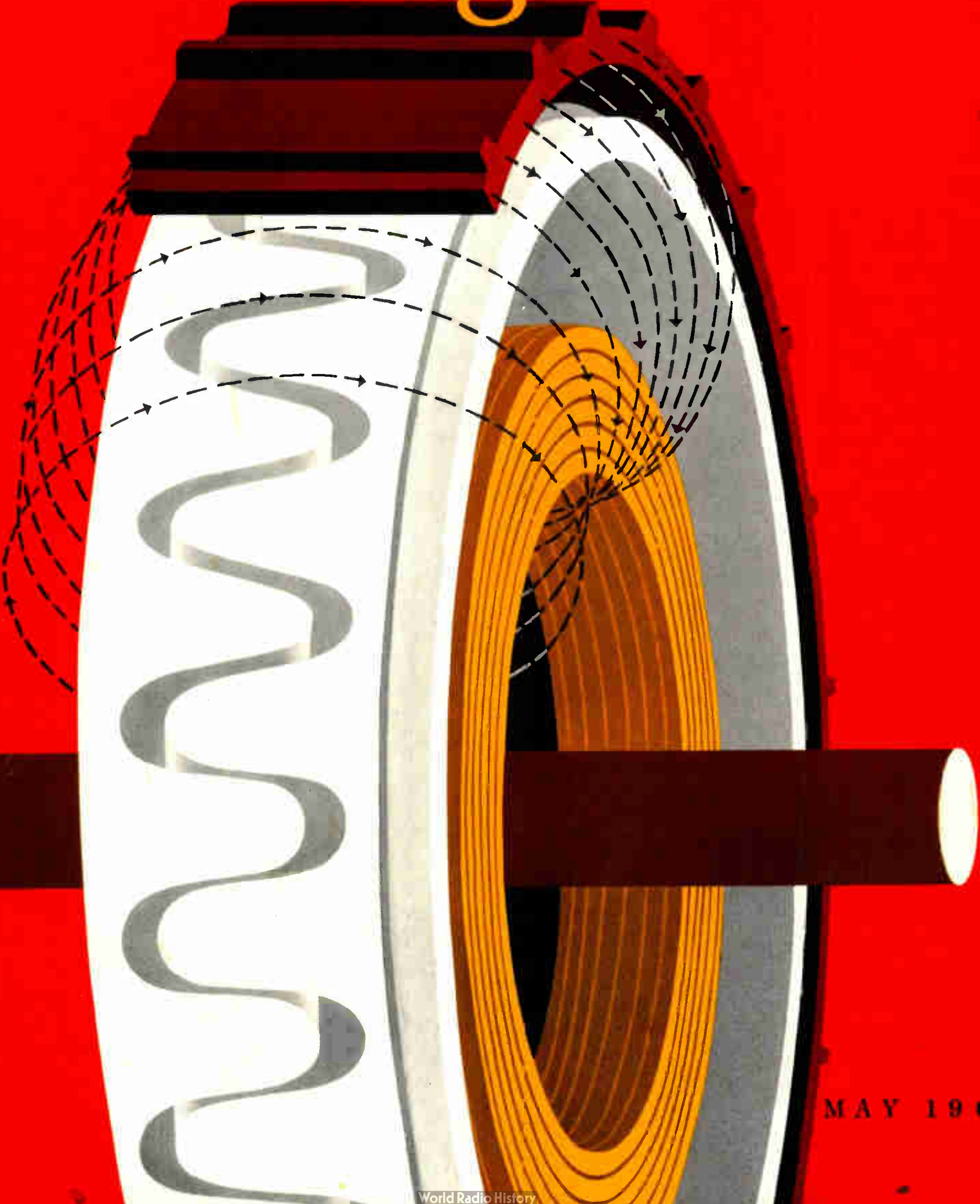
WESTINGHOUSE

Engineer



MAY 1960

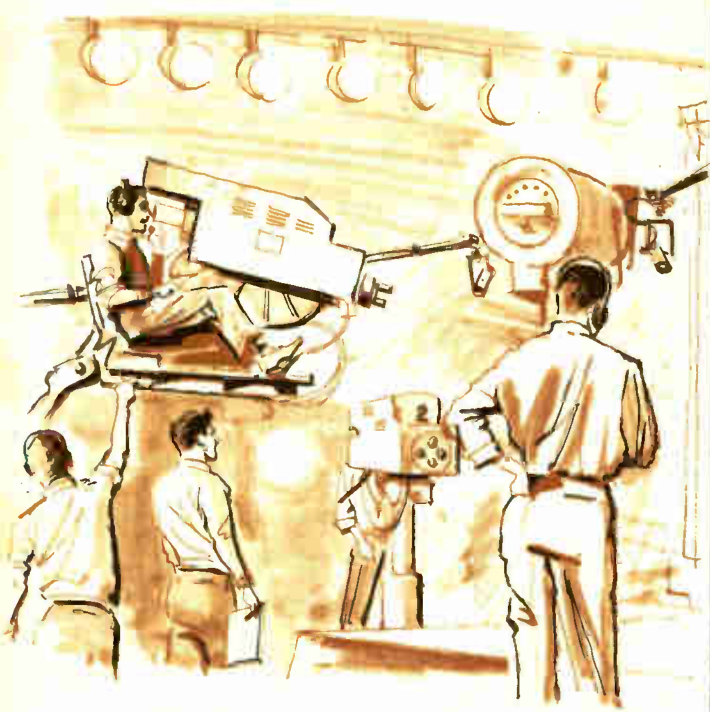
LAB 30

A NEW TV SCIENCE SERIES

Three years ago, scientists at the Westinghouse Research Laboratories started a series of classes designed to expose selected high school students to new concepts and problems in science. By necessity, this Science Honors Institute was limited to students from high schools in the Pittsburgh area.

However, the program was so successful that it led to a new television series, called LAB 30, produced by the Westinghouse Broadcasting Company in cooperation with the Westinghouse Research Laboratories. The new series consists of ten half-hour programs covering different advanced concepts in the physical sciences; the programs include demonstrations of the basic principles of each of the subjects, as well as discussions of the theories involved. The ten lecturers and their respective subjects are shown at right.

The first of these new programs appeared on television in March, over Westinghouse Broadcasting Company stations and selected commercial stations. Present plans call for the series to be shown on educational television this Fall. The programs, now on video tape, will be made available on film for classroom use.



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DR. PAUL FLINN

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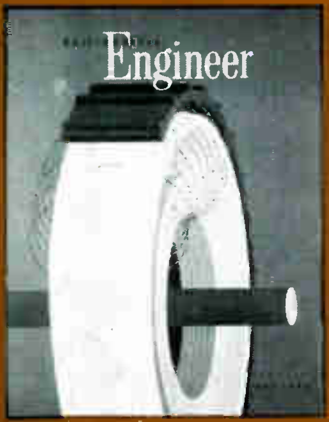

COVER DESIGN: An electromagnetic coupling (p. 71) has three basic components—a rotor made up of multiple pole pieces, an iron cylinder that surrounds the rotor, and a coil to provide the primary electromagnetic fields to the system. Cover artist Dick Marsh has used these elements for this month's cover design.

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

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THE CONCEPTS AND CAPABILITIES OF MOLECULAR ELECTRONICS

Today, an electronic subsystem, such as an amplifier, is constructed of many components connected in a suitable circuit. Tomorrow, as a result of a new concept called molecular electronics, a small block of material may perform the same function. Such devices have been demonstrated.

DR. S. W. HERWALD
Vice President, Research
Westinghouse Electric Corporation
Pittsburgh, Pennsylvania

Efforts to elevate air and space craft to new plateaus of capability are continually made more difficult through a technical paradox. As these craft are made more sophisticated through the use of advanced electronic gear, the risk of failure among components and connections grows. And as this more complex electronic equipment is added, providing for its weight and size becomes more difficult.

As a result, focused programs for the improvement of reliability, plus weight and size reduction of electronic equipment, are now underway in several locations. These problems can be approached in several ways. For example, improved reliability can be realized by better quality control of components and connections. However, the probability of simultaneous successful operation of all components in any system is the product of all the individual probabilities of a component functioning without failure, and better quality control does not invalidate this limitation imposed by the laws of probability. Smaller and lighter components in more compact packages can be obtained by miniaturization, but such techniques, while exploiting modern technology, do not yield maximum reliability. On the contrary, the emphasis placed on size and weight reduction has usually meant that components and internal connections become so critical that they must be built with extreme precision if their failure rate is to be acceptable.

In the recent past, a substantial part of Westinghouse research and development effort has been focused on a new and quite distinct approach to both problems. This involves a new concept in the design and function of electronic systems, called "molecular electronics," to indicate its dependence on *phenomena occurring within or between domains of molecules in the solid state.*

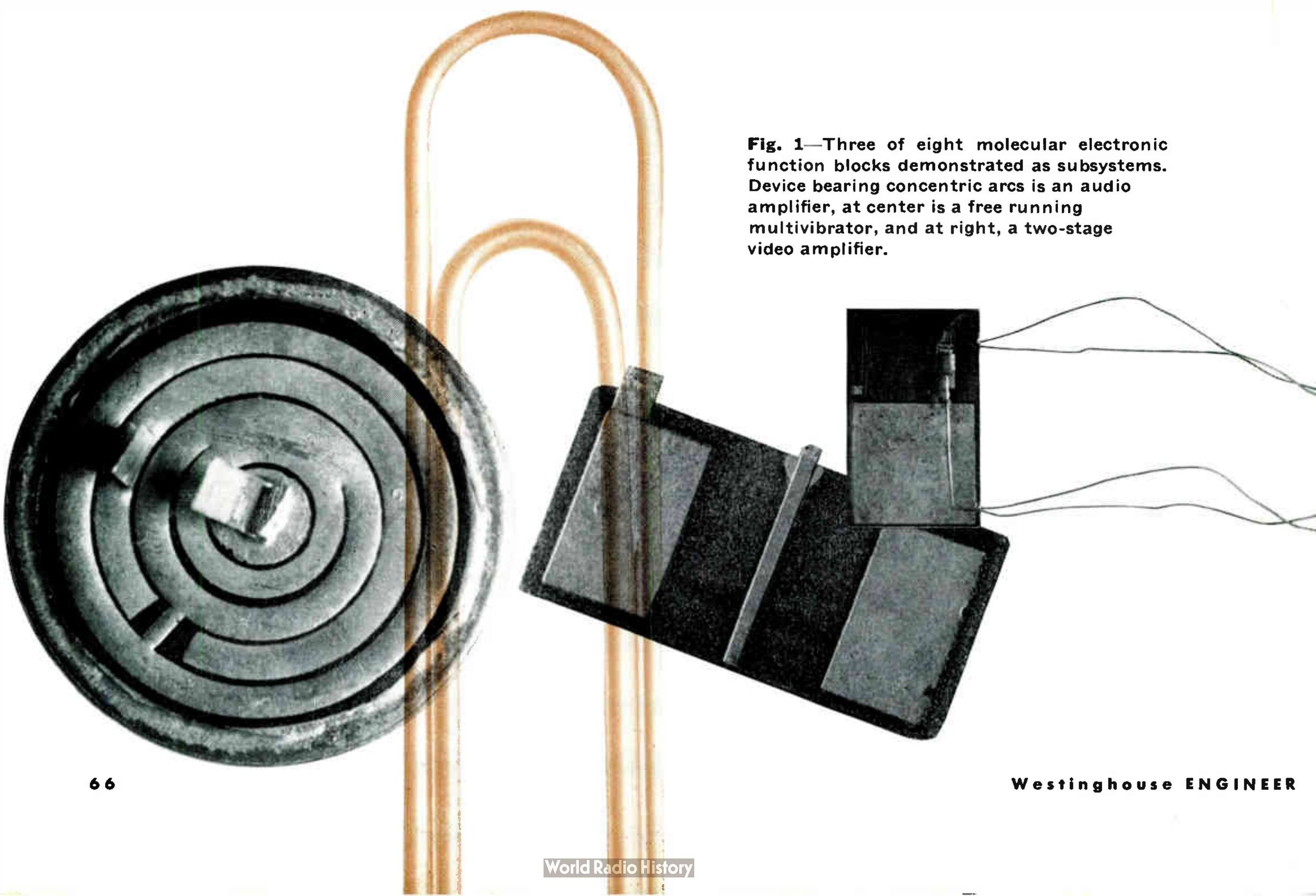


Fig. 1—Three of eight molecular electronic function blocks demonstrated as subsystems. Device bearing concentric arcs is an audio amplifier, at center is a free running multivibrator, and at right, a two-stage video amplifier.

Recognizing the potential importance of this concept to defense, the Wright Air Development Division's Air Force Electronic Technology Laboratory contracted with Westinghouse in a program to prove its feasibility. Specific objectives were: to determine to what extent molecular electronics can be used to perform complex functions in several systems of basic importance to the Air Force; to develop subsystems for those systems; and to develop new materials to advance the usefulness of the concept.

progress to date

As one accomplishment of the joint program, a variety of molecular electronic "function blocks" are being produced, three of which are shown in Fig. 1; these solid-state elements achieve, entirely within themselves, electronic results previously gained only by assembling many varied items of electronic hardware. Because of this, these elements are not intended as "components," such as transistors and tubes, but rather as "subsystems." Examples of functions performed by function-blocks are such electronic operations as amplification, oscillation, and telemetering.

Because there are no internal connections or components, and the only external connections needed are those for coupling inputs and outputs to the complete system, risk of failure of subsystems should be equal to or less than that of familiar solid-state devices, and perhaps one-thousandth of that for a subsystem built of many parts. This ability of molecular electronics to reduce the number of components and connections required is illustrated by a comparison of three designs for a light telemetering subsystem, Fig. 2a and 2b. When designed to use electronic tubes, this subsystem required 16 components and 18 soldered connections; when designed to use transistors, it required 14 components and 15 connections. In contrast, a molecular electronic subsystem to achieve the same purposes needed but one component and two connections.

Also, because their internal functions involve distances of a few atomic spacings, these function blocks are almost microscopically small and virtually weightless. For example, weight of light telemetry subsystems has been reduced from about one ounce to one quarter of an ounce; the weight of the monolithic element is about *seven ten-thousandths* of an ounce.

As a result of the joint program, eight classes of function blocks have been developed to demonstrate the feasibility of molecular electronics at frequencies ranging from infrared to direct current. These function blocks are: (1) a five-watt directly cascaded audio amplifier; (2) a two-stage video amplifier; (3) a frequency selective amplifier with notch filter in a feedback loop around the amplifier structure; (4) a variety of multivibrators—bistable, monostable and astable; (5) a variable potentiometer based on logarithmic addition of two inputs; (6) a variety of multiposition switches (including an "OR" switch, a multiple NPNP Dynistor switch, and a multiple NPNP Trinistor switch with firing electrode); (7) an analog-to digital converter employing an NPNP relaxation oscillator; and (8) a two-stage cooler, using the Peltier effect, covering frequencies from one cycle or less to three megacycles, for cooling infrared detectors to proper operating temperatures.

Substantial knowledge of solid-state phenomena developed over the past 30 years serves as the basis for these

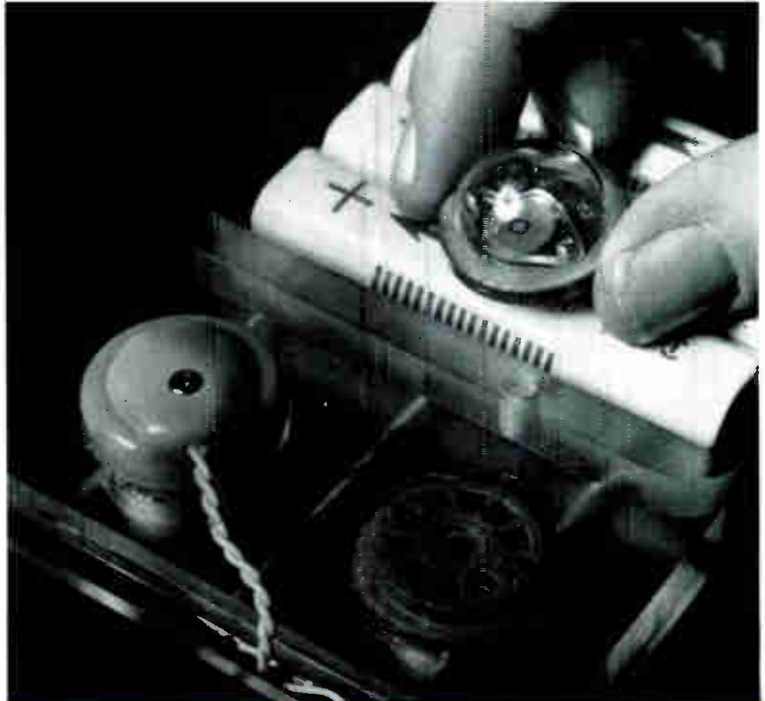


Fig. 2a—Light telemetry subsystem in which a single light-responsive monolithic element delivers an output whose frequency is measure of light intensity.

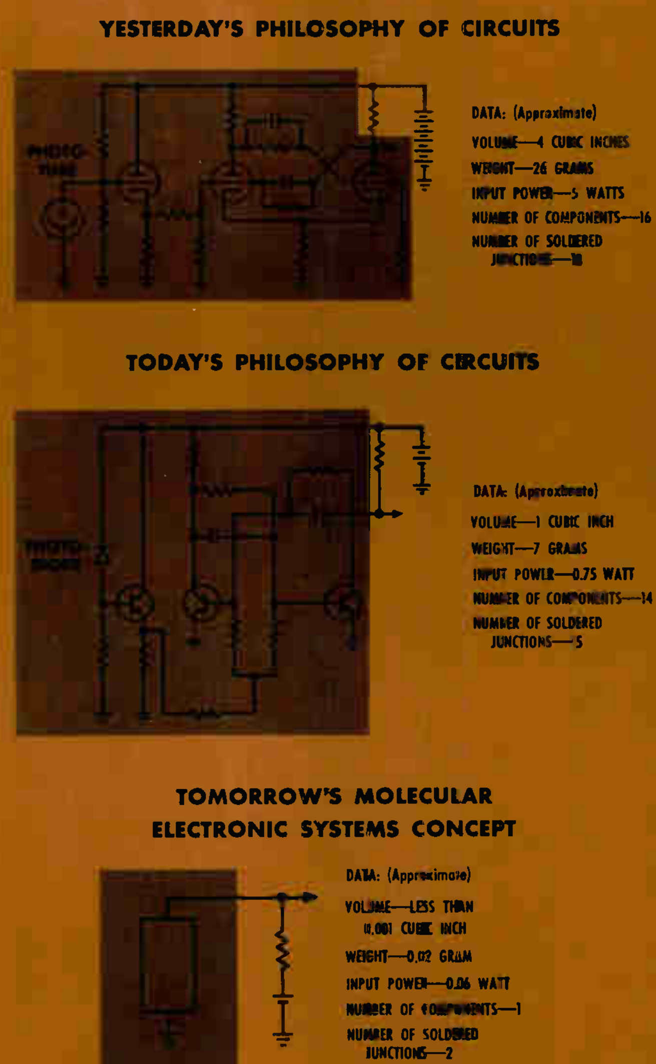


Fig. 2b—Schematic drawing of light telemetry subsystems showing extent of circuitry required for systems using (1) electronic tubes, (2) transistors, and (3) molecular electronic element.

molecular electronic subsystems. Materials having excessive positive or negative electrical charges are simple to create and, by placing these materials in physical contact with related materials, such phenomena as rectification or amplification can be achieved. Another phenomenon that can be used to advantage is the ability of radiation to cause charge paths to occur in a semiconductor material, along which current will flow when the material is irradiated.

Effects of this general type are used in molecular electronic blocks by creating—usually in single crystals—a number of distinct operative domains, which can be regarded as molecular "communities" having a common civic purpose, in that each domain will sustain a desired electronic occurrence. The domains border one another at boundaries called interfaces, which are like political frontiers in their ability to initiate phenomena different from those occurring inside the molecular domains.

As a simple example, the element diagrammed in Fig. 3 is composed of two domains that meet physically at one interface. One of these domains is composed of a resistive material selected and shaped to present a resistance R_1 to the passage of current; the other domain is also resistive, but is so planned that it has a resistance R_2. At the interface, the interaction between domains causes a capacitive effect. Thus, this tiny element is a subsystem equivalent to a time-delay circuit.

Another illustration of the uses of domains and interfaces is a function block designed as an ac-to-dc power supply for transistor circuits. It makes use of the Seebeck effect for the thermoelectric generation of electricity to convert 110-volt ac to 9-volt dc power. In contrast, the conventional circuit, Fig. 4, requires five individual components—a transformer, a diode, and the inductive and capacitive elements making up the LC filter circuit. To accomplish this purpose with molecular electronic methods requires a function block comprised of the three separate domains. When ac power is applied to the resistive domain, the heat generated passes through the domain at the center (this domain is an electrical but not a thermal insulator) and into the thermoelectric domain where the energy is converted into electrical energy by the Seebeck effect. By proper control over the materials used, the 9-volt dc output can be provided. An interesting aspect of the power supply is that elimination of ripple as an undesirable variation in voltage is inherent, since heat flows from the resistive domain to the thermoelectric domain at practically a constant rate.

As these two examples suggest, the concept of molecular electronics makes no use of the traditional circuit-and-component approach to electronics. Instead, the objective is to use knowledge of the structure of matter to synthesize function blocks whose arrangement and composition permit each to serve as a substation to perform an electronic function in control or transformation of energy.

To achieve function blocks with this capability, a number of effects and phenomena of the solid state are available. The only firm limitations on choice are that the effect must not react adversely on system reliability, and

Demonstration of high-level amplifier as a dc amplifier. Intensity of light impinging on solar cell is fed to function block as dc signal voltage. Supplied from battery, function block amplifies signal and delivers matching dc output to head lamps.

