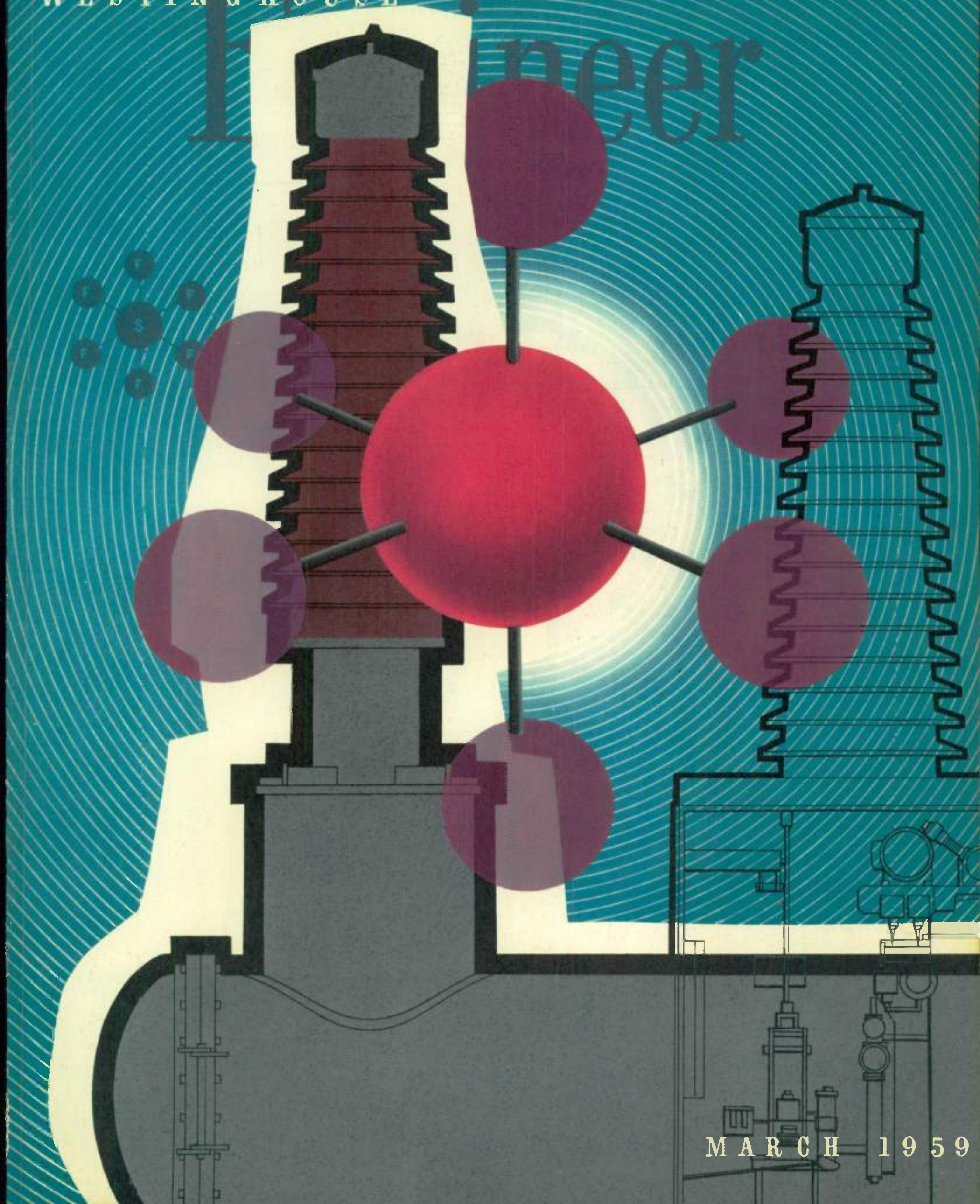
WESTINGHOUSE Engineer



MARCH 1959

OPCON AT WORK

Opcon—a machine that duplicates the informed behavior of a human being in controlling industrial manufacturing processes—is now at work in several installations. The one shown here is an early version of Opcon (for optimizing control) control. Here it mans one of the test stations on the capacitor production line of the new Westinghouse switchgear plant. Opcon automatically balances an a-c bridge in the test station.

In the Opcon control, the controlled variables are set at some arbitrary set of values, and the resulting output from the process observed. Then one or more of the variables are changed by a prescribed amount and the new output compared with the first one. The next step depends upon whether the second output was better or worse than the first. Opcon then proceeds to make successive moves until the optimum output is reached. Opcon was conceived to incorporate the desirable features of a human operator's behavior; with its built-in mathematical logic, it detects unforeseen changes in a situation and reacts sensibly to them. In December, Opcon won for Westinghouse the 1958 Industrial Science Achievement Award of the American Association for the Advancement of Science.

COVER DESIGN: The unusual arc-interrupting and insulating properties of the gas, sulfur hexafluoride, have made possible a basically new high-power circuit breaker design, described in this issue. The heavy SF_6 molecule and the horizontal tank design of the new breaker are the featured elements of this month's cover design by the R. G. Marsh Associates.

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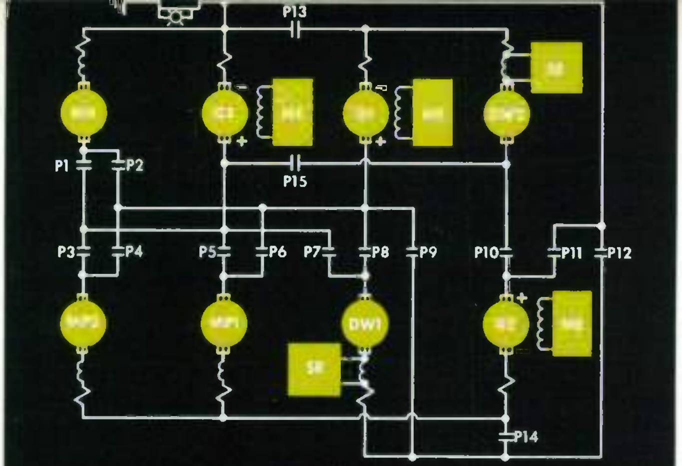

DRILL

	MAIN CONTACTOR CLOSED														
MAIN POWER CONTACTORS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
NORMAL					●			●			●	●	●		
SUPER POWER								●			●			●	●
G1 OUT					●					●		●	●	●	
G2 OUT					●			●				●	●	●	
G3 OUT						●				●		●	●	●	
DW1 OUT						●					●		●		●
DW2 OUT					●			●			●	●	●		
MP1 OUT			●					●			●	●	●		
MX	●														
MX G3 OUT		●											●		

HOIST

	MAIN CONTACTOR CLOSED														
MAIN POWER CONTACTORS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
NORMAL	●							●		●				●	
SUPER POWER								●			●			●	●
G1 OUT							●			●			●	●	
G2 OUT								●				●			●
G3 OUT								●		●				●	
DW1 OUT	●								●	●				●	
DW2 OUT	●							●			●		●	●	

Fig. 2—Main power-control system for a diesel-electric rig. The assignment chart shows the generator-motor arrangements that can be selected.

