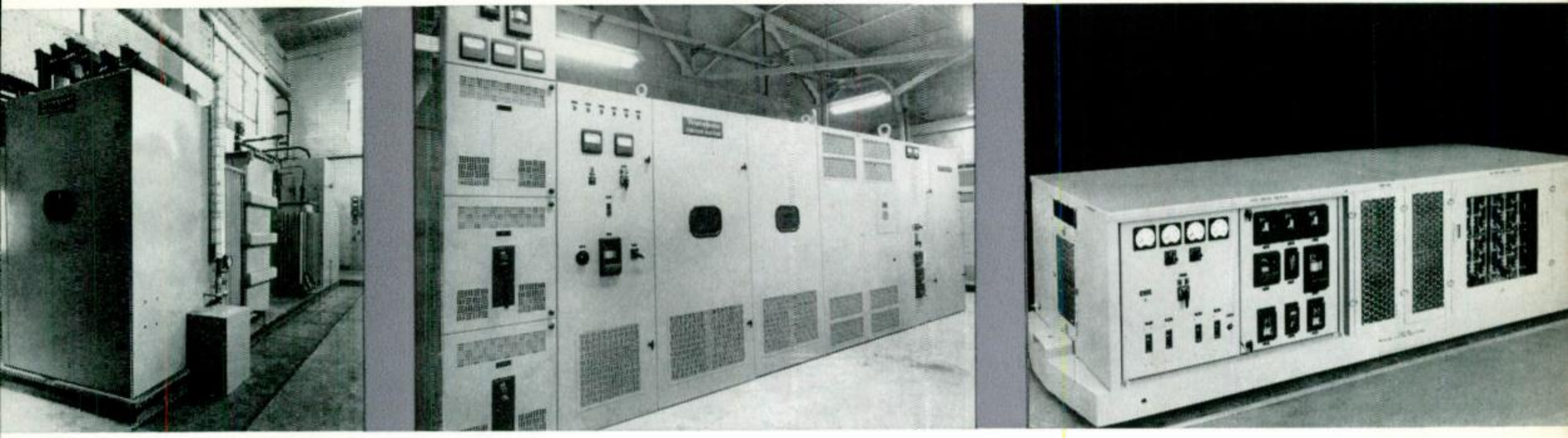


Fig. 7 (left)—When paralleling silicon cells, "C" cores can be used to force current balancing.

Fig. 8 (right)—Method for monitoring series-connected cells. Two silicon cells and two resistors form a bridge. Normally, current through the lamp is only a fraction of its rated value; but should either cell fail, the bridge is unbalanced and the bulb lights.



Left—A 5000-ampere, 125-volt silicon rectifier unit used in light metal production. **Center**—A 500-kw, 250-volt power supply installed in a foundry shop. **Right**—A 500-kw, 275-volt portable silicon rectifier unit for coal mining service.

significant that the values given on the curve are for an overall unit including, in addition to rectifying cell losses, the loss of the supporting transformers and various accessories.

Power Factor—The power factor of a silicon unit will have the same approximate value as that for a mercury arc rectifier—roughly 95 percent lagging. Actually, power factor is not an inherent characteristic of rectifying devices, but is determined by the total reactance and the circuit connection. Thus a given circuit feeding a rectifier with a total reactance of, say, 10 percent, will give the same power factor whether the rectifier is a mercury arc, mechanical, or a semiconductor device.

Voltage Adjustment—No inherent means of adjusting the output voltage from a silicon rectifier exists, such as is possible with field control on a motor-generator set or phase delay on an ignitron. Therefore, by whatever ratio the process requires that the d-c voltage be adjusted, means must be provided, such as induction regulators, regulating transformers, or saturable reactors, to adjust the a-c input voltage by a similar ratio. Saturable reactors have been used rather extensively on small units up to a few hundred kilowatts. However, in larger sizes, reactors are expensive and have poor power-factor characteristics. On larger electrochemical installations, regulating transformers combining a small-range-under-load tap changer with a wide range of no-load taps have been used extensively in the past with ignitrons and will find similar application with silicon rectifiers. Some applications require completely smooth or stepless control. This requirement can be met with induction voltage regulators.

Voltage Regulation—The inherent regulation curve of the silicon rectifier unit is a straight line from no load to full load; no-load voltage is about five to eight percent above full-load voltage, depending upon the service. This natural regulation curve is satisfactory for most applications. Where essentially constant voltage at loads below 100 percent are required, an automatic voltage regulator can be provided by dropping the inherent curve down, but the voltage output cannot be increased above the inherent curve under overload conditions.

Parallel Operation—With the regulation curve described, the silicon rectifier is basically suitable for parallel operation with any other type of conversion equipment that also has a drooping characteristic and the same rated d-c voltage. Silicon units can be applied in parallel with other equipment in essentially the same manner as ignitrons.

Regenerative Loads—Where regenerative loads, such as overhauling cranes, are supplied from a bus energized by silicon rectifiers, some provision must be made to absorb regeneration. If other loads on the bus will always be sufficiently large to absorb the power regenerated by the overhauling load, no further provisions are required. However, where this is not the case, an absorbing resistor with suitable automatic controls must be provided as a part of the rectifier unit, such that the resistor will be energized once the bus voltage begins to rise from the regenerated load. When the regenerative cycle has been absorbed, current relays will disconnect the resistor. This is the same situation that exists with ignitron units.

conclusions

From an initial start three years ago, silicon rectifiers are now being installed almost exclusively for electrochemical applications. Likewise, they are being installed extensively in mills, shops, and mines. Silicon rectification is also being seriously considered for rapid transit service.

Silicon conversion equipment is available for 250-volt d-c industrial service in ratings ranging up to 3000 kw at specific values corresponding to the preferred series of numbers. For 275-volt mining service, 500- and 750-kw units are in use. In 600-volt rapid transit service, ratings as high as 3000 kilowatts are practical. In electrochemical service, unit ratings from 5000- to 25 000-amperes are well within the standard range. At the higher end of the scale, two or more rectifier cubicles are connected to a single transformer to obtain the total rating. In this service, the d-c voltage ranges from a few volts to 1000 volts.

The conversion unit that will supply d-c power to industry in the 60's is built around a wafer of metal only as large in diameter as a five cent piece, and not nearly so thick as a dime. It is quiet; it does not move; it is efficient; it is simple; and it is reliable; and in spite of all these virtues, it offers first cost savings. ■

CERAMIC AND METALLIC BARS OF UNLIMITED LENGTH . . . from powder form

This novel compaction process will allow the advantages of powder metallurgy to be used in many new metalworking applications.

F. EMLEY **C. DEIBEL**
Materials Engineering Departments
Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania

A new process, capable of compacting metallic or ceramic powders into bars and strip of large cross-section and unlimited length, promises to be the answer to many complex material requirements of industry.

Many new alloys and metal-ceramic mixes needed today can only be produced with powder metallurgy techniques. What is needed is a process that can compact large volumes of metal and ceramic powders that can be used either as a finished product after sintering, or easily handled by further processing steps. Previous methods are limited because of small strip thicknesses, small batch quantities, and expensive equipment.

This continuous compaction process is as versatile as it is simple. Loose powder is placed in a trough and is then pressed with a punch. By a succession of pressing operations, a continuous bar or strip is produced.

how it works

Powder under the sloping portion of the punch is pressed with an infinite number of pressure values from zero to the maximum pressure under the horizontal surface. The punch is raised, and the powder is moved forward. Vertical punch travel is arbitrary except that the punch should clear the loose powder on the next stroke.

If the powder advance is not too great, some fully compacted powder still remains under the finishing area. Because it cannot be compacted any more, it shows no density discrepancies or surface marks. Powder under the sloping portion of the punch receives another increment of compaction during the next pressure stroke. By repetition of this cycle, loose powder is pressed into a continuous bar. The bar then can be sintered and further processed.

Experiments indicate the punch slope can vary with little effect on the compaction process. Low angles reduce process speed and efficiency, but might be desirable for pressing a small powder fill; high angles displace the powder laterally, resulting in bar thickness variation. A proper balance must be established, depending upon the end requirement.

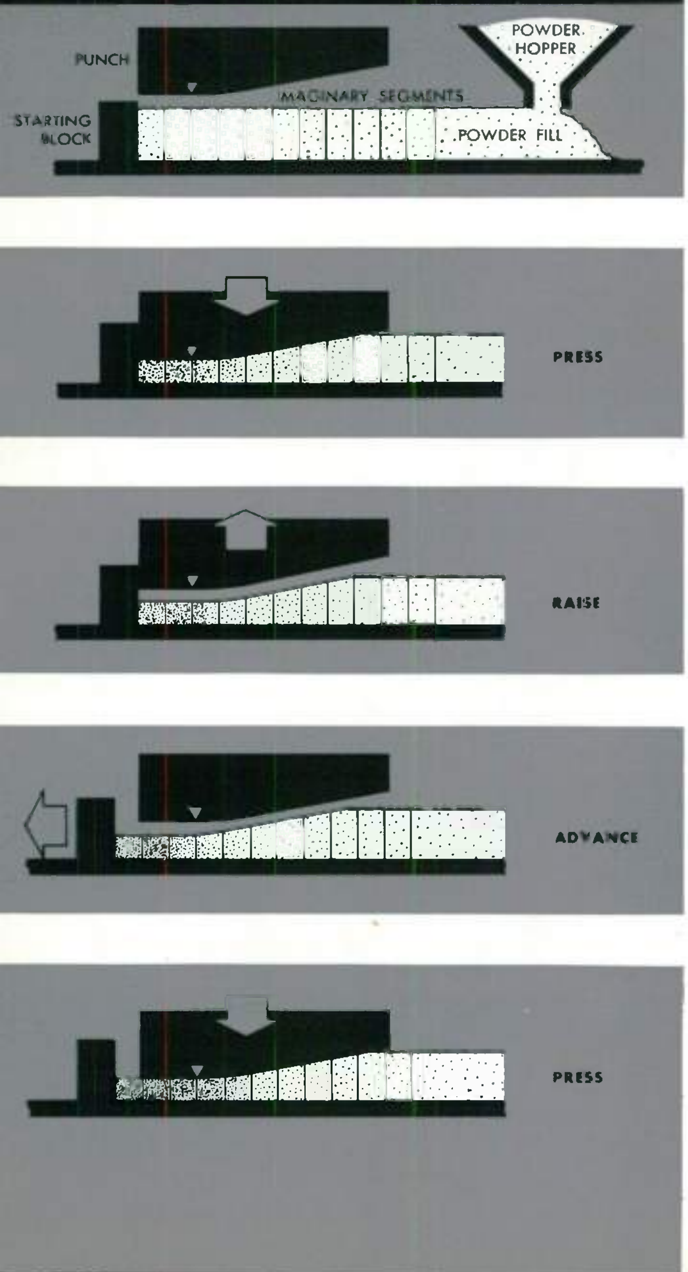
Many cross-sectional shapes and sizes can be produced with the process. Only one- and two-inch channels have been produced so far, but there is no reason why wider bars cannot be pressed. The required capacity of the press, other conditions being equal, increases with the strip width. Thickness is not severely limited, although a practical limit will probably be encountered for any given press. Although bar thicknesses up to one inch have been produced with no difficulty, thicker pressings have not been attempted. The lower limit of thickness has not been established, but materials probably can be compacted into strip of 5 to 10 thousandths of an inch.

The amount of advance per stroke can vary over a wide range. If it is too short, the operation will be inefficient; and if too long, a smooth bar cannot be obtained. The length of the punch finishing area is a design factor that can vary. It should be somewhat longer than the minimum advance per stroke, but it can be increased with no appre-

TABLE OF TYPICAL EXPERIMENTAL RESULTS

Material	Compacting Load (Tons)	Sintering Treatment	Pressed Size (inches)	Sintered Density (Percent Theoretical)	Results and Remarks
Copper	60	1 hr at 1000 degrees C	0.25 x 2 x 28	90	Excellent bars—easy to compact.
Copper (Repressed)	100	1 hr at 900 degrees C	0.23 x 2 x 28	94	Slight surface marking.
Electrolytic Iron	60		0.50 x 2 x 24		Good bars if powder is freshly annealed.
Tungsten plus 1 percent paraffin	30	3.5 hrs at 1200 degrees C plus 3.5 hrs at 1600 degrees C	0.50 x 2 x 24	61	Binder and low compacting pressure is necessary.
Tungsten plus 1 percent paraffin	40	1 hr at 1200 degrees C plus 3 hrs at 1650 degrees C	0.75 x 0.75 x 30		To be used as consumable electrode.
Easton RZ Iron	60	16 hrs at 1300 degrees C	0.625 x 2 x 28	71	Excellent bars.
Molybdenum	15	1 hr at 850 degrees C plus 3 hrs at 1600 degrees C	0.50 x 2 x 24	82	Good bars. Low green density. Heavy shrinkage.
Columbium sponge	50		0.75 x 0.75 x 26		For use as consumable electrode. Green bar is flexible.
A-104 Iron sponge	50	15 hrs at 1150 degrees C	0.75 x 0.75 x 26		For use as consumable electrode. Green bar is flexible.
Titanium sponge	50		0.25 x 2 x 28		Compacts well. Used for "getter" sheets in sintering.
Nickel-Aluminum-Iron Alloy	95	4 hrs at 1125 degrees C	0.50 x 2 x 28		Compacts well.
Iron-Cobalt-Vanadium Alloy	50	Pre-sinter ½ hr at 600 degrees C	0.15 x 2 x 24	62	Excellent bars.
Iron-Cobalt-Vanadium Alloy (Repressed)	100	17 hrs at 1200 degrees C	0.12 x 2 x 24	89	Slight surface marking. Subsequently processed to 0.004-inch tape.
Iron-clad Copper	60	1 hr at 850 degrees C	0.30 x 2 x 12		Excellent bar. Special powder filling technique was necessary.

SEQUENCE OF OPERATIONS IN CONTINUOUS COMPACTION



ciable effect, except that a greater force is required for the initial pressing stroke.

advantages

Other powder metallurgy processes can either produce a thick bar with limited length, or long strips of small cross section. With this process, the thickness of the bar can be greatly increased, and the length of the bar is virtually unlimited. Thus powder metallurgy techniques can now be used to advantage in many new metalworking applications.

Section shapes can achieve the entire range now possible with conventional powder metallurgy pressing, considering shapes permissible in sections parallel to the pressing direction with single-action pressing. Multiple pressing action also can be envisioned, at least from the top pressing surface.

Bars produced with this method are constant in cross section if the powder fill is maintained. Another important advantage is the consistency of the density that can be achieved over the length of the bar. The excellent quality of the surfaces, edges, and corners is another feature.

An iron-clad copper bar has been produced with this process. One end of the bar is solid iron; the copper center starts midway and continues to the other end. This suggests many other interesting variations.