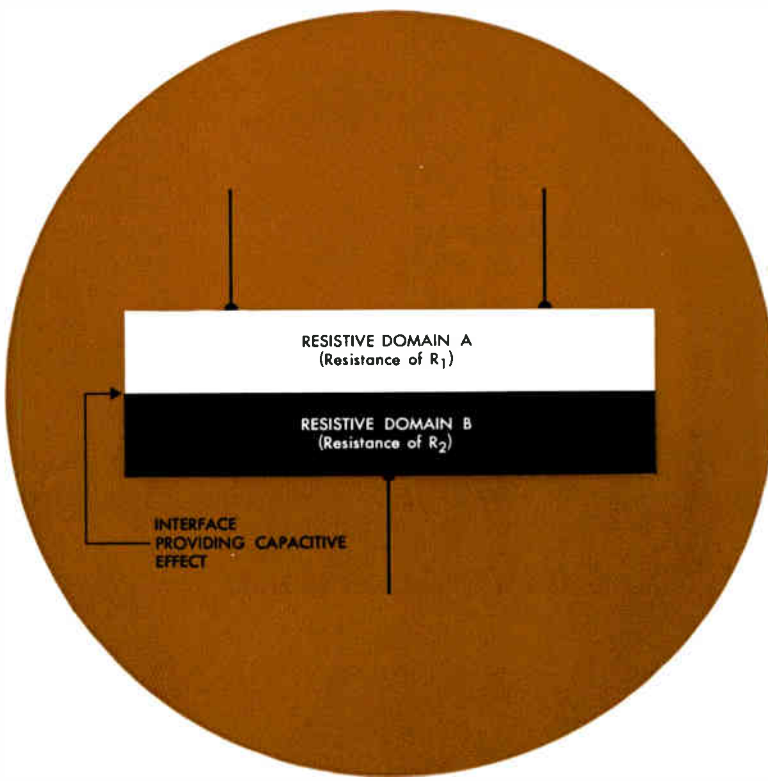


Fig. 3—Schematic drawing of function block of two resistive domains and one capacitive interface, whose total effect is that of an RC or time-delay circuit.

must lend itself to consistent results when included in a function block. Methods typical of practice so far include: solid-state phenomena, such as Seebeck generation, Peltier cooling, and Hall-effect multiplication; the use of PN semiconductor junctions arranged to produce a result that otherwise would require numerous individual components; and when necessary, fabrication of circuit elements within a function block. Although such phenomena will be used most often for the control of electrical signals, they will also be suitable when quantities like electromagnetic radiation, heat, and mechanical displacement are inputs or outputs.

The design of a subsystem begins with the designer's analysis of the system requirements, to establish the functions to be performed by the function block. After logic processes are determined and suitable physical effects settled upon, a topologist—a mathematician who works with shapes—determines the structure of the block by designing, on paper, the arrangement of domains and interfaces that is to control the flow of energy in the block. The block is then produced by the materials engineers, who use germanium and silicon as the basic materials.

These blocks are not assembled from various tiny components. Rather, the starting point is a basic semiconductor wafer and the necessary domains and interfaces are produced by techniques used in the production of conventional semiconductor devices, including diffusion, plating, electron beam machining, etching, cutting, radiation, alloying, and photographic processes. Although the block so produced can now perform its function, additional processing steps are required to encapsulate the block, protect it against shock and vibration, and make it stable under the conditions of temperature and radiation it will encounter.

the materials problems

The essential philosophy of molecular electronics is that materials can now be created, modified, and processed to endow them with the ability to accomplish electronic tasks through solid-state phenomena. The foundation for success is the ability to develop new materials and to process available materials in new ways.

One important illustration of the contributions made by materials scientists is the development of a method for the rapid production of semiconductor crystals in a form that requires no removal of material to make them into suitable wafers for use as transistors or as the basic elements of molecular electronic elements. This is the *dendrite process*, in which germanium crystals in the form of ribbons about one-eighth inch wide and a few thousandths of an inch thick are produced by drawing them from a molten mass. In the conventional method, germanium crystals are grown as thick ingots, or boules, which require x-ray or crystallographic inspection before they can be sawed into precisely oriented wafers and then must be lapped, etched, and polished to obtain a satisfactory working surface. In addition to the waste of material and the cost of machining involved in the standard method, a serious disadvantage to its use for the production of molecular electronic blocks is the wide variation in characteristics frequently displayed

A molecular electronic function block as audio amplifier in a conventional phono system. Frequency range is 0 to 20 000 cycles, output is 5 watts when heat sink is used. Amplifier is at right in black mounting. At left is a molecular electronic preamplifier.

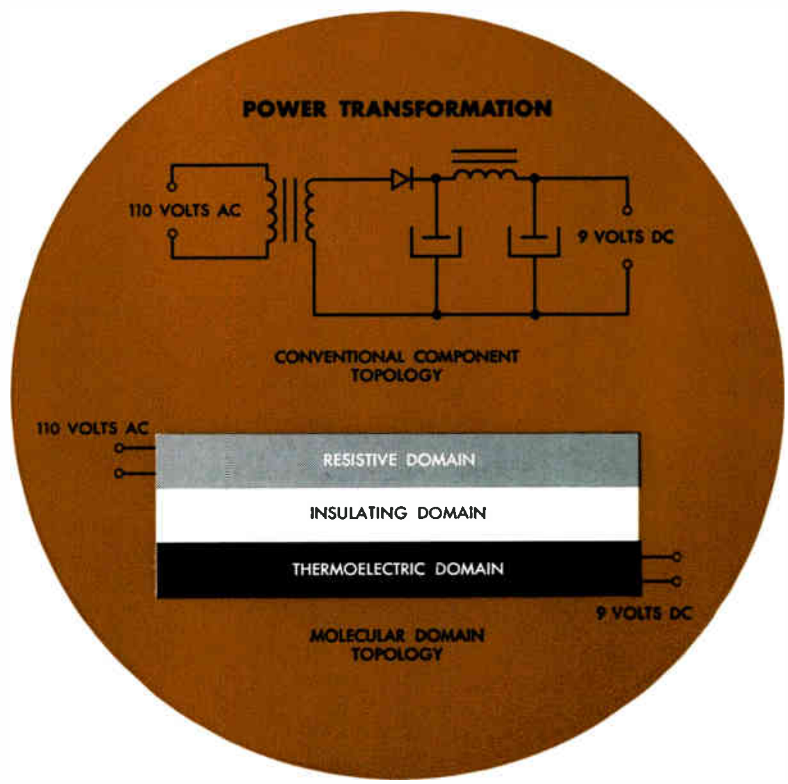


Fig. 4—Schematic drawing of ac-to-dc power supplies: (1) conventional method using transformer, diode, and filter circuit; and (2) molecular element with resistive, electrical-insulating, and thermoelectric domains.

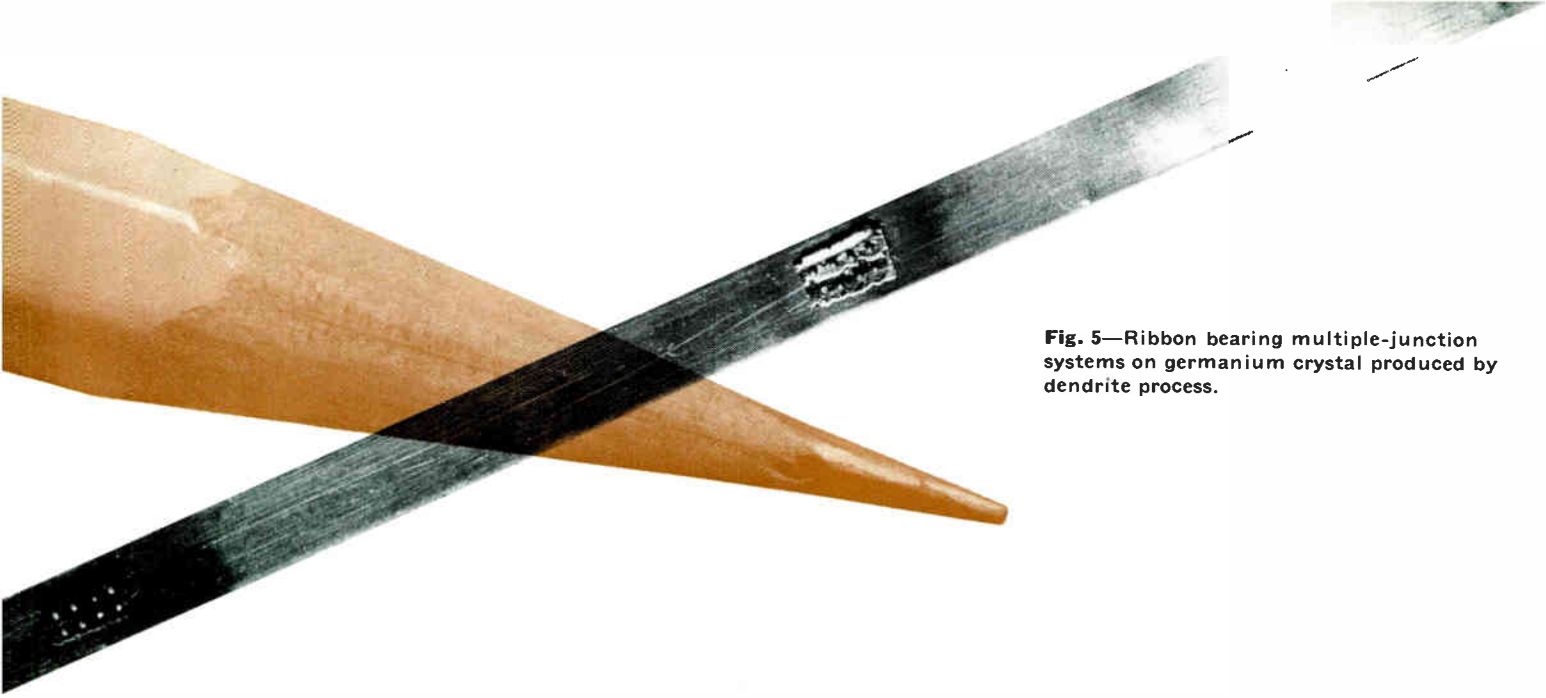


Fig. 5—Ribbon bearing multiple-junction systems on germanium crystal produced by dendrite process.

by wafers, even by those cut from adjacent regions of a single ingot and processed identically. In the production of transistors, this difficulty can be circumvented by testing a production run to select those with proper values. In molecular electronics, however, junctions must be built in adjacent portions of the same crystal; thus it is essential to have materials whose characteristics are uniform if the yield is to be acceptable.

Other advantages of this dendritic method of importance to molecular electronics are these: It is essentially a continuous process in which the germanium ribbon grows at a rate of 6 to 12 inches per minute and in the precise direction of crystal growth required for application. Thus, no x-ray or crystallographic examination is necessary, and the surfaces of the ribbon are always correctly oriented, optically flat, and immediately usable as working surfaces. An additional advantage is that if a contaminant enters the melt during the process, the resulting inclusion is "self-healing" so that when the process is completed, the affected portion can be cut away and the unaffected portion put to use.

Although this dendritic method has immediate usefulness in molecular electronics, its greatest significance is its ability to bring about a number of completely new processes for producing functional blocks. A recent modification makes it possible and practical to carry out diffusion, plating, and evaporation processes directly on the crystal as it grows from the furnace melt. With this technique, semiconductor devices can be created that are ready for the attachment of leads. One of the first uses has been to grow transistors in the form of a long germanium crystal.

When the ribbon-like crystals are cut into segments, only simple processing is needed to produce transistors at a yield very near 100 percent. By this method, lengths of ribbon have been produced along which small multiple-junction subsystems are distributed, Fig. 5. Since these ribbons can easily be processed to become a long series of tiny amplifiers, this ribbon can be "snipped into lengths" to provide amplifiers of any desired gain.

A more recent and extremely significant achievement is the discovery of a method of growing multizoned crystals as dendrites, directly from the furnace melt. This development is a major event in new technology of molecular electronics. It makes available basic building blocks having at least three layers of zones and two interfaces. Thus it will no longer be necessary to perform many operations to create multizone elements.

In considering the implications of this basic method for crystal growth, one most interesting possibility is that it will prove practical to combine our ability to grow multizoned crystals with our ability to perform operations on the crystal at the time it is growing in the furnace. Admittedly, to achieve near-automatic production of semiconductor devices and molecular electronic function blocks is a long-range objective, but it is probable that some items of electronic equipment as complex as radio receivers and amplifiers can eventually be "grown" from a pool of molten semiconductor materials.

Present programs of planned research will yield solutions to such problems as the development of materials that will withstand very high temperatures and intensive radiation, and the development of function blocks that will have high power handling capacities. Also, the ability to produce large, perfectly flat working surfaces on crystals of germanium will be basic to increasing the power-handling capacity of molecular electronic function blocks.

the future of molecular electronics

The urgent need for light, small, and highly reliable electronic systems can be answered by application of the molecular electronic concept. At first, of course, application will be limited by cost and the necessities of defense to uses where the need for reliability, lightness, and compactness is greatest, as in airborne systems; later, as experience is gained in developing and fabricating molecular electronic blocks, they will find application in land-based military equipment and, ultimately, in commercial and industrial applications.

Although there was a 20-year interval between the invention of the vacuum tube and its first significant application, and an 8-year interval between the development of the transistor and its first uses, it is almost certain that no such delay is likely for molecular electronics. In three to five years the molecular electronic concept will probably be widely applied in air/space electronic systems for such important applications as telemetering, fire control guidance, communications, counter weapons, and flight control. ■

THE ELECTROMAGNETIC DRIVE . . . AN ECONOMIC ANSWER TO MANY DRIVE PROBLEMS

The electromagnetic coupling, used in conjunction with a squirrel-cage induction motor, provides a versatile adjustable-speed drive.

R. P. BLEIKAMP
Industrial Engineering Department
Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania

The squirrel-cage induction motor is inherently simple and rugged in construction, and is relatively inexpensive because of this simplicity and because of its great volume of manufacture. It is almost automatically selected for the great majority of constant-speed drive applications and is used in conjunction with other apparatus to power the majority of adjustable-speed drives. This "other apparatus," which provides adjustable output speed from constant speed, runs the gamut from simple pulley changes through the complex combinations of dc machines and control that make up large adjustable-voltage systems.

The electromagnetic (or eddy-current) coupling is one of the simpler methods of obtaining adjustable output speed from the constant input speed of squirrel-cage motors. Its use has grown rapidly in recent years because modern drive designs provide reliability and minimum maintenance, good space economy, high efficiency, and a variety of special operating functions.

principles of operation

An electromagnetic coupling provides the same basic function as the familiar mechanical clutch—an adjustable output speed is obtained from constant input speed by controlling the amount of slip between the two rotating members. However, unlike such clutches, the electromagnetic coupling has no mechanical contact between the members to cause wear and require adjustment or replacement; torque is transmitted by an electromagnetic reaction between the two rotating members. Also, the slip produced by this reaction can be continuously controlled much more precisely and over a wider range than is possible with the mechanical clutch.

An electromagnetic coupling has three basic components—a rotor made up of multiple pole pieces, a hollow iron cylinder or drum that surrounds the rotor, and a coil to provide the primary electromagnetic fields to the system. These basic parts are shown diagrammatically in Fig. 1.

The coil is energized with direct current; the magnetic fields thus established are as shown. The radial air gaps between the rotor pole pieces and the drum are small relative to the direct gaps between the poles. Therefore, essentially all the magnetic flux from the rotor poles on one side of the coil flows through the drum in reaching the opposite poles on the other side of the coil. The flux, of course, concentrates in the drum in the area directly between the adjacent opposite poles. When either the drum or rotor is turned, these flux concentrations sweep circumferentially through the drum since they always remain adjacent to the rotor poles, which are moving relative to the drum. This continual change in flux density at all points around the inner surface of the drum induces eddy currents in the drum. These eddy currents establish secondary magnetic fields, which interact with the primary fields produced by coil current to develop torque between the drum and rotor.

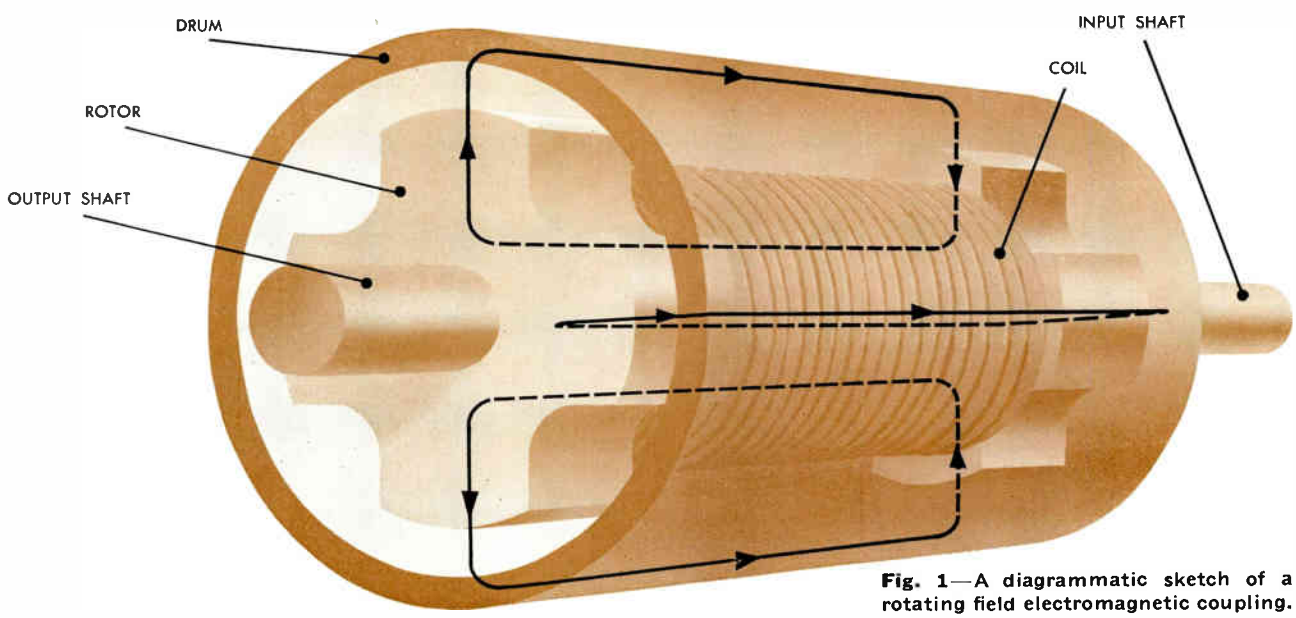


Fig. 1—A diagrammatic sketch of a rotating field electromagnetic coupling.

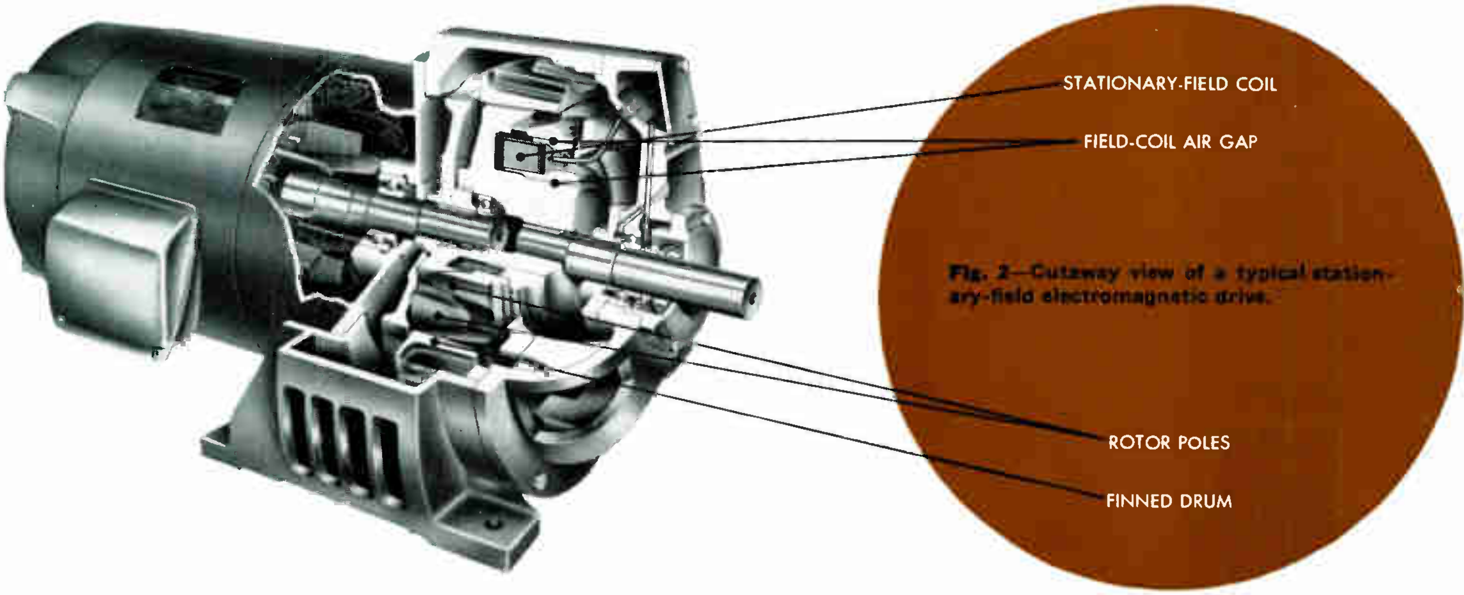


Fig. 2—Cutaway view of a typical stationary-field electromagnetic drive.

If the drum is the externally driven member, then this torque drives the rotor in the same direction as the drum and the torque is transmitted to any load driven by the rotor. (With the rotor externally driven, the converse would apply.) However, the driven or output member can never attain the same speed as the driving or input member; relative motion, or slip, must exist to produce eddy currents and torque.

While some couplings are built essentially as shown in Fig. 1, the most advanced designs use variations of these basic principles to obtain more desirable operating characteristics and mechanical features. For example, Westinghouse devices—called Magnaflow drives—from 1 to 125 hp use the coupling configuration shown in Fig. 2. The rotor has a large number of "interdigitated" poles of special shape to produce the most desirable torque characteristics. To avoid the use of slip rings and thus increase the reliability and reduce the maintenance of the coupling, the field coil is not mounted on the rotor. It is mounted on the end bracket of the coupling and projects into an annular pocket in the rotor. The extra air gaps thus created between the coil support and the inner and outer surfaces of the annular pocket do not affect operation of the coupling; significant eddy currents and torque are not produced at these gaps because they are smooth and therefore do not produce flux concentrations. Also, the use of this stationary field coil arrangement necessitates supporting the rotor poles to the right of the coil from the poles to the left, rather than directly from the rotor hub. This is accomplished without magnetically shorting the poles by using a nonmagnetic metal support ring integrally welded between the two sets of poles.

The drum in which the eddy currents, and hence heat, are generated is used as the constant speed input member to obtain maximum cooling even when the output member is running at reduced speed. The drum is finned in the case of air-cooled couplings as shown, but is smooth in the case of liquid-cooled couplings.

Note the integral mounting of flanged motor on the coupling for maximum compactness and minimum number of parts. In the smaller drives (Fig. 3) the same space and parts economy is accomplished by mounting the motor and coupling in the same frame.

Another variation in the basic electromagnetic coupling principle, used in Magnaflow couplings above 125 hp, is shown in Fig. 4. The stationary coil is mounted outside the drum. The flux path is from the field housing through the drum into the rotor poles and back through the drum to the other side of the field housing. A nonmagnetic strip in the center of the drum prevents the flux from being short-circuited directly through the drum. The poles of the rotor produce flux concentrations in the drum, and hence eddy currents and torque, as described in Fig. 1. Significant eddy currents and torque are not produced at the gap between the field housing and the outersur face of the drum because these are smooth surfaces.

characteristics

The torque transmitted by an electromagnetic coupling is proportional to primary field strength and, within limits,

Fig. 3—An induction motor and electromagnetic coupling are mounted in a single frame in this integral-horsepower Magnaflow electromagnetic drive.