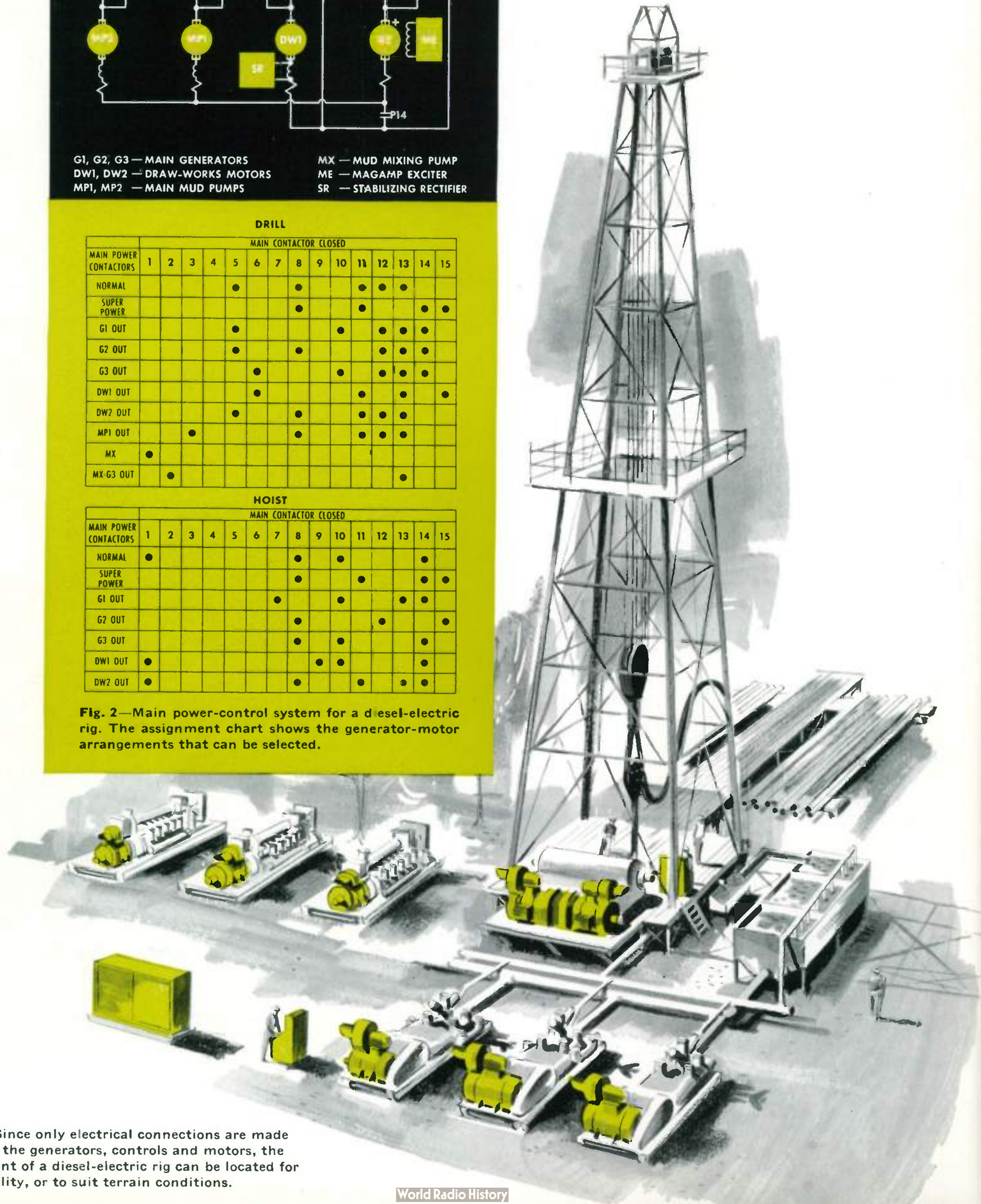

Fig. 1—Since only electrical connections are made between the generators, controls and motors, the equipment of a diesel-electric rig can be located for accessibility, or to suit terrain conditions.

DRILLING FOR OIL ELECTRICALLY

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As oil drills probe deeper into the earth's crust, more accurate control is required. This is one reason why electric drives are finding more and more applications; others are savings in space, rig-up time, and flexibility of equipment location.

One hundred years ago, Colonel Edwin L. Drake produced oil from a 69½-foot well near Titusville, Pennsylvania. Last September, the Phillips Petroleum Company set a new world's record by drilling to a depth of over 25 000 feet, or just short of 5 miles. Drilling to this depth can be compared to applying a twist to one end of a piano wire, 0.05 inch in diameter and 277 feet long, and expecting a bit at the other end to drill the hole.

Obviously techniques and equipment during the past 100 years have been drastically improved to penetrate the earth's crust to 360 times the depth of Colonel Drake's well. Basically, however, drilling methods have changed only from cable tool to rotary type drilling during this century. One notable difference, however, is that electricity is supplying an increasing portion of the power in this never-ending search for oil.

electric drive system for drilling rigs

The electric drive system for an oil-well drilling rig can be one of several types—either an a-c variable-speed type, receiving power from a transmission line, or a d-c variable-speed type, receiving power from engine-generator sets on the drilling site. Other a-c and d-c arrangements have been built, but these two have been predominant; the most popular is the d-c diesel-electric system.

Rotary drilling consists of three basic operations: the bit is rotated to drill the hole; a mud slurry is pumped through the drill pipe and bit to remove the chips from the bottom and to lubricate the hole; and the drill pipe is periodically hoisted to change the bit. An all-electric rig provides one or more electric motors for each of these main functions. These motors are force-ventilated with top-mounted blowers and are suitably enclosed to prevent the entrance of water and rodents.

The rotary table, which rotates the drill pipe and bit, operates from 75 to 300 rpm, depending on the location and drilling practice. On the Gulf Coast, approximately 125 to 135 rpm maximum is used. Most of the horsepower requirements of the rotary table are used in overcoming friction between the pipe and the wall of the hole, for oil-well holes are anything but straight; drillers must constantly correct for angular deviation of the hole. The horsepower rating of the rotary table varies from 100 to 500 hp, depending on the depth rating of the rig and the type of hole being drilled. For instance on the Pacific Coast, where oil deposits are found just off the shoreline, land rigs are used and holes are directionally drilled; to reach the oil deposit, the hole can be drilled horizontally up to 3000 feet as well as in the vertical direction. Naturally the friction between the drill pipe and the wall of the hole is increased, and more horsepower must be supplied to the rotary table.

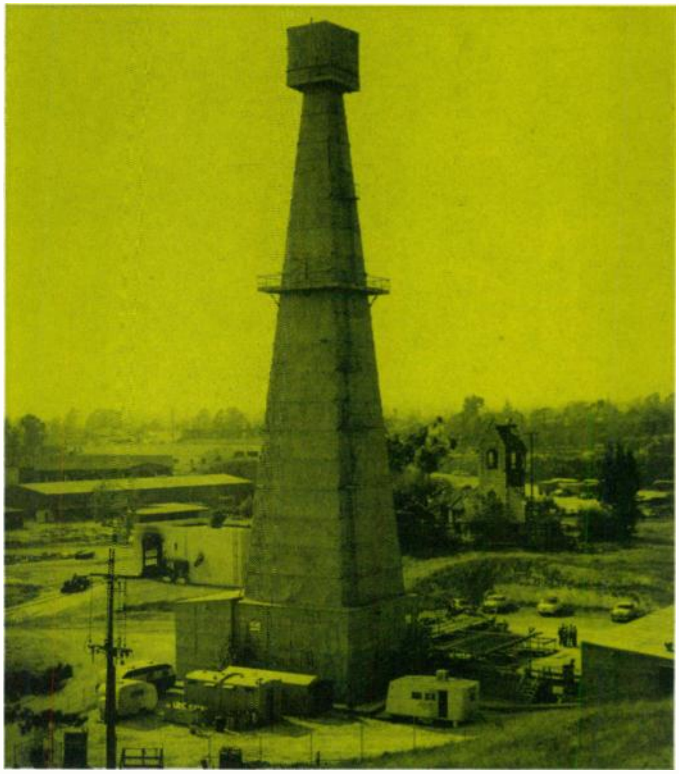
The mud pumps force the drilling mud down through the center of the hollow drill pipe, out through the bit removing the chips and debris, and up through the annulus between the wall of the hole and the drill pipe. Mud pumps vary in size from under 100 to 2000 hp, with an increasing use of the 1000- to 2000-hp range because of the recent trend to jet drilling in soft strata where the mud actually "washes" a hole ahead of the bit.