An automatic set-up can be made, capable of producing bars of unlimited length that can be fed directly into a sintering furnace and then to further processing steps, such as rerolling. For experimental purposes, however, a simpler set-up was used to produce bars of limited length.

applications

Bars have been made from various commercial types of iron powder including: electrolytic iron, type RZ iron, and Swedish sponge iron.

In addition to pure metal powders, a variety of alloys were pressed from elemental powder mixes. These include iron-nickel magnetic alloys, iron-silicon alloys, Kovar alloy (an iron-nickel-cobalt glass sealing alloy), and many others. Titanium sponge, sponge-iron melting stock, columbium roundels, and tungsten and molybdenum powders have been made into electrodes for further melting.

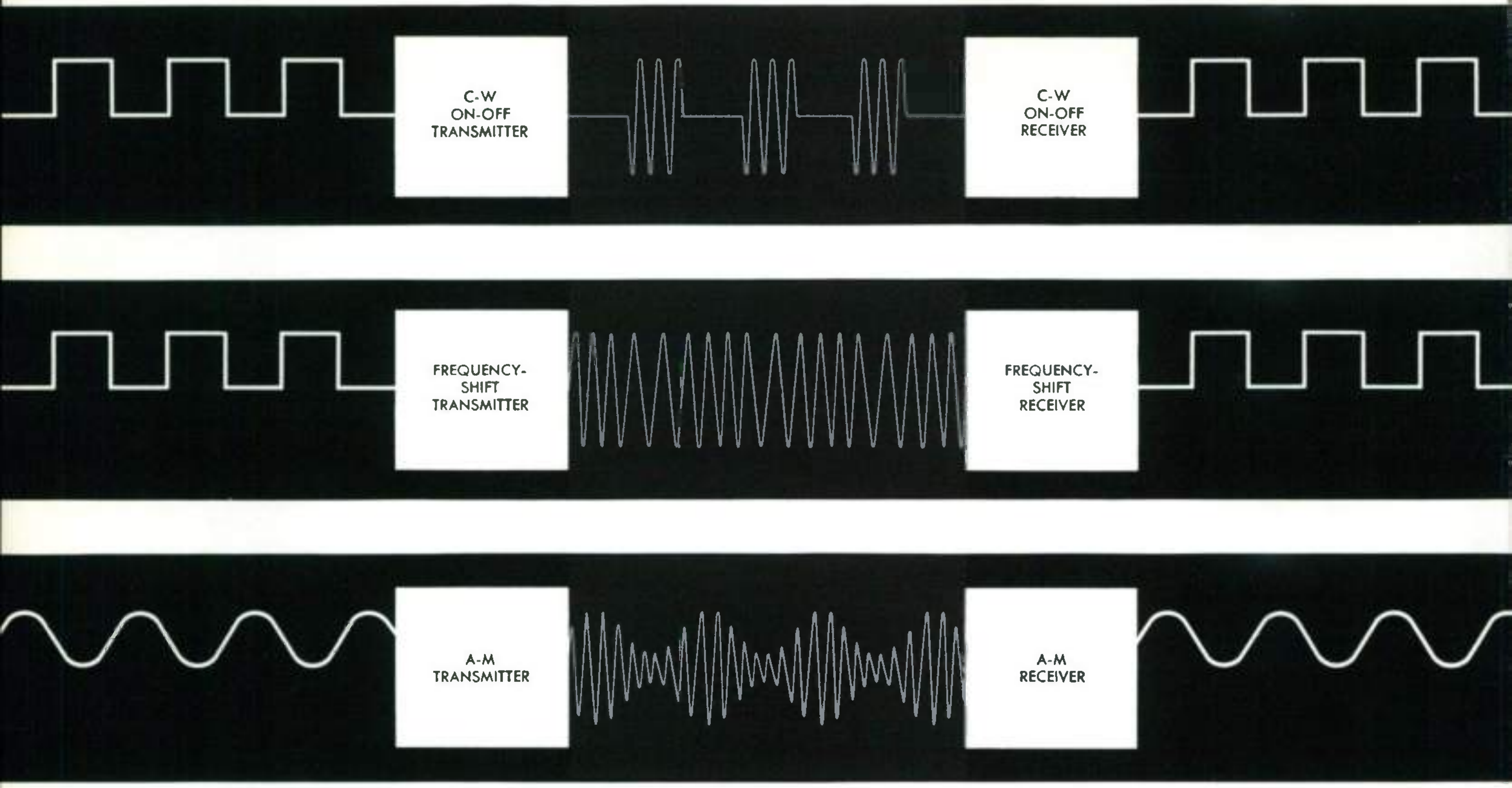
This compaction process might be used to fabricate large sizes of refractory metal sheet, strip, or bar, such as tungsten, molybdenum and tantalum. Continuous fabrication of tungsten powder into filaments is also a possibility.

Precise composition can be maintained in fabrication of sheet and strip alloys. Also, alloys too brittle for conventional working techniques can easily be worked after the continuous compaction process.

The process can also make possible low-cost fabrication of powder sponge and highly reactive metals and alloys. The metals can then be processed by sintering and working, or by vacuum-arc melting. This technique would enable high-purity, low-cost raw materials to be used, and would avoid problems such as excessive segregation.

Single-step preparation of composite or clad bars, sheet, and strip of different metals should also be possible, such as thermal bimetals and bearing bimetals.

When lower cost powder materials become available, this continuous compaction process will provide economical large-scale production of common metals and alloys directly from powders. ■



TRANSISTORIZED TONES . . . telegraphic communication for utilities and industry

Freedom from maintenance, small size, and low power requirements are advantages of transistorized type KA tone equipment.

R. H. KLINE
Air Arm Division
Westinghouse Electric Corporation
Baltimore, Maryland

Tone telegraph has been the workhorse of the "rapid transit system" of moving information from one location to another for many years. The use of telegraph equipment started humbly with Samuel F. B. Morse tapping out his famous "What Hath God Wrought" on a simple d-c on-off telegraphic channel between Washington, D.C. and Baltimore, Maryland. Since this beginning, telegraphic-type functions have pyramided beyond count.

The development of audio tone equipment was a vast improvement over the first d-c telegraph channel. Where the d-c channel contributed only one information channel, tone equipment provides 18 telegraphic communication channels in one usable voice channel. (A voice channel usually provides an audio frequency bandwidth of 300 to 3500 cycles per second.) In this way, industrial and utility users can add multiple channels for telemetering, control, supervision, or other telegraphic function over each voice channel operating on telephone lines, carrier systems, or microwave systems.

Tone equipment designs have employed the vacuum tube as a basic ingredient for many years. However, as the need for tone equipment multiplies in the giant industrial and utility complex of communications, equipment is needed that will operate maintenance free for years at a time. The transistor, with its long life, small size, and low power requirement, provides this needed reliability. In the past few years, the transistor has replaced tube types, until now, most audio tone equipment designs can use the transistor exclusively.

type KA tone equipment

The new type KA tone equipment is the result of a transistorization program that was started several years ago with the development of the first completely transistorized power-line carrier equipment.[1] KA tone equipment is designed to incorporate all of the advantages of

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[1] "Modernizing Power-Line Carrier with Transistors," by E. E. Scheneman, *Westinghouse* ENGINEER, July 1958, p98-101.

Fig. 1 (facing page)—Diagrammatic representation of three basic types of tone transmission.

Left—KA tone equipment is shown mounted in a standard 19-inch rack, which also houses microwave equipment above. Shown are two frames of transmitters and receivers with associated power supplies.

Top—Front view of type KA tone equipment features a bookshelf "flip-out" design.

Right—Flip-out design and routine check test points make the transistorized KA tone equipment extremely simple to service.

transistors, printed circuits, miniaturization, and system operating improvements. The result is a completely new line of equipment, consisting of three audio tone transmitters, three compatible receivers, and a power supply.

KA tone equipment can be divided into three categories: *continuous-wave on-off*, *frequency shift*, and *amplitude modulated* (Fig. 1). C-w on-off equipment simulates the basic type d-c telegraphic circuit by interruption of the continuous carrier wave into on-off or mark-space pulses. Frequency-shift equipment provides the same type of response to impulses; namely, on-off or mark-space interruptions by shifting carrier frequency a small amount and allowing this slight shift to be detected for on-off output at the receiver end. However, frequency-shift equipment has a basic advantage in that the carrier is left on continuously for monitoring or guarding the channel. For example, the receiver relay output can have contacts wired to an alarm circuit that will ring an alarm bell or turn on an indicator light if, for any reason, the carrier transmitter or receiver should fail so that no signal is received. These guard type channels are important for those functions that must be taken care of in case of channel failure.

Amplitude-modulated tone equipment is used for frequency-type telemetering systems. Here, a telemetering transmitter or end device provides a sub-audio 15- to 35-cycle output in proportion to the metered quantity. This sub-audio output is fed to the a-m modulated tone equipment, where it modulates the carrier wave, which is transmitted to the remote receiver. The receiver detects the sub-audio signal and applies it to the metering-end device.

All three types of tone equipment can be applied singly or simultaneously on each available voice channel. For example, 18 c-w on-off channels can be applied, or 6 each of c-w on-off, frequency shift, or amplitude modulated, or any other combination thereof. Any of these channels can be changed, substituted, or removed at any time without upsetting the complete system.

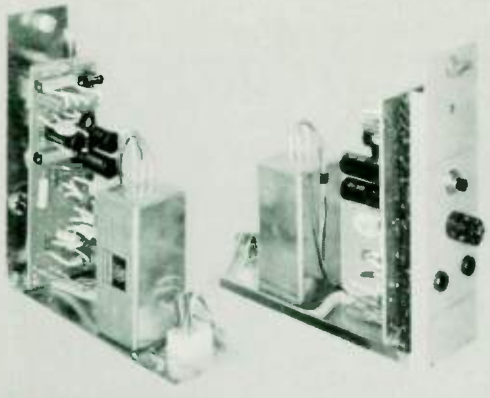
application of tone equipment

The process industries, gas transmission utilities, power utilities, water-supply systems, and many other types of industry can use tone telegraphic communication to great advantage. Power utility systems have used tone telegraph equipment for transfer trip, impulse duration, and frequency-type telemetering. Other types of new applications may well be in the automatic dispatch system field.

Gas transmission systems use tone equipment for many of the same functions as the electric utility group, plus remote control of pipeline functions, start-stop-reverse of motor controls, or pressure regulators.

A number of functions can be accomplished with KA tone equipment. For example, consider a few applications that are typical in gas transmission systems, but which also have other industrial or utility applications:

On-off tones can be applied for many purposes. The control of pump motor starting and stopping can be accomplished easily by one c-w on-off tone channel. Re-



Front and rear view of transistorized type KA c-w on-off transmitter.

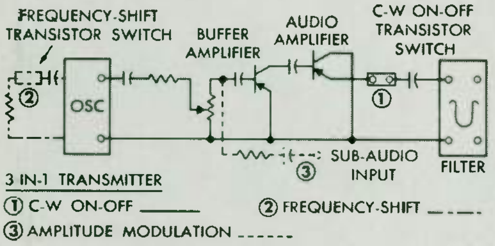


Fig. 2—Simplified schematic diagram of the KA tone transmitter, with modifications indicated for conversion to c-w on-off, amplitude modulation, or frequency-shift operation.

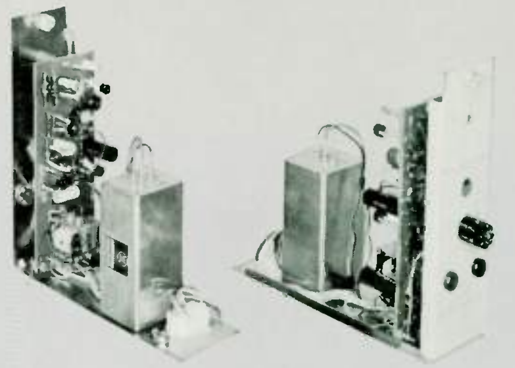
Box A—TRANSMITTER DESIGN

The basic transmitter is designed to obtain a simple configuration to cover the band required at 18 fixed-frequency steps. A 2N610 transistor is used as the oscillator in an r-c network feedback oscillator circuit (Fig. 2). The output of the oscillator is capacitor coupled to a gain control and to the next amplifier stage using a 2N403 transistor in a common emitter configuration. The final transistor amplifier is a 2N403 transistor in a common collector configuration. This output is controlled by the action of a transistor switch (2N112) that effectively opens the emitter circuit of the final amplifier in a switch-off condition. The keying circuit uses B+ voltage to open and close the switch through a diode, 1N63. The diode presents a large back resistance to any impedance seen by the base of the switch. A 1000-ohm telephone line with 130-mmf capacity may be used with this switch.

The a-m transmitter uses the same r-c oscillator and two amplifier sections as the on-off transmitter. The 2N112 switch is removed and a modulating network is inserted including a modulation potentiometer and capacitor C13. The second amplifier is base modulated from a 50 000-ohm, 10-volt, 15- to 35-cps source.

The frequency-shift transmitter also uses the 2N112 switch in the oscillator circuit. The frequency is shifted by switching a resistor in and out of the last r-c ladder stage. This provides a simple and effective switching circuit without upsetting oscillator stability.

As can be seen from the above transmitter circuits, the basic printed circuit board is standard and may be connected at option into the transmitter configuration desired.



Front and rear view of type KA c-w on-off receiver.

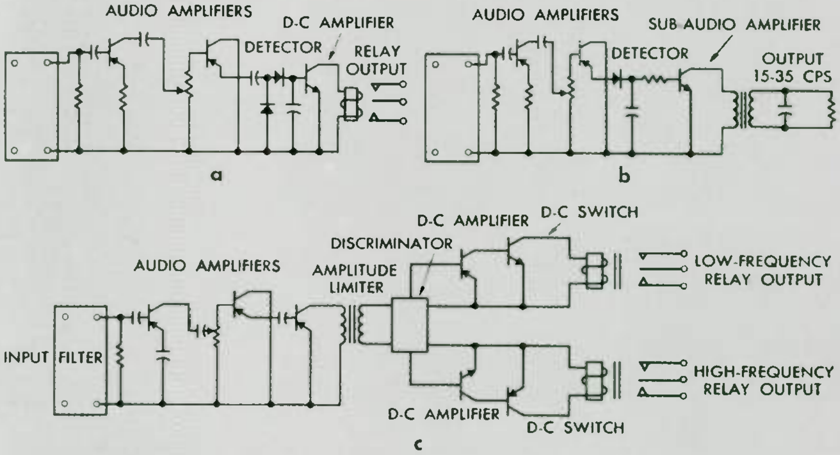


Fig. 3—Simplified schematic diagrams of type KA tone (a) c-w on-off receiver (b) amplitude-modulation receiver, and (c) frequency-shift receiver.

Box B—RECEIVER DESIGN

The design approach to the compatible receivers required a different approach than for the transmitters. The output sections for the sub-audio demodulation, the c-w on-off, and the frequency-shift receivers are different in design and layout. The basic on-off receiver was designed as the standard receiver. Once this design was completed, other configurations for a-m demodulation and frequency-shift relay output were made.