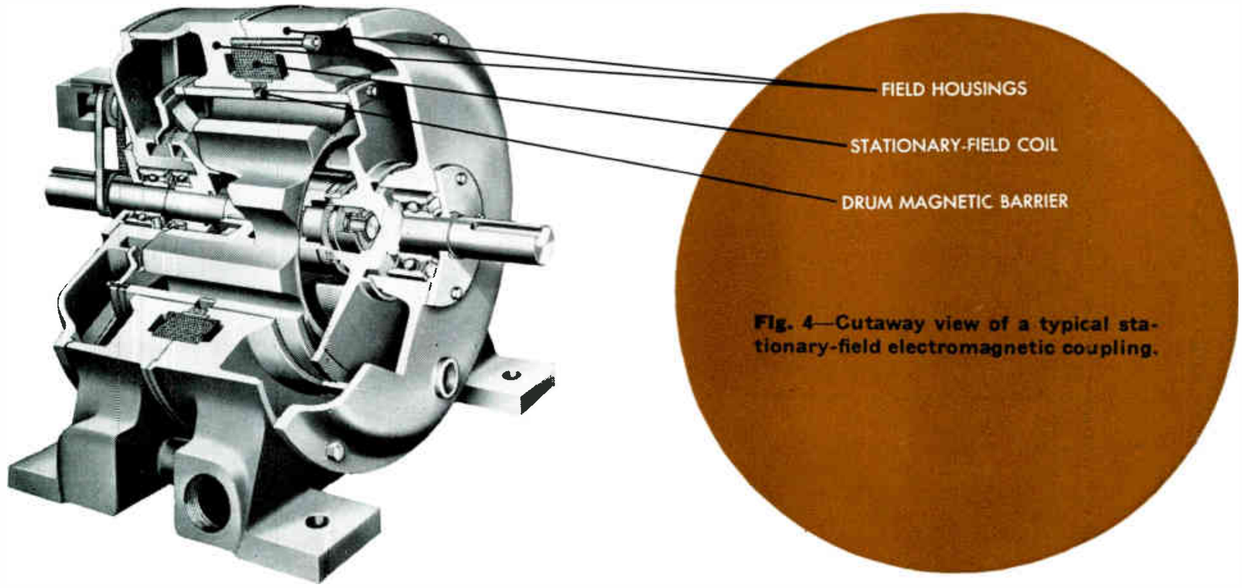


Fig. 4—Cutaway view of a typical stationary-field electromagnetic coupling.

to slip. In other words, the torque increases with increases in excitation and with increases in the difference between the input and output speeds. This is shown more precisely in Fig. 5 by four typical speed-torque curves, shown for maximum and three reduced values of excitation. The changes in torque resulting from changing excitation provide the means for operating the output at selected speeds below the input speed. The coupling excitation is adjusted so that coupling torque and load torque are equal at the desired operating speed. Any change in load torque requires a compensating change in excitation to maintain constant output speed.

The foregoing discussion of torque transmission by an electromagnetic coupling assumes a variable torque input prime mover, such as an induction motor, that is capable of producing whatever torque is called for by the load and hence the coupling. As previously noted, the electromagnetic coupling is similar to a slipping mechanical clutch insofar as its torque transmission characteristics are concerned; output torque is essentially equal to input torque (neglecting friction, windage, and inertial torques). The electromagnetic coupling is not a torque converter.

excitation control

The usefulness of the electromagnetic coupling depends on proper control of excitation. Several basic controls and a wide variety of auxiliaries or modifications for special functions are available.

Open Loop Control—The simplest type of basic control is adjustable excitation through a rheostat from a dc source, as shown in Fig. 6. This type of control does not provide automatic regulation of output speed to a preselected value. Adjustment of coupling excitation merely establishes the speed torque curve (Fig. 5) upon which the coupling will operate. Output speed is determined by the intersection of the load speed-torque characteristic with the coupling speed-torque characteristic. If output speed is to be held reasonably constant, the intersection of these characteristics must be relatively sharp. If this intersection is not sharp, small transient variations in load torque demand, or drift in coupling characteristic due to such effects as heating, may result in large speed changes.

Therefore, this type of control is usually not applied even for the simpler cases where speed control is desired. However, it is a very desirable means of obtaining controlled acceleration of a load and adjustable torque limiting.

Tachometer Feedback Control—Most electromagnetic drives are used to provide a range of speeds that can be preselected by the operator and then automatically maintained with variations in load demand or to automatically adjust the speed through a cycle in coordination with some other process variable. The basic excitation control for such drives is a tachometer feedback speed regulator. In this control (Fig. 7) a tachometer generator, mechanically driven by the coupling output shaft, provides a voltage signal proportional to speed. This signal is compared to a reference voltage and the resulting error signal used to adjust coupling excitation to hold a speed proportional to the reference voltage. The desired reference voltage is established either by operator adjustment of a speed-setting rheostat as shown, or by a signal from some process variable that is to control the speed of the drive.

Since this type of basic control is the most widely used, it is considered standard in the Magnaflow drive. Compact ac brushless tachometer generators are integrally incorporated in all couplings. Also, packaged controls containing all components, including reference source, necessary for providing regulated dc coupling excitation from an ac power source are available in both the electronic and transistor-magnetic amplifier types.

The simplest Magnaflow electronic control holds steady-state pre-set speed within ±2 percent of maximum drive speed with 75 percent load change. A long-time speed drift of ±1 percent of maximum speed is also to be expected. Other standard electronic controls providing steady-state speed regulations as low as ±0.5 percent with 75 percent load change and ±0.5 percent long-time drift are available at only slightly increased cost. Special controls providing

±0.25 percent speed regulation and ±0.25 percent drift, or ±1 percent speed regulation and ±0.1 percent drift are also available for certain types of load characteristics.

Standard transistor-magnetic amplifier controls provide steady-state speed regulation of ±2 to 2.7 percent (depending on drive rating) with 75 percent load change and long time drifts of ±2 percent.

Because excitation requirements of electromagnetic couplings are extremely low in relation to the power they transmit (1 percent or less), very compact static controls of the above types operating directly from the usual ac power source can be provided without sacrificing conservative sizing of components for long life and dependability. The Magnaflow electronic control for drives up to 30 hp is shown in Fig. 8.

losses and efficiency

Slip loss is the major loss in an electromagnetic coupling. It is essentially equal to the difference between input shaft power and output shaft power and can be evaluated as follows:

T = *input torque* = *output torque (lb-ft)*
N_1 = *input speed (rpm)*
N_2 = *output speed (rpm)*

$$Input\ power\ (HP) = \frac{N_1 T}{5250}$$

$$Output\ power\ (HP) = \frac{N_2 T}{5250}$$

$$Slip\ Loss\ (HP) = \frac{N_1 T}{5250} - \frac{N_2 T}{5250}$$
$$= \frac{T \times (N_1 - N_2)}{5250}$$
$$= \frac{Torque \times Slip\ rpm}{5250}$$

Other losses are: Windage and friction, 0.25 to 0.75 percent; magnetic drag, 1 percent or less; excitation, 1 percent or less; and in the case of liquid-cooled units, coolant acceleration loss, 0.5 to 0.75 percent.

These losses appear as heat and must be dissipated by the cooling fluid—air in the case of air-cooled couplings, and water or oil in the case of liquid-cooled couplings.

As the formula shows, slip loss, the only loss of major concern, increases with increasing torque and with increasing slip, or decreasing speed. Therefore, the amount of operation and the torque required at reduced speed is the prime consideration in determining the suitability of an eddy-current drive for any given application and in selecting the type of such drive to be used—air or liquid cooled. On many industrial applications, operation at drastically reduced speed is of very short duration and/or considerably less than full-load torque. In such cases, air-cooled units dissipate the heat adequately and conveniently. Applications involving continuous operation at very low speeds with high torques require a liquid-cooled coupling. Westinghouse Magnaflow liquid-cooled couplings and drives are capable of transmitting full torque continuously at stall.

At rated torque and maximum output speed, the slip loss of an electromagnetic coupling will be from 2 to 4 percent of output power. Therefore, peak efficiency is in the neighborhood of 92 to 96 percent (100 less slip loss and other losses mentioned above). At reduced speeds, slip loss becomes the dominant factor and efficiency is essentially equal to the ratio of output speed to input speed.

Because the electromagnetic coupling is a slip device, frequently the initial inclination is to assume that it is quite inefficient. Actually, for many types of adjustable-speed loads and operating cycles, the electromagnetic coupling is the most efficient type of drive available. For ex-

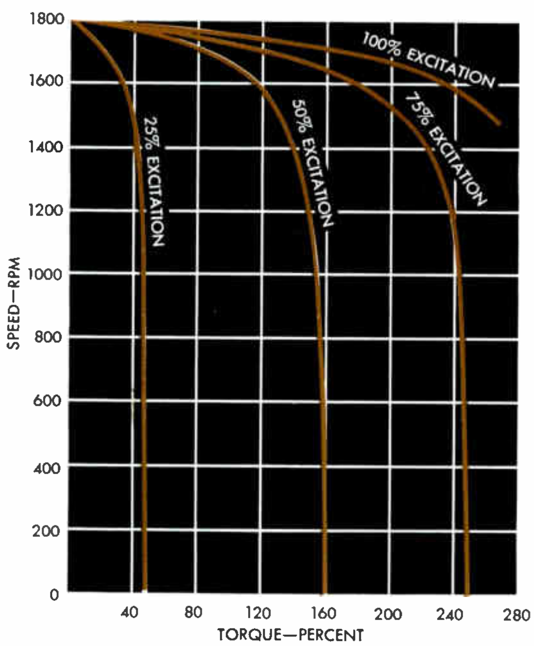


Fig. 5—Typical speed-torque curves for electromagnetic drives.

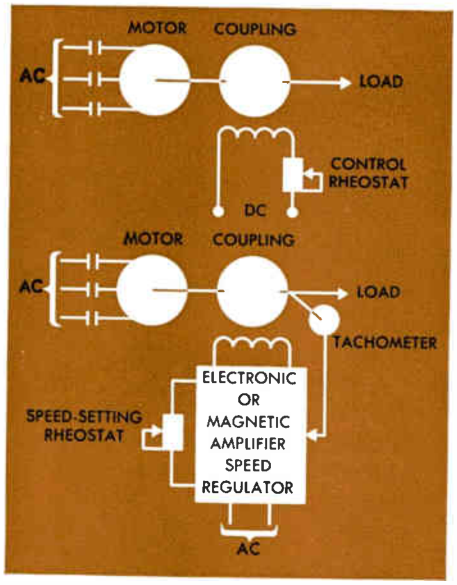


Fig. 6—(Top) Manual excitation control system for electromagnetic drive. **Fig. 7—(Bottom)** Feedback speed control system for electromagnetic drive.

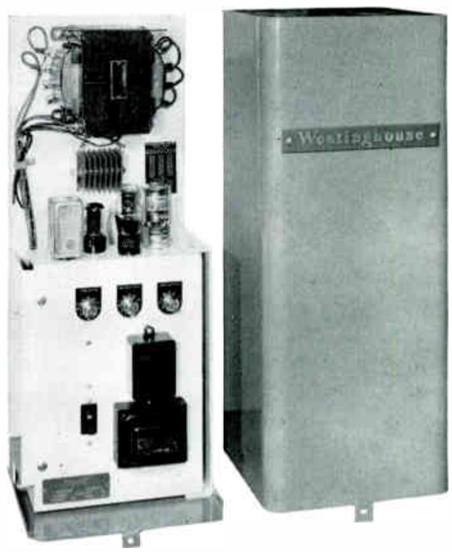


Fig. 8—Magnaflow electronic control for electromagnetic drives up to 30 horsepower.

ample, in the medium integral horsepower ratings a dc generator and motor combination used in adjustable-voltage control will have a maximum combined efficiency of approximately 70 to 75 percent (exclusive of the ac motor driving the generator). As mentioned above, an eddy-current coupling has an efficiency of about 92 to 96 percent at maximum speed and full torque, decreasing to the 70 to 75 percent range at about 75 percent speed. Therefore, for applications where most running is in the high end of the speed range (particularly at high torques), the overall operating efficiency of the eddy-current drive will be considerably superior.

application considerations

In general, the same factors must be considered in applying electromagnetic drives that are considered in applying any electric motor drive. The more important of these factors are mentioned here with specific comments applying to the electromagnetic drive.

Running Torque—First, the coupling must be capable of transmitting the torques required by the load at the various speeds at which it is to operate; and second, it must do so without excessive temperature rise, taking the time of operation at the various speeds into consideration. In many cases, particularly in the medium integral horsepower range where the integral motor-coupling drives are usually used, this can be easily determined with a knowledge of the horsepower that is required to drive the load at maximum speed, and the manner in which the torque requirement of the load varies with decreasing speed. As previously noted, the large majority of industrial machines requiring adjustable speed have constant or decreasing torque requirement with decreasing speed. In such cases it is a simple matter to determine if the lowest continuous operating speed is within the continuous full-torque operating range of the drive.

In other cases it may be necessary to determine that the operating speed-torque points fall within the 100 percent excitation speed-torque curve of the electromagnetic drive and that the slip loss associated with operation at high torques at any speeds, and with any torques that are at low speeds outside the continuous operating range, will not cause heating in excess of the thermal rating of the specific coupling under consideration.

Accelerating Torque—The coupling must have sufficient torque-transmitting ability over and above steady-state load torque to break away and accelerate the driven machine. In all Westinghouse Magnaflow integral motor-coupling drives the coupling is designed to exceed the torque capability of the standard NEMA B motor at all points. Therefore, if it is known that a standard NEMA B motor is capable of accelerating the load in question, there is no doubt that the integral motor-coupling electromagnetic drive will be capable of doing the job. In those cases where a NEMA B motor would not accelerate the drive or where separate motors and couplings are to be selected, it will be necessary to refer to the coupling characteristic curves. However, it should be kept in mind that the induction motor locked-rotor torque is of no concern and only its pull-out torque need be considered because in electromagnetic drives the induction motor is started and up to speed before the coupling is energized to start the load. Therefore, full induction motor pull-out torque is available for starting the load through the coupling.

Decelerating Torque—Some industrial drives must develop decelerating torque under certain conditions, either to limit speed when the load becomes overhauling, or to force the driven machine speed from a higher operating speed to a lower operating speed or to a quick stop. Caution must be exercised in applying electromagnetic drives to loads requiring braking torque for either of these reasons because electromagnetic couplings with speed regulating control will not develop braking torque. When such braking torques are required, an eddy current or other type of brake must be added to the drive along with control to energize the brake when a speed reduction or stop is desired. Standard control modifications to provide either automatic braking when the stop button is pressed or braking as part of the automatic speed regulating function are available in Westinghouse Magnaflow Drives. Also, integral eddy-current or disc brakes can be easily provided in the coupling. The latter type of brake is usually used only for an emergency stop feature.

Before deciding to go to a braking system, a check should be made to determine if the driven machine has a high ratio of load torque to load inertia. In such a case the speed may drop quickly enough without any external braking so that the simple drive may be adequate.

Duty-Cycle Application—Machines that present cyclic loads can normally be powered by drives that are continuously rated at less than the peak load requirement of the driven machine. If the period of the cyclic load is short compared to the thermal time constant of the coupling, the only calculation required in selecting the coupling is to determine that the average slip loss is no greater than the coupling thermal rating.

High-Inertia Drives—The slip energy generated in an electromagnetic coupling in accelerating a given inertia is:

$$W\ (watt\text{-}seconds) = 0.000231 \times WR^2\ (S_1^2 - S_2^2)\ (rpm\ input)^2$$

where S_1 is slip rpm at beginning speed and S_2 is slip rpm at ending speed.

The temperature rise this energy will cause in the coupling is dependent upon drum mass and material, and the accelerating period. Excessive temperature rise in the coupling from this source will not be encountered in the majority of industrial applications. If temperature rise is a factor, appropriate acceleration controls can be employed.

summary

Where the electromagnetic drive meets application requirements, it is frequently a desirable choice for providing adjustable speed.

The device is simple in construction, and rugged, thereby requiring a minimum of maintenance. No power converting equipment is required, only a low-power, wall-mounted excitation unit. The device has a wide speed range. For example, the Magnaflow Drive can provide regulated speed down to 100 rpm. With the popular 4-pole induction motor, a 17-to-1 regulated speed range can be obtained. Special functions are easily added to the control, either during initial manufacture or in subsequent field modifications. Furthermore, the electromagnetic drive is easily coordinated with other drives of the same or different types. ■

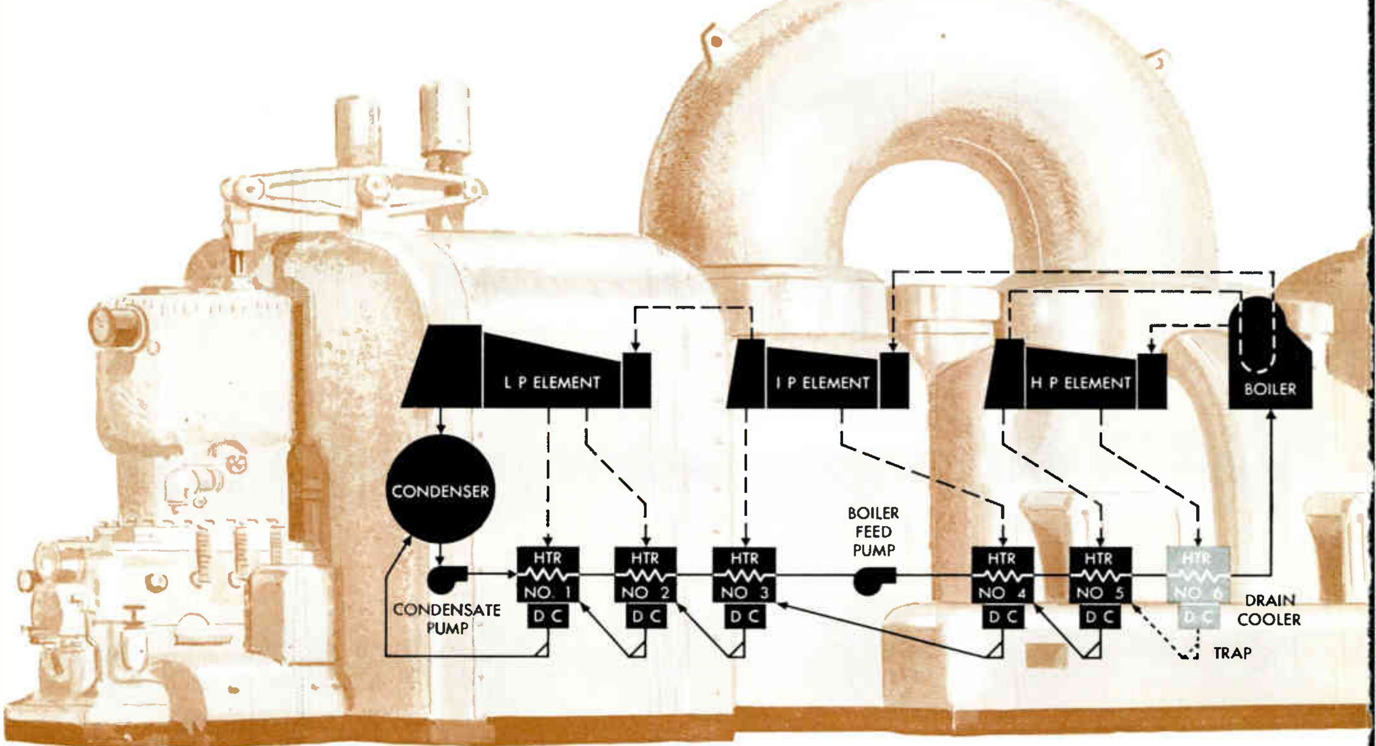


Fig. 1—General arrangement of basic elements of a reheat-regenerative steam cycle.

HEAT POWER CYCLE FUNDAMENTALS

While steam power plants have changed markedly during the past several decades, the basic principles that guide their design still apply.

S. LEMEZIS, District Steam Engineer
Steam Division
Westinghouse Electric Corporation
Los Angeles, California

The purpose of any power plant is to convert heat energy from fossil fuels, or nuclear fission, into mechanical or electrical energy. This is accomplished by setting up a closed thermodynamic cycle of some working fluid—nearly always steam, although ordinary air is the working fluid in diesel and gas turbine plants. Steam turbines represent the "expansion" element in steam power cycles.

heat rate

Any thermodynamic cycle is made to operate by putting work into the cycle fluid by pumping (or compression) at low energy levels and adding heat at relatively high energy levels, and then extracting energy in the desired form at intermediate energy levels. Efficiency of cycles can be expressed in general terms:

$$Efficiency = \frac{\textit{Useful Energy Output in Desired Form}}{\textit{Heat Energy Input}}$$

in which useful energy output can be either electrical or mechanical, and heat energy input is usually at a high level, and in a relatively unavailable form before conversion.

In plants intended for electric power generation, this ratio is usually inverted to form the *plant heat rate:*

$$Heat\ Rate = \frac{\textit{Heating Value of Fuel, Btu/lb} \times \textit{Fuel Fired, lb/hr}}{\textit{Net Power Plant Output, kw}}$$

This is the plant heat rate published in Federal Power Commission and Edison Electric Institute statistics, and charges the plant with all losses between the maximum potential energy present in the particular fuel fired and the actual net electrical energy available for transmission to utility customers.

Since steam turbines and their associated feed heaters and piping represent about one-third of the total cost of a new power plant, the performance level of proposed turbines and details of the regenerative feed heating cycle arrangement always receive careful attention from plant designers. Turbine and feed heating cycle performance are invariably expressed and guaranteed as a *turbine heat rate,* defined as follows:

$$Gross\ Turbine\ Heat\ Rate = \frac{\textit{Total heat supplied to the steam turbine cycle, Btu/hr}}{\textit{Generator Output, kw}}$$

The total heat supplied to the steam turbine cycle in this case would include that in throttle steam, reheat steam, makeup water, boiler blowdown water or steam, plus that from miscellaneous sources.