The workhorse of any rotary rig is the draw-works—a hoist which raises the drill pipe in 90- or 120-foot stands to change the bit when it becomes dull. This operation, referred to as a "round trip," can occur every 12 to 15 hours. Naturally, the driller wants to obtain maximum drilling time; therefore, the time required for a round trip should be minimized by hoisting the load as fast as possible. The hook loads sometimes reach 1 000 000 pounds or more and require 2000 to 2500 hp during hoisting.

A-C Rigs—Electrical equipment for an a-c rig usually consists of one or more wound-rotor motors for each of the main drives. Often, a "twin draw-works" drive is used, consisting of identical wound-rotor motors with magnetic control arranged so that either or both of the motors can supply hoisting or rotating power to the draw-works.

The mud-pump motors are also of the wound-rotor type; however, their secondary controls are usually manually operated as the motors are run for long periods at one speed. The pumps and controls are located approximately 100 feet from the hazardous area near the drill floor; therefore, the motor is usually force ventilated with a top-mounted blower, which supplies the necessary cooling air during long periods of operation at low speed.

Power is derived from either company-owned portable substations or nearby utility substations. In urban areas such as Los Angeles, where considerable drilling activity takes place,



This a-c drilling rig is covered to reduce noise and painted "sky blue" to be as inconspicuous as possible.

the utility power for a drilling location is easily obtained.

Diesel-Electric Rig—Most drilling locations are so remote from any power source that drilling power must be generated at the site with internal combustion engines. On electric rigs, d-c power is more economical and practical because a fine degree of speed and torque control is possible. Direct-current generators and motors serve as an electric torque conversion system, whereby the engine speed-torque characteristics are converted to match the requirements of the main drives.

An engine-generator set for each main drive on the drilling rig is neither practical nor necessary because very rarely do all drives require full power simultaneously. The main power control system provides the flexibility required to switch the main generators to the drives as desired. For instance, on a large drilling rig, the draw-works may require 1800 hp, the main mud pumps 2000 hp, and the rotary table 300 to 500 hp. The power plant for such a rig might have three engines of approximately 850 hp, each driving one or two main d-c generators. The main power control should be able to switch these generators to each drive motor, as needed.

In a d-c variable-voltage rig, power is generated at the engine-generator sets and fed to a control cubicle, which distributes power to the selected main drive motors, Fig. 2. The speed of the motors is controlled from the driller's console or at the mud-pump console, where speed controllers, ammeters, alarm lights and pushbuttons are centralized.

operating characteristics

Mechanical Rig—The diesel engine has essentially a constant-torque characteristic in its operating range from idle to full speed, Fig. 3. The engine cannot pick up heavy loads directly from standstill because of the high accelerating torque required. Any owner of a "straight shift" automobile knows this limitation. Therefore, on mechanical or direct-drive drilling rigs, as on a straight-shift auto, a friction clutch must be used to disconnect the engine while the load is at rest and to accelerate the load up to engine speed by slipping the clutch. Air-operated clutches are used on mechanical rigs, but they produce sudden changes in engine speed and shock the mechanical parts of the drive system.

Torque Converter Rig—Many direct-drive drilling rigs are

A d-c diesel-electric draw-works drive using two 1000-hp motors on a large offshore platform.

in use today; however, modern rigs use a torque conversion system to reduce engine stalling and shocks to the mechanical system as well as to eliminate clutch maintenance. These systems also provide the desired limits of maximum light-load speed and maximum applied torque without exceeding the mechanical limitations of the chains, air clutches, hoisting line, derrick, and other mechanical parts.

The torque converter automatically adjusts to the load requirements as they change without "lugging down" the engine or requiring a change in engine speed, Fig. 3. Also the maximum output torque is three to five times that developed by the engine alone, which results in a reduced number of gear ratios required in the transmission to develop maximum line pull. The torque converter offers a reasonably constant horsepower load to the engine over a wide range of torque requirements; however, the drive should be operated between the 70-percent efficiency points.

Control of the drive operating speed must be accomplished by variation of engine speed because adjustment of the torque converter output speed for a given load is not possible by any other means. Engine throttle control does provide a smooth application of torque for load acceleration, which eliminates shocks to the engine and the load.

The outputs of the engines on a torque-converter rig are

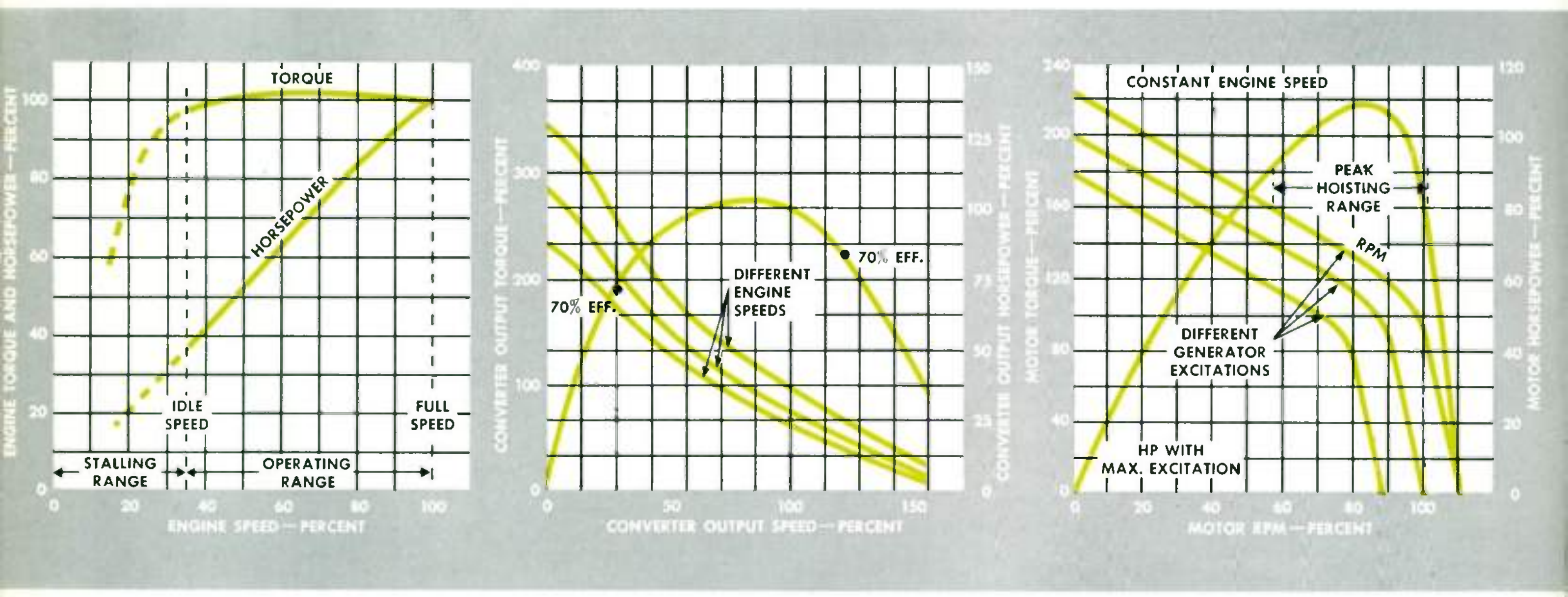


Fig. 3—Performance curves for a diesel-engine mechanical rig (left), an engine torque-converter combination (center), and a d-c diesel-electric drive (right).

connected into an engine-chain compound from which the draw-works, mud pumps, and rotary table are driven. This means that the power plant and pumps must be located near the draw-works, as in the case of the mechanical rig.