The basic receiver (Fig. 3a) consists of two 2N525 transistor r-f amplifier stages and one d-c switch using a 2N332 transistor. The output section consists of a sensitive relay with a 2500-ohm coil. The relay picks up at 4 milliamperes and drops out at 3 milliamperes. The r-c time constants and delay time are such that most of the delay is in the mechanical relay. The standard relay supplied with the unit is satisfactory for 15 pulses per second, as required for supervisory control and many on-off control applications.

The a-m receiver (Fig. 3b) was designed to use the first two stages of the on-off receiver, using the same parts configuration. Also, the d-c switch is used as a 2N332 sub-audio amplifier. To convert the on-off to a-m detection required the output of the final 2N525 stage to be capacitively coupled to the detector circuit, and its output in turn fed to the sub-audio amplifier. The amplifier output is then coupled to a matching transformer to deliver the required 15- to 35-cycle output.

The frequency-shift receiver (Fig. 3c) required a unique design approach from the standpoint of the use of transistors in discriminator circuits, and the layout factor for standard packaging. The first two audio stages were again taken from the on-off receiver. Additional amplification was required in the form of the third amplifier, a 2N525 transistor, in the common emitter configuration. The output from this amplifier is transformer coupled to discriminator circuits and the d-c amplifiers.

Output transistor switches were chosen for the low I_{co} in the d-c amplifier sections and suitable switching power in the relay circuits. The output relays for the standard adaptor board are designed with unique taper-pin plug-in facilities. The relays for the two output sections have the same characteristics as the on-off receiver. Other output adaptors using special high-speed relays, polar relays, or transistor switches can be designed as required for specific applications.

mote alarms can also be designed to warn of abnormal conditions, such as an overheated motor, or unauthorized personnel break-in.

Pressure regulators can be controlled for "high" or "low" operation with one channel of frequency-shift equipment. A shift in frequency below nominal channel frequency would be used for the control of one output relay, and a shift in frequency above nominal channel frequency would serve as the control for another output relay. Since these functions can be accomplished with only one channel space, valuable channel allocations are saved for other needed functions.

Another function needed in gas transmission is remote metering, which is necessary to keep a check on the operating pulse of the complete system. Two completely different types of remote metering or telemetering are possible with KA tone equipment: An impulse-rate or duration-type system uses a c-w on-off channel, which is pulsed at a given rate or duration for a given metered quantity. A second system uses a sub-audio frequency to modulate an audio tone channel for transmission to a remote location. The sub-audio frequency is changed from 15 through 35 cps for different values of metered quantity.

With these two types of remote metering devices, any quantity that must be metered from one or dozens of different locations can be remotely transmitted to a given location. In this way, instant visual control of the entire system can be achieved through constant metering of important quantities.

Gas transmission and other utilities use the versatile tone equipment for supervisory control. This type of system needs only two c-w on-off tone channels for the control or operation of 10 devices. One channel is used to select the right operation or device to control, and the second channel is used for checking back the operation to indicate to the operator that the correct operation was performed.

Other unique applications can be made at the option of the system designer. With the three basic types of KA tone equipment, the system designer has considerable leeway in providing the various types of services required by modern utilities.

equipment design

Transistors are used throughout the entire line of KA tone equipment for c-w on-off, frequency shift, and amplitude-modulated designs. The overall electronic design of the three basic transmitters and three receivers employ stable, dependable circuits to complement several standard-type transistors. For example, the Westinghouse types 2N610 and 2N403 are used in all three transmitters.

The mechanical design has incorporated a "flip-top" unit, which is completely accessible from the front, and permits rack mounting against a wall. The basic units—power, transmitter, and receiver panels—are mounted on a frame the size of a standard 19-inch wide relay panel, 5 panel units high. All transmitter and receiver unit panels are identical in size so that any combination of transmitters and receivers totaling six panels plus one power supply panel can be mounted side-by-side in a 19-inch frame.

This type of packaging fulfills the three basic requirements necessary in any good layout: (1) ease of manufacture, (2) simple and flexible installation, and (3) freedom in maintenance. The increased problem of placing all necessary parts in close proximity was solved and yet space is provided for minor maintenance checks. The panel can be removed quickly if desired. Normal routine check test points are provided on the front of the panels.

Two types of power panels are provided: the *power supply panel* operates from 120 volts 50/60 cycles; the *power unit panel* operates from 26, 52, 129, or 258 volts d-c. Either panel provides all the power requirements necessary for any combination of transmitter and receiver panels in a single 19-inch frame.

The transmitter and receiver channel filters used in KA tone equipment were especially designed to permit assembly on the pivoting panel. To obtain minimum size, the filters were designed with a minimum number of inductors, which occupy most of the space in conventional audio filters. The capacitors are mica, mylar, and polystyrene, and are subminiature.

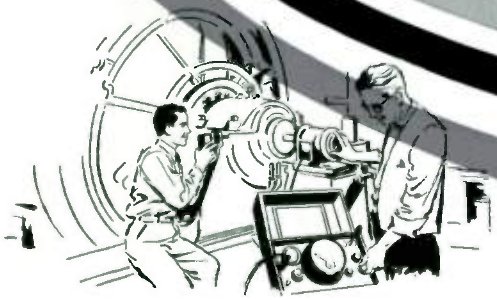
All discriminator tank circuits and interstage transformers for the frequency-shift receiver are encapsulated for improved temperature and humidity performance.

The type KA tone equipment was designed to use the new transistor circuits and engineering techniques that have accrued over the past several years. Units are now going into service over pipeline circuits for control and telemetering, electric utilities for remote trip, and industrial process control for automatic factory production. KA tone equipment is a new basic tool for fulfilling communicating requirements. ■

Table I—DESIGN SPECIFICATIONS OF KA TONE EQUIPMENT

Transmitter:	
Output	+3 dbm
Frequency Range	425 cps through 3315 cps
Frequency Stability	±15 cps
Output Impedance	600 ohms, balanced or unbalanced
Contact Keyed	c-w on-off, frequency shift
Amplitude Modulation	15 to 35 cps
Frequency Shift	±45 cps
Selectivity	−8 db ±170 cps, −3 db ±60 cps
Receiver:	
Sensitivity	−35 dbm
Frequency Range	425 through 3315 cps
Input Impedance	600 ohms, balanced or unbalanced
Output Contacts	1½ amp., 125 volt dc, non-inductive
Standard Selectivity	−32 db ±170 cps, −3 db ±60 cps
Demodulated Output	10 volts minimum, 50 000 ohms
Power Requirements:	117 volts ± 10 percent a-c, 60 cps, or 129 volts or 48 volts d-c to provide 24 volts d-c nominal to the equipment with a 21- to 28-volt d-c variation permitted
Environmental:	0 to +55 degrees C 95 percent humidity

VIBRATIONS IN ROTATING SYSTEMS



With new computer techniques, a rotating system can be simulated, and vibrational disturbances eliminated during design. But for accurate results, all factors should be included, such as flexible rotor supports.

D. C. PHILBRICK
Large Rotating Apparatus Department

M. RASHEVSKY
Analytical Department

P. J. HAWKSHAW
Marine, Aviation & Transportation Facilities

Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania

Included in the design of any large rotating system should be a careful vibration analysis to ascertain that the system is free from any perceptible vibratory disturbances throughout its operating range of speed and load.

With present computers, a system can be readily simulated and a vibration analysis made before the design is completed. Careful consideration of vibratory excitation sources, both lateral and torsional, and their effect on the system, permits the design engineer to make changes to render the system insensitive to the known excitation sources. This is particularly important on large, complex drives where field adjustment can be extremely costly.

lateral vibration analysis

Generally, all units in a large rotating system are connected by flexible couplings that do not transmit any bending moment and only a small part of the shear force. Therefore, each rotating unit is considered laterally independent and analyzed separately. One objective, then, is to design each unit such that its lateral natural frequency differs enough from the running frequency so that vibration amplitude is held within acceptable limits.

For the simplest case of a single concentrated mass on a flexible shaft on two rigid supports as in Fig. 1, the critical speed corresponds to the natural frequency of lateral vibrations in one plane.

$$N_{cr} = 187.7\sqrt{1/Y_{st}}\ RPM$$

The term, Y_{st}, is the static deflection of the shaft under the influence of gravity. The static deflection of the rotor

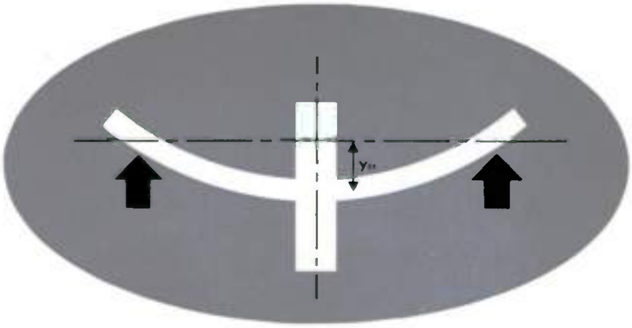


Fig. 1—The rotor deflection (Y_{st}) at standstill, is a measure of rotor flexibility, which determines the critical speed.

is only a measure of the flexibility and mass of the shaft. The critical speed remains the same whether the shaft is rotated in the horizontal or vertical position, and would remain unchanged if the gravitational force disappeared.

For accurate location of the lateral natural frequency, or critical speed, calculations based on rigid supports are insufficient. The flexibility and damping of the rotor support system have a marked effect on the location of the critical speed and must be considered, Fig. 2.

In addition to the location of the critical speeds, the vibration amplitude should be calculated at any frequency. This can be done only with a forced vibration method in which flexibility and damping are considered. Any method that does not consider damping does not give an accurate location of the critical speed and does not permit a study of the vibration amplitude at resonance. Three sources of damping are present in most rotating systems:

Internal hysteresis damping of the shaft material results from the stress-strain relation of steel under an alternating load, such as that produced by lateral or torsional vibrations. This type of damping can be represented by a thin loop as shown in Fig. 3, the area of which equals the energy lost per cycle of vibration in one cubic inch of material. This energy is subtracted from the system and thus reduces the vibration amplitudes.

Aerodynamic or hydrodynamic damping, in the case of compressors or pumps, is due to the work done by vibrations in shearing the viscous medium. In the case of electric motors, aerodynamic damping is negligible.

Bearing oil-film damping in sleeve-type bearings is produced by shearing forces in the oil film, which separates the shaft journal from the bearing.

Oil-film damping is the largest source of lateral damping in most rotating equipment. The magnitude of oil-film damping and flexibility has been determined experimentally and verified by comparing the calculated amplitudes with amplitudes recorded on actual rotors. Because oil-film damping in an average sleeve bearing is high, vibration amplitudes even at resonant frequencies are low. This explains why many machines have no difficulty in going through these speeds and, in fact, can operate close to resonance.

Although lateral vibrations are usually caused by mechanical unbalance, several other sources of lateral disturbance exist, such as:

(1) Thermal unbalance can be caused by nonuniform bending of the shaft due either to internal strains or nonuniform temperature distribution on the shaft periphery.

(2) In a self-excited vibration, the alternating force that sustains the motion is created or controlled by the motion itself; when the motor stops, the alternating force disappears. An example of a self-excited vibration is oil whip, which is caused by instability of the oil film in generously lubricated sleeve bearings.

(3) Elliptical journals or journals with flat spots cause vibration that cannot be corrected by balancing. This can only be remedied by remachining the journal.

(4) Shafts with variable elasticity also can cause lateral vibrations. For example, in the cross section of a two-pole rotor, flexibility through the pole centers is different from flexibility between the poles. As a result, twice running frequency vibrations are found on the shaft. Such vibrations can be eliminated by cutting dummy slots in the poles, making the shaft flexibility equal in both planes.

After numerous studies on rotating machines, an important phenomenon was discovered. Long overhanging shaft ends, (the portion of the shaft outside the bearing) have critical speeds that are different from the critical speeds associated with the main rotor body, and the vibration amplitude for a given unbalance is usually greater than the amplitude in the main rotor body. Flexible couplings often are mounted on the shaft ends, and small unbalance in the couplings can cause serious vibratory disturbances. Shaft ends should be designed so that their critical speeds differ enough from the operating speed range to hold vibration within acceptable limits.

The following generalizations can be made regarding the method of analysis used on large rotating systems.

(1) In general, the flexibilities of the oil film and pedestal lower the critical speeds while damping raises them.

(2) The effect of flexibilities (of oil film and pedestal) on rigid rotors is much larger than on flexible rotors. The critical speed on rigid supports and the static deflection curve determine the rotor flexibility or rigidity.

(3) The gyroscopic effect raises the critical speeds, but it is important only if large diameter discs (flywheels) are mounted on the shaft. For average rotors, the gyroscopic effect is negligible.

(4) Flexibilities and damping effects of the oil film and pedestal increase with the order of critical frequency.

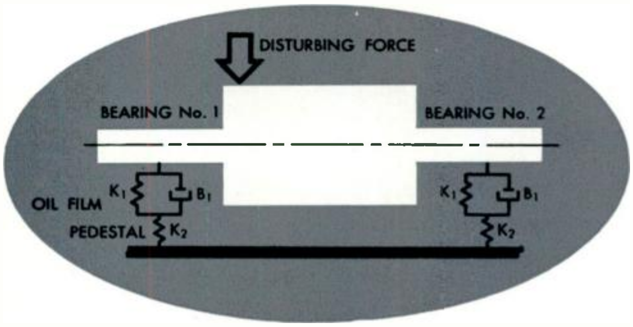


Fig. 2—Simplified diagram of a rotor, resting on flexible damped supports.

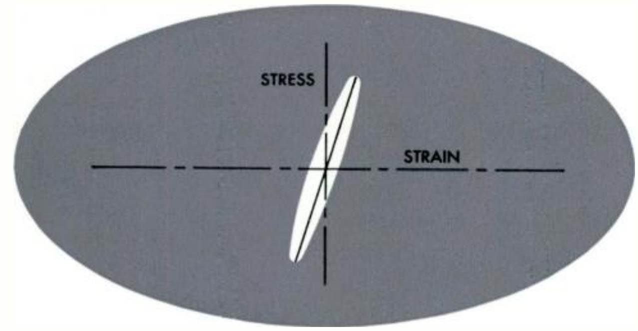


Fig. 3—Energy loss due to internal hysteresis damping in one cubic inch of shaft material equals the area in the above loop.

(5) Oil-film flexibility and damping can be considered as linear functions in most applications.

(6) Due to high oil-film damping in the bearing, vibration amplitudes even at critical speeds are low, and on a well balanced rotor, the critical speeds cannot be detected. Therefore, the locations of the critical speeds are not always the most important consideration. Establishing vibration-amplitude limits is equally important.

(7) Long overhanging shaft ends introduce resonant frequencies, which differ from the resonant frequencies associated with the center section of the shaft.

torsional vibration analysis

Torsional critical frequencies and vibration amplitudes in a multi-mass system must be determined because failures due to torsional vibrations usually do not give any warning signals prior to breakdown.