This gross turbine heat rate is numerically equal to the plant heat rate if all components except the turbine and

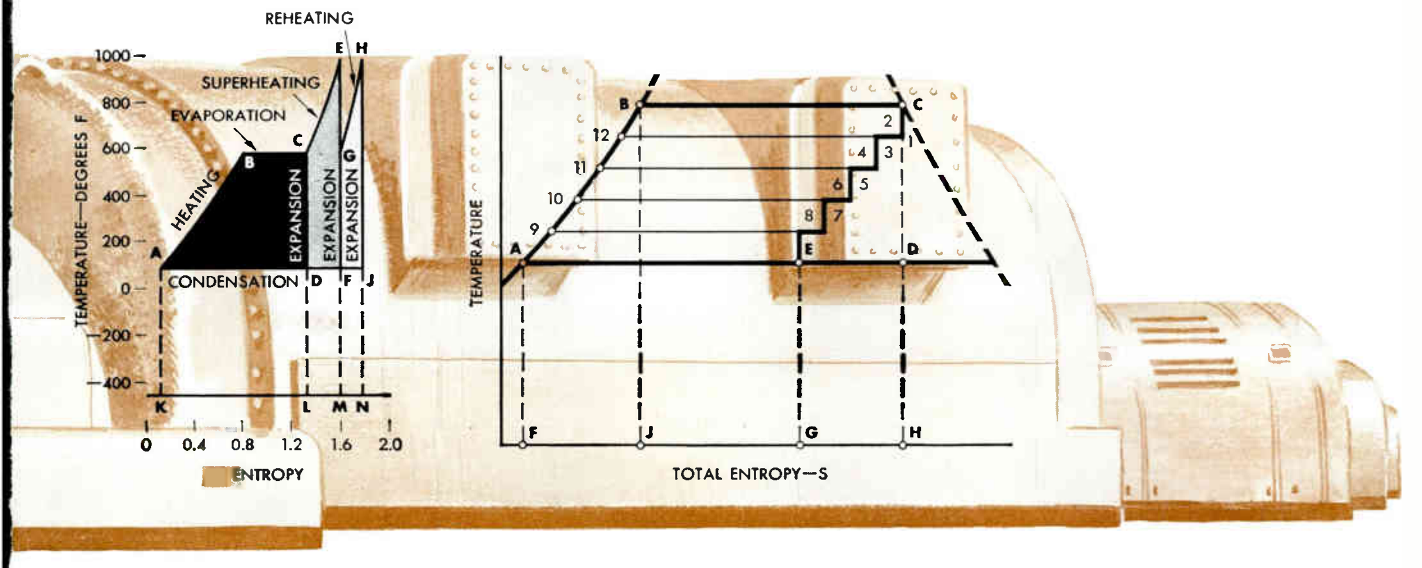


Fig. 2—Temperature-entropy diagram showing ideal steam cycles.

Fig. 3—Temperature-entropy diagram showing saturated steam regenerative cycle.

feedwater heaters are assumed to operate at 100 percent efficiency or with zero power requirements. Heat rate equations are completely arbitrary, and there is considerable variation in the practice followed by various consultants, users, and manufacturers when expressing the performance of a given turbine and feed heating cycle in this manner. Comparisons between performance of several alternate turbine feedwater heater cycles will be valid only if the same heat rate equation is used for all.

Because the entire useful output from any power plant is obtained by converting heat into mechanical energy of rotation in the turbine element, the turbine itself and its operating cycle must be designed for the highest conversion rate attainable within the plant's economic limitations.

steam turbine cycles

Historically, steam-turbine cycles have fallen into three broad classes, each of which has been dominant during some era, and all of which are used today to an extent depending upon the economics of a particular installation. Note that all steam plants whose primary purpose is the generation of electric power operate on a condensing cycle; that is, the working steam is expanded from throttle pressure and temperature down to an exhaust pressure that is only ½ to 1½ psi above absolute zero. These low exhaust pressures are obtained by condensing the exhaust steam to water at temperatures near or slightly above room temperature. Condensate is all returned to the boiler, to begin another circuit. Seldom does a chemical process or a heating system require low pressure and temperature steam in the quantities that a turbine would exhaust when expanding steam to pressures near atmospheric; but in the few instances where this might be true, a noncondensing turbine might prove to be most economical.

Three arrangements of a condensing steam cycle are:

Straight Condensing—This technique was used almost exclusively before 1920, and is still used in small installations (usually industrial plants under 10 000 kw) today. Throttle steam may be saturated or superheated, but every pound is expanded down to exhaust pressure and is converted into water in the condenser. This water at condenser hotwell temperature is then fed to the boiler.

Regenerative Feed-Water Heating—This method is used almost universally today. Some two-thirds of the total heat energy present in each pound of steam at throttle conditions still remains when it has been expanded to condenser pressure; and each pound of steam leaving the turbine exhaust must be condensed to maintain the condenser shell pressure at its low absolute value. Thus it follows that some two-thirds of the heat put into the steam by a boiler working with a straight condensing turbine is necessarily lost in the condenser circulating water.

Regenerative feed-water heating was introduced in the early 1920's to prevent the loss of at least a portion of this "latent heat" from the cycle. Condensate from the condenser hotwell is passed through a series of feed-water heaters before being reintroduced to the boiler. Some 20 to 35 percent of the throttle steam flow is extracted from between turbine stages at various points during the expansion process and this "extracted steam" is allowed to condense in the feed heaters, thus giving up its latent heat to the feed water instead of rejecting it in the condenser. For each pound of throttle steam then, only 0.65 to 0.80 pound actually has to give up its latent heat to the condenser circulating water; the remainder of the latent heat is "plowed back" into the boiler feed water. Fitting even a few heaters to a straight condensing cycle in this way increases the cycle efficiency by a good percentage.

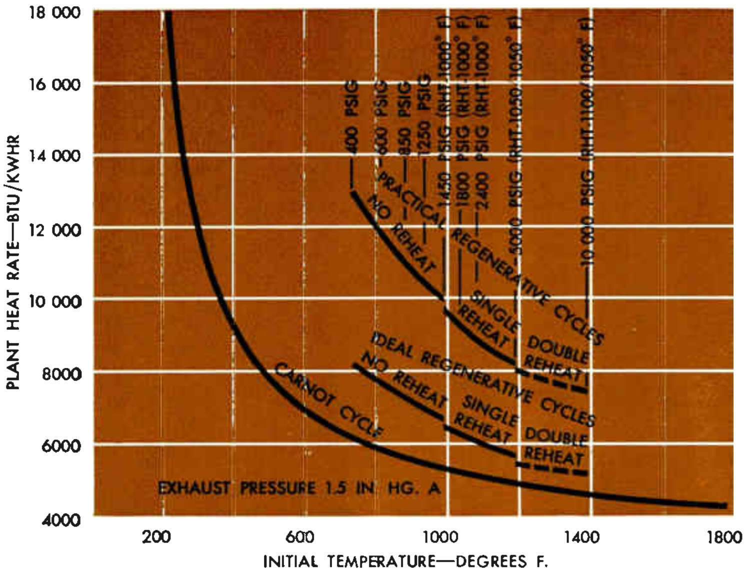


Fig. 4—Heat power cycle developments.

Reheat—Reheat is employed almost exclusively today in units rated 60 000 kw and larger, always in conjunction with regenerative feed-water heating. Reheat involves sending the steam back to the boiler after it has been expanded to about 25 percent of throttle pressure in a high-pressure turbine, and there adding sufficient heat to raise its temperature close to that at the throttle; this lowered-pressure, high-temperature steam is then expanded to exhaust pressure in intermediate and low-pressure turbines. The gain in cycle efficiency is achieved at the cost of complication and extra expense for turbines, boiler, and piping. For larger units, this extra cost is nearly always justified.

The flow path of the working fluid in a reheat regenerative cycle of moderate rating is shown in Fig. 1. By mentally subtracting out the reheater and/or the feed-water heaters, the same diagram can represent a nonreheat regenerative and a straight condensing cycle, respectively. Representation of the turbine as three separate elements is diagrammatic only. Physical size of the complete turbine (rating, steam pressure and temperature) will determine whether all these elements should be built separately, or even in multiple, or combined into one or two casings.

effect on efficiency

The effects of introducing superheat, regeneration and reheat into steam cycles can be explained thermodynamically by reference to Figs. 2 and 3.

A temperature-entropy diagram for water vapor is shown in Fig. 2. The abscissa is entropy (S), a mathematical factor that is a measure of the unavailable energy in a thermodynamic system. It is used as a coordinate primarily because of its dimension—Btu per degree F per pound of fluid—so that areas on the diagram represent heat, and the relative amounts of heat involved in processes can be compared visually. Several ideal steam cycles have been drawn on the T-S diagram. These can be recognized as ideal cycles because the expansion processes are shown as vertical lines (no increase in entropy during the process), and therefore represent the performance of 100-percent efficient turbines.

Use of the diagram can be shown with the saturated steam cycle $ABCDA$; i.e., one in which steam is supplied to the turbine with no moisture and zero degree superheat —or "saturated." Total thermal energy supplied to the cycle above absolute zero level is shown by area $ABCLKA$, while the total energy available for conversion above exhaust temperature level is shown by $ABCDA$. The theoretical thermal efficiency of the cycle is the ratio:

$$\frac{\textit{Available Energy } ABCDA}{\textit{Total Energy Supplied } ABCLKA}$$

If the throttle steam pressure is 1450 psig and the exhaust pressure 1.5 inches Hg absolute, this theoretical thermal efficiency will be 39.25 percent.

To consider the beneficial effect of superheating steam before expanding it in the turbine, consider the relation of area $CEFDC$ to the total heat added $CEMLC$. The theoretical efficiency of this superheating alone is 54.62 percent for an initial temperature E of 1000 degrees F. The efficiency of heat addition in the "superheat" portion of this diagram is greater than that of the "saturated" portion because the heat is now added at a higher average temperature level. Actually, the "superheat" cycle $ABCEFA$ represents the theoretical cycle upon which the great majority of steam turbines in service operate today. For an initial pressure of 1450 psig and temperature of 1000 degrees F, exhausting at 1.5 inches Hg absolute, its theoretical efficiency is 42.7 percent.

Reheating can be added to the cycle by expanding to pressure G in the turbine, heating the steam to some elevated temperature H at constant pressure and then expanding to the exhaust pressure. Again, the theoretical gain in cycle efficiency is shown by the ratio of the ***available energy*** and ***total heat added*** areas. Adding reheat to 1000 degrees F to our previous 1450 psig—1000 degrees FTT—1.5 inches Hg absolute cycle will raise the cycle theoretical thermal efficiency to 44.34 percent, a gain of 3.84 percent over the nonreheat cycle.

Changing the exhaust pressure has the effect of moving the line $ADJF$ up or down, thus altering the ratio of the areas representing available and unavailable total heat energy. Since the exhaust pressure is maintained at its usual low absolute level by condensing steam and removing air and noncondensable gases in the condenser, the level that can be attained in any plant depends almost entirely upon the temperature and flow quantity available in condenser circulating water. As an example, changing the exhaust pressure of our 1450 psig, 1000 degrees/1000 degrees reheat cycle from 1.5 inches Hg absolute to 1.0 inch Hg absolute will improve the theoretical cycle efficiency from 44.34 percent to 45.26 percent. This effect is so pronounced that power stations are nearly always designed for the lowest exhaust pressure (temperature) that can be obtained using the available supply of circulating water.

In any actual cycle, expansion would not take place at 100 percent efficiency, and some pressure drops would be involved in superheating and reheating; therefore, there would be a greater increase in entropy during each process than indicated on the theoretical diagram Fig. 2, and the ratio of the "available energy" to the "unavailable energy" areas would be lessened. Obviously, no real cycle could attain the efficiency levels calculated for a theoretical cycle, but the effects of changing steam conditions can be studied on a theoretical basis and valid conclusions drawn.

In explaining the thermodynamics of regenerative feed-water heating, it is helpful to refer to a modified *T-S* diagram, Fig. 3, on which entropy is considered a distributive quantity and the abscissa is then total entropy. *ABCDA* would represent a theoretical saturated steam cycle, in which the steam flow to the condenser was exactly equal to the throttle steam flow. To heat the feed water from temperature *A* to temperature *12*, steam is extracted from the turbine at pressures *1*, *3*, *5* and *7* and gives up its latent heat in four feed heaters which successively heat the feed water through temperature ranges *A-9*, *9–10*, *10–11* and *11–12*. Feed water enters the boiler at temperature *12*; on such a plot, the available energy is represented by the area *ABC12345678EA*, while the unavailable energy is represented by *AEGFA*. Regenerative feed heating has reduced the unavailable energy by a greater percentage than it has reduced the available energy. In fact, a calculation of the old 1450 psig, 1.5 inches Hg absolute cycle shows that the theoretical efficiency can be raised from 39.25 percent to 47.85 percent by introducing the maximum amount of feed heating possible (infinite number of heaters, feed-water heated to saturation temperature at throttle pressure). The gains attainable from regeneration are so great in proportion to the cost of attaining them that feed-water heating is used in every utility station today.

From studying theoretical steam cycles and accurately measuring their *T-S* diagrams, the general conclusion can be reached that the way to improve the efficiency of any given cycle is to raise the throttle pressure, throttle and reheat temperatures, number of reheats, and number of feed-water heating stages. Careful study of the figures shows that the beneficial effect of any given increment in pressure, temperature, or number of heaters or reheats is less the higher the level from which one starts to add these increments. In actual power plants, the design problems associated with pressures and temperatures and the complication resulting from many reheaters or feed heating stages set practical economic limits to the use of these devices for increasing plant efficiency.

heat-power cycle improvements

The heat-power cycle has come a long way since the early steam turbine, when plant heat rates of fifty thousand Btu per kilowatt hour were representative.

The lower curve (Fig. 4) marked "Carnot Cycle" shows the ultimate efficiency of a power cycle for any given initial temperature. This is from the familiar equation:

$$Efficiency = \frac{Initial\ Temperature - Final\ Temperature}{Initial\ Temperature}$$

The temperatures are absolute, or Fahrenheit plus 459.4. In the Carnot cycle all heat is presumed to be added at a constant temperature and waste heat is also rejected at a constant temperature. However, in any practical cycle heat is added at varying temperature. Therefore, heat addition is an irreversible process. In the steam cycle, heat is added to the feed water at a varying temperature, evaporation is at a constant temperature, and superheat and reheat are added at varying temperatures. Heat is rejected to the condenser at a constant temperature.

The three curves marked "Ideal Regenerative Cycle" show the difference between the irreversible regenerative steam cycle and the reversible Carnot cycle. This establishes a new and higher limit of heat rates that can be approached but never reached. In these nonreheat, single reheat, and double reheat ideal regenerative cycles, there are none of the losses that occur in all practicable cycles. These cycles, then, are comprised of a perfect boiler having no losses; a turbine having 100 percent efficiency; a feed heating system having an infinite number of heaters heating the feed to a temperature corresponding to saturation at the throttle pressure; a generator having 100 percent efficiency; and no power requirement for fans, pumps and other auxiliary equipment. The gains with increasing temperature for the Ideal Regenerative Cycles are greater than for the Carnot Cycle because the initial pressures have been increased with the increases in temperature.

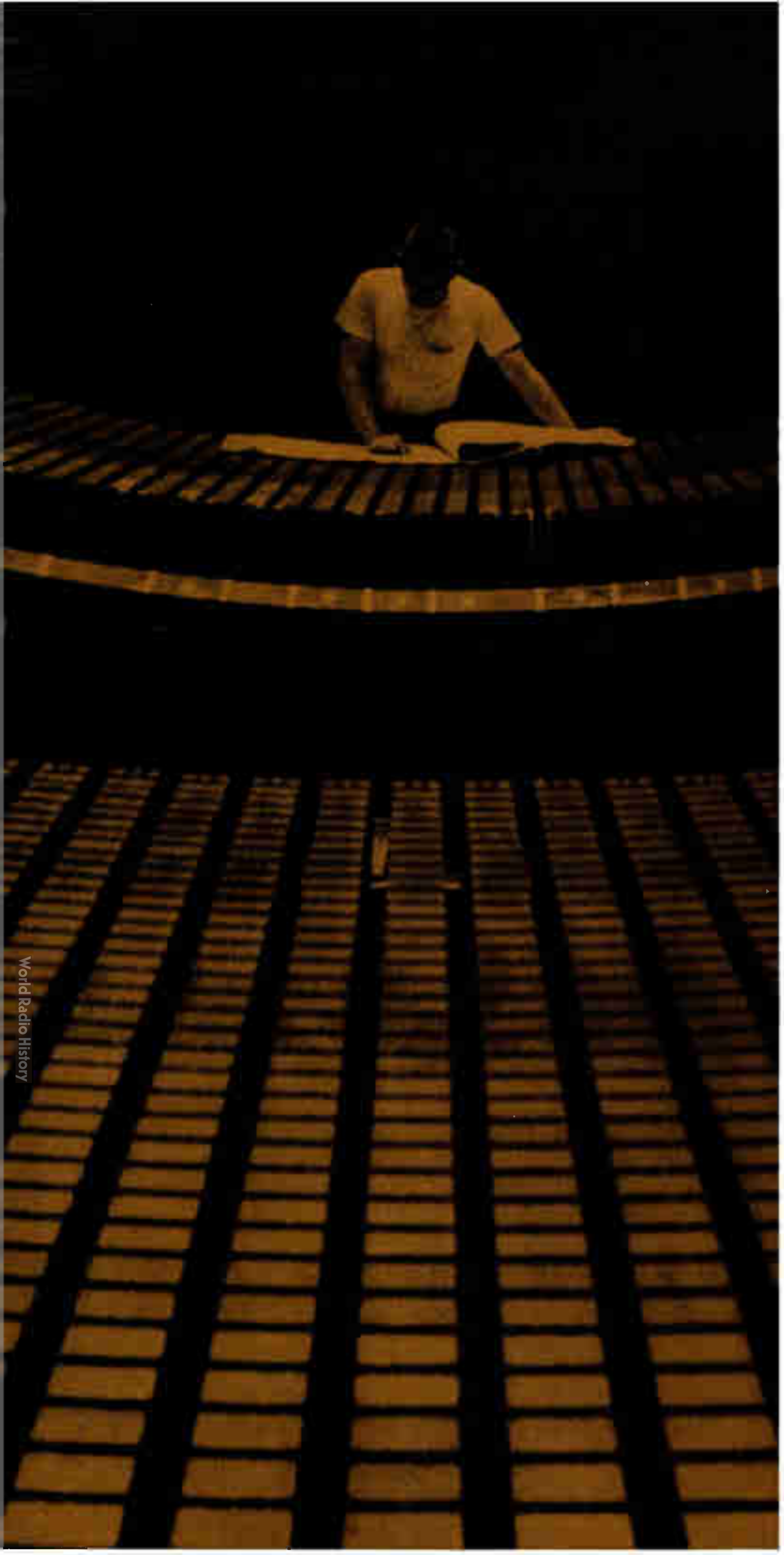
The three curves marked "Realizable Regenerative Cycles" show the record of progress made in the development of the steam cycle from 400 psig, 750 F, 1½ inches Hg absolute in 1926, to 5000 psig, 1200 F with two stages of reheat each to 1050 F and a back pressure of 1½ inches Hg absolute in 1955. The increased slope of these curves, as compared to the curves for the ideal regenerative cycles, represents the improvement in component efficiencies.

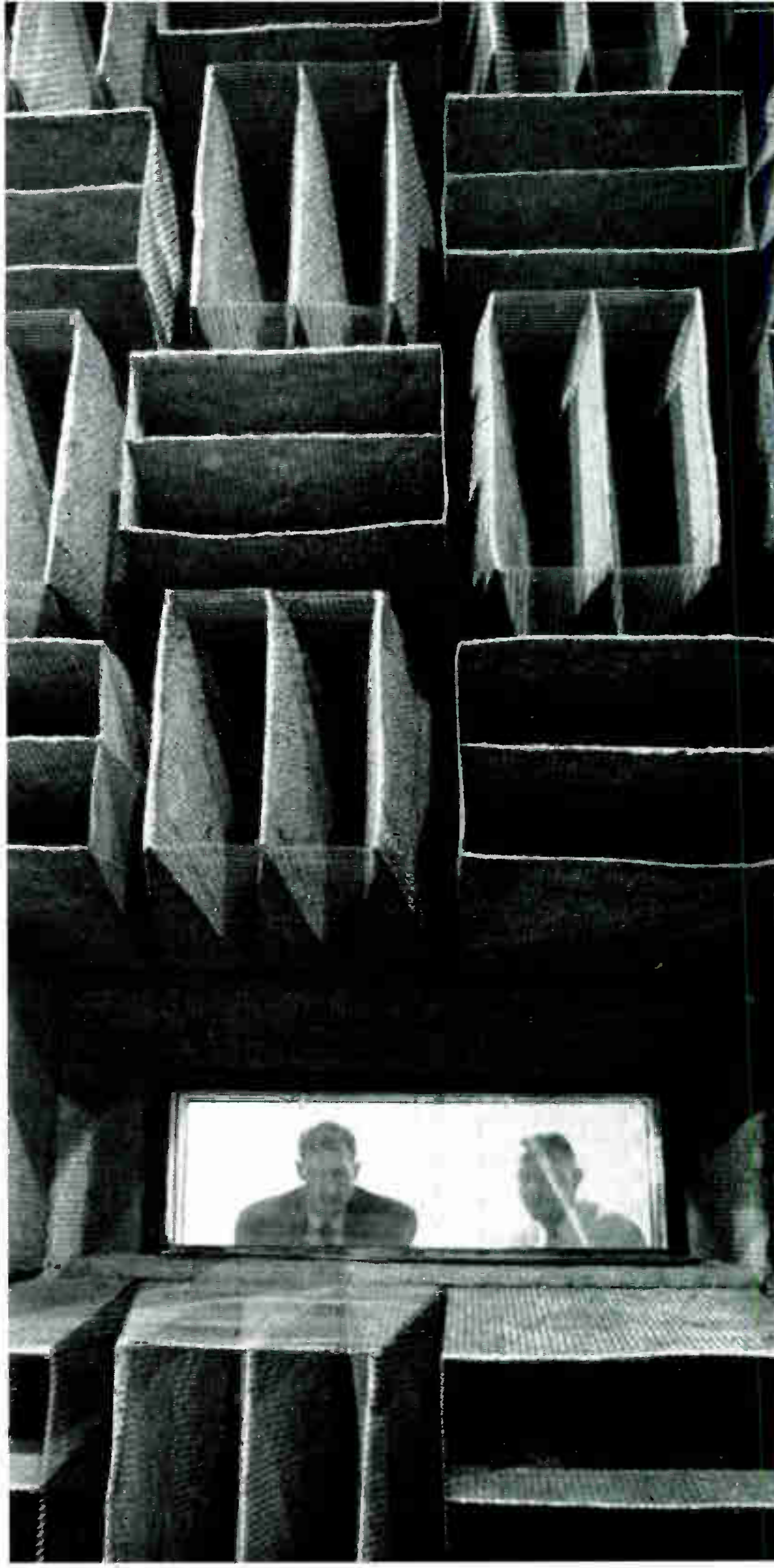
The difference between the "realizable" and "ideal" cycles represents the stack gas losses (the difference between the stack gas temperature and the ambient air temperature); the turbine inefficiency (blading inefficiency, leakage losses, throttling losses, exhaust losses); the feed heating cycle losses, including the boiler feed pump losses; the electrical and the mechanical losses, and the auxiliary losses such as fans, pumps, and lights. Since the difference between the "realizable" and "ideal" cycles is much greater than the gains to be made by steam temperature increases, the greatest economic gains probably are to be made by reducing these losses.