D-C Variable-Voltage Rig—The characteristics provided by a d-c variable-voltage drive system are similar to those of the hydraulic torque converter in that speed is traded for torque automatically. For this reason, the d-c system is often referred to as an electric torque converter. The outstanding advantages over the hydraulic torque converter are that the only connection between the engine and the load is a set of electrical cables, and that the drive operating speed can be changed merely by adjusting the main generator excitation.

The d-c motor, whose output is shown in Figure 5, receives power from one or more d-c generators. Several possible combinations are provided by the main power control; one or more engine-generator sets can be assigned to a particular drive motor, depending on the load requirement and the rating of the drive motor, Fig. 2. Being a torque converter, the d-c drive has an optimum operating range in which the hoisting performance can be greatly improved if the driller pays attention to the hoist motor ammeter. By changing the mechanical gears in the draw-works to maintain the motor hoisting torque within the desired range, the driller obtains optimum electrical efficiency and maximum horsepower to the drive, which results in minimum hoisting time. This can be easily accomplished by marking the motor ammeter with the desirable operating range and changing the draw-works gears at the proper time.

With the d-c system, the motor speed can be designed to meet the drive requirements without considering the engine speed. The engine can be operated continuously at full speed or at any selected speed while the motor speed is adjusted from zero to full speed. Therefore not only can the desired limits of maximum speed and stalled torque be provided with the d-c rig, but the rig can be operated without engine speed control, and the engines, generators, mud pumps, and draw-works can be located at the most convenient point on the drilling site. Flexibility of equipment location is one reason why the diesel-electric rig is popular in off-shore drilling.

The motor output, shown in Fig. 3, is obtained by controlling the generator characteristics so that the maximum current is limited and the engine output is matched as closely as possible. As the driller's controller raises the generator excitation, the current builds up to a preset maximum and the load accelerates smoothly. With this volt-ampere curve (Fig. 4), the horsepower requirement of the engine is also limited to a preset maximum, similar to the performance of the hydraulic torque converter. The difference is that this maximum can be adjusted to match a number of engines simply by changing the generator excitation.

A magnetic-amplifier, saturable-reactor control scheme is used to control the separate excitation to the main generator. This static system offers the advantages of a simple, reliable, maintenance-free control with a minimum of moving parts. When the generator characteristic is applied to the main drive motor, the family of corresponding speed-torque curves of Fig. 3 results.

the trend

Historically, the d-c variable-voltage transmission has been considered the deluxe system for oil-well drilling rigs, and has not enjoyed wide popularity until recently. Primarily, this has been due to the high initial investment required to replace the mechanical chain compounds, hydraulic couplings, or torque converters with the electric transmission. But today the trend is toward diesel-electric drilling for medium and large size rotary rigs. Offshore, in the Gulf of Mexico, approximately 25 percent of the rigs are full diesel electric or electro-mechanical.

The prime reason for the trend to diesel-electric drives in offshore drilling is the advent of low-cost, lightweight, electrical equipment, which has been obtained by modification of proven railway apparatus. Another important reason is that offshore, where deck space is precious, the diesel-electric drive allows a considerable saving in space and arrangement of equipment. Onshore, a saving in rig-up time between location changes is gained.

An increased use of this type of transmission will be seen within the next few years, both offshore and onshore, because as wells are drilled to ever increasing depths and as loads become larger, more accurate control will be required. ■

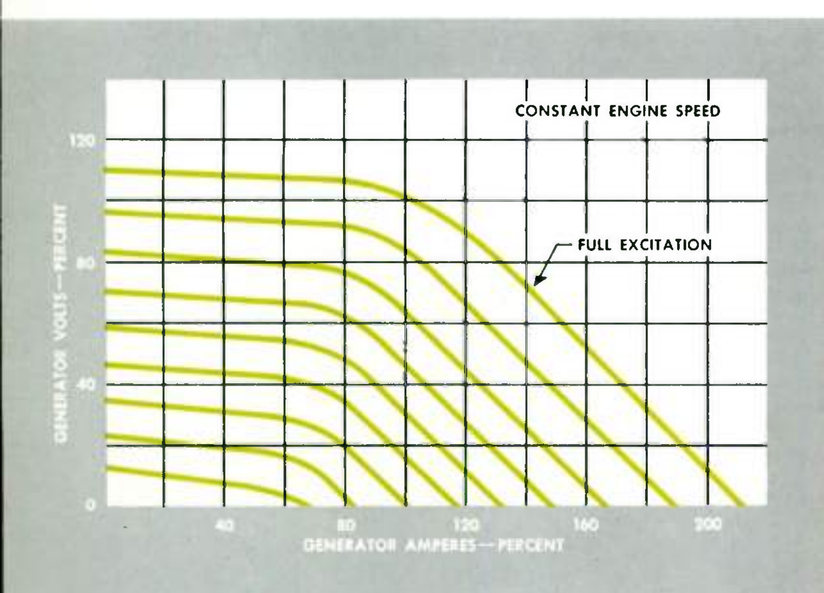
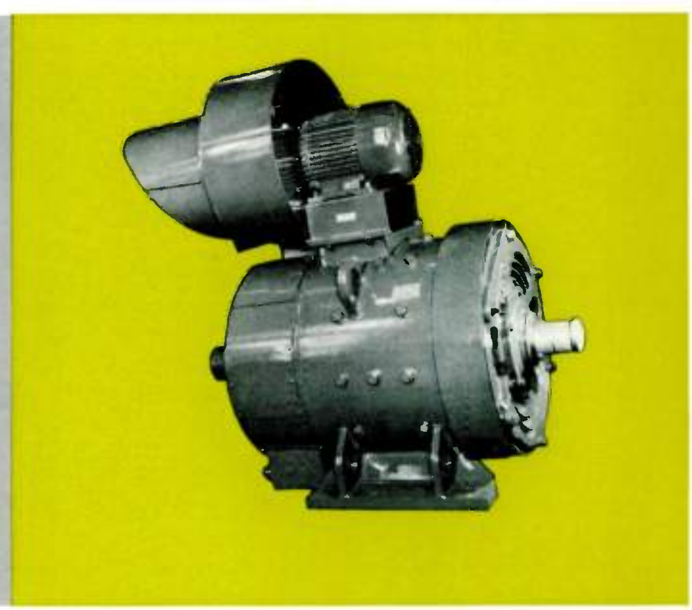


Fig. 4—Typical generator characteristics of a diesel-electric drive, obtained at constant engine speed.



This 1000/1600-hp motor and a 550-kw generator using the same frame have been specifically designed for oil-well drilling.