Correction of torsional disturbances usually requires a fundamental change in the system. Therefore, torsional frequencies should be carefully considered during design, because after the system is installed, compensation for torsional vibrations is difficult.

To understand the nature of torsional vibrations, consider the system illustrated in Fig. 4. If a force is applied to the disc, the disc rotates through an angle (α). When the force is removed, the disc rotates back through its original position to a new position ($-\alpha$). Without friction losses and damping, the disc oscillates back and forth between these points, at a frequency determined by the torsional spring constant of the shaft and the inertia of the disc. This is called the torsional natural frequency.

Most rotating systems, however, are not this simple, and consist of several masses connected by flexible shafts. In such a multi-mass system, $N-1$ torsional natural frequencies exist, where N equals the number of masses in the system. Each natural frequency is determined by the shaft spring constants and the inertias of the masses in the system as is the frequency of the simple system as shown in Fig. 4.

Generally, sources of torsional excitation are more numerous than those of lateral excitation. In a-c motors, some sources of excitation are: electrical short circuits which occur at line frequency; pulsating torques which occur at a frequency equal to the number of stator punching slots times the number of revolutions per second of the rotor; and in the case of a wound-rotor motor, a pulsating torque, due to rotor-resistance unbalance, which occurs at double the slip frequency. In gear units, lateral motion in the gear pinion causes a periodic force to be applied to the gear teeth. This force becomes a source of torsional excitation in the output shaft, and its frequency is a function of the frequency of lateral vibration. An uneven gear tooth also can generate similar pulsating torques.

Sometimes system torsional disturbances are excited by forces in the load. In the case of compressors, one source has a frequency that is equal to the number of fan blades times the revolutions per second. If the compressors are connected to a wind tunnel, variations in the air-stream velocity transmit a pulsating load to the compressor.

The significant sources of torsional damping in addition to those mentioned previously are:

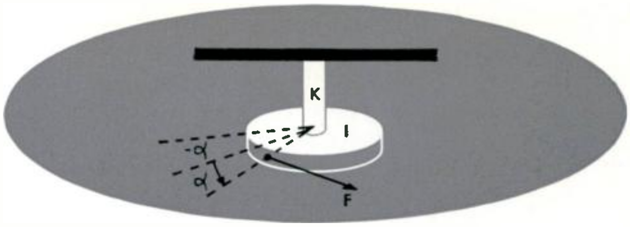


Fig. 4—Simple torsional vibration of a disc and a flexible shaft, where F is the disturbing force, k the spring constant of the shaft, I the inertia of the disc, and α the angle the disc turns due to the disturbing force.

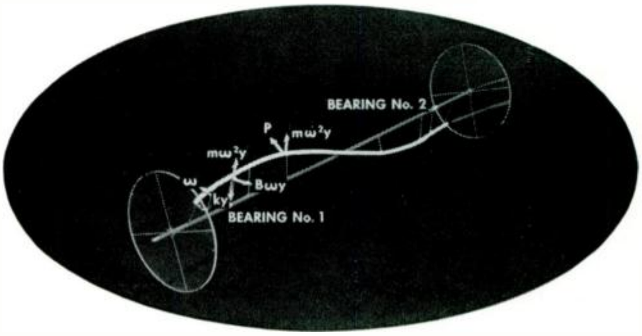


Fig. 5—At the second resonant frequency a rotor shaft, supported in two sleeve bearings, takes on a spiral shape around the true center line.

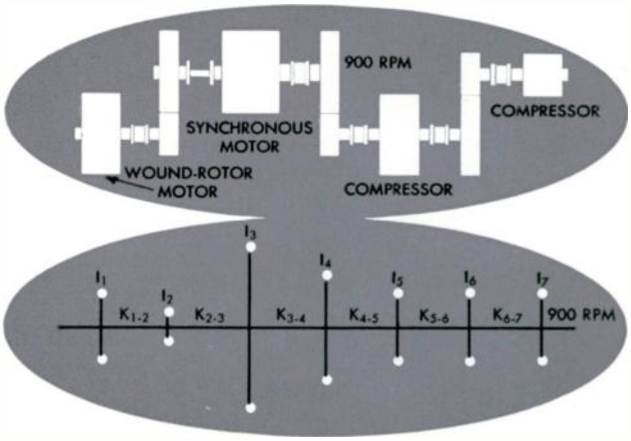


Fig. 6—An actual rotating system and its equivalent, used for computer calculations. Note that the speed of the synchronous motor has been used as the base speed of the system.

(1) Electrical damping—rotor torsional vibration in electric motors causes a flux to be created in the winding, which restrains the rotor vibration.

(2) Coupling, spider, and spindle fit damping—if the vibratory forces are great enough to cause relative motion in the various interference fits, the friction forces produced restrain this relative motion.

(3) Vibration dampers—vibration dampers can be added to a system to provide resistance to the vibratory

motion in addition to the inherent resistance in the system. Two general types of vibration dampers are the dynamic and the damped vibration absorber.

computer analysis

Of immediate concern to the design engineer is the determination of natural frequencies and vibration amplitudes of the system and components, both torsional and lateral. Lateral analysis of components consists of calculation of vibration amplitudes in two perpendicular planes for a given range of frequencies. These vibration amplitudes are calculated on an IBM-704 computer using a Holzer-type iteration method.

Calculated amplitudes are plotted against frequencies, and from this can be found the natural frequencies or critical speeds, which correspond to peak amplitude values.

Phase effects are introduced by the damping; that is, deflections at different positions along the rotor are neither in phase nor 180 degrees out of phase with each other. Instead, particles along the rotor differ in phase with respect to each other and with respect to the exciting force. The magnitude and phase of each amplitude is determined by the magnitude and sign of the components.

When the rotor reaches its second resonant frequency, the line connecting the vibration-amplitude vectors along the rotor becomes a spiral curve (Fig. 5). The curve projection on the horizontal or vertical plane yields the mode shapes in these planes at each given frequency at a given instant in time.

The spiral shape of the rotor has been calculated assuming vertical oil-film flexibility and damping. Oil-film properties in the horizontal direction are different. Therefore, vibration amplitudes change every fourth of a revolution, so that each particle moves on an elliptical track at a given frequency. The resonant frequencies corresponding to the horizontal properties of the oil film are usually lower than the resonant frequencies corresponding to the vertical properties.

Forces acting on the rotor (Fig. 5) are shown by arrows only at two points: bearing number one and a point one fourth of the way between bearing centers where the disturbing force is applied.

All along the rotor the inertia forces ($m\omega^2y$) are in phase with the radial displacement. The bearing damping force ($\beta\omega y$) lags behind the radial displacement by 90 degrees and opposes the journal velocity (vibration). The bearing spring force (ky) opposes the journal displacement. The disturbing force (P) at the point of application leads the rotor displacement at that point by ϕ degrees.

Work done by the disturbing force (P) is equal to the work absorbed by the bearing damping for any steady-state condition. All through the calculations, the results are checked for each assumed frequency by equating the forcing energy to the damping energy. Under any given steady-state condition, the displacement vector of each rotor section is constant in magnitude and rotates about the axis. At any time, the displacement of any point along the rotor can be expressed by the X and Y components of this vector.

In making the torsional vibration analysis of the system, the inertias and spring constants of the actual system are converted into an equivalent system by referring them to the speed of the driving motor, because this is the point at which most of the torsional excitation is applied. An example of the actual and equivalent systems is shown in Fig. 6. With the data in this form, calculations can be made on a large-scale, general-purpose analog computer by forming a direct passive-element electrical analog of the mechanical system and exciting the analog by the forcing function. If a digital computer is used, the linear, constant-coefficient, differential equations are solved by a step-by-step in-time method.

Natural torsional frequencies, mode shapes, and relative shaft torques of a lossless system are calculated on a digital computer using a Holzer-type iteration method.

An initial frequency and a deflection of one radian at the first mass are assumed. Using the equivalent mechanical system, a check is made on the condition of zero output torque at the last mass. By taking incremental frequency steps and interpolating, accurate resonant frequencies, mode shapes, and relative shaft torques are obtained for the lossless system.

Losses, of course, are present and these factors must be taken into account. The significant losses or damping occur in the motor, and in some cases, in the load. Electrical damping is calculated from the motor constants. The mechanical damping factor in the shaft is conservatively estimated at ½-percent per cycle on an amplitude basis. If the load is an axial flow compressor, then the slope of the speed-torque curve at the speed in question is used as the damping factor.

When all factors are taken into account, a multiplier is used to convert the computed mode shape and relative torques of the lossless system to actual values.

Torque build-up should be determined when the system is accelerating through resonance and compared with steady-load torque. Oscillatory torque in excess of steady-load torque is an intolerable condition and should be avoided at all cost. Torque build-up is limited by system damping and also because of the fact that the system merely passes through resonance during acceleration. Calculation of torque build-up during acceleration consists of two parts.

A computation is first made of system build-up due to known damping, under the fictitious condition that the system is running at a speed corresponding to a resonant frequency with no acceleration.

Then a multiplying factor is calculated, which approximates the effect of acceleration through resonance. The approximate total build-up during acceleration through resonance is a product of these two calculations.

conclusion

A thorough and accurate system vibration analysis is advantageous, because the designer can build a system with increased assurance that it will be free from harmful vibrations. However, absolute assurance is not possible because an installed system can be excited from unpredictable sources. Even in this event, with prior knowledge of system natural frequencies, correction can be made more easily. Unquestionably, a thorough vibration analysis is a prerequisite to obtaining a smooth running system, and saves time and money by eliminating costly delays and system revision after installation. ■

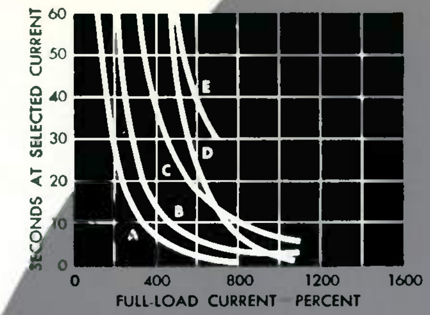


Fig. 1—Time-current relationships for motor protection. The curves represented are: A—motor acceleration; B—thermal relay; C—time to allowable cable temperature; D—fuse (three times motor rating); and E—time to allowable motor temperature.

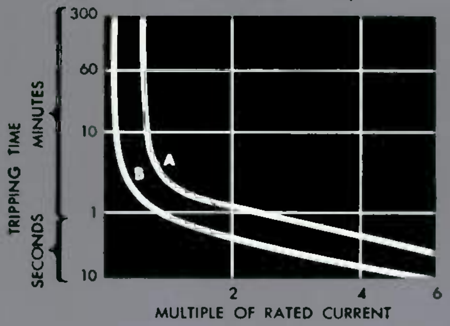


Fig. 2—Average time-current curves for a type MW bimetallic relay. The curves represented are: A—cold-start; and B—preheated at 80 percent of rated current.

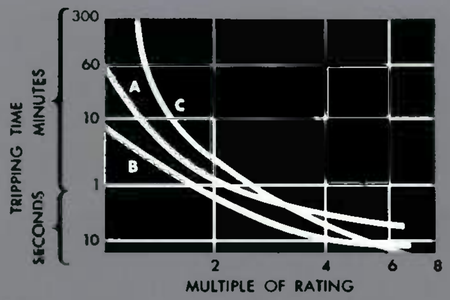


Fig. 3—Comparison of time-current curves for minimum motor capability and a type MG bimetallic relay (60 cycles, reset time less than 10 seconds, temperature compensation, and plus or minus 15-percent current adjustment). The curves represented are: A—both poles energized; B—one pole energized; and C—minimum motor time-current curve.

TEMPERATURE PROTECTION FOR INDUCTION MOTORS

. . . today and tomorrow

In addition to regular refinements in relays and circuits for temperature protection of induction motors, a revolutionary device is being developed that reacts directly to temperature changes in the motor winding.

J. K. HOWELL, Manager
Southwestern Engineering & Service Dept.
Westinghouse Electric Corporation
St. Louis, Missouri
J. J. COURTIN
Motor Department
Westinghouse Electric Corporation
Buffalo, New York

What kind of protection does a motor need to prevent overheating and failure? This depends on many considerations: the size of the machinery, the type and design of the motor, the importance of the process, and the load features of the application. For many applications, code requirements, such as those specified by the National Electrical Code, ASA, and NEMA are sufficient.

However, new control devices are being developed that hold promise of greatly simplifying the problem and increasing the reliability of motor overtemperature protection. Recently, a new switching thermistor was developed that has a positive temperature coefficient. Placed in the winding of a motor, the thermistor acts as a switch when dangerous temperatures are reached. Because it reacts directly to the winding temperature, and has fast switching action, it is better suited than replica-type relays.

A basic review of minimum motor-protection requirements and present relay-control schemes will help place these new developments in their correct perspective.

code requirements

The control for a typical motor branch circuit specified by the National Electrical Code includes the following devices or functions: (1) motor controller, (2) motor overcurrent protection, (3) motor branch-circuit disconnecting means, and (4) motor branch-circuit overcurrent protection.

Generally, the control of an a-c induction motor has: a contactor to start and stop the motor; a thermal overload relay for motor overcurrent protection; branch overcurrent (primarily short circuit) protection; and a disconnecting means, provided with circuit breakers or fused disconnects. A rating or setting of branch-circuit overcurrent devices of 115 to 400 percent is permitted, depending on the starting and accelerating requirements.

The operation of motor-overcurrent and branch-circuit overcurrent devices during acceleration and short-circuit conditions is shown in Fig. 1. These curves represent an ideal application where the thermal relay permits ample time for acceleration, yet is well below the motor and allowable cable-temperature curves. In the short-circuit current range, circuits, thermal relays, and contactors are protected by branch-circuit overcurrent devices (fuses in this case). However, many applications are not this simple.

Before applying protection devices, the inherent temperature limitation of the motor should be known for all operating conditions.

motor temperature limits

Most industrial polyphase motors from 1 to 200 hp in the United States are manufactured with Class A insulated, mush- or random-wound stator coils and die-cast, aluminum-alloy rotors. Stator windings and other motor parts should be prevented from reaching temperatures that will unduly shorten their life. Of secondary consideration is the protection of the branch circuits to the motor.

For short periods, stator-coil, rotor squirrel cage, and end-ring temperatures can exceed normal-load running temperature. For Class A designs, short overload periods (seconds) are based on a total stator-coil temperature of 150 degrees C in a 25 degree C ambient. However, some Class A materials are available that have enough margin so that the short overload period can be based on a total temperature of 200 degrees C. The permissible short overload period for aluminum die-cast rotors is 200 to 250 degrees C total for acceleration, and 300 to 400 degrees C total for locked-rotor conditions.