Perhaps a breakdown of the heat distribution for a typical modern large coal-burning reheat steam power plant will be of interest and point up the relative magnitude of the losses that stand between actual performance and complete conversion into electrical energy of all heat energy present in the fuel. The figures for a 300 mw, 2400 psig, 1050/1000 F, 1 inch Hg absolute, 3600/1800 rpm, cross-compound unit are:

Salable Kilowatts	39.6%
Boiler Loss	6.0%
Hydrogen in Fuel Loss	4.0%
Unavoidable Condenser Loss	34.5%
Turbine and Feed Cycle Loss	13.5%
Auxiliary Power	1.5%
Electrical Loss	.6%
Mechanical Loss	.2%
Boiler Feed Pump Loss	.1%
	100.0%

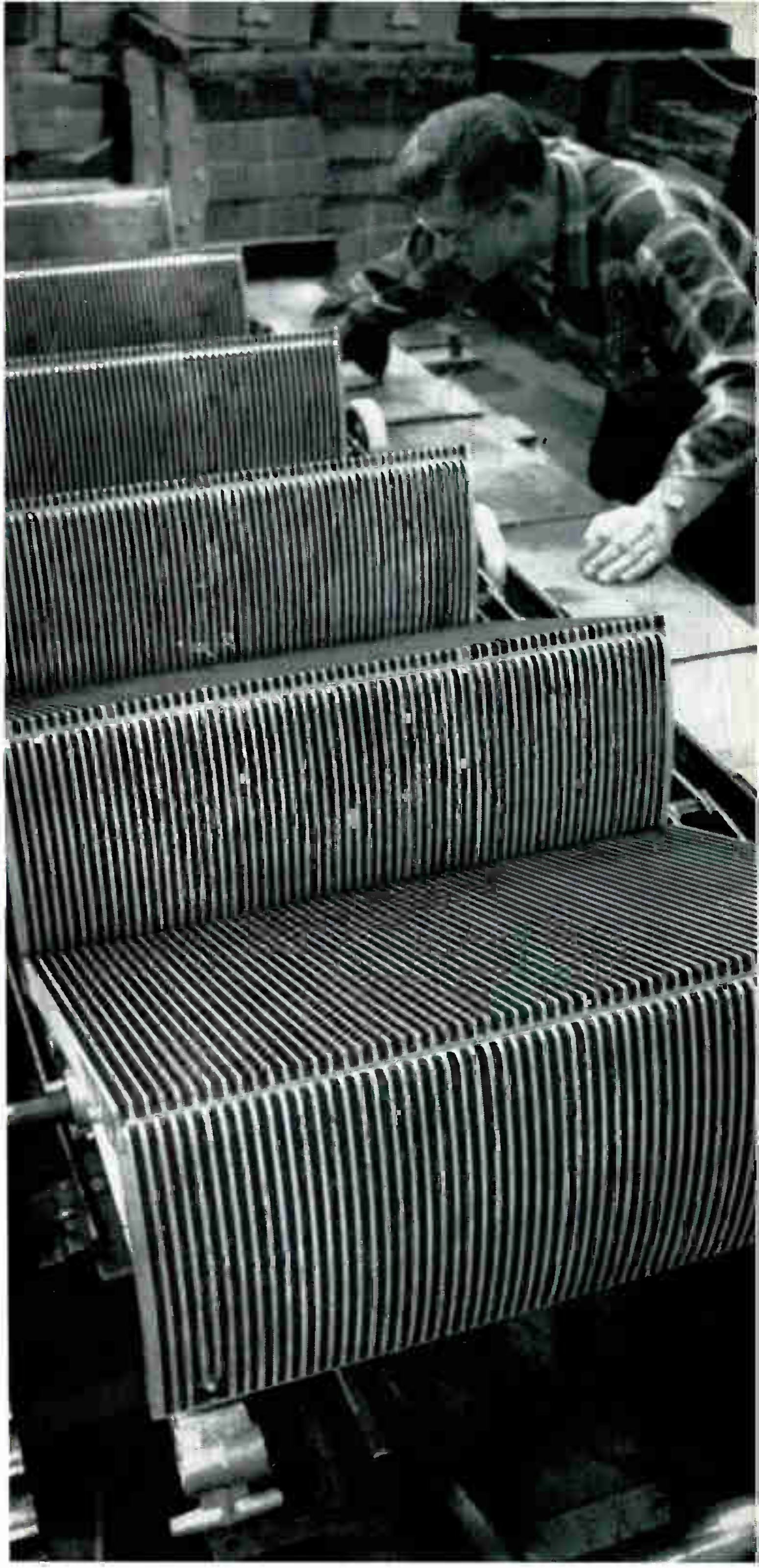
Continual development of components used in the stream power plant have produced a steady reduction of losses and consequent improvements in plant heat rate. While the steam power plant will never reach the "ideal" situation, further reduction of losses is probable. ■





PATTERNS FROM INDUSTRY

A carefully chosen perspective can often transform a familiar object into an artistic study in geometric design. Many industrial plants can provide a ready source of material for the photographer in search of interesting geometric

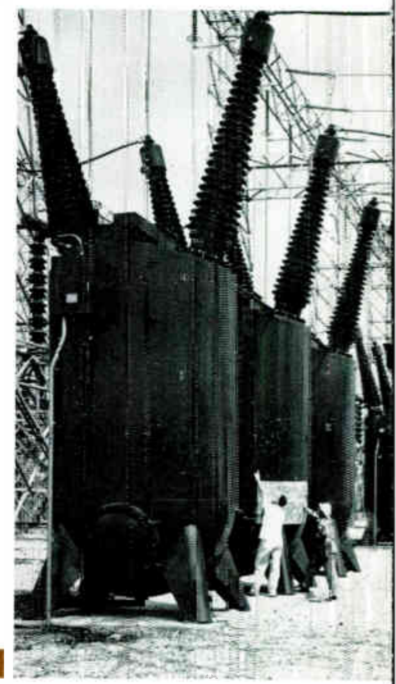


shapes. Herewith, a sampling of patterns recently taken by Westinghouse photographers:

(Left) Part of the stator for a hydroelectric generator during construction; **(Left Center)** Lining of an anechoic vault, where sound measurements are made on large transformers; **(Right Center)** Teeth of a low-speed gear of a main reduction gear assembly for a Navy destroyer; **(Right)** Steps for an electric stairway, during final inspection.

CIRCUIT BREAKERS . . . OIL

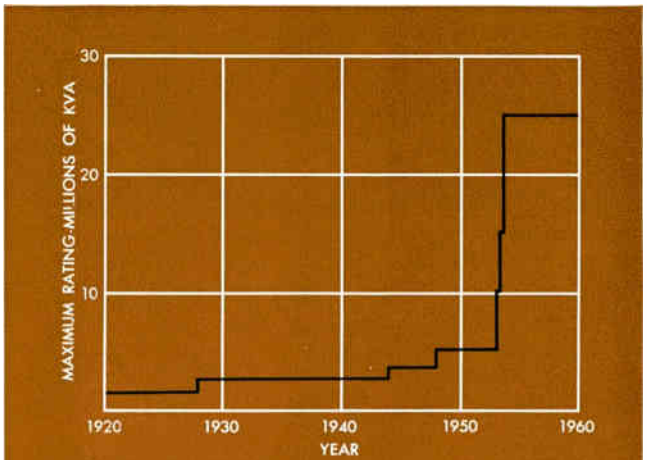
A. W. HILL
Engineering Manager
Power Circuit Breaker Department
Westinghouse Electric Corporation
Trafford, Pennsylvania



345-kv. 25-million kva oil circuit breaker

Today, oil is the most widely used interrupting medium for high-voltage high-power circuit breakers; but the outstanding arc-quenching ability of sulfur-hexafluoride gas makes this medium a particularly good bet for the future.

For the first time, the electric utility industry in this country has its choice of three major types of high-voltage, high-power circuit breakers—oil, air, and gas. Each type has its own peculiar advantages.



Maximum published ratings of circuit breakers manufactured by Westinghouse.

Until about five years ago, most of the major progress in circuit breaker design in the United States was made with bulk oil breakers. Then, new design innovations brought the air breaker back into style to some extent, particularly in locations where the use of oil was objectionable. And recently, the high-power sulfur-hexafluoride gas breaker was introduced.

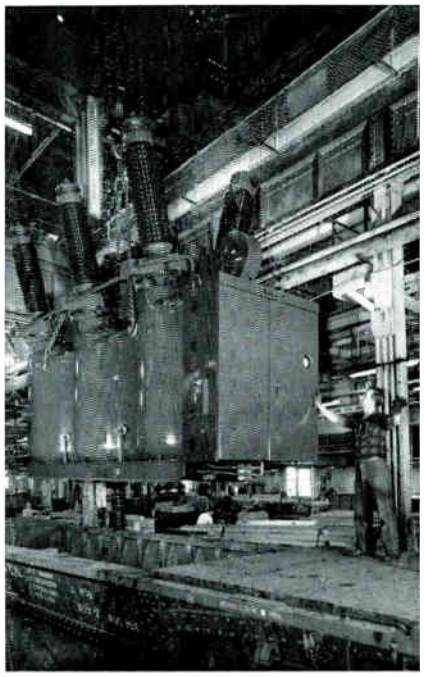
Engineers borrowed freely from the many gains already achieved with oil breakers in designing both the air and gas breaker. For example, both breaker types employ grounded metal tank construction, a common subframe, mechanical tie between poles, and bushing-type current transformers. With these features common to all three designs, the major differences between breakers lie in the actual performance of the interrupting medium.

oil

In spite of the complaints about oil maintenance, the bulk oil breaker continues to be the "workhorse of the industry" and probably will remain so for several years in the future. It has a good record of performance, is available in all needed ratings, fits well into most station layouts, and its built-in interrupting ability is relatively free of delicate or sensitive valves.

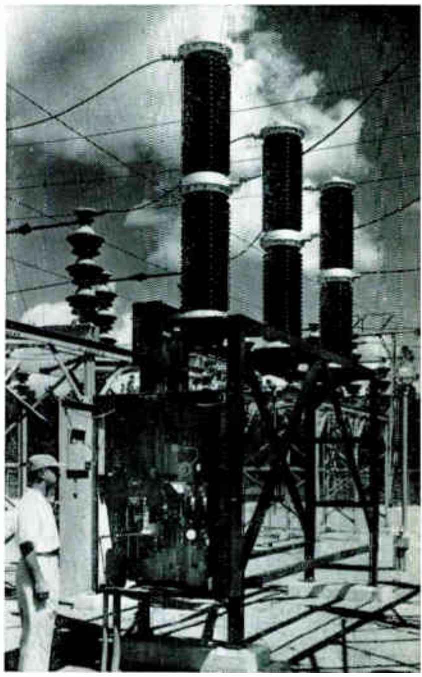
Even for indoor service, where fire hazards could be an important consideration, oil breaker installation has con-

AIR



138-kv, 10-million kva compressed air breaker

GAS



This 115-kv SF_6 breaker has been in service three years.

tinued at a fairly uniform rate for many years. True, the one million kva and larger breakers have been discontinued, but these were mostly generator breakers in early years, and little need is found for any kind of breaker for this service now. Not only has the general demand for indoor oil breakers of moderate size kept up, but new design effort has been warranted to reduce sizes (20 rather than 22-inch tanks for 250 000 kva) and improve interrupting characteristics.

In certain locations, such as chemical plants, the open arc of an air breaker could touch off an explosion. Obviously the fully enclosed oil breaker affords the protection needed here, since the arc is under oil and inside a steel tank. In dusty areas, it is difficult to keep breaker contacts clean, and the enclosed oil breaker design again finds favor.

Outdoor oil breakers have been in a continual state of improvement, marked by higher voltage and kva ratings, such as the 345-kv, 25-million-kva unit during the past few years. More than half the breakers produced now for voltages of 115 kv and above carry an interrupting rating of 10-million kva or more. At the lower end of the size scale, the interrupting ratings of common-tank 15-kv designs have been doubled, from 250 000 to 500 000 kva. And interrupting times have been speeded up to better than twice their fault-clearing speed of two years ago.

At no time has higher continuous current proved to be a serious limitation—witness the 6000-ampere generator voltage breaker, and 2000- and 3000-ampere transmission-voltage breakers.

Much has been done in the past few years to add to the attraction of the bulk oil breaker. For example, with better oilproof gaskets, it has been possible to put a manhole on the side of the tank rather than the top, adding much convenience for the maintenance man. The three tanks have been welded to a sub-frame, permitting delivery to the site of a completely assembled and adjusted breaker—only one piece to lift off the freight car for ratings as high as 161 kv. Oil volumes have been reduced by one-half through more efficient interrupters, and by one-half again when the "Watch Case" tanks were applied at 230 kv and above. This design could well be applied at 460 kv also. "Watch Case" tanks are not used at 115–138 kv because with the ultimate reduction in electrical clearance, there is not enough space left for a man to work inside the tank.

In all these areas, and in faster timing, better reclosing properties, sound insulation, minimum radio interference, and overall practical reliability, the oil breaker has long

Table I—INTERRUPTING RATINGS OF WESTINGHOUSE POWER CIRCUIT BREAKERS (MVA)

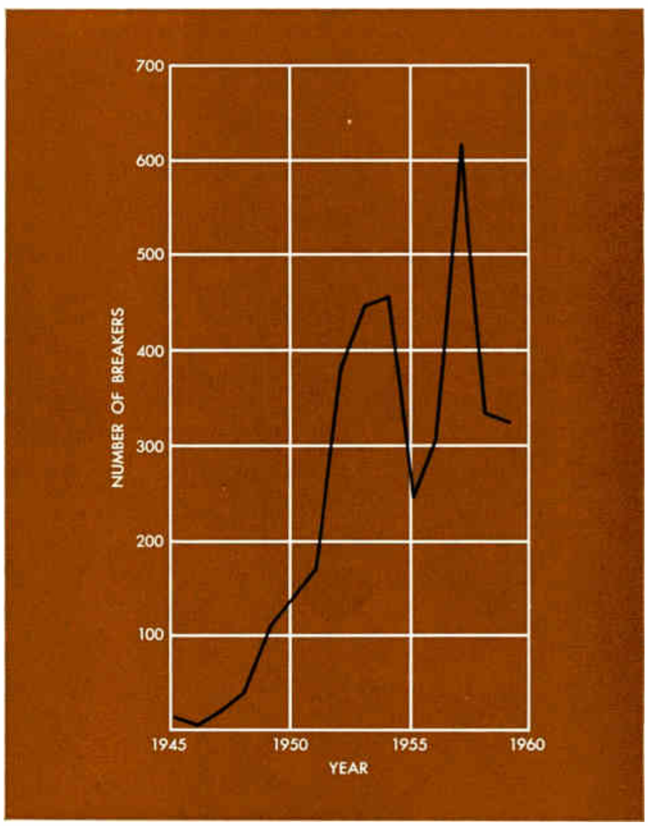
	INDOOR		OUTDOOR		
Voltage Class (kv)	Oil	Air	Oil	Air	SF_6
345			25 000		
230			20 000		15 000
161			15 000		
138			15 000	10 000	10 000
115			10 000	6000	1000
69		5000	5000		
46			2500	3500	250
34.5	1500	2500	2500		
15	1500	2500	1500		

been accepted as a well-established device. It will not be easy to displace it with some alternate device.

air

The desire to eliminate oil has been recognized for many years in switchgear development programs. Designers were quite sure that utilities in this country would not accept a mere reduction in oil volume, such as in the oil-poor breakers of European design. The oil-poor design does not eliminate the fire risk and messiness of oil handling—and, in fact, only adds a measure of hazard from flying porcelain. Furthermore, the addition of current transformers adds considerable expense to the oil-poor units, so no effort was directed to this end.

Westinghouse switchgear designers have long known that good interrupters could be made using compressed air instead of oil, and several times in the past 15 years experimental designs were built in an effort to adapt this principle to outdoor, high-voltage service. However, the primary problem was to provide a container for such a device that would meet demands for safety, installation dimensions, current measurement, and manufacturing and operating costs. This problem existed until about 5 years ago, when designers realized that utility needs could be met by a pressurized steel tank, whose air is used in common orifice-type interrupters and then discharged through hollow bushing studs—truly a conventional breaker type, scarcely showing any external difference from an oil breaker. Air at 15-atmospheres pressure furnishes the insulation to ground inside the tank, and since it surrounds the interrupters, gives prompt extinguishing action when the valves are opened and the contacts separated. The loud report usually associated with the operation of compressed-air breakers is greatly reduced in severity by the baffling effect of the long hollow lead-in bushings.



Number of breakers shipped each year by Westinghouse with ratings over 2½ million kva.

In moderate high-voltage areas, this compressed-air design is a good breaker, but appears to be unsuited to extremely high voltages for economic reasons. Units have been produced from 46 to 138 kv, and neither high kva nor continuous current have been a limitation. A low ohmic resistor has been used across each main break during the switching operation to control recovery voltages, so the breaker is not limited in any way by a power system that has a high rate-of-rise of recovery voltage. The breaker determines its own recovery rate. The breaker is no larger than a conventional oil breaker, and enjoys the same desirable features of grounded steel tanks for safety, economical bushing-type current transformers, delivery fully assembled in one piece, and inspection and maintenance at ground level and inside the tank during inclement weather.

For indoor service up to 34.5 kv, weather-proofing is no problem and the solution is much simpler than for outdoor breakers. However, since an external air supply is needed, this design usually cannot be justified for reasons of economy for ratings less than one million kva. Micarta laminate can be used in place of porcelain, thus avoiding fragile mechanical structures. Much costly field assembly labor can be eliminated by furnishing most of these breakers in metal cubicles, factory built. So this breaker is generally specified for those cases where a main generator breaker is desired. Preferred ratings (ASA C37.6) up to 5000 amperes continuous current have been established. However, these current ratings are not high enough for the largest modern machines. It is quite feasible to add forced-air cooling for ratings up to 7000–8000 amperes with no increase in copper cross-section. Even higher ratings have been considered, using multiple-contact members for added conductivity. This type of breaker, with its cross-blast interrupter, has worked out very successfully for highly repetitive operations, such as arc furnaces and capacitor banks, where deterioration of oil and contacts is unacceptable.

sulfur hexafluoride

By 1947, Westinghouse research scientists had a good picture of the desirable arc-interrupting properties of the gas, sulfur hexafluoride. Switchgear engineers were encouraged to put SF_6 to practical use in the field of arc interruption. The details of several designs have been described[1], and it is evident that this gas stands out in comparison with both oil and air in all areas of insulation recovery after arcing, dielectric strength, nonflammability, safety, operating pressures, and chemical stability. SF_6 approaches the ideal arc-interrupting medium more closely than any other known material. Being new in the field, this gas will need a somewhat different approach in design work. But circuit breaker engineers are convinced that when the "nuts and bolts" are arranged properly, they will be building the breaker of the future.

[1]"Sulfur Hexafluoride—for Arc Interruption," Westinghouse ENGINEER, March 1959, p 46-50.
"SF_6 Circuit Breaker—A New Design Concept," by R. E. Friedrich and R. N. Yeckley, ibid., p 51-5.

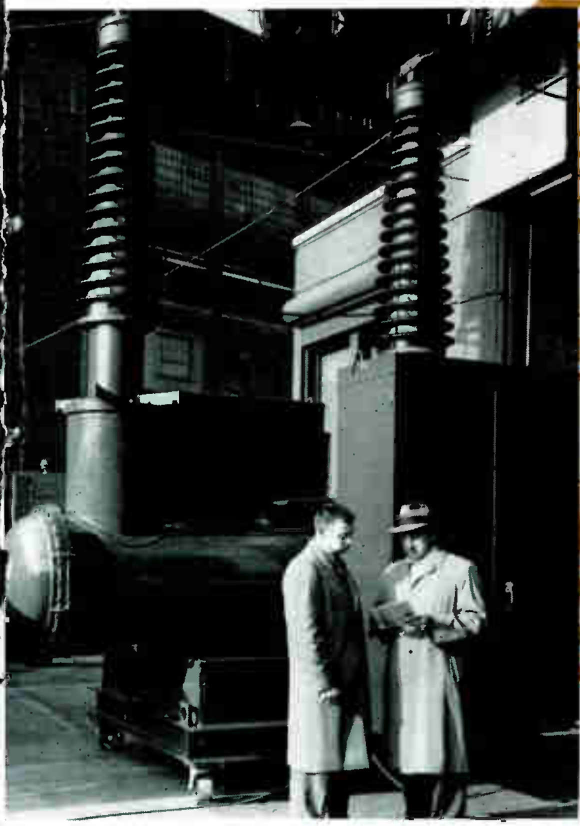
Sulfur hexafluoride can be handled safely and easily. In ten years' experience, no problems of personnel safety have arisen in either routine shop manufacture, or laboratory development work, and never has any special mask or glove been required. An air hose is used to flush out a breaker after testing, and the testers then work on the inside parts without delay. The gas is costly enough to warrant pumping it out rather than throwing it away when a breaker is opened, and conventional pumping equipment can store enough for a 3-pole, 230-kv breaker in about 20-cubic feet of tank at 35-atmospheres pressure.