OPTIMIZING CONTROL SYSTEMS FOR THE PROCESS INDUSTRIES

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This automatic optimizing control can be applied to chemical and petroleum processes with a minimum of information, since process equations are not required.

A new concept in control systems is incorporated in a recently developed device called Opcon (for optimizing control). Opcon replaces the pre-set, routine functions performed by a conventional system with the human-like process of reaching a logical conclusion through experiment. Basically, Opcon duplicates the informed behavior of a human being in controlling complicated industrial processes.

optimizing control

The concept of optimizing control is related to the more familiar feedback control. In a conventional feedback control system the actual value of the quantity to be controlled is compared with the desired value of this quantity (set point) and the control operates to reduce any difference to within the allowable tolerance. Such controls—sometimes called *set-point controllers*—are now widely used to maintain flow rates, temperatures, liquid levels, and many other variables at their desired values. Their importance in modern process industries can hardly be overestimated.

If a process is completely instrumented, i.e., all important quantities are measured, and the important variables are controlled by set-point controllers, the operation of the process, once started, is automatic. A human operator may be needed only for start-up, shut-down, making minor adjustments to meet changing conditions, and for emergencies. Since most processes in operation today follow this picture, and are reasonably successful, the need for further improvements in control might be questioned. If the answer could be reduced to just one statement, it might be: increased competition, particularly in the chemical process industry, has made necessary continued search for methods of reducing unit costs. No one, least of all process engineers, will claim that present control methods result in optimum operation; therefore, control is one of the areas to be studied in process improvement.

The possibility of improving process operation by proper coordination of the set-point values of the controlled process variables has been recognized for some time. One function of a human operator may be to make changes in settings to compensate for changing conditions; to the extent that he does this, he becomes an optimizing control. An operator is, however, seldom given the information or the opportunity to seek optimum settings under all conditions and at all times.

An optimizing control system attempts to get the best performance from a plant or process according to a criterion such as maximum production or minimum unit costs. It does this by adjusting the input variables, noting the effect on the performance criterion, and deciding on a logical basis what further changes of input variables should be made.

an example

Consider the block diagram of Fig. 1. The process has inputs x and y and an output z. Inputs x and y are shown for this example as flows through pipes, controlled by valves positioned by set-point controllers. Set points of these controllers can be adjusted either manually or by a supervisory control device. The output z is measured by an appropriate sensing device; for this example, z is the performance characteristic to be maximized.

Assume that an automatic optimizing control is not used in Fig. 1 and that a human operator is going to attempt to maximize the output. He might start by making a change in the set points of x or y, or both. After the process and instruments have reached equilibrium, z would be observed and compared with the previous value of z. A decision must then be made as to which variable or variables to move, and the size and direction of the move to give the best chance of increasing z. This sequence of making a move, observing the effect on the output, comparing this with previous results, and making a logical decision as to the next move is continued until no further improvement can be noted. At this point the searching is either stopped or can be continued to follow any drift that occurs.

This method of searching for the optimum and following drift is similar to the way Opcon works. The advantages of an automatic optimizing device over a human operator are that a machine can have built into it a better strategy than most operators know, and will be more diligent in its search. Of course, the human is more flexible and hence is better able to handle emergencies and other unusual situations.

The rules by which Opcon makes the logical decisions as to the move to be made after observing the effect of the last move on z is called a *strategy*. Only the results of a small number of past observations are used in making decisions because older data is made useless by drifts caused by uncontrolled variables—such as catalyst deterioration or change in the composition of feed. Clearly, continued search for the best operating point is required to compensate for drifts.

digital computer control of processes

Digital computers have been proposed for use as optimizing controls. The computer usually must be provided with the process equations, that is, the relations between the input and output variables. Using these equations and measured data, the computer calculates the next set-point values. In most cases the versatility of a digital computer is utilized also to provide data logging and alarm functions.

While digital computer control has many attractive features, some disadvantages are also apparent. The equipment is complex and expensive. Process equations are usually unknown at the beginning and may be expensive to find. Opcon control differs basically from computer control in that it uses the process itself rather than a mathematical model in its search for optimum conditions.

application of Opcon control to a chemical process

The first application of Opcon control to a chemical process has been made in cooperation with the Dow Chemical Company. The process is a miniplant used for the catalytic dehydrogenation of ethylbenzene in the production of styrene. The controlled input variables are the feed flow rate of ethylbenzene and the temperature of the reactor. The output is a mixture of styrene, unconverted ethylbenzene, and some contaminants. The production rate of styrene is the quantity to be maximized.

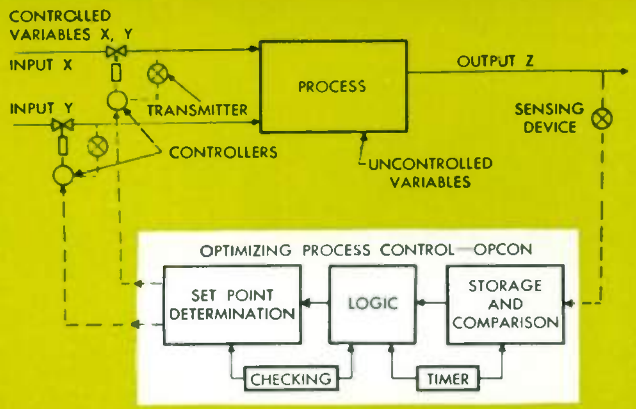


Fig. 1—**Block diagram of Westinghouse optimizing process control applied to a two-variable process.**

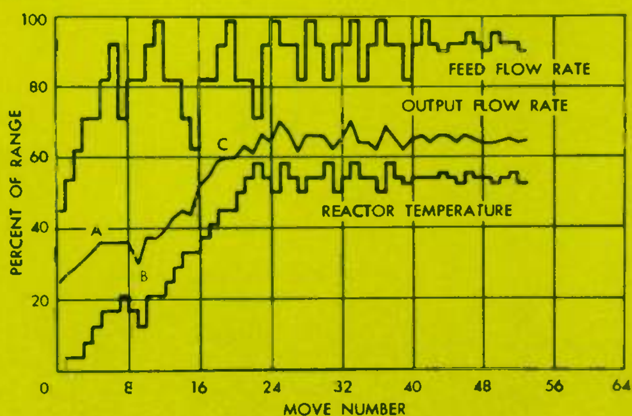


Fig. 2—**Test results of Westinghouse Opcon controlling a chemical process.**

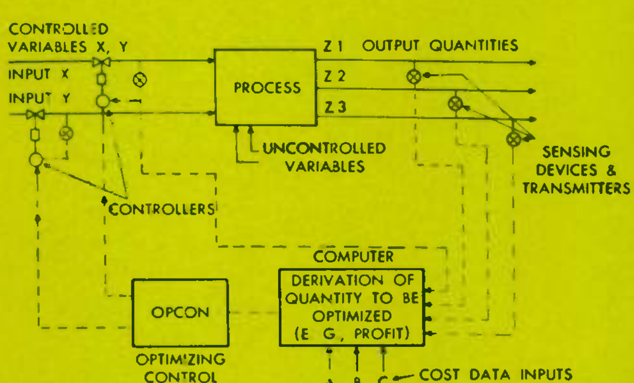


Fig. 3—**Process optimization requiring a complex definition of optimum performance.**