The rotor becomes the limiting factor in large and high-speed motors, because the larger the motor, the longer the stator coils take to reach the limiting temperature. Conversely, on small motors, stator-temperature limits are reached much quicker than rotor-temperature limits.

For continuous-running, 40 degree C rise motors with a service factor of 1.15, overload protection of not greater than 125 percent of motor full-load rating is provided. Motors rated at 55 degree C rise are provided full-load protection set at a maximum of 115 percent of motor-nameplate current. Motors operated in ambient temperatures lower than 40 degrees C have a capability greater than their nameplate rating.

motor capability versus overload characteristics

When severe duty cycle or other abnormal usage is considered, the motor manufacturer should be consulted. If locked-rotor time is known, and calculated accelerating time exceeds it by a factor of more than 1.35, the application should be carefully reviewed, to be sure that the motor is suitable and the overload relay provides an acceptable margin of protection.

Conditions that can cause a motor to overheat and for which thermal overload relays are applied are: (1) overloads, high running currents, (2) stalled-rotor conditions, and (3) phase unbalance, including single-phase during starting or during running in a polyphase machine.

The bimetallic overload relay is most commonly used for protection of integral-horsepower, three-phase, general-purpose motors. The device attempts to duplicate the heating characteristic of the motor on a small scale within the relay. A review of 2-, 4-, 6-, and 8-pole polyphase, NEMA Design B motors from 1 through 30 hp shows that 20 seconds can be used as a reasonable permissible locked-rotor time. These motors can be protected by a bimetallic relay with a time-current curve as shown in Fig. 2.

The characteristics of the relay in Fig. 3 are applicable to most motors rated 30 to 200 hp that would not be suitably protected with the characteristics shown for the relay of Fig. 2. Superimposed on this illustration is the minimum motor time-current characteristics that overload relays are called upon to protect. This curve is representative of 3600-rpm motors at 150 to 200 hp. This relay (MG) is adjustable to approximately plus or minus 15 percent of its rating. Because the relay has two poles, it affords extra single-phasing protection. The MG relay is also temperature compensated.

Bimetallic relays that are not temperature compensated can be troublesome when applied in ambient temperatures different from the motor ambient. Nuisance tripping often results from abnormally high ambients due to improper ventilation of the control room, the control enclosure, or effects of direct rays of the sun in outdoor installations. Because bimetallic relays and motor ratings are based on a 40 degree C ambient, they should be derated when applied in higher temperature ambients.

Thermal-overload relays have an inverse-time characteristic, which, in general, follows the heating curves of the motors. The minimum tripping currents of nontemperature-compensated, bimetallic relays vary with change in ambient temperature at approximately the same rate as the change in motor capability. Heaters selected for protection in a 40 degree C ambient, therefore, provide motor protection at other ambients. The actual change in minimum trip for nontemperature-compensated relays is approximately one percent per degree difference from 40 degrees C. This should be considered when the motor and the relay are located in different ambients. Ambient temperatures for the relay should be interpreted as inside the enclosure and not in the room or outdoors.

a new temperature-compensated relay

Thermal-overload relays are being continually improved to make their operation correspond more closely to motor temperatures and to increase the motor's protection against various hazards.

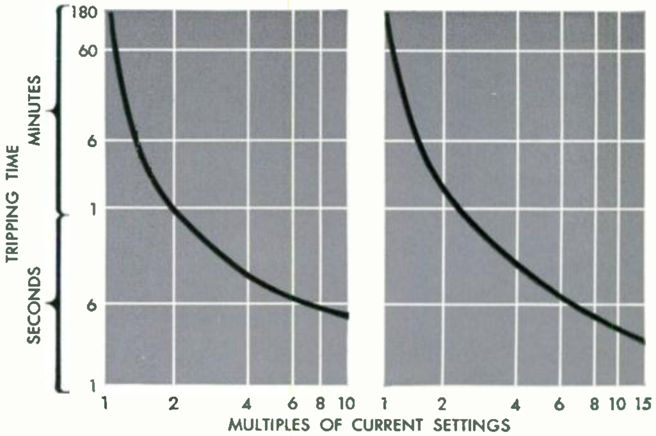
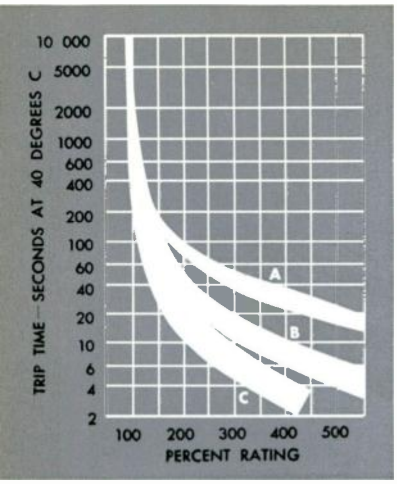


Fig. 4—Time-current curves for a TC-45 (left) and a TC-125 (right) relay—both are three-phase adjustable overload relays.



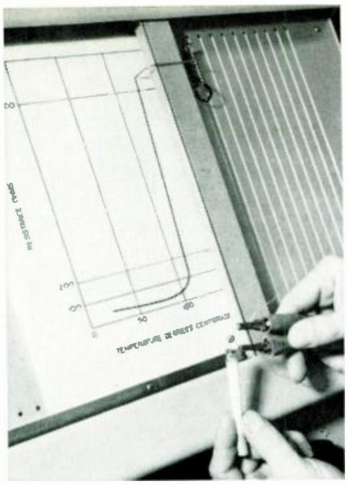


Fig. 5 (far left)—Time-current curves for Quick Trip thermal relays, used in hermetic motors. The curves represented are: A—type MW11 relay; B—B-series relay (air conditioning); and C—R series relay (air conditioning).

Fig. 6 (left)—Resistance-temperature characteristic of PTC thermistor.

Fig. 7 (right)—A typical PTC thermistor harness assembly for a three-phase winding.

Fig. 8 (facing page)—A control circuit for inherent motor protection using PTC thermistors.

Time-current curves of an improved relay (TC) are shown in Fig. 4. This relay has a tripping characteristic averaging 7 to 9 seconds at 600 percent of its rating. It is a three-pole device using bimetal strips with fixed heaters. Each bimetal strip operates on a common trip bar so that in case of an overload, a toggle switch is actuated. A compensating bimetal is used to cause the trip current to be substantially independent of ambient temperature.

For a given size, the continuous rating is adjustable over a 2-to-1 range. The relay carries the current at its setting, and trips at approximately 115 to 125 percent above its setting. With the load and relay at operating temperature, close settings can be accomplished by gradually reducing the relay setting until tripping occurs and then adjusting the setting upward slightly. However, the setting should not exceed the motor nameplate rating.

The inverse time-current characteristic of these relays gives a wider margin of protection for locked-rotor conditions, single-phase starting, and a single-phase or unbalanced voltage when running. They are also temperature compensated, which eliminates nuisance trips when the controller is located in high ambient temperatures.

relays for special applications

In many special motor applications, a standard type of industrial overload relay does not provide adequate protection. Hermetic motors used extensively in sealed air-conditioning units, for instance, have loading practices that require special attention. These motors operate closer to pull-out torque than general-purpose motors and thus at a lower ratio of locked-rotor current to full-load current. The average ratio is about 400 percent compared to 600 percent for general-purpose motors. As low as 275-percent locked-rotor current to full-load current ratios have been encountered. Hermetic motors may have the same locked-rotor current, torque, and losses as a general-purpose motor. However, because they operate at higher torque and draw a higher continuous load current, relays with a more inverse characteristic are required to carry the continuous current and still give positive locked-rotor protection. The operating characteristics of a standard bimetallic overload relay and a special bimetallic overload relay, developed to protect hermetic motors, are compared in Fig. 5. These relays are essentially the same as thermal industrial overload relays except that heating characteristics have been changed to alter the bottom part of the curve at values above 150 percent of the ultimate trip current. If less than 10 seconds tripping time is required on locked-rotor conditions, and the ratio between the relay rating and the locked-rotor current is less than 400 percent, an R-series relay (curve C) should be selected in preference to a B-series relay (curve B).

inherent motor protection

The air-conditioning industry has not been wholly satisfied with the protective scheme of thermal-overload relays and/or pressure switches because of nuisance trips and failures.

Recently a protection scheme has been developed that can be applied and installed by the motor manufacturer. Its purpose is to provide a motor protective system based on winding temperature alone, rather than on devices sensitive to line currents.

As a consequence of studies of oxide semiconductors, a unique type of thermistor has been developed at the materials engineering departments. In contrast to NTC thermistors, these thermistors exhibit *increased* resistance when heated; i.e., they have a positive-temperature coefficient and are called PTC thermistors, Fig. 6.

Because the PTC thermistors are placed in motor windings, they are made small for good thermal response, large enough to carry the coil current of industrial-type control relays, and rugged enough so that special handling is not required for installation. In the Guardistor motor-protective system, the element is a ceramic disc about the size of an aspirin tablet. The faces have a metallic coating and are fitted with leads. The element is encapsulated in an epoxy resin with compatible thermal, electrical, and mechanical characteristics. In practice, three PTC thermistors, one in each phase and connected in series, are used for a three-phase motor, Fig. 7.

At normal winding temperatures, the resistance of the PTC thermistor is low and remains virtually constant up to its critical temperature. Beyond this point, a small increase in temperature greatly increases the resistance. When the temperature of any of the PTC thermistors transgresses the critical or switching temperature range, the circuit operates to disconnect the power. When cooling occurs, the circuit returns to normal resistance and the motor can be restarted. Either manual or automatic reset can be used. By varying the composition of the ceramic discs, the critical range can be changed.

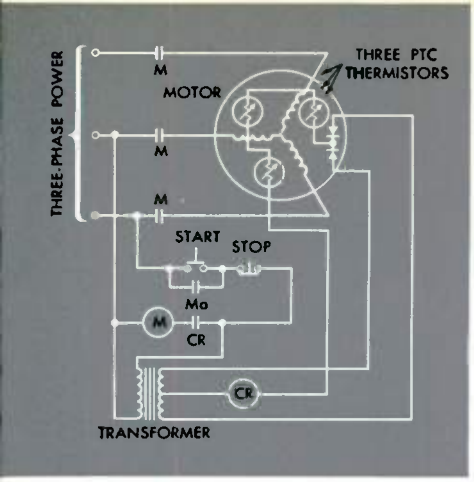


Table I—TEST MEASUREMENTS ON A 10-HP, THREE-PHASE HERMETIC MOTOR PROTECTED BY 110 DEGREE C PTC THERMISTORS

	Winding Temp. °C At Trip	Time* to Trip Seconds	Winding Temp. °C —Reclose	Time to Reclose Minutes
Running Overload	112	..	94	2.75
Locked-Rotor—Three-Phase—Rated Voltage	135	35	95	2.33
Locked-Rotor—Three-Phase—110-Percent Voltage	145	29	94.5	3.24
Locked-Rotor—One-Phase—Rated Voltage	133	50	94	1.66

*From Cold Start

Many field installations have been made to test the reliability and effectiveness of the new system. Simple inexpensive control circuits are possible and several different types are in use. In one circuit (Fig. 8), an industrial Type Z relay is used in series with PTC thermistors. Power is removed from the motor when any thermistor reaches its critical temperature, and is restored when the winding cools about 15 degrees C. The circuit can operate over a range of 85 to 115 percent of rated voltage. Any opening or grounding of the thermistor circuit causes the relay to drop out, shutting off the motor; thus the thermistor is also fail-safe.

For hermetic motors, PTC thermistors having a 110 degree C critical temperature have been used. Typical tripping features are listed in Table I.

PTC inherent protection

Great interest has also developed in the potential of the Guardistor motor-protective system for standard general-purpose motors.

Present thermal-overload relays are actuated by line currents, and thus operate on factors that are only proportional to winding temperature. These devices are often difficult to set where there are variations in duty cycle, variations in starting load friction or inertia, wide variations in ambient temperature, and unbalanced voltages. In many cases, independent judgment at the installation site is used to establish protection at whatever level precludes nuisance trip-outs.

In the Guardistor motor-protective system, the PTC thermistors are in the winding phases, in close proximity to motor hot-spots where they perform their switching function. Positive protection is provided on the basis of total winding temperature alone. Whether a motor has lost its ventilation, or an intermittent motor has run overtime, or the motor is overloaded, the protective system operates only at the limiting winding temperature, established by the manufacturer, thereby protecting against overheating in all cases, but without unnecessary trips.

With the Guardistor motor-protective system, full motor capability can be used without endangering the life of the motor. However, when this is done, the time-current curve for the protection might possibly be above that for the line cables (see curve C of Fig. 1), and care should be taken to check that the cables are adequately selected.

At present, it appears that standard components can be used, regardless of motor size or enclosure. The contactless thermistor, a semiconductor, requiring little electrical insulation, has little thermal lag between a change in its temperature and winding temperature. This is important in protecting against stalled-rotor conditions due to mechanical failure or loss of one phase from the power source, when the rate of heating is rapid.

In extending the Guardistor motor protective scheme to NEMA ratings up to 200 hp, rotor protection should also be considered. When the control is fully developed, PTC thermistors will be installed in the winding and will protect the rotor as well as the stator. The user need not be concerned with the level of motor protection or selection of heaters, etc. The system also can supplement other protective elements or can sound an alarm. Above 200-hp ratings, thermistors or other temperature-sensing elements in the stator cannot protect the rotor during a linestart-stalled condition. This also applies to motors under 200 hp with copper-bar rotors.

Guardistor motor-protective system field trials—oil-well pumping motors

In July 1959, a number of Guardistor motor-protective systems were applied to oil-well pumping installations; the motor ratings ranged from 2 to 40 hp. From these field trials, data on actual operational conditions will be obtained. The motor windings are equipped with three PTC thermistors rated at 110 degrees C and three thermistors rated at 125 degrees C. Overload relays are also in the line. The control panel is arranged so that when the winding reaches 110 degrees C, a clock starts; when the overloads in the line operate, another clock starts; and when the winding reaches 125 degrees C, the power to the motor and panel is interrupted. Thermocouples in the windings are used to check actual tripping temperatures. Data obtained will be useful in determining proper temperature-protection levels for oil-pumping and similar applications, as well as to provide service experience on the system.

summary

With careful application, adequate temperature protection can be obtained in most cases with conventional protective devices. However, revolutionary advancements, such as the PTC thermistor, will greatly increase the reliability of overtemperature protection, and will eliminate many complex application problems. ■

PERSONALITY IN SCIENCE

Ely M. Gelbard

A digital computer makes possible the solution of problems that otherwise would be enormously difficult or perhaps impossible. However the existence of a large machine is not in itself sufficient to ensure technical success. A major difficulty remains; namely, the reduction of a complex problem to a form that the computer—which basically can only add and subtract—can solve. This is a complicated process even when a broad base of experience exists in the particular technical area; it is considerably more difficult when the science and technology of the field is limited. Such is the case today with the design of cores for nuclear reactors.