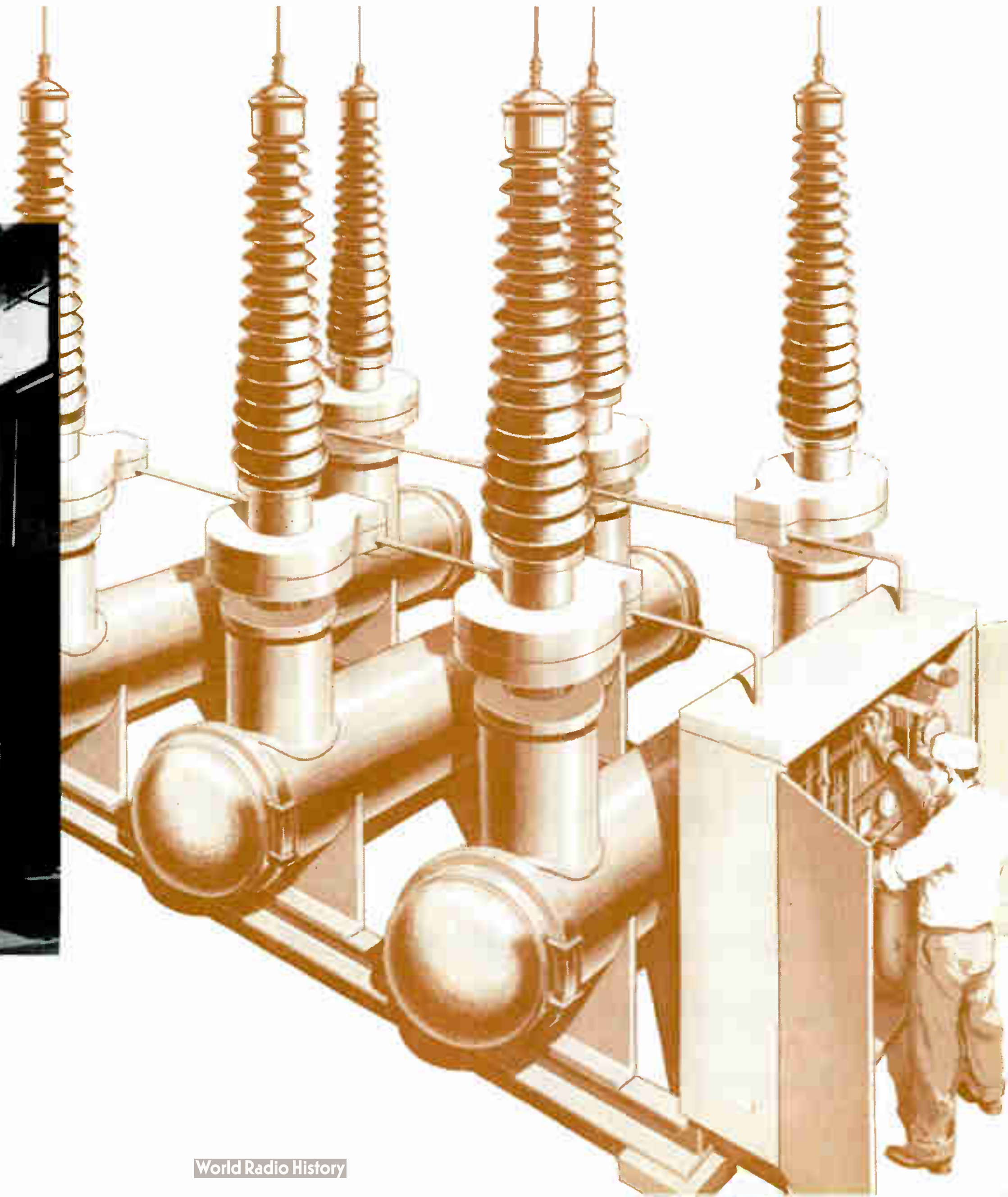
The larger ratings were tackled early in the program to be certain that this design would not have a limited ceiling. And, again, all the proven good points in the oil breaker design were retained—grounded steel tanks, bushing current transformers, and convenient maintenance at ground level. The identical pneumatic operating mechanism used on oil breakers for the past 10 years is used on this new breaker. Gas pressures need not be high, for SF_6 has inherently the qualities needed for insulation and interruption. Ground shock, even at highest fault duty, is absent, thus greatly simplifying breaker foundation structure. And even the 230-kv, 15-million kva breaker can be shipped fully assembled on a welded steel base, bushings and all, to most of the stations in this country.

conclusions

The favorable characteristics of sulfur hexafluoride—unusual arc interrupting ability, freedom from carbon, and high dielectric strength—are making possible new breaker designs that can combine the better features of both insulating-oil and compressed-air circuit breakers. This new breaker can, therefore, be expected to assume a major role among circuit interruption devices.

Over the next 5 to 7 years, the SF_6 breaker shows promise of replacing the well-established bulk oil breaker, first at transmission voltage levels, and shortly thereafter at the higher distribution voltages. Further study will be required to determine whether (or how) SF_6 will find application to breakers rated 15 kv and below. The decision will be based on economic factors, which have already shown advantages for SF_6 at high voltages. ■





(**Above**) One pole of the 15 000-mva SF_6 circuit breaker. (**Right**) Artist's drawing of the 3-pole assembly for a 230-kv, 15 000-mva SF_6 breaker.

THE FLASH EVAPORATOR . . . A VERSATILE DEVICE

Uses for the flash evaporator include the production of potable water, high-purity boiler make-up, and ultra-pure water for industrial processes.

R. L. COIT **E. F. STALCUP**
Heat Transfer Department
Westinghouse Electric Corporation
Philadelphia, Pennsylvania

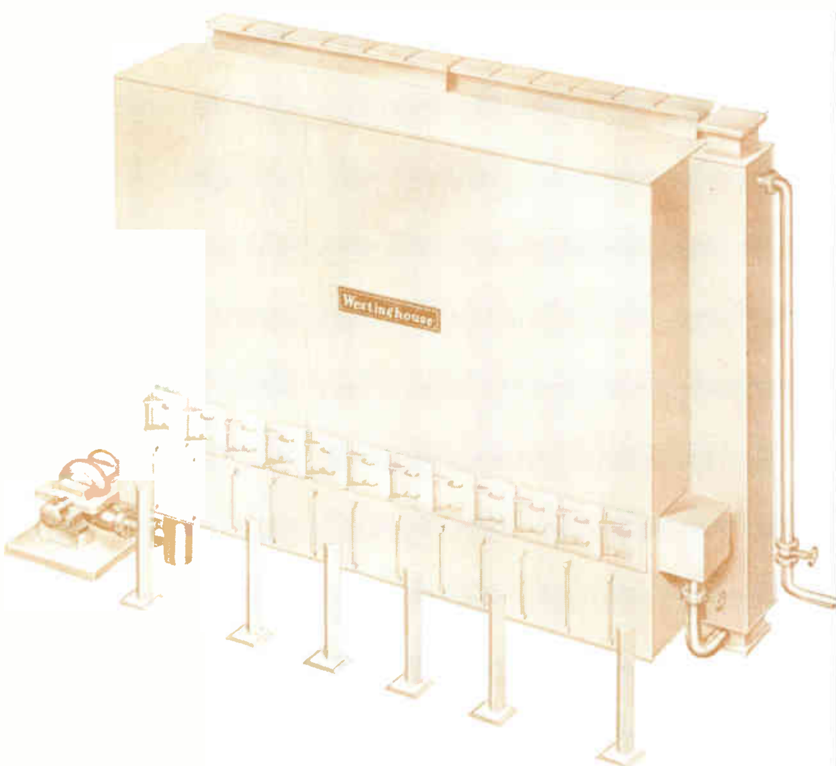
Interest in water purification has increased rapidly during the past ten years and the technology has advanced in many areas. The Office of Saline Water in the Interior Department continues to support research and development in the demineralization of saline waters by many techniques. These include freezing, ion exchange, electrodialysis, and several distillation techniques. In terms of installed capacity, distillation units far exceed any of the other processes. The total installed capacity of land-based sea-water evaporators is shown in Fig. 1.[1,2] The semi-logarithmic scale indicates the rapid increase in the use of this process. An appreciable portion of the installed distillation capacity is of the older submerged-tube design, but the additions that are being made largely consist of multi-stage flash-type units.

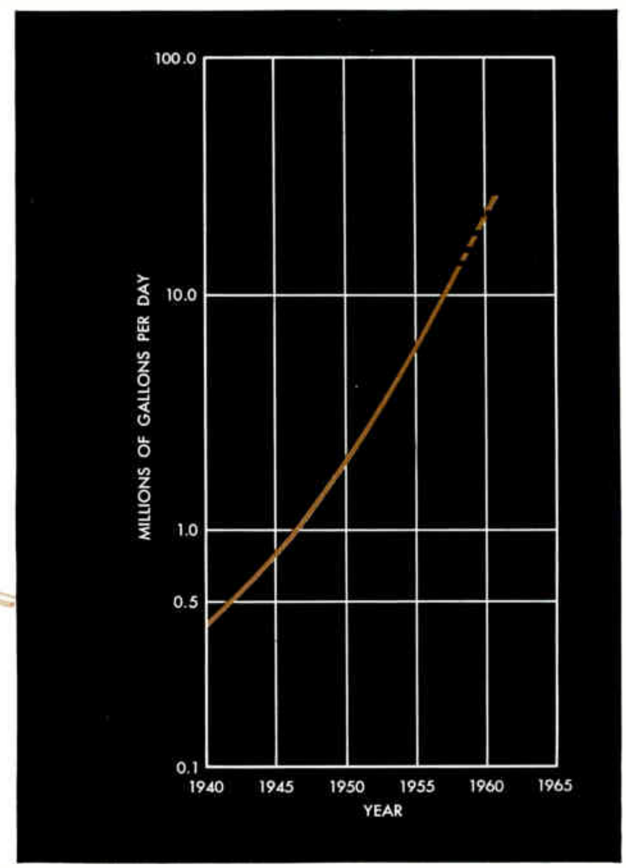
Successful operation of multi-stage flash evaporators for producing potable water from sea water led to the investigation of flash-type evaporators for producing high-purity boiler make-up in modern power plants and ultra-pure water for use in industrial processes.

design of flash evaporators

In principle, flash evaporation is a relatively simple process. Basically, it consists of spraying warm or hot water under pressure into a chamber that is at a lower pressure and temperature. A portion of the water "flashes" into vapor and then is condensed. Flashing results from the difference in the heat storage ability of water under higher and lower pressures. The vapor is formed almost simultaneously with the disintegration of the liquid mass.

A simplified flow diagram of a single-stage flash evaporator is shown in Fig. 2. Make-up water enters the unit through heat exchangers, which utilize energy from the distillate and the steam heater drains. This make-up is deaerated as it joins the recirculating "brine," which is pumped through the brine heater where low-pressure steam





Above—Artist's conception of a 12-stage vertical flash evaporator.

Fig. 1—Total installed capacity of land-based sea-water evaporators.

heats the brine. Deaeration of the make-up decreases the corrosiveness of the brine and enables the use of carbon steel shells in the unit, even for sea water applications. The heated brine then passes through a restriction into the flash chamber, which exists at a lower pressure, the pressure being maintained by the evaporator condenser. The evaporator condenser condenses the distillate by transferring the latent heat of the flashed vapor to colder raw water. The desired distillate purity is achieved by passing the flashed vapor through appropriate steam separation devices. The unit shown in Fig. 2 is a single-stage device, which would produce slightly less than one pound of distillate per pound of low-pressure steam supplied to the brine heater, and would, therefore, result in an uneconomic installation for the production of large quantities of water. Multi-staging can be used to increase the ratio of distillate produced to steam supplied, as shown in Fig. 3. This diagram shows one of the four 640 000 gallon-per-day units that have been in operation in Kuwait, on the Arabian Peninsula, for over two years.

In this unit, hot brine containing 84 000 ppm total dissolved solids enters the heater at the top, then flows to the first-stage flash chamber. A portion of the water is flashed here, the remainder flows to the second stage, which is at somewhat lower pressure and temperature than the first-stage; more water is evaporated in the second stage, and still more in the third stage. In each of the three stages, the water used in the condensers is recirculated. The water remaining after the fourth stage of flashing is supplemented by make-up water, then passes successively up through the condensers of the third, second, and first stages in that order, picking up heat as it goes. The final heating is supplied by steam at the top, or beginning of the cycle.

The fourth-stage condenser is supplied with raw sea water. Distilled water flows from the fourth-stage to storage facilities.

applications of flash evaporators

Single-stage submerged-tube evaporators, such as shown schematically in Fig. 4, have been used for many years to produce boiler make-up for steam power plants. Extraction steam is passed through a heating coil to evaporate raw water and produce pure vapor, which is normally discharged into a deaerator or lower-pressure heater. The operation of the submerged-tube unit results in a decrease in the steam flow through the turbine between the number 3 and number 2 extraction points, thereby decreasing the work done by the turbine.

A flash evaporator can be integrated into the regenerative feed-heating cycle, as shown in Fig. 5. Since the heat transfer, both in the brine heater and the evaporator condenser, involves condensing rather than boiling, low temperature differences can be employed and high heat-transfer rates maintained. Advances in the design of steam separation equipment have also enabled the operation of sub-atmospheric evaporators.

The location of the flash evaporator, as shown, results in a significant improvement in the turbine generator heat rate since all of the energy associated with the steam ex-

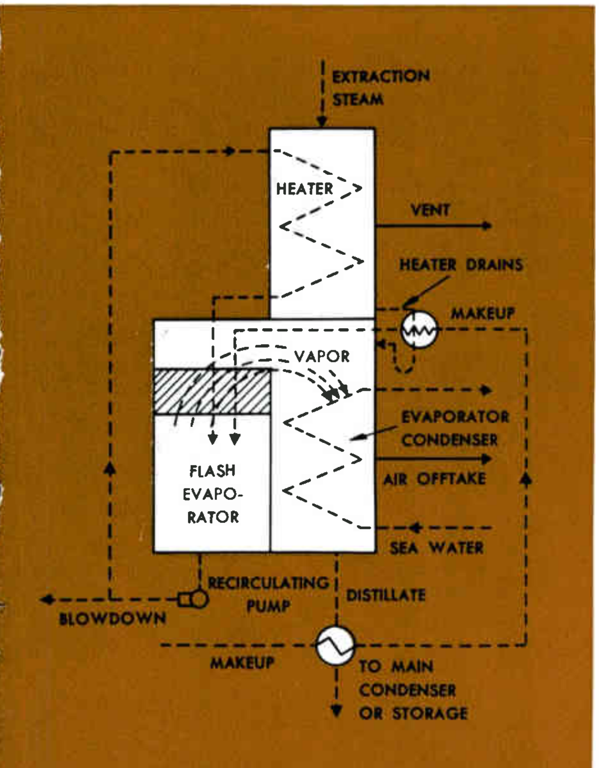


Fig. 2—Simplified flow diagram of a single-stage flash evaporator.

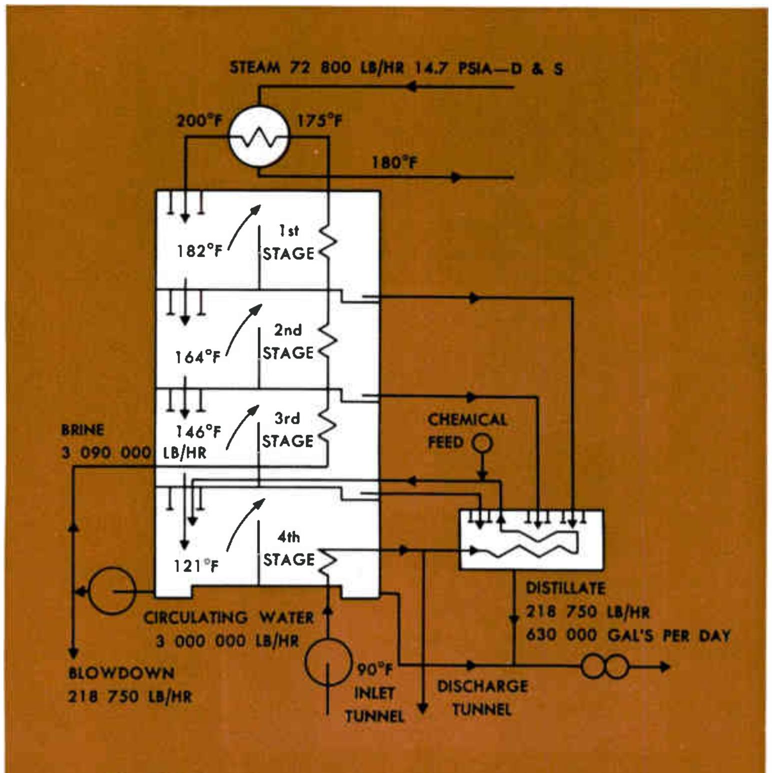


Fig. 3—Flow diagram of a four-stage flash evaporator.

tracted by the flash evaporator is returned to the regenerative cycle with no degradation. The evaporator could be thought of as a "zero" point heater, which precedes the number 1 low-pressure heater and receives steam in parallel with the number 1 heater. Sufficient extraction steam is taken from the turbine by the flash evaporator and the number 1 heater to provide the proper temperature rises of the condensate.

The introduction of make-up into a regenerative cycle increases the cycle heat rate since additional steam must be extracted to heat the make-up from its entry temperature up to the final feed temperature. The effect of adding various amounts of make-up to a typical large turbine generator cycle by several processes is shown in Fig. 6. For example, at one percent make-up the turbine heat rate is increased approximately 27 Btu per kwhr when the make-up is provided by a submerged-tube evaporator without the use of an evaporator condenser. If the same one percent make-up is produced by either a demineralizer or a flash evaporator located as shown in Fig. 5, the increase in heat rate is approximately 16 Btu per kwhr. The differential effect on heat rate at one percent make-up is thus about 11 Btu per kwhr, a significant improvement when evaluated for a large central station unit.

Additional heat rate improvement can often be achieved by discharging boiler blow down into the flash evaporator. Since the flash evaporator operates at a low temperature level (usually 110 to 125 degrees F), a greater percentage of the energy in the boiler blow down can be recovered than if it were admitted to the shell of a conventional submerged-tube evaporator, which operates at a higher pressure level.

An additional area of application of the flash evaporator is to provide high purity water for older power stations that are operating as peaking units and are unable to produce the required quantities of make-up. An artist's conception of a unit that is to be installed by Philadelphia Electric Company is shown on page 86. This 12-stage vertical unit will supply 50 000 pounds per hour of make-up to supplement the available submerged-tube evaporator capacity. A multi-stage unit was chosen since high-pressure steam will be used for the heat source, and the unit is not incorporated into the regenerative cycle. The process diagram is an adaptation of that used or the Kuwait units (Fig. 3), with the final stage heat rejection to river water.

A logical extension of the application to older power plants is to use multi-stage flash evaporators for the production of large quantities of high-purity water for industrial processes. In many chemical and petroleum processes, where the percentage make-up is very high, a multi-stage flash evaporator is often the most economical means of producing the desired high-purity make-up.

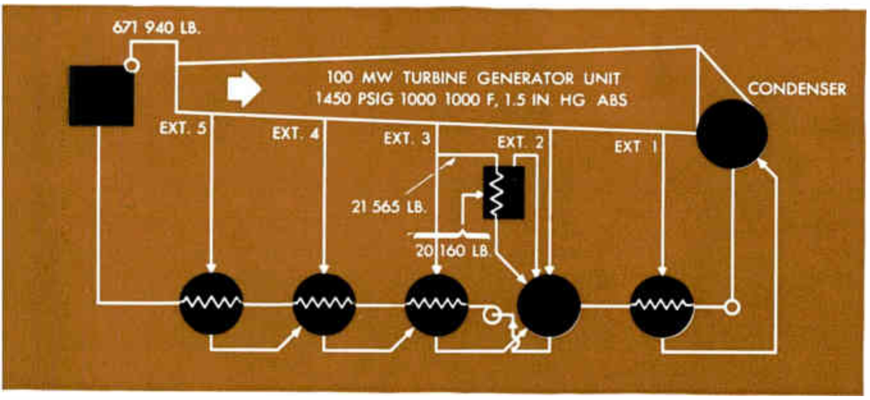


Fig. 4—Single-stage submerged-tube evaporator located in power cycle.

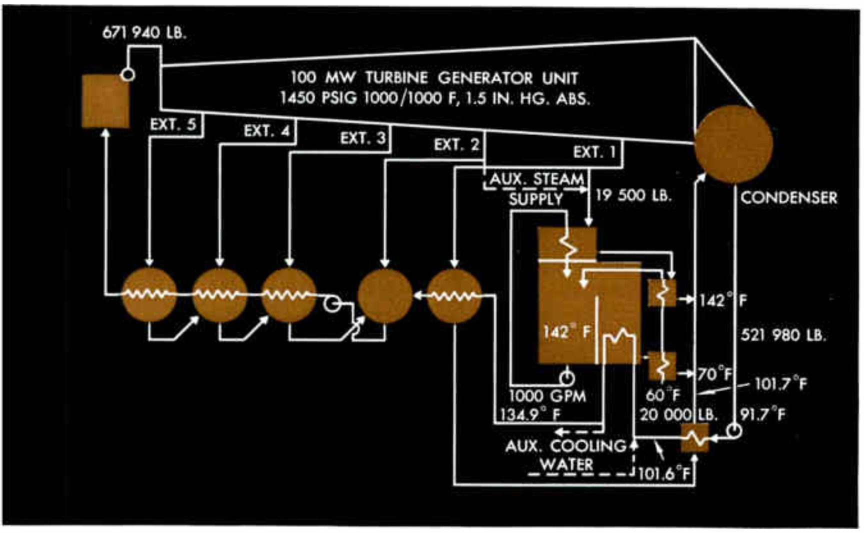


Fig. 5—Single-stage flash evaporator located in power cycle.

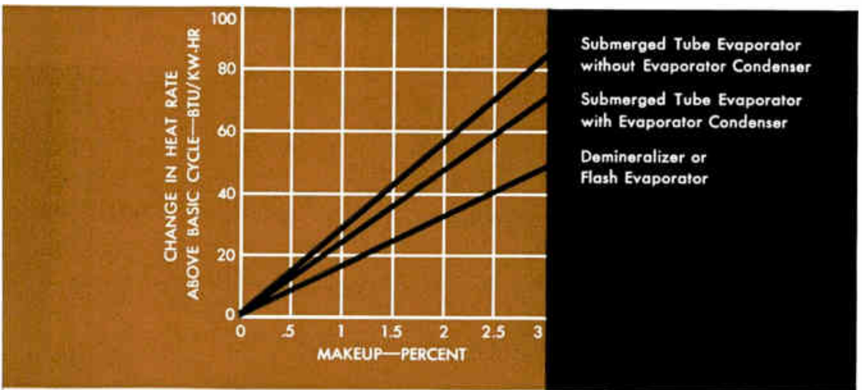


Fig. 6—Effect of make-up on heat rate of a typical plant cycle.

summary

Single-stage flash evaporators incorporated into steam power plant cycles effect an improvement in heat rate over cycles using submerged-tube evaporators. The development of flash evaporators has progressed rapidly and at present this apparatus has several significant advantages. The equipment does not require descaling, whether it is fed with fresh or sea water; the distillate is of extremely high purity—0.05 ppm total solids from fresh water feed concentrated to 3000 ppm, or 0.25 ppm from salt water feed concentrated to 70 000 ppm; and chemical treatment can be incorporated into the cycle, where necessary. ■

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2—"Flash Evaporators for the Distillation of Sea Water," by A. Frankel, The Institution of Mechanical Engineers, 1959.