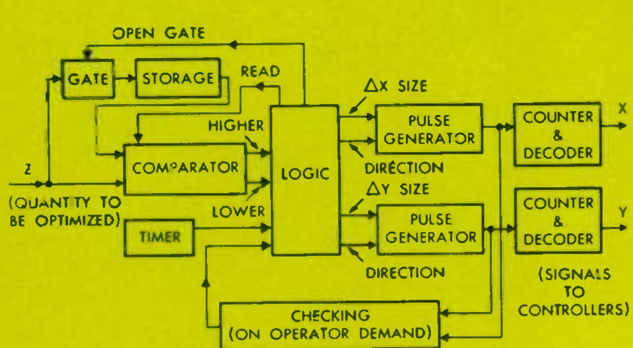


Fig. 4—**Detailed block diagram of Opcon optimizing process control unit.**

results of test

The results of a test run on the dehydrogenation process are shown in Fig. 2. The move number is plotted along the abscissa while the percent of range is plotted along the ordinate. The output flow rate of styrene increases steadily until about move 20. Thereafter, it fluctuates somewhat as the inputs change, and finally settles down when the move sizes of the inputs are reduced. The reactor temperature is started at a low value and generally increases until about the 20th move. At about the 38th move, the step size is decreased by the optimizing control, and for the remainder of the curve the temperature fluctuates around this point. The feed flow rate of ethylbenzene climbs rapidly at first and then makes some rather wide swings. This is because at lower temperatures the output flow rate is not very sensitive to the feed flow rate. After a period of time, the feed flow rate has its size reduced by Opcon and continues to operate around a steady value. The curves do not cover a long enough period of time to show a drift and the recovery made by the optimizing control.

maximizing profit

The next step in the cooperative program with the Dow Chemical Company is to maximize the profit obtained from this process. The way Opcon control maximizes profit on a fictitious process is shown in Fig. 3. The inputs to the process are again variables x and y, each of which is controlled by a set-point controller. The outputs are $z1$, $z2$, and $z3$, where $z1$ might be the desired product and $z2$ and $z3$ are each by-products. These outputs are measured and, together with the magnitude of y and cost data a, b, and c, are fed to a special purpose analog computer used to solve the profit equation for the process. This equation is a simple one to set up and does not involve the process equations. The output of this computer is a voltage proportional to operating profit rate of the process. The Opcon control seeks to maximize this voltage just as it would any other process characteristic fed to it.

equipment used for optimizing control

The Opcon optimizing control can be described with block diagrams. Fig. 1 shows Opcon split into its main sections, storage and comparison, logic, and set-point determination. Also, a timer provides the time delay necessary for the process to reach equilibrium after a change has been made in the input variables.

The output from the sensing device measuring z feeds into the storage and comparison block. Here, the present value of z is compared with the last best value of the output z, called the *base-point value*. If the present value for z is better than the stored base-point value, the move may be called a success, and if z is worse than the base point value, the move may be called a failure. The output of the storage and comparison block is then either a success or a failure signal, which is fed to the logic block. The logic block uses this information plus other information it has stored from past moves, and makes a decision as to the input variables to be moved and the size and direction of the move. This information is given to the set-point determination block which, following the commands of the logic block, makes the proper adjustments in the process inputs x or y or both.

A more detailed block diagram of Opcon control is shown in Fig. 4. The section to the left is the storage and comparison section, the center is the logic, and the right is the set-point determination section. When it is time to make a move, the timer feeds a start signal into the logic, which then puts a read signal into the comparator. The comparator compares the present value of z with the base point value which is in the storage block. The comparator provides a success or failure signal (labeled "higher" or "lower" in the diagram). The logic then takes this signal, plus information obtained from past moves, and makes a logical decision as to the variables to be changed and the magnitude and direction of the change. This information is sent to the proper pulse generator. The output of the pulse generator is a series of pulses whose number and direction determine the size and direction of the move. These pulses are fed to the counter and decoder block, consisting of a reversible binary counter which is constantly decoded to produce an output voltage or current level. This output determines the set point of the controller. If the previous move was a success, the logic provides an open gate signal, which allows the new value of z to be put into storage and become the new base point value. If the move was a failure, the old base point value is retained in storage.

checking circuit

The checking circuit is used to determine if any part of the logic or the pulse generators is malfunctioning. Since the logic section contains a large number of static components, malfunction is not easy to tell by external observation. When checking the logic, the success and fail signals from the comparator are prevented from entering the logic, and the pulse generators are disconnected from the counters so that the process may continue to operate at the last settings. The checking circuit then feeds the logic a sequence of successes and failures from a test program stored in the checking circuit. The logic responds by calling for x and y moves of various sizes and directions. These responses are stored in the checking circuit, which at the end of the test program determines if the logic called for all the correct moves.

strategy

The logic section is designed to mechanize the search strategy of Opcon control. Sets of rules that describe strategies have been devised for specific purposes, such as to find the optimum most rapidly, or to follow drifts due to uncontrolled variables most efficiently. The rules use the concept of a base point about which a search pattern of moves is made. A new base point and base point value are accepted when a move results in a value of output greater than at the previous base point. Large moves are used in the initial search. A certain pattern of successes and failures is used to determine that the large moves have brought the operation near the optimum. The move size is then reduced to search this area for the optimum. After reaching the optimum, as again determined by a certain pattern of successes and failures, either the original strategy or a different one can be used to detect and follow drift. Provision can be made for increasing move size if the drift becomes too fast to follow.

Any number of strategies can be devised for finding the optimum operating conditions. The selection of a strategy must be based on a compromise between the need for simplicity and the desire for maximum searching efficiency.

logic

The rules are carried out in the logic section using transistorized NOR circuits. The NOR circuit is a basic logic element, which in combination with other NORs can perform any logical function. This well-engineered logic block has undergone extensive testing and has proved highly reliable.

A schematic of a transistor NOR circuit is shown in Fig. 5. It contains a p-n-p transistor operated in the common emitter

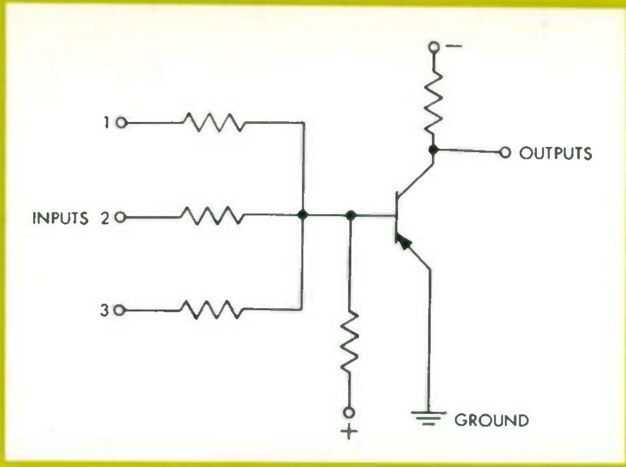


Fig. 5—Schematic diagram of transistor NOR circuit.

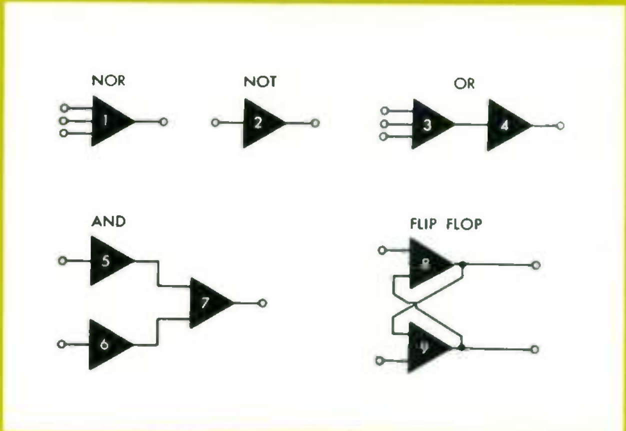


Fig. 6—The symbol used for the NOR is a triangle. When there is a signal present, it will be called *one*, and when there is no signal, it will be called *zero*. The first logic function, of course, is the NOR. With zero on all inputs, there is a one output; with a one on one or more of the inputs, there is zero output. The next logic function is the NOT, which is simply a NOR with one input. A zero on the input gives a one output, and a one on the input gives a zero output.