Much progress has been made at the Bettis Atomic Power Laboratory toward the day when nuclear cores can be designed entirely by computer. A key group in this effort is the Reactor Methods Section, whose job is to analyze the physics of the problem, reduce it to a simplified "model" that can be translated into mathematical formulae; subsequently these are programmed for the computer. A key member of this methods group is a young physicist named *Ely M. Gelbard.*

The task is one that requires strong analytical ability, since the overall physics design is extremely complex, yet must be reduced to a relatively simple model. Gelbard is eminently qualified in this respect. As one of his acquaintances says, "When you talk to Ely, you get an almost immediate impression that here is a highly analytical mind generating ideas at an unusual pace."

In his work, which Gelbard describes as a team effort, physicists and mathematicians must not only work closely, but also be conversant with each other's problems. Thus, just as reactor design has developed technical people who are cross-breeds of physicists and engineers, utilization of a large computing machine has required blending of the areas of physics and numerical analysis. Gelbard's interests and his early background are strongly associated with both areas, so this hybrid activity comes naturally to him.

Gelbard's interest in science began as a young schoolboy in the Bronx, where he developed a fascination for astronomy and proceeded to read everything he could find on the subject. At the time, however, astronomers were not in great demand. The choice of a scientific career seemed impractical. Thus, when he entered City College of New York in 1942, Gelbard decided to study engineering. But he was not to study engineering for long. In 1943, he was drafted and assigned to meteorology. The Army Air Force sent him to Brown University to study, but shortly thereafter discovered itself with a surplus of meteorologists, and reassigned him to radar. After a period at Massachusetts Institute of Technology, he became an instructor in GCA, the radar approach system, then in its early stages.

When Gelbard left the Air Force in 1946, he enrolled at the University of Chicago, majoring in physics. While in school, he supplemented his income with part-time jobs that ranged from putting belt buckles on belts in a factory to translating French and German in a technical library. While working for his advanced degrees, Gelbard also served as an instructor in undergraduate physics. He earned his Master's degree in 1949, and his Ph.D. in 1954. Shortly thereafter, he joined Westinghouse at the Bettis Atomic Power Laboratory.

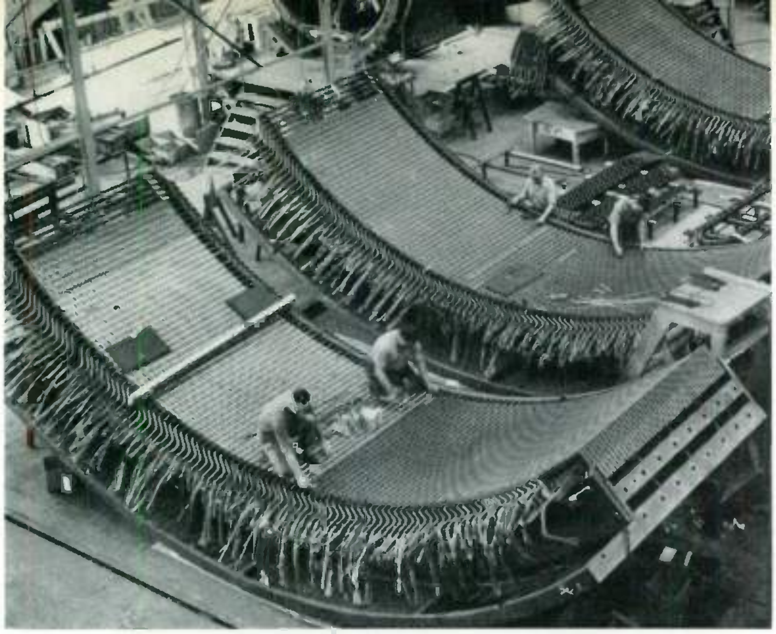
Gelbard is already an expert in his profession. He is immensely impressed by the advances in computer technology at Bettis since he first started, and although he would be the first to play down his own role in that progress, it is clear that it has been an important one.

In his field, which involves ideas rather than specific material devices, Gelbard's contributions are difficult to pinpoint, except to the computer expert or physicist. Most problems in reactor theory reduce to three basic questions: What is the neutron density at a given spot in the reactor? In what direction are the neutrons traveling? What is their energy? Gelbard has been associated with computer codes created to explore all three of these questions. His specific contribution has been to specify equations that describe some particular aspect of the problem in such a manner that a numerical program can be written for the computer. This job is a formidable one, since present computers are still far too small to permit a practical attack on the full-blown transport equation, the solution of which answers, in mathematical terms, the three questions posed above. For example, certain reactor design programs solve as many as a hundred thousand simultaneous algebraic equations. However, the result is still a crude approximation of the correct physical picture. Under these circumstances, a long-range systematic program is called for. Experts in nuclear physics must supply the required nuclear data. Numerical analysts must find the most efficient numerical method for solving the descriptive equations. Programmers must translate the specified equations and method of solution into a machine program. Intermixed with all this, scientists like Ely Gelbard must specify the details of some particular extension of the code system and, from the results obtained using the extension, determine what further development ought next to be attempted.

Any conversation with Gelbard's associates quickly indicates their respect for his abilities. Among the qualities mentioned are his thorough insight into technical problems. As one associate put it, "He has a striking ability to pinpoint difficulties and thus narrow the entire problem to a few essential questions."

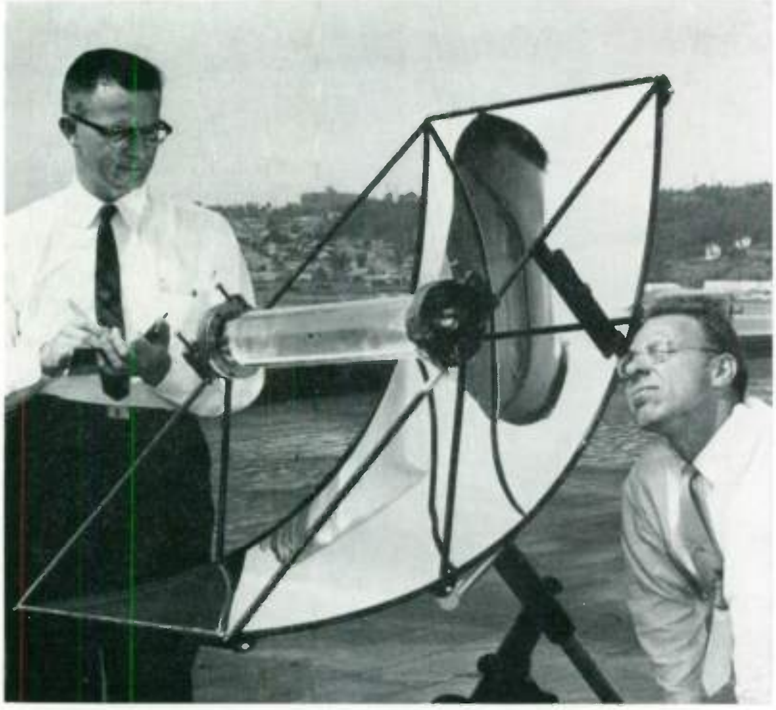
Perhaps the best way to describe Gelbard's personal characteristics is in the words of an associate—"unpretentious excellence." This is evident in his attitude toward associates. He feels strongly that the solution of reactor problems requires the collaboration of many different people with diverse talents. Characteristically, he is much impressed by the unusual degree of communication that exists between mathematicians, physicists, and engineers at Bettis, and credits this with much of the success of the organization. There is little evidence that he has ever given a second thought to his own ability and his contribution to the computer design effort. His concentration goes into his work.

In science, a new technology frequently demands a new mixture of talents. Ely Gelbard is an excellent example of the type of scientist required to take full advantage of the increasingly large and complex computers becoming available. ■



These stator sections are destined for the New York State Authority's Niagara power project. Fifty-two stator sections will be used in 13 water-wheel generators, each with a capacity of 167 000 kva.

WHAT'S NEW IN ENGINEERING



Solar energy powers this thermoelectric generator, which can produce 2.5 watts of electrical power. The concave mirror concentrates the sun's rays on the cylindrically shaped generator.

THERMOELECTRIC REFRIGERATOR-AIR CONDITIONER-HEATER FOR THE NAVY

An experimental three-purpose device that combines into a single system a thermoelectric air conditioner, space heater, and refrigerator-freezer will be built for the Navy's Bureau of Ships to test the suitability of thermoelectricity for air conditioning and refrigeration on ships. The design of the experimental model will be such that it lends itself to the construction of a full-scale system.

The three thermoelectric components of the system will be made of identical thermoelectric elements, which can be individually removed and replaced, and can act as building blocks for a thermoelectric system of larger size.

A central thermoelectric air-conditioning unit will supply chilled water that will be pumped to a standard Navy unit space cooler. Heat removed in chilling the circulating water can be used for space heating or can be dumped as waste heat into the sea water. The air-conditioning unit will have a one-ton capacity, which is larger than the average window-type unit used in the home.

The central thermoelectric heater will supply heated water to a standard Navy unit space heater.

The two-cubic foot refrigerator-freezer is capable of maintaining a temperature of zero degrees F, continuously.

Although heating can be accomplished by reversing the flow of current through a thermoelectric cooler, separate heating and cooling units will increase flexibility of operation and simplify gathering test data. ■

THERMOELECTRIC GENERATOR FOR OUTER SPACE

Long-mission satellites and manned space vehicles of the future will be able to tap a limitless supply of electrical energy by means of a solar-powered thermoelectric generator.

A model of a solar-powered thermoelectric generator, designed by a Boeing and a Westinghouse engineer, indicates the system is a practical source of electrical power in outer space

The generator weighs three pounds and measures 20 inches in length. It is capable of converting the energy of the sun into 2.5 watts of power—enough to operate a radio transmitter.

A sun-powered thermoelectric unit shows considerable merit as a source of auxiliary power for space missions that may take months or years. Requirements for this kind of equipment are stringent, for weight is at a premium, reliability must be high with little or no maintenance, and life expectancy must be long.

The first design problem was getting the sun's heat into the system; the second was dissipating the waste heat in the vacuum of outer space.

To evaluate these problems, a bench model generator was built, which could be instrumented but did not represent an attempt to attain the optimum flyable system.

Because a mirror device must be used to concentrate the sun's rays, mechanical problems arose due to the fact that the collector must have a large area, but also must be in a collapsed form during ascent, and must be extended or erected when in space. ■

MAGNETIC STIRRER FOR STEEL FURNACES

Though man has overcome the problems of mixing and blending culinary delights with electric mixers, some industrial problems are of slightly larger proportions—for example, how to blend several tons of molten white-hot steel and additives, such as chromium, to produce high-alloy steel.

Various types of mechanical stirrers have been used, but lifetime is obviously short, and in addition, accessibility is a problem when steel is melted in an electric-arc furnace.

One answer is a magnetic stirring device. The stirrer—a two-pole electromagnet—is placed beneath the bottom of the furnace, and as it rotates, a magnetic field sets up eddy currents in the molten metal. Interaction of eddy currents and the magnetic field produce a rotary force within the bath similar to that in the rotor of a squirrel-cage motor.

Magnetic field intensity can be varied with an adjustable-voltage, d-c motor-generator set that supplies excitation to the magnet. In addition, the magnet can be rotated in either direction over a range of speed from one-third to one cycle per second. The combination of adjustable magnetic field intensity and magnetic field rotation allows selection of the best stirring action for a particular melt.

Continuous stirring not only improves homogeneity of steel, but reduces slag and impurity content, temperature variations in the bath, and the amount of additives trapped in the slag layer on top of the melt. In addition, stirring reduces the time required for a particular melt.

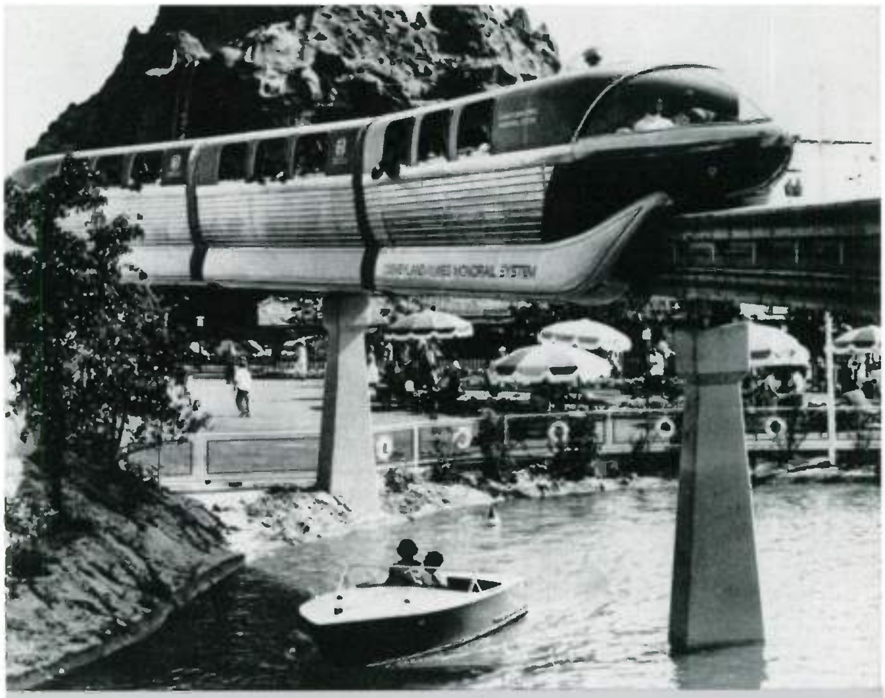
Such a stirring device was first applied to a 19-foot shell diameter electric-arc furnace for the Armco Steel Corporation. A second stirrer will now be used on a 13½ foot diameter electric-arc furnace, built by the Swindell-Dressler Corporation for the Midvale-Heppenstall Corporation. ■

GAS TURBINE FOR BLAST FURNACE BLOWING

The steel industry's first blast-furnace blowing gas turbine will supply 125 000 cubic feet of air per minute to furnaces at U. S. Steel's South Works in Chicago.

More than seven years of research went into the project to determine advantages of the new system in comparison to conventional methods of blast furnace blowing. Studies revealed that the gas-turbine system not only was lower in initial cost, but operating and maintenance costs also should be less. In addition, the gas-turbine system requires less space and uses practically no water.

Eliminated is the boiler and its



Electrical propulsion equipment is used to power two three-car monorail trains in a 3650-foot loop within Disneyland park at Anaheim, California. Because this is the first commercially operated, electrified monorail in the United States, operating experience will be used in comparing the monorail system with other types of transportation for metropolitan areas.

The trains are mounted on trucks that run on the top of a supported beam, and are stabilized with rubber-tire guide wheels which run on the sides of the beam. Each three-car train is mounted on four trucks. The two center trucks are each powered by a traction motor geared 8.81 to 1 on 30-inch diameter rubber-tire wheels. Rates of acceleration and braking are regulated by the pedal position of foot-operated power and brake pedals.