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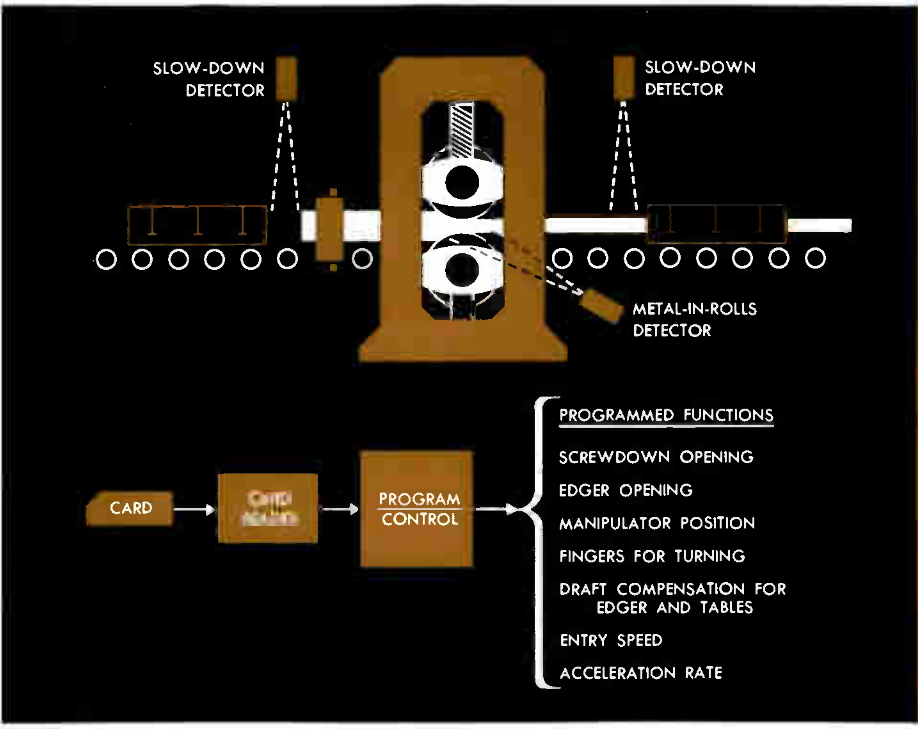
Fig. 1—Reversing roughing mill and operator's pulpit.

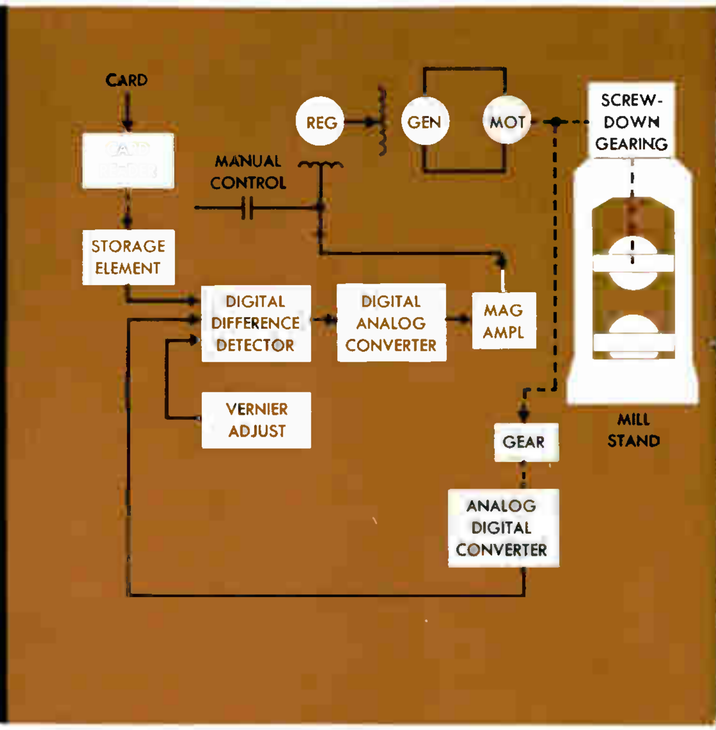
ADVANCED ELECTRICAL SYSTEMS FOR APPLICATION TO METAL INDUSTRY DRIVES

New techniques in electric drive systems are being applied rapidly in the metal industries.

W. H. DAUBERMAN
Industrial Engineering
Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania

A revolution is taking place in electrical drive systems for steel and nonferrous rolling mills. Many factors are contributing to the changes now taking place. Perhaps the salient motivating forces are: the need for and acceptance of a high degree of automation; the existence of new digital control techniques with broad use of transistor circuits; and the development of in-line computers to calculate, optimize, and automatically program mill schedules. The increasing demand for means of improving process operation has resulted in the rapid application of these new tools to the steel and nonferrous industries.





primary reducing mills

The longest and most extensive experience in automatic mill programming and in the digital control techniques has been obtained with primary mills, such as the blooming mill and reversing roughing mill.

The 44-inch reversing roughing mill shown in Fig. 1 has been in service over two years. This mill has 6000-hp total drive power, with a 3000-hp motor on each of the main rolls. A motor speed of 40/100 rpm and 42-inch diameter roll produces a maximum speed of 1100 fpm. Each of the attached edger rolls is 24 inches in diameter and is driven by a 750-hp motor. Slabs from 5 to 9 inches thick are rolled to approximately one inch minimum. The mill is designed for full automatic operation; to roll a slab to its final thickness the operator need only press a button for the initial start of the slab into the mill.

The functions programmed are shown in block form in Fig. 4. For each schedule a punched card shows the mill roll and edger roll position for each pass. Also punched on the card is the mill speed for each pass, and the draft compensation required to match the edger speed to that of the mill. Both the mill speed and the compensation are selected from the fixed number of available values. Some functions, such as the operation of sprays and side guards, are programmed if they are to be used on the pass, and limit switches or hot metal detectors then control the motion. Hot-metal detectors are used at times to initiate slowdown of the slab as the tail end approaches the mill, and they (or roll-force gauges) indicate when the bar leaves the mill. Thus they serve as a signal to the program to proceed to the next pass.

All the information on a card is read and stored in transistor memory circuits or on magnetic cores and the data read out as required. If a number of slabs are to be rolled on the same schedule, the card itself is read only once and the program information kept in storage and used for all the slabs. To roll on a new schedule the operator has only to press a "pass advance" button—the stored information is erased and the next card is automatically put in the card reader, read, and the data stored.

The basic components of the programmed, automatic screwdown control are illustrated in Fig. 3. The analog-to-digital converter, which develops the displacement of the screws from a zero position, consists of a transistorized pulse counting and accumulating circuit and a Rotrac pulse generator, which is coupled to the screwdown drive, directly or through gearing. This pulse generator has two discs that face each other—a rotor attached to the generator shaft, and a stator. Each disc is impregnated with a radial bifilar winding. The rotor winding is excited at a high frequency and induces a current in the stator winding. When the two radial windings are electrically in phase, a maximum voltage is developed in the stator; when they are displaced 180 electrical degrees, the stator voltages cancel with a zero result. As the screwdown motor turns, sine waves are produced; for each revolution of the screwdown motor the number produced depends on the design of the Rotrac winding and on the manner in which the Rotrac is geared to the mill screwdown motor. (The generator has an output even at zero speed, which is necessary for a position regulator, and the magnitude of the pulses are independent of the speed of rotation.)

In the digital difference detector, the actual screw position is compared to the programmed position and the difference drives a magnetic amplifier to excite the screw-

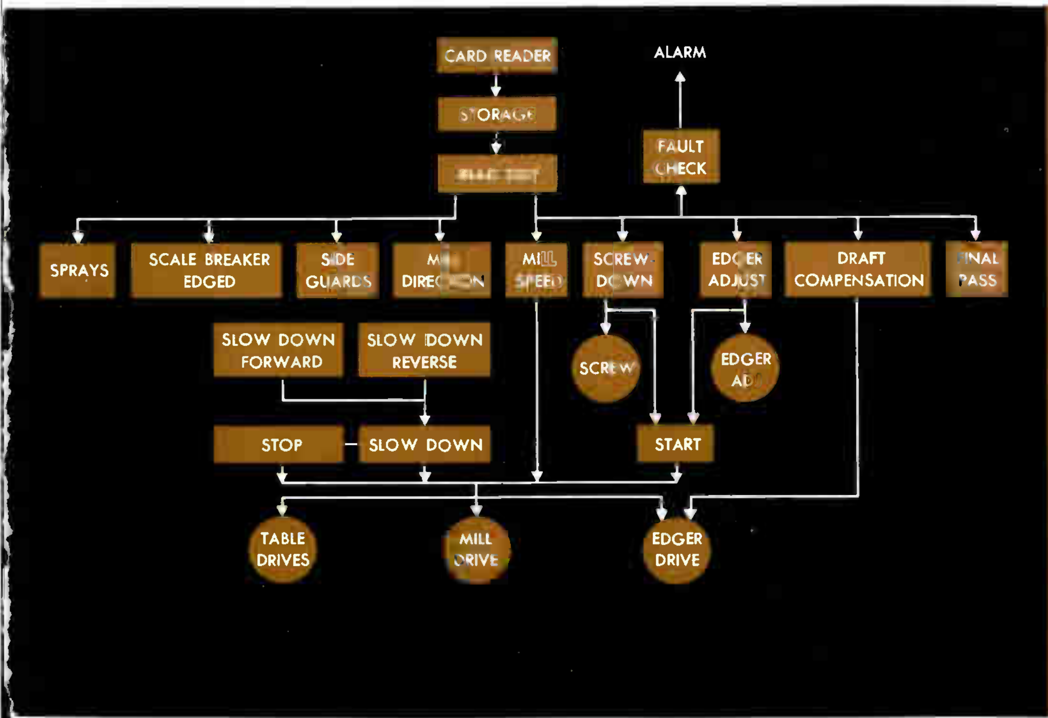


Fig. 2—(Far left) Programmed functions for a high-lift blooming mill.

Fig. 3—(Center) Programmed automatic screwdown control.

Fig. 4—(Left) Card programmed, automatic control of reversing roughing mill.

down generator to move the screws and obtain a zero difference or error.

Through the digital-to-analog converter the screw position error is used to control the screwdown speed. Once the minimum screw stopping distance has been established the drive always runs at top speed until reaching this displacement, then decreases in speed by steps as it approaches its zero error position.

On consecutive passes an indication of the screw displacement from its ultimate position is also used to start the mill tables for entering the slab in the mill. For example, tests may indicate that if the tables are started to enter a slab when the screws are one-half inch from their final position the slab will enter the mill just as the screws reach their position. This signal to start the tables can then be programmed and given automatically.

A high-lift blooming mill was installed about a year ago with complete automatic operation (Fig. 2). This mill offered the additional challenge of programming manipulators and fingers for turning the ingot or bloom. The turning of an ingot on edge is especially difficult to automate since it is not a positive motion like the screwdown; actually it is more like turning over a large cake of ice and more than one attempt may be required to get the ingot up on its edge.

Fig. 5—Manual take-over control for blooming mill using small master switches.

The program indicates, for each pass, whether or not the ingot is to be turned. The program then includes information as to how far the manipulator should move away from the ingot before the fingers turn it, and how high the fingers should lift. These two bits of data depend on the size of the ingot. The tilting fingers are on the right manipulator, so the manipulators confining the ingot for an edging pass are instructed to move to the right with the ingot; then the left manipulator opens and the ingot is turned flat on the mill table.

Hot-metal detectors are used to initiate slowdown and mill reversal. The mill can be made to slow down while metal is still in the rolls to prevent the bloom from shooting too far from the mill when it leaves. A hot-metal detector at the roll knows when the bar has cleared, and is used to reverse the mill and initiate the screwdown motion.

In the newest packaging for the static transistor and core storage control for the blooming mill, the encapsulated elements are plugged into a module, which in turn is plugged into a rack. The equipment has been designed to meet the need for continuity of operation and maintenance requirements. For the automatic mills some operators favor a reduction in the desk size and the use of small control switches (Fig. 5) for manual control instead of the mill master switches of Fig. 1.

For a high-lift blooming mill, the relation between screwdown direction and speed, mill table voltage, main drive speed, and manipulator operation for a series of passes is shown in Fig. 6. The shaded areas indicate time when the ingot is in the mill. The oscillogram shows that the tables start to accelerate as the screws approach their destination. This is readily observed after passes 2, 6, 8, 10 when a large screwdown travel is made permitting the tables to come to a stop. A comparison of the screwdown speed and manipulator speed charts shows that after passes 2 and 8, the manipulator and screws complete their operation at about the same time. After passes 6 and 10, the mill waits almost 2 seconds for the screws. When the screw is opening, such as following passes 6 and 10, the screwdown speed chart shows that the screws overshoot a slight amount going up and then position in the downward direction to eliminate any error from backlash in the screws.

Since there is so much lost production time when steel is not in the mill, the time required for these operations must be minimized. Also repetitive performance is essential, so that completions of a maneuver can be accurately anticipated to make additional time economies.

computers for mill drives

The in-line computer for mill drives is a recent development. This device will compute and program the mill rolling schedule and calculate, from mill and process data feedback, corrections to the initial program information.

One steel plant with an automatic programmed reversing roughing mill has over twenty thousand different schedules, hence as many punched cards on file to use as needed. The in-line computer eliminates these completely; while a punched card is prepared for each order rolled, it will have a minimum amount of information, such as order or slab number, slab size, finish size, and hardness characteristic. Other data, such as electrical and mechanical drive limitations, and relations of speed and torque, are permanently stored. The computer calculates and puts into magnetic core storage the number of passes, draft, and speed for each pass of the mill schedule. Such a system is shown in Fig. 7.

A far more significant advantage of the in-line computer on the reversing roughing mill is its ability to examine individual slab sizes entering the mill, the mill stand conditions, and the product characteristics occurring during the rolling of a pass, and from these data make adjustments to the program to more closely achieve the desired output.

In some cases, the length of a slab must be controlled when cross rolling or broadsiding, because in certain subsequent rolling operations, this length becomes the width of the final product.

A computer can calculate and predict the final rolled length from information consisting of the actual weight of the slab and programmed settings of mill and edger roll openings. If the predicted result is significantly different from the required length, the mill roll separation can be changed before the slab enters the mill, thus varying the thickness accordingly and achieving the correct length. The computer then can change the programmed data for subsequent rolling operations to compensate for changes in the thickness dimension.

The computation for mill setting includes a factor for the strain of the mill housing, so the rolling mill would have roll force load cells. The roll force, as integrated for a pass, is fed back to the computer; if different from the anticipated value it modifies the screwdown settings for later passes to compensate for the error in the pass that has just been completed.

The roll-force load cells can also be used for an indication of metal in the mill, and with the pulse generator wheels on the mill drive can measure the length of the plate for the pass rolled; the computer can then calculate what the length will be after the next pass and then program mill slowdown for the end of the next pass. The pulse-counting circuit then locates this slowdown position during the subsequent pass to initiate the slowdown action.

As a further refinement, thickness for some passes can be measured by x-ray gauges. The gauge readings can be averaged over the length of each pass and the value fed back to the computer. Again, if this deviates from the set value, corrections can be made in the screwdown setting for the remaining passes.

With this system, it should be possible to operate the mill with or without the roll force or x-ray gauge feedback, and also manually if desired.

iron ore to shipping floor programming

The programmed automatic mills now in service represent a great stride forward in the method for rolling steel and other metals. The mill system with in-line computers to determine and to optimize mill schedules is another large step.

In the future a more completely coordinated program will be made for rolling the ingot from the blooming mill through the cold mills with the full history of the ingot accompanying it. Thus steel characteristics and bar profiles will be known in advance and mill adjustments can be made to compensate for them as they reach the mills; the result will be a higher premium product. ■

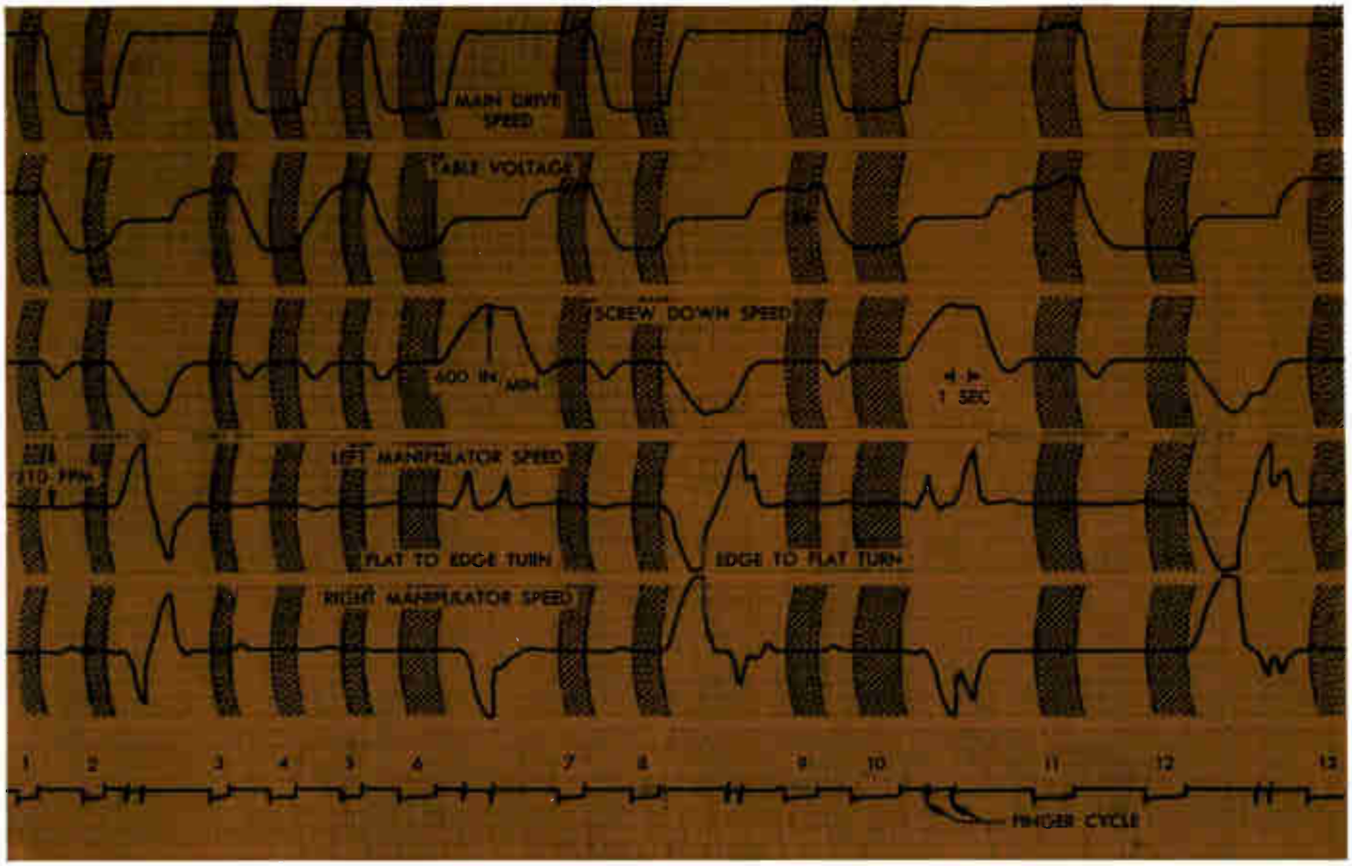


Fig. 6—Time relations for mill auxiliary drives.

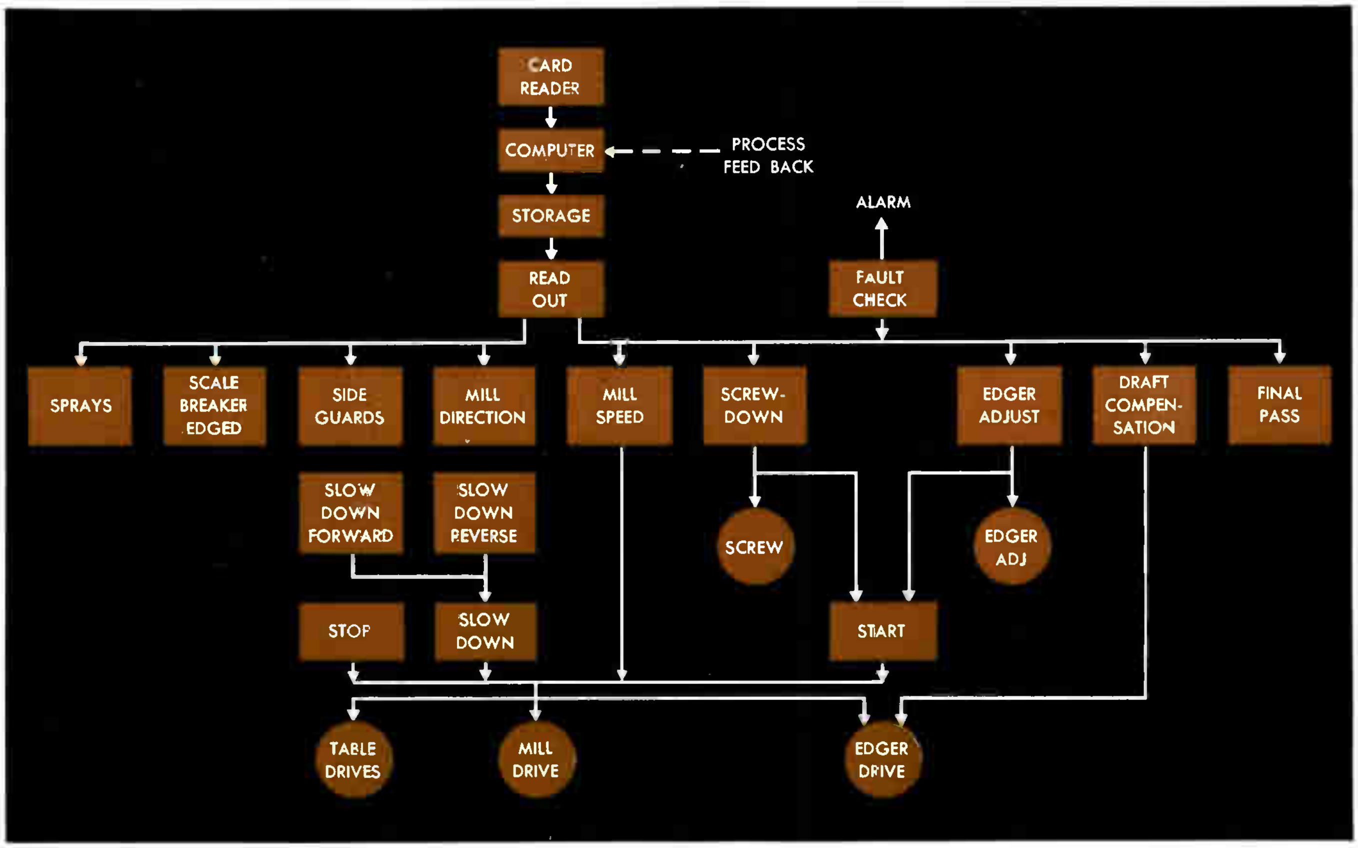


Fig. 7—Block diagram for computer controlled plate mill.

WHAT'S NEW IN ENGINEERING

THERMOELECTRIC MODULES FOR COOLING

Practical thermoelectric cooling devices for military and industrial applications have now emerged from an extensive research and development program. These are "thermoelectric modules" for cooling electronic components, and other applications where compactness, silent operation with no moving parts, and a controlled cooling rate are desired.

The modules are designed in a variety of shapes and sizes for simple mounting in any position when used with transistors, diodes, and other electronic components.

The basic units can be physically paralleled to cool a large flat area, or stacked in series like building blocks for increased cooling.