The OR function is performed with two NORs, 3 and 4. With a zero on all the inputs to 3, there is a one output from 3, a one input to 4, and so a zero output from the OR. With a one on one or more of the inputs to 3, there is zero input to 4, which gives a one output from the OR.

NORs 5, 6 and 7 form a two input AND. The AND gives a one output only when both inputs are ones. Assume there are zero inputs to NORs 5 and 6. They each have a one output which causes 7 to have a zero output. If there is a one input to NOR 5, it has a zero output but NOR 6 still has a one output holding NOR 7 to zero output. If both NORs 5 and 6 have a one input, they both have zero outputs. The inputs to 7 are then zero and so it has a one output. These three NORs therefore perform the AND function.

A flip-flop is composed of NORs 8 and 9. Assume that NOR 8 has a one output, and NOR 9 has zero output. The one output from NOR 8 goes to the input of NOR 9 holding its output to zero, and with two zero inputs to NOR 8, its output is one. Now apply a one signal to NOR 8, causing its output to go to zero. NOR 9 now has both inputs zero and so gives a one output. This one output goes to the input of NOR 8 holding its output to zero. The flip-flop has changed state with 9 now having a one output, and 8 a zero output. A one to the input of NOR 9 will change the flip-flop back to its original state. The flip-flop is a basic memory element and is used in constructing counters and registers.

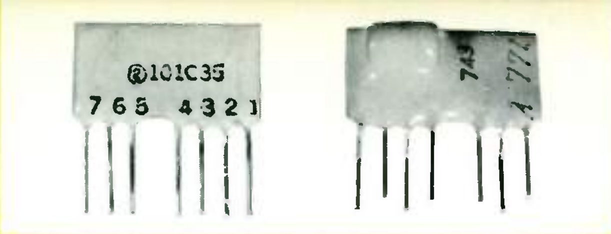


Fig. 7—Physical appearance of the NOR circuit, with a front and rear view of a NOR module.

Fig. 8—Printed circuit boards on which NOR units are assembled.

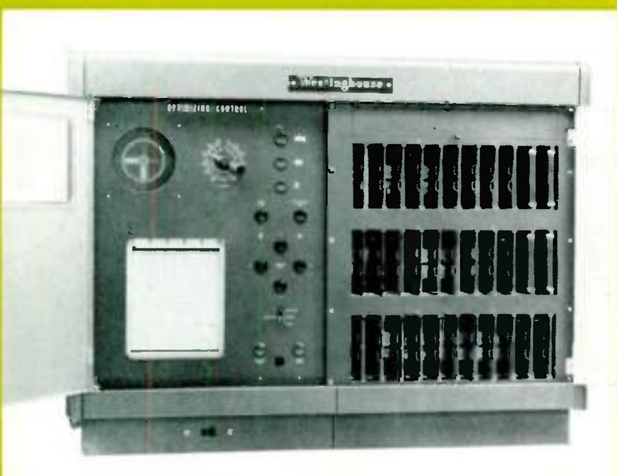
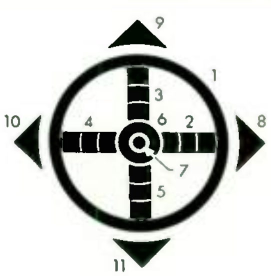


Fig. 9—Cabinet used for Opcon optimizing control unit.



SEGMENT NUMBER	INDICATION WHEN LIGHTED
1	60 CYCLE POWER IS "ON"
2	AN INCREMENTAL INCREASE IN VARIABLE X
3	AN INCREMENTAL INCREASE IN VARIABLE Y
4	AN INCREMENTAL DECREASE IN VARIABLE X
5	AN INCREMENTAL DECREASE IN VARIABLE Y NOTE: Segments 2, 3, 4, and 5 are each divided into three sections which light successively from the center to indicate the three increment sizes
6	CHANGE IN BASE POINT OR BASE POINT VALUE
7	OPTIMUM HAS BEEN FOUND
8	VARIABLE X HAS REACHED ITS UPPER LIMIT
9	VARIABLE Y HAS REACHED ITS UPPER LIMIT
10	VARIABLE X HAS REACHED ITS LOWER LIMIT
11	VARIABLE Y HAS REACHED ITS LOWER LIMIT

Fig. 10—Operation indicator for Opcon control unit.

connection. The output is taken from the collector of the transistor, and the inputs go to the base of the transistor through individual resistors. When there are no inputs to the transistor, a positive bias to the base holds it cut off, and therefore there is an output. When a negative voltage is applied to any one or all of the inputs, the transistor becomes saturated, the output is grounded and becomes zero. Thus, with no inputs, there is an output, and with one or more inputs, there is no output. The output of one NOR can be used to provide inputs to several others.

As stated before, NOR circuits can be connected so as to perform any logical function. Simple logical functions can be performed with NORs, as shown in Fig. 6.

The physical appearance of the NOR circuit is shown in Fig. 7, with a front and a back view of a NOR module.

The NORs are assembled on printed circuit boards as shown in Fig. 8. The tubes along the left edge of the board are indicator tubes, which are compatible with transistor circuits, and are for indication only.

Opcon cabinet and control panel

A photograph of a cabinet used for an Opcon optimizing control is shown in Fig. 9. The front of the panel is covered by doors, which can be locked to prevent tampering. The main operating controls and indicator are located on a hinged panel covering the left half of the cabinet. This panel can be swung open to allow access to components located behind it. The right half of the cabinet contains the card rack. The previously described printed circuit boards containing the NORs can be seen in this rack. Above the rack is another door covering a subcontrol panel, which contains controls not needed for normal operation. Most of these controls are used for troubleshooting and maintenance. In the upper left corner of the main control panel is an electroluminescent display. The electroluminescent display is used as an operation indicator, and presents a graphic picture of the last move made by Opcon. This picture is retained in the display until the next move is made. A sketch of the display, giving the meanings of the various segments when lighted is shown in Fig. 10.

other possible applications of optimizing control

The chemical process industry represents one of the largest and most important fields of application for optimizing control, but others may also prove important. Foremost among these is the petroleum industry.

Another specific application might be combustion control in furnaces with the object of minimizing fuel consumption. Optimizing control can be used with engines of piston, jet, or rocket types to maximize the range or thrust or minimize fuel consumption.

Opcon optimizing control has proved successful in its first chemical process application An application in the petroleum industry will soon be tested. Expanding use of automatic optimizing control can be predicted from the development effort to date and from the planned reduction to practice of continuing theoretical studies.

Because of its nature, Opcon control can be applied to existing processes with a minimum of information about the process. One basic model can control a variety of processes because the built-in strategy is not tailored to fit a specific process. While simple equations may be required for computing the performance characteristic to be optimized (e.g., profit), process equations that might be difficult and expensive to determine are not required. ■

HIGHWAY LIGHTING WITHOUT GLARE

A NEW LIGHTING TECHNIQUE

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Superhighways may eventually be lighted along their entire length. When this happens, new approaches to highway lighting will be necessary.

Since 1950, the number of registered motor vehicles in this country has increased by better than a third. This tremendous increase in vehicles has led to increasing emphasis on the construction of more highways, and highways of greater capacity. The increase in long-distance pleasure travel by the public has promoted the growth of freeways, limited-access highways, and turnpikes of the multi-lane, dual-roadway type. Most authorities agree that, for maximum safety, these highways should be lighted—not just in congested areas, but along their entire length. This requires a new look at highway lighting practices, and probably a whole new approach.

The Federal Bureau of Public Roads has recommended that all new roads built with their cooperation have medial strips at least 32 feet wide. This trend requires that such roadways be considered individually from a lighting standpoint. Heretofore, standard type streetlighting systems have been provided only at interchanges and service areas, and the deceleration and the acceleration lanes leading to and from these areas on the modern turnpike type roadways. This practice has generally been satisfactory for guiding the motorist to and from these areas and for providing advance warning of traffic merging areas. However, such systems do not help the motorist discern traffic and obstacle hazards along the highway between these areas. As a result, the motorist must depend entirely on the automobile headlights for the necessary illumination. Present vehicle speeds and recognition distances provided by automotive headlight systems do not always permit sufficient time for the average motorist to execute the necessary safety or precautionary maneuvers. Based on two-second reaction time and 0.4 coefficient of friction, the American Association of State Highway Officials recommends design values of driver stopping distances as 480 feet and 610 feet corresponding to 60 and 70 mph respectively. Actual tests show that these values of stopping distances may be substantially lower than those in actual practice, due to the many variations of vehicles, drivers, and pavement conditions. The modern automotive systems provide 0.1 to 0.2 footcandles on a vertical surface 750 feet in front of the car, so the possibility exists that a motorist can fail to recognize an obstacle in time to take the necessary corrective action.

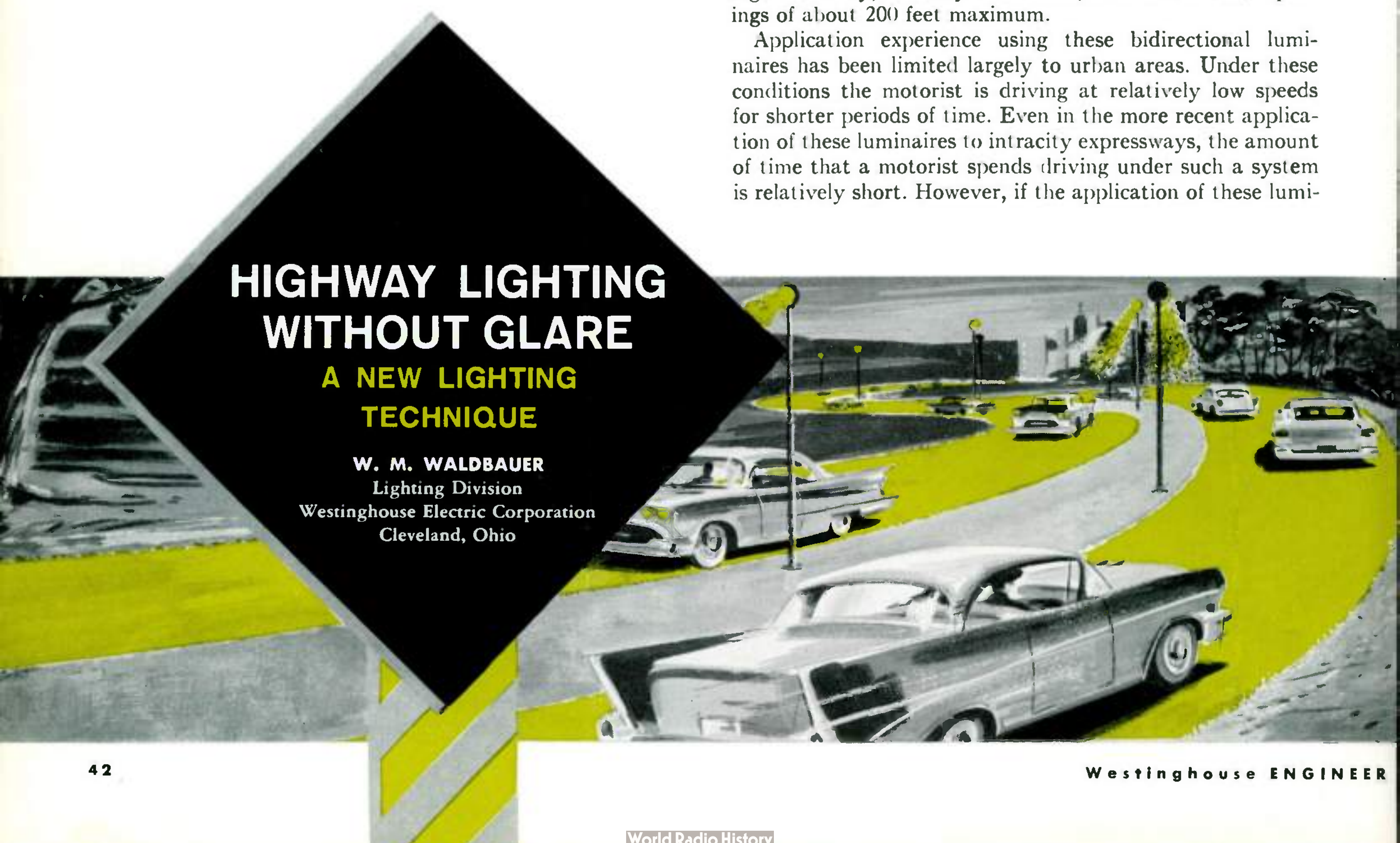
In discussing this lighting problem a highway of the multi-lane, dual type is assumed. Specifically, roadways 36 feet wide with a 32-foot medial strip separating the two roadways are a likely prospect for the future. A 36-foot width, therefore, provides for two high-speed traffic lanes plus an emergency lane located on the right-hand side of the traffic lanes.

major types of systems

Whenever the lighting industry has been faced with a new application for streetlighting, the natural tendency has been to extend the use of present luminaires with little or no modifications to the optical principles involved. Until recently, intracity expressways, turnpike interchanges, access roads, and even some turnpikes have used standard bidirectional streetlighting luminaires to provide the necessary illumination. This use is based largely on the fact that: one, they are commercially available, and two, a great deal of application experience is available.

The Federal Bureau of Roads suggests that lighting arrangements and illumination values should follow certain standards. In general, these would require a minimum average maintained illumination level of 0.8 footcandles, while maintaining a 4-to-1 average-to-minimum ratio. Using modern, high efficiency, mercury luminaires, this would allow spacings of about 200 feet maximum.

Application experience using these bidirectional luminaires has been limited largely to urban areas. Under these conditions the motorist is driving at relatively low speeds for shorter periods of time. Even in the more recent application of these luminaires to intracity expressways, the amount of time that a motorist spends driving under such a system is relatively short. However, if the application of these lumi-



naires is extended to lighting many miles of turnpike or limited-access roadways, an entirely different situation arises. As the car travels along such a roadway a pronounced "blink" occurs each time the windshield cuts off the light from the approaching luminaire. At normal turnpike speeds, this blinking, or so-called shutter effect, would occur at the rate of 24 to 30 times per minute. While specific data on the subject is not available, many people have expressed concern that a pronounced blinking effect, rapidly repeated, will produce a state of mild hypnosis