Although the propulsion equipment is capable of high speeds, the trains are run at slow speeds to give passengers an opportunity to view the park.

A 200-kw silicon-rectifier unit provides 300-volt, d-c power for the monorail. The rectifier is a self-contained unit with the transformer, silicon cells, regulator, and cooling and protective equipment in one package.

auxiliary equipment, because the blast furnace gas is burned directly in the gas turbine. The connected axial compressor supplies air to the blast furnace and to the combustion system of the gas turbine. ■

SEMICONDUCTOR EXCITATION SYSTEM FOR WEST PENN POWER COMPANY

After six years of development work, a 180-kw, 250-volt rotating rectifier system is being built for use on an a-c generator of the West Penn Power Company. This excitation system eliminates current collecting brushes, rings, and commutators.

The system consists of an a-c exciter and a rotating rectifier, and is mounted on the same shaft as the a-c turbine-generator field. The a-c exciter's rotating armature output is fed along the shaft of the rotating rectifier. The rectifier's output, in turn, is fed to the field of the a-c turbine-generator. A regulator, acting on the field of the a-c exciter, controls the strength of the a-c turbine-generator field. Thus, current collecting brushes are not required. Also, the conventional a-c generator field collector rings and the conventional d-c exciter commutator are eliminated.

The a-c exciter is a proven design with a rotating armature and a stationary field. The exciter generates 420 cycle, three-phase power, which is fed to the rectifier. This exciter can be separately excited, or it can be excited by a permanent-magnet, a-c pilot exciter whose output is rectified by a stationary rectifier.

The rectifier is composed of silicon diodes, which are arranged for the desired d-c output to meet the requirements of the a-c turbine-generator field. Sufficient capacity is provided so that the diodes will not be overloaded even if approximately 30 percent of each phase is out of service. ■

HIGH-POWER TRANSISTOR

The power-handling capabilities of transistors are ever increasing, thanks to ultrapure silicon. A prototype silicon transistor has been developed that can control 5 kilowatts of power when operated as a switch.

The low thermal drop from junction to case, coupled with a higher temperature capability, enables the power transistor to dissipate up to 250 watts internally. Now one transistor can be used in applications that previously required a number of germanium units connected in parallel.

The unit is made of ultrapure silicon produced by the Siemens-Westinghouse process. They are of the n-p-n configuration, and use a case designed to take advantage of the high current and high voltage of the new device. The case is of double-ended construction and is hermetically sealed.

The transistor is suited for high-power switching and linear-power applications because of the following characteristics: collector-to-emitter voltage ratings from 30 to 200 volts; maximum operating junction temperature of 150 degrees C; and saturation resistance of less than 0.1 ohm. With a minimum current gain of 10 to 15 amperes of collector current, these devices have a maximum collector current rating of 30 amperes.

Other possible applications for these transistors include high-power dc-to-dc and ac-to-dc converters; dc-to-ac inverters; high-power d-c regulators for current and voltage regulation; and high-power linear amplifiers. ■

Up to 5 kw of power can be controlled when this silicon transistor is operated as a switch.

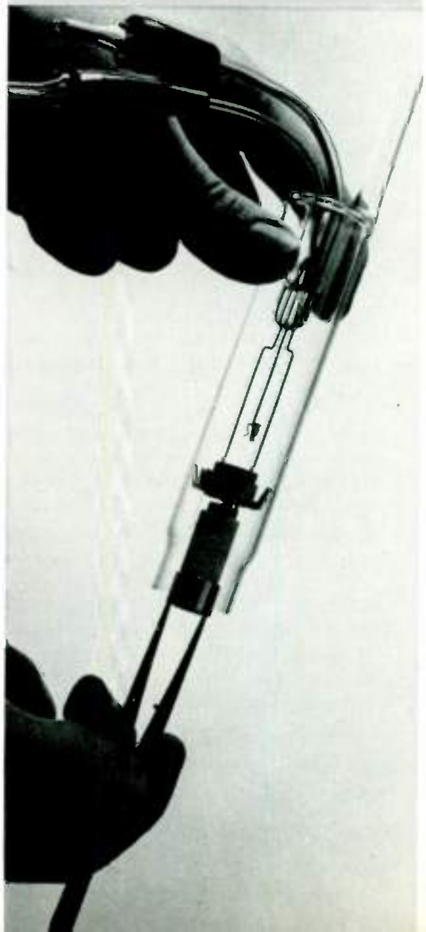
NEW SOURCE OF ELECTRONS FOR ELECTRONIC TUBES

If practical use can be made of a new discovery, electronic tubes may some day be transistorized. Physicists have discovered that a constant flow of electrons can be obtained directly from the surface of certain semiconductor materials. Thus semiconductor materials might be used to replace the conventional cathode emitter in electron tubes. The latest semiconductor to yield this unique flow of electrons is silicon carbide—a hard, crystalline solid, best known for its use in impure form as an abrasive in grinding wheels.

An electronic tube functions by regulating the flow of an electron stream across a vacuum. Conventionally, these electrons are boiled out of a coated metal wire, or cathode, at high temperatures. Considerable electric power is required to supply the necessary heat; the heat then must be dissipated to prevent the tube from overheating.

This new method of electron emission would eliminate this inefficient process. The heated cathode would be

A supply of electrons in this experimental electronic tube is obtained from a tiny crystal of silicon carbide, no larger than the head of a pin.



This three-phase testing reactor, with a rating of more than 300 000 kva, will be used to study the thermal and electrical characteristics of modern high-capacity turbine-generators.

The reactor can be used to test turbine-generators rated above 400 000 kva at certain voltages. And provisions have been made to extend the ampere rating so that future turbine-generators can be tested with ratings as high as 600 000 kva.

A turbine-generator is best tested when loaded at rated conditions. However, a large machine would require a full-size steam plant to drive it and a medium-size city to absorb the power. However, actual conditions can be simulated with a testing reactor by loading the machine at rated kva, but with zero-percent power factor.

Previously, generators usually have been tested by the open- and short-circuit method. However, considerable engineering analysis is required to relate results to operating conditions. Also, the data obtained is not as complete and the accuracy is not as high as zero-percent power-factor testing.

replaced by a small semiconductor crystal having a built-in junction like that in a transistor. The crystal would consume a negligible amount of power and would yield electrons instantly and indefinitely when a small electric voltage is applied across it.

Such a device would combine many of the advantages of both semiconductors and vacuum tubes.

The escape of electrons from silicon carbide accompanies the emission of visible light from the crystal. This visible light is in a form of electroluminescence, and occurs when enough voltage is applied across the junction to cause breakdown.

When breakdown occurs, small blue spots of light appear in the crystal in the region of the junction. Electrons escape from these bright, light-emitting spots, especially from those located nearest the surface of the crystal. The spots are small, only about 50 millionths of an inch in diameter. From the spots, currents as high as one millionth of an ampere have been measured, indicating that the density of the electron flow is comparable to that from the cathode of a conventional vacuum tube.

Although one millionth of an ampere is a small current by everyday standards, many sophisticated electronic tubes, such as beam-type camera and display tubes used in television and military electronic systems, may use considerably less current.

The pinpoint source of electrons would have many advantages in the construction of complicated tubes. Focusing of the electron beam would be simplified, and much complicated tube construction would be eliminated.

By removing the most serious limitations of the ordinary electronic tube, this discovery in semiconductors might give a new lease on life to the very device which semiconductors seem destined to outmode. ■

325-MW TURBINE GENERATOR

A 325-mw, cross-compound, steam-turbine generator unit will be built for the Sewaren Generating Station of the Public Service Electric and Gas Company, and is scheduled for operation in 1962.

Inlet steam conditions of the 3600-rpm cross-compound turbine are 2400 psi, 1100 degrees F, reheat temperature of 1050 degrees F, with eight stages of feed-water heating. The turbine will use four rows of 28-inch last-row blades, giving the largest exhaust annulus area of any four-flow 3600-rpm turbine ever built.

Each of the two inner-cooled generators is rated at 208 000 kva under 45-psig hydrogen pressure. The 18 000-volt generators will be arranged for outdoor service with walk-in enclosures over the collector rings. Each generator shaft will drive a one-half capacity boiler feed pump. ■

DATA LOGGING FOR A STEEL PLANT

Six data-logging systems are now being built for a large eastern steel producer. Of the six systems, three extensive systems will be applied to electrolytic tinning lines, and three simpler systems will be applied to coil preparation lines in the same plant.

All the data-logging systems will use NOR circuitry and plug-in modules as do the Prodac installations now in operation in various steel plants.

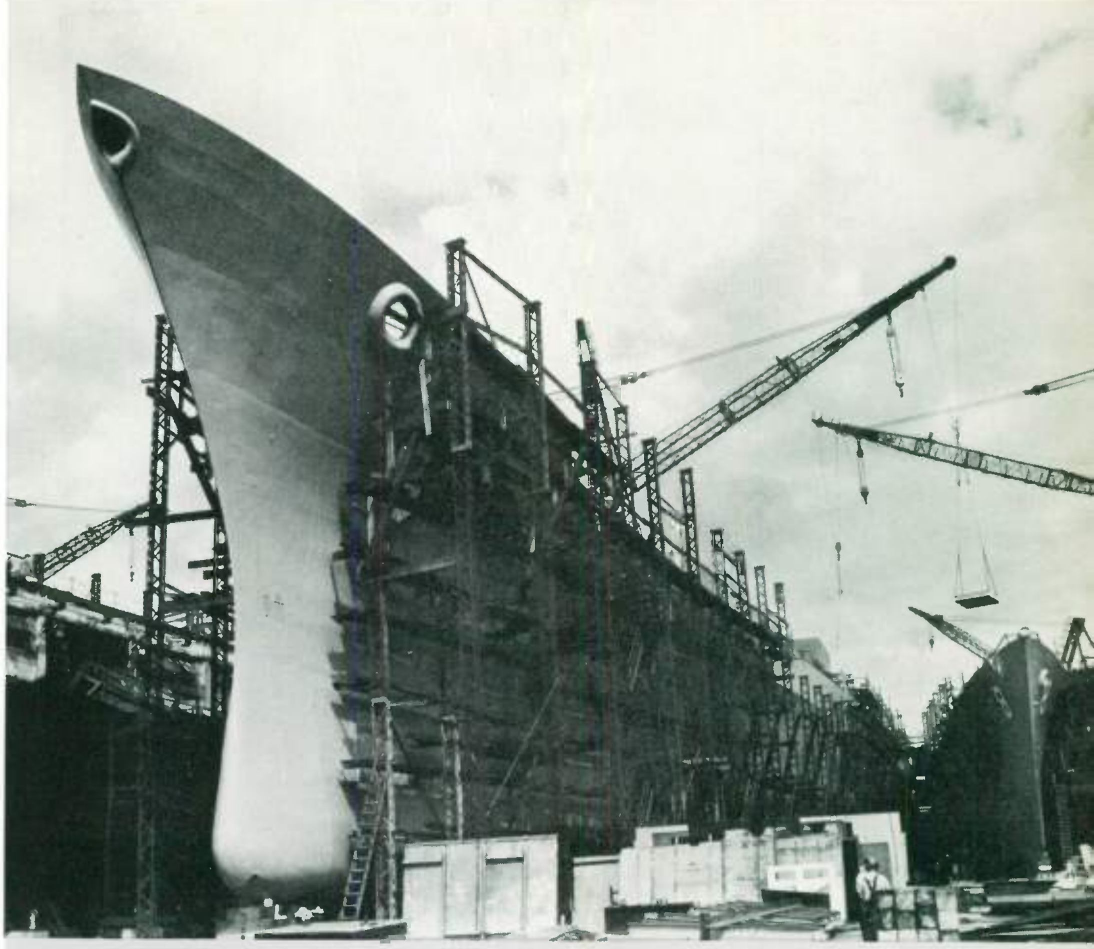
The static NOR element has proven itself a completely reliable building block, suitable for mill duty. This element has been incorporated into plug-in modules to comprise standard pulse shapers, counters, gates, shift registers, memory, and coding matrices. These modules are interconnected as required to provide complete data accumulation facilities.

A NOR element consists of eight precision resistors and one pre-aged transistor, packaged as a single potted unit in which all components operate at less than 50 percent of their rating. This unit is used universally as a static on-off switch for handling all logic at high speed. ■

SIMULATOR TRAINS CREW OF NUCLEAR MERCHANT SHIP

A training simulator that responds exactly as does an atomic propulsion plant will play an essential part in practice drills for officers of the world's first nuclear-powered merchant ship, the N.S. *Savannah*.

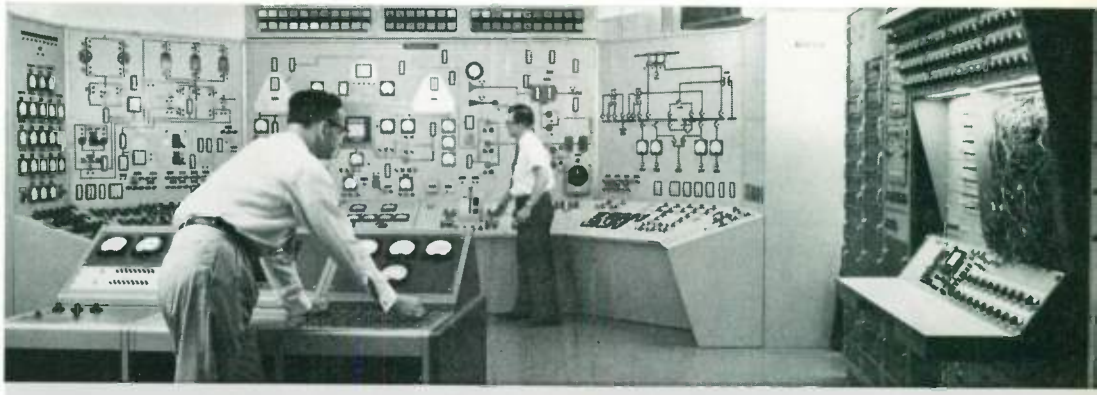
Trainees will operate the control console of the simulator as though they were aboard ship, taking orders from the bridge, represented by the instructor's desk.



The latest developments in reactor technology are incorporated in the two pressurized-water reactor plants of the U. S. Navy's first nuclear powered surface ship, the cruiser, *Long Beach* (see also back cover).

Design work for the *Long Beach* reactors was started in the fall of 1955. The land prototype reactor for the *Long Beach*, located at the AEC's Naval Reactors Facility in Idaho Falls, Idaho, was used for final testing, in a land-based section of a surface vessel's hull.

The cruiser, *Long Beach*, designed and built by the Bethlehem Shipbuilding Division of the Bethlehem Steel Company, is about 721 feet long, has a beam of approximately 73 feet, and displaces about 14 000 tons.



Officers of the nuclear-powered merchant ship, N.S. *Savannah*, will experience realistic drill at the controls of this training simulator.