The need for an efficient cooling of electronic components stems from the rapidly changing electronic field itself. Of necessity, component parts have been miniaturized along with their associated circuitry to meet critical requirements of space, weight, and operating temperatures. However, these compact designs can present major heat dissipation problems. Cooling of electronic equipment by present techniques is complicated by the non-uniform distribution of heat generated by certain components. The resulting "hot-spots" cause a severe heat rise in the component, and effectively derate the total equipment and limit its maximum operating temperature.

Heat dissipating devices using ambient air improve the heat transfer from the critical components, but these techniques can only limit the temperature rise of the components *above* ambient temperatures. They cannot cool the component below ambient temperatures.

Thermoelectric cooling, on the other hand, provides a lower local temperature environment for electronic components. As a result, the probability of early component failure due to "hot-spots" can be significantly reduced, and equipment can be operated in higher ambient temperatures with greater reliability.

The heat-pumping capacity (rate at which heat can be removed from the cold surface of the module coolers) depends on the temperature difference between the hot and cold surfaces of the cooler, and on the power input to the unit. As an example, one module (Type WX816) can maintain a temperature differential of 25 degrees C with a heat load of more than 17 Btu's per hour. To supplement the heat rejection capacity of the module, air or liquid cooling can be applied to the "hot" side of the thermoelectric cooler. The exact amount and type of this cooling will affect the heat-pumping capacity and ultimate temperature of the cold surface temperature of the module. In general, the modules require power at high input currents and at low voltage. The current must be supplied from a dc source or a filtered rectifier output.

In addition to providing the inherent advantage of thermoelectric cooling—compactness with no moving parts—the unique modular construction of these new spot coolers permits a wide range of flexibility in application. This means, in many cases, that electronic equipment need not be redesigned to accommodate the thermoelectric devices. ■

CYPAK CONTROL SYSTEM FOR STEEL PIPE PRODUCTION

Steel pipe for the oil industry is automatically positioned at each welding station by a Cypak control system at the Consolidated Western Steel Company in Provo, Utah.

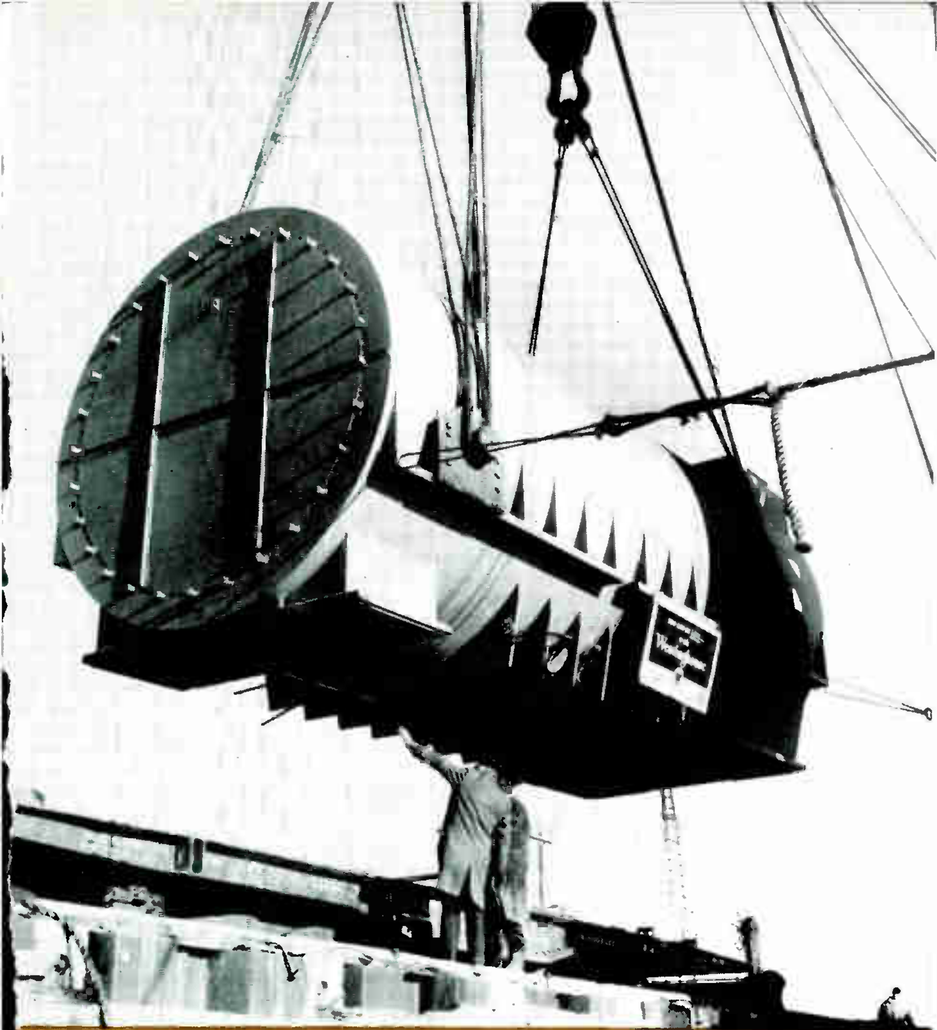
The Cypak system sequences the pipe-manipulating devices so that the first pipe to enter the storage area will stop at the first inside-diameter, semi-automatic welder station. If one of the succeeding welders at one of the five stations should need this pipe, the operator merely presses his "call" button, and the pipe automatically advances to his station.

The steel pipe is held either in the conveyor or waiting station. The conveyor stations are filled in the order of 1, 2, 3, 4 and 5, while the waiting stations are filled in the reverse sequence (5, 4, 3, 2, 1). By use of the waiting station before each conveyor station, storage capacity of the area is doubled and maximum availability of steel pipe is provided without requiring reversal of the pipe-handling equipment. The positions of pipe and the operation of the pipe manipulators are detected by Cypak proximity switches.

The proximity switch detects the presence of steel pipe by the change of reluctance in the detector magnetic field. This method protects the detector from mechanical damage and provides a convenient means of adjusting clearances between the detector head and the pipe. When the steel pipe is in the proper position, the proximity switch stops the conveyor and initiates the manipulator control to discharge the pipe to the inclined rails.

When the inside diameter weld is completed, the operator presses a control button to discharge the pipe from his station. The Cypak system takes over at this point to automatically gather the pipe from the parallel-flow welding stations and transfers it to the series-flow pipe conveyor. The pipe is then automatically directed through a flux-recovery station and, finally, to an inspection station.

The Cypak system cubicles are mounted on a balcony and each cabinet is equipped with a Cypak system tester for maintenance use. Ten percent additional space is provided in each cabinet to allow for changes in the pipe-mill sequence. ■



Top—The generator that will produce electricity for the 275 000-kw atomic power plant of the Consolidated Edison Company at Indian Point, N. Y., is shown above being hoisted from a railroad car to a barge for transshipment up the Hudson River. The stator section of the generator, which weighs 448 000 pounds, represents one of the heaviest lifts ever made by a floating derrick in the Port of New York. The stator was shipped from Jersey City to Indian Point, which is 24 miles north of New York City in Westchester County on the east bank of the Hudson.

Bottom—Thermoelectric cooling modules can be adapted with different mounting fixtures for cooling various sizes and types of transistors, as shown here. By removing the cover of the unit in the right foreground, a mounting configuration for chamber-cooling two transistors can be seen. Clockwise, the photograph then shows: a basic module adapted for cooling four transistors; a smaller device with a chamber-type fitting for cooling one transistor; and a basic 1½-inch module adapted with a fitting for mounting a high-power transistor.

WORK STARTS ON SAXTON NUCLEAR REACTOR

Construction of a nuclear reactor near Saxton, Pa., for the Saxton Nuclear Experimental Corporation was scheduled to begin during the month of February. Excavation work, which involves the removal of an estimated 6000 cubic yards of material, mostly rock, was expected to require about three months to complete.

A cylindrical-shaped, dome-topped building 50 feet in diameter and 110 feet high will be erected in this "pit" so that 40 to 50 percent of it will be below ground level. The building will be constructed of 238 tons of steel plates, up to three-quarters of an inch in thickness.

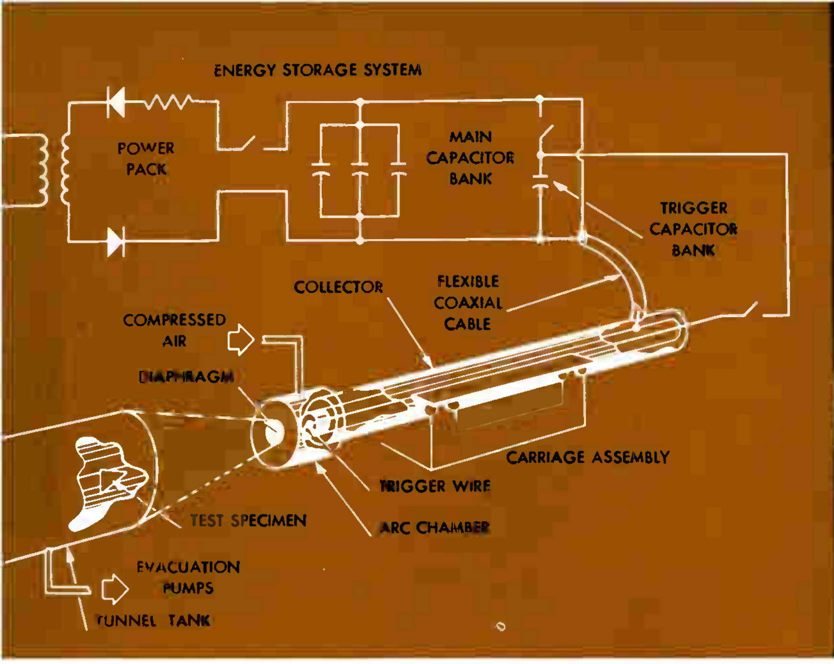
The general contract for construction is held by Westinghouse, designers of the reactor. Westinghouse will supply the nuclear material and will be responsible for operations.

While work on the building progresses, parts of the nuclear reactor will be fabricated by several suppliers. One of the major components will be a reactor vessel. Cylindrical in shape, the vessel will be 58 inches in diameter with an overall height of 17 feet and a weight of 50 tons. The walls, approximately five inches thick, will be constructed of carbon steel and lined with stainless steel.

Inside this comparatively small unit, uranium oxide will be fissioned and heat given off in the process will be used to generate steam to operate a turbine in Pennsylvania Electric Company's nearby Saxton power generating station.

The primary purpose of the project is to find ways in which more useful heat can be obtained from burning nuclear fuel, and ways in which the heat produced can be used more efficiently in producing electric power. It is not anticipated that the reactor will be an economic producer of electric power since it is being built for research and development purposes.

Pennsylvania State University will participate in the research program, which is being financed as a contribution to scientific knowledge by several companies: the Pennsylvania Electric Company, Metropolitan Edison Company, New Jersey Power and Light Company, and Jersey Central Power and Light Company. ■



Left—Diagram of a typical capacitor-discharge wind tunnel, or "hotshot" wind tunnel. This type of tunnel is used to approximate conditions encountered in supersonic and hypersonic flight. The collector shown in the diagram is mounted on a carriage so that it can be disconnected from one tunnel-tank and attached to another in a matter of minutes. Thus, both tunnel-tanks can be operated with only one power pack, one capacitor bank, and one collector.

Right—This new image orthicon tube (7611) has double the life expectancy of the standard 5820 tube.

ENERGY STORAGE SYSTEM FOR McDONNELL WIND TUNNEL

An energy storage system to power a hypervelocity impulse wind tunnel—commonly called a "hotshot" wind tunnel—is being developed for McDonnell Aircraft Company. This facility will allow engineers to investigate the thermal and aerodynamic properties of missiles and aircraft at speeds from nine to twenty-four times the speed of sound, and at simulated altitudes above 100 000 feet.

Four basic sections—an expansion cone/test section, a vacuum reservoir, an arc chamber, and an energy storage system—comprise the entire facility. The arc chamber is separated from the tunnel-tank by a thin diaphragm. Prior to test, the arc chamber is filled with highly compressed air and the tunnel-tank is evacuated to a pressure of one micron of mercury. Then electric power from the energy storage system is delivered to the arc chamber, increasing the pressure and temperature of the air in the chamber to approximately 100 000 psi and 14 000 degrees F. The diaphragm separating the arc chamber from the tunnel-tank is vaporized, and the high-pressure air expands through a tungsten throat to hypersonic velocities.

The energy storage system has the capacity to deliver electrical power at the average rate of two and one-third million kilowatts—more than six times the rating of the largest turbine-generator ever ordered. Few, if any, electrical units have the capability to supply this requirement.

The energy storage system consists of 29 racks, each containing 80 fused capacitors bussed together in groups of ten. From each bus, a coaxial cable delivers the energy to a unique collector, which in turn connects to the terminals of an arc chamber. The collector, composed of coaxially oriented conductors, can be disconnected from one chamber and connected to another within five minutes.

A transformer-rectifier power pack in conjunction with a bi-stable amplifier-regulator can charge the capacitor bank to any predetermined potential up to 12 kv, with an accuracy of plus or minus one percent, in 30 seconds. At 12-kv, the seven megajoules of energy stored in the system can be delivered to the gas in the arc chamber in less than three milliseconds.

The McDonnell hypervelocity impulse wind tunnel will be able to perform an 0.08-second test every 15 minutes. When the facility is completed, the tunnel will have a 50-inch and a 30-inch-diameter test section. Moreover, provisions have been incorporated for future expansion to a stored energy level of 10 megajoules. ■

NEW IMAGE ORTHICON HAS DOUBLED LIFE EXPECTANCY

A new target material and a new processing method virtually eliminate image retention in a recently developed image orthicon tube. The result: a longer operating life for this television camera tube. Specifically, the new tube (7611) has a 1000-hour warranty rather than the 500-hour warranty applying to other image orthicons. Since the cost of the new tube is only about 20 percent above the cost of a standard 5820 image orthicon, television station operators can realize a substantial reduction in the hourly cost of camera tube operation. At KDKA-TV in Pittsburgh, where one of the first 7611 image orthicons was tested in service, the new tube remained in service for 1825 hours.

Other advantages resulting from the tube's immunity to image retention are its low susceptibility to raster burn and elimination of the need for an orbiter. With the new tube, the camera can be focussed on a stationary studio scene for several minutes without permanent damage.

The 7611 orthicon is directly interchangeable with the 5820 orthicon and has identical performance characteristics, except for the 7611's higher sensitivity over a longer operating life. ■

PERSONALITY PROFILES

S. W. HERWALD directs the activities of the Westinghouse Central Laboratories, which includes the research laboratories, new products department, and the materials engineering laboratories, and thus is a logical spokesman on the subject of molecular engineering. A closer look at his background, however, reveals even more experience that is closely related to the subject. Molecular devices seem to have the greatest immediate potential in control and guidance devices for missiles and planes, where their extremely small size and low weight can be used to great advantage. Before his appointment to his present position, Herwald had been, in succession, engineering manager and manager of the air arm division, where equipment of this type is developed.

Herwald obtained his bachelor's degree in mechanical engineering from the Case School of Applied Science, and a PhD from the University of Pittsburgh. He joined Westinghouse in 1939, where his early work was in the development of servomechanisms. In 1947 he was made section manager in the special products division and in 1951 the engineering manager of that division. In 1952 he became engineering manager of the air arm division, in 1956 he was appointed the manager, and in 1958 was elected a vice president.

Herwald has written numerous articles about servomechanisms, feedback control systems, and analog computers and has been granted a number of patents on control systems. He is also an active member of several professional societies, including the AIEE, ASME, and IRE.

R. P. BLEIKAMP graduated from Washington University (St. Louis) with a BSEE in 1950, and came with Westinghouse on the Graduate Student Course.

He joined the transportation section of the Industrial Engineering Department in 1951, and three years later transferred to the general mill section. Here, he works primarily with the application of electrical equipment to the rubber and lumber industries.

Bleikamp obtained MSEE in 1956 from the University of Pittsburgh, and has also completed the Westinghouse Business and Management Program at the University of Pittsburgh.

Away from work and study, Dick's two favorite pastimes are sailing his own boat (a Snipe) and golf.

In his basic article on heat power cycles, **S. LEMEZIS** displays a talent for discussing complex subjects in simple terms. Actually, the original use for this discussion was as a short talk, outlining basic thermodynamics for a group of electrical engineers. In this area Lemezis can base a talk on solid experience.

After graduation from Marquette University in 1943 with a bachelor's degree in mechanical engineering, he served three years in the Navy as a ship repair and engineering officer. After leaving the service in 1946, he joined Westinghouse, where he spent the next seven years designing gas turbines and specialized heat exchange equipment (during this period, he also earned his master's degree from the University of Pennsylvania). Then he shifted to steam turbines, and spent five years in design and application. Last year he moved to California, where he is now a steam product engineer, serving utilities and industry in the Los Angeles area.

A. W. HILL, manager of the Power Circuit Breaker Engineering Department, continues in this issue where he left off in May 1954, with a follow-up on the state of the art in high-power circuit breakers. His engineering department has developed two major new types of high-power breakers since his last article—the outdoor compressed-air breaker, and the SF_6 breaker. Both breakers have been described in previous issues.

In September 1959, Hill got a chance to observe, first hand, the manufacture and application of circuit breakers in Europe. In a three-week period, he visited England, Germany, Belgium, France, Switzerland, and Italy. His comment? "One of the busiest business trips I've ever been on."

R. L. COIT makes his second appearance on these pages to talk about flash evaporators. When his first article was published in March 1957, the device was still in the "proposed" category; today, flash evaporators have been built for sea-water distillation and are being built for feedwater purification; many more possibilities are being investigated.

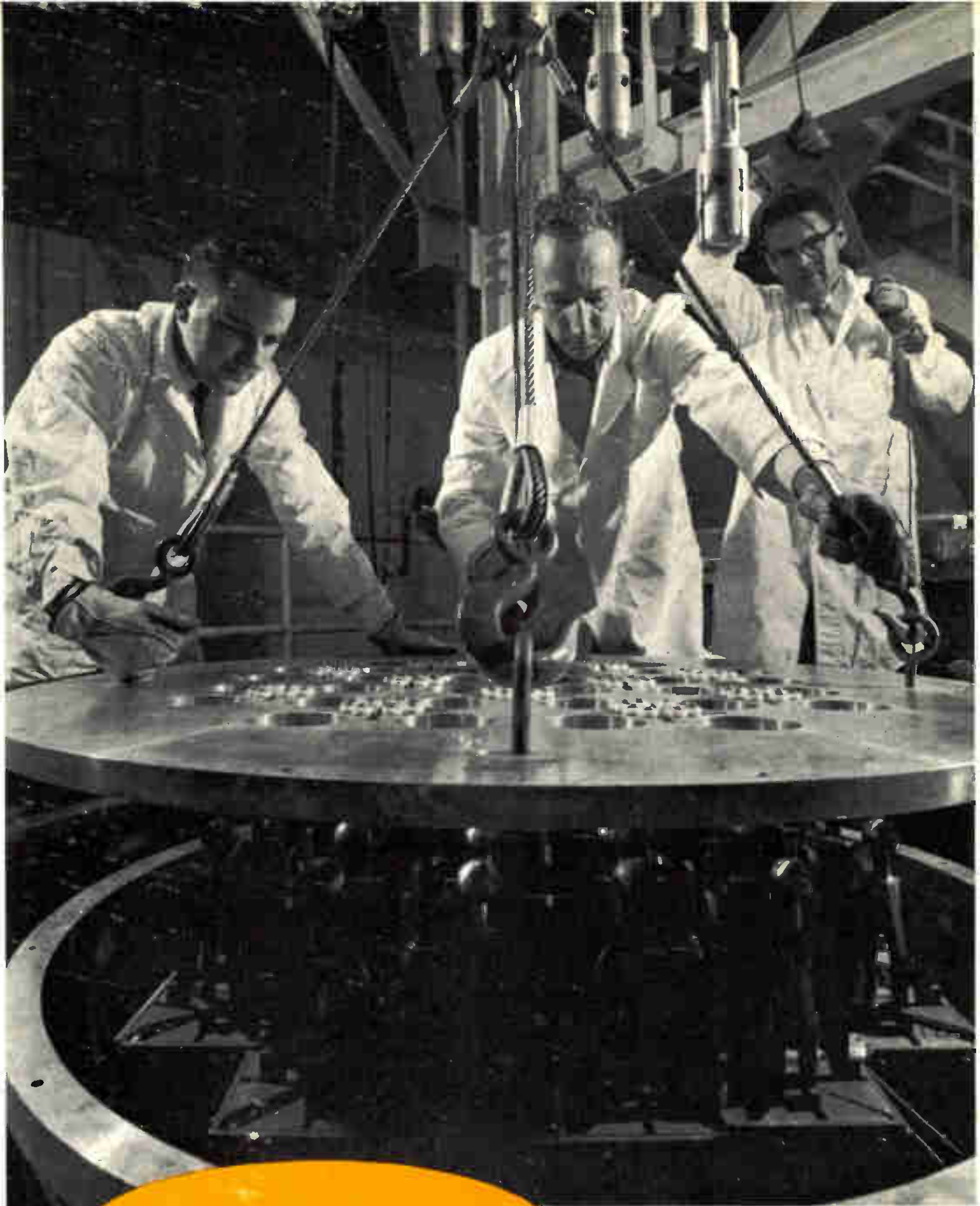
When Coit wrote his previous article, he was supervisor of the development section for heat-transfer apparatus. In 1957, he was made section manager of the same activity. He became Engineering Manager for the heat transfer department in 1959.

E. F. STALCUP, who joins Coit to describe the present state of the flash evaporator, is a graduate of Kansas State College with a BSME in 1922. Stalcup is a Senior Application Engineer in the heat transfer department, and has more than 35 years experience in the application of turbine generators, condensers, feedwater heaters, steam jet refrigeration, and evaporators. He holds several patents and has actively participated in both the submerged-tube and flash evaporator developments.

W. H. DAUBERMAN is a graduate of Bucknell University (BS in EE), and joined the Westinghouse industrial engineering group in 1940. His first assignment was in the petroleum and chemical section, where he worked on electrical systems until 1945. Then he became a district engineer, first in Pittsburgh and then in Cleveland, where he gained first-hand experience in steel mill drive and control problems. Last year he returned to industrial engineering as a sponsor engineer in the metal working section, where his primary interest is again in steel mill drives.

Dauberman has varied outside interests. He tells us he's a skier—"back yard" variety; a golfer—sometimes breaks 100; and a small game hunter.

Aside from these interests, Dauberman has also done graduate work at the University of Pittsburgh and taught in the Westinghouse Technical Night School. He is also active in the AIEE.



ATOMIC LID

Shown above, the core plate being lifted off the nuclear core for the first U. S.-built power reactor designed for use abroad. Following an extensive testing program at the company's reactor evaluation center, the core is being disassembled for shipment to Mol, Belgium, where it will be installed in the 11 500-kw atomic power plant of the Centre d'Etude de l'Energie Nucléaire. The Belgian group is a nonprofit organization formed by that country's government, scientific centers of the universities, and Belgian industry.