The operators can start up the nuclear power plant, stand watches, simulate emergency drills, and perform all functions necessary to operate a ship's atomic engines. A total of 54 switches enables the instructor to cause simulated malfunctions or mock situations. At the instructor's desk are controls for a chart recorder, which transcribes data to be used in evaluating the performance of the student operators. When plotted on a strip chart, changes in pressures, and other variables reveal the speed and accuracy of the student's responses.

A practice drill might involve a runaway control rod in the reactor. When the instructor simulates this condition, indicators inform the operators that a control rod has been raised unintentionally and the power level of the reactor has been increased. The console operator should then adjust the controls that lower other control rods to reduce the power level. If the operator fails to take proper action, the console shows that the simulated reactor has automatically shut itself down as a safety precaution. Like the power plant that will be installed aboard the *Savannah*, the training simulator is fail-safe; it will shut down if it tends to operate beyond limits set for safety.

The system is installed in a classroom building at Lynchburg College in Lynchburg, Virginia, where a training program is being conducted for the Maritime Administration by the Babcock & Wilcox Company. ■

Employing more than 1000 scale-model machines and turbine components, this miniature plant is used in planning the rearrangement and modernization of facilities for the manufacture of steam turbines, condensers, heat exchangers, and nuclear steam generators, as well as marine propulsion turbines and gear units.

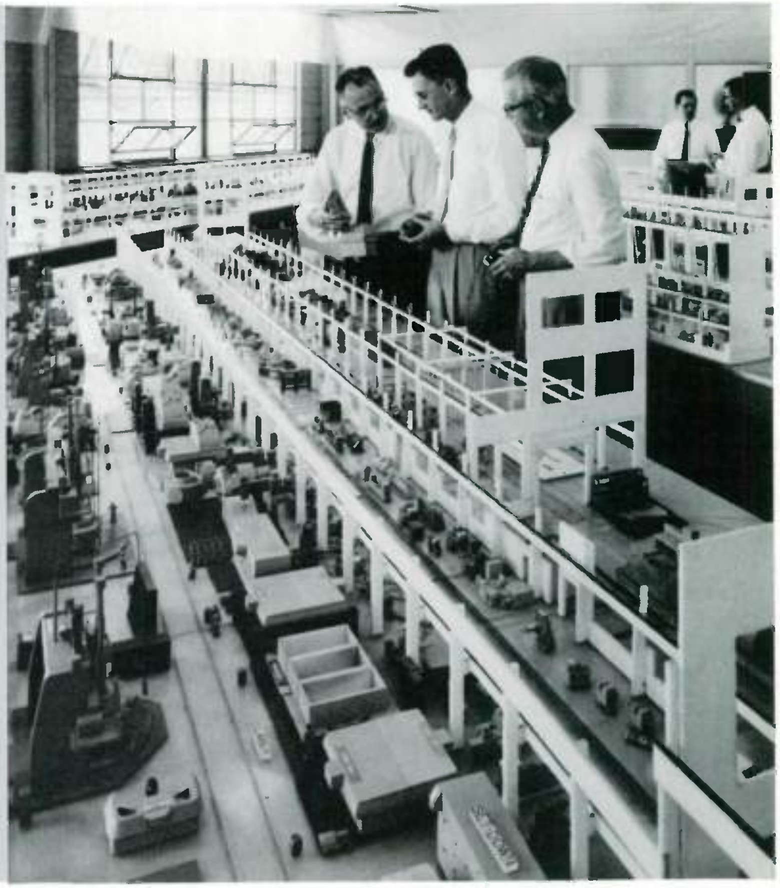
At the heart of the modernization program is a new engineering concept—the development of pre-engineered steam turbine components, which can be manufactured in duplicate sets and used as needed.

In the past, steam turbines have been almost completely custom engineered. Frequently this applied to individual components as well as the overall turbine arrangement.

Now engineers have pre-engineered many elements common to most turbines, taking into consideration user's requirements for steam turbine temperatures and pressures, ratings, and turbine arrangements. The pre-engineered basic elements can be assembled like building blocks in almost any combination from tandem-compound, double-flow units to cross-compound, octuple-flow units, and for ratings from 100 000 to 800 000 kw.

Among the advantages of the building block concept are greater flexibility of turbine arrangement, improved quality of components, and more reliable delivery schedules, because duplicate major parts will eliminate production delays caused by defective materials or parts damaged during production.

Use of the modular design, coupled with the extensive modernization and rearrangement of facilities is expected to permit a continued downward trend in the cost per kilowatt generated of turbine generators as they increase in size.



After 2½ years of outdoor operation, this dripproof, 500-hp, 2300-volt induction motor is still running—thanks to Thermalastic insulation.

To accelerate degrading factors, the motor has been operated under no-load conditions for 40 to 50 hours each week. At no-load, there is insufficient heat generated to produce any drying effect. Also, the large amount of down time gives ample opportunity for severe condensation. The motor has operated through two winters, and has been exposed to a typical northeastern climate, including snow, sleet, rain, dust, and heat.

Periodic maintenance tests have been conducted, including dielectric absorption studies at various voltages and a d-c overpotential test at the 6-kv level.

To date, the tests have not revealed any pending difficulty. A detailed examination of the mechanical features of the motor will be made at the next periodic test.

Engineers anticipate that the results of this test program will allow them to recommend these indoor-type motors for outdoor applications.

PERSONALITY PROFILES

Our team of authors for the article on transformer vapor cooling also paired up in the development of the first vapor-cooled unit.

PAUL NARBUT is a design engineer in the section that concentrates on long-range development. A native of Siberia, and a graduate of a Russian high school, Narbut came to this country 32 years ago. He went to Stanford University, where he obtained his AB in Engineering (Electrical Engineering), and later his PhD in Engineering and Mathematics. Narbut came to Westinghouse in 1940, and has spent the ensuing years in development work at the Transformer Division.

He was a charter member of the long-range development group, and has entered 60 patent disclosures in the course of his engineering design work.

G. A. MONITO assisted Narbut in collection of basic gas-vapor insulation data, and using this data, the two designed, built and tested the first vapor-cooled network unit. Subsequently Monito headed a task force to plan and design the 7500-kva unit.

Monito is a graduate of the University of Pittsburgh, where he earned his BS in EE in 1948. He joined the Transformer Division immediately and helped design coreform transformers for a year and a half, before being assigned to the Advanced Development Section where he worked first with Dr. Narbut.

Monito was promoted to Supervisory Engineer and then Section Manager of network and dry-type transformer design engineering in November 1957.

Both **A. P. COLAIACO** and **C. S. HAGUE** have been working with the silicon rectifier since its conception—Colaiaco has been developing the rectifier, while Hague looks for applications. This month's article on silicon rectifiers is one of their many team efforts.

Colaiaco graduated from Penn State with a BSEE in 1942, and joined Westinghouse on the Graduate Student Course. One of his first assignments was on high vacuum systems, or more specifically, the vacuum pumps used on the atomic project at Oak Ridge.

In 1947, Colaiaco was assigned to the rectifier development section where he worked with ignitrons. When the semiconductor appeared suitable for power devices in 1952, Colaiaco's efforts were directed to this new field.

A new section was created to handle expanding activity in semiconductor rectifiers in 1956, and Colaiaco was made Section Manager of Semiconductor Rectifier Engineering, which is his present position.

Hague graduated from Washington College (Chestertown, Md.) with a BS degree in 1938, and followed this with a BSEE degree from John Hopkins University in 1940.

After first touching base on the Graduate Student Course, Hague began a succession of assignments throughout the Industrial Engineering and Sales Departments. Starting in 1941, he worked in the steel mill, the electric utility, and the power electronics sections of industry engineering. In 1948, Hague went to the chemical and petroleum group of industrial sales, and four years later, to aviation sales.

He returned to industry engineering in 1952, when he was made manager of the power conversion section. This group was recently moved to the Rectifier and Traction Equipment Dept.

After three years of sea duty during World War II, **F. EMLEY** enrolled at Rensselaer Polytechnic Institute in Troy, New York and he graduated in 1949 with a BS degree in metallurgical engineering.

After graduation, he joined Westinghouse and went to work for the Materials Engineering Departments, his present location.

From 1953 to the present, he has devoted his time to solving materials problems through powder metallurgy techniques.

C. DEIBEL graduated from the University of Notre Dame in 1942 with a BS degree in metallurgy. He came to Westinghouse on the Graduate Student Training Course, and after a stay in the Research Laboratories, he then took a permanent assignment in the Materials Engineering Departments.

During World War II, he was assigned to the Manhattan Project at the East Pittsburgh plant. After the war, he returned to the Materials Engineering Departments and worked on nonferrous metal application problems, and as a metallographer. Deibel then concentrated on development of powder metallurgy techniques, his present bailiwick.

R. H. KLINE came with the company on the Graduate Student Course in 1945 directly from the University of Denver, and accepted his first assignment with the Electronics Division Sales Department.

He transferred to the Engineering and Service Department of the Middle Atlantic Region in 1952, where he served as both a consulting and application engineer, and an electronics field service engineer.

Kline returned to the Electronics Division as a systems engineer in microwave engineering in 1956, and a year later was placed in the design engineering department, where he was responsible for the design of the KA tone equipment of which he writes in this issue.

After serving in the Marine Corps for four years during World War II, **P. J. HAWKSHAW** attended Catholic University in Washington, D. C. He graduated with a BSEE degree, and came to work for Westinghouse on the Graduate Student Training Course. He took a permanent assignment in the Marine, Aviation and Transportation Facilities Engineering Department.

Hawkshaw has coordinated the overall application of electrical equipment to many wind-tunnel drives. His most recent assignments include two wind-tunnel drives which are now being readied for service by NASA at Langley Field, Virginia.

D. C. PHILBRICK graduated from Northeastern University in 1948 with a BSME degree. He came directly with Westinghouse on the Graduate Student Training Course and took a permanent assignment in the Large Rotating Apparatus Department. In 1954, he obtained an MS degree in mechanical engineering from the University of Pittsburgh.

Philbrick has worked on the design of many large motors, including the complete mechanical design of a 20 000-hp and a 36 000-hp compressor motor for two of the NASA's wind tunnels at Langley Field, Virginia. He also was responsible for the mechanical design of a motor-generator set for the new magnetic particle accelerator at Brookhaven National Laboratory.

M. RASHEVSKY obtained his Diploma of Engineering—the equivalent of a Master's Degree—from Prague Polytechnical Institute in Czechoslovakia. After graduation, he left Czechoslovakia and went to work for Westinghouse in the transmission line section of the General Engineering Department.

During the depression years, Rashevsky used his knowledge of foreign languages, which includes French, German, and Russian, to translate many reports, papers and patents. He then specialized in the design of steel strip mills, and at the start of World War II, he went to work for the Navy's Bureau of Ships.

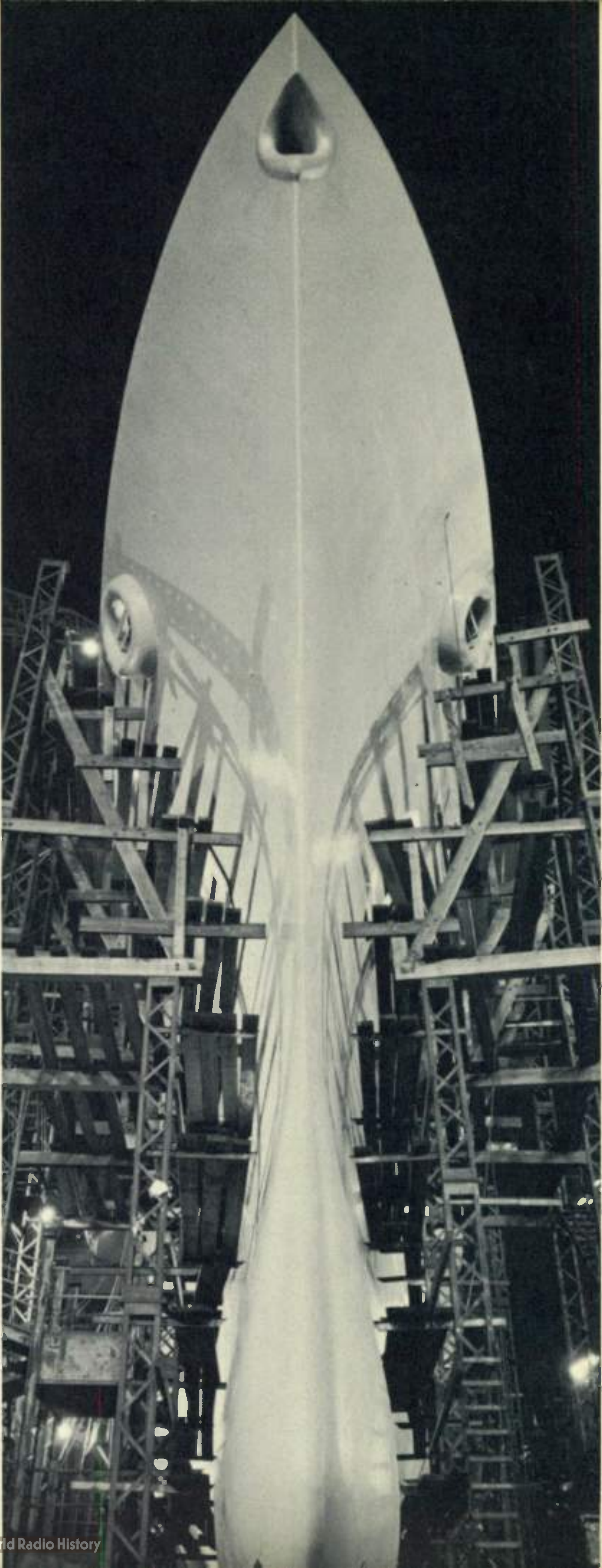
In 1943, he returned to Westinghouse and worked in the industrial heating section of the d-c engineering department. In 1945, he transferred to the turbine-generator section of the a-c engineering section. During this assignment, he worked on the mechanical design of turbine generators and became particularly interested in vibration problems.

In 1954, he was sent to Princeton to work on Project Matterhorn, a feasibility study for a prototype thermonuclear reactor. In 1957, he was transferred to the Analytical Department, where he works on mechanical problems of all types.

J. J. COURTIN graduated from the University of Villanova in 1938 with a BSEE degree. Two years later, he made his first acquaintance with Westinghouse as an Inspector of Naval Material in the Motor, Control, and Switchgear Divisions.

After World War II, Courtin joined Westinghouse in the motor engineering department as a design engineer. Since then he has helped develop standard lines of induction motors, under 200 hp. Courtin is now a Senior Engineer in the A-C Motor Development Section.

A year ago last September, **J. K. HOWELL** coauthored an article on application of electrical equipment to oil-well pumping installations. Howell's interest in oil-well equipment is evident from his position and location—Engineering Manager of the Southwestern Region.



The U. S. Navy's first atomic-powered surface ship, the cruiser **LONG BEACH**, shown prior to christening. (See story, p. 191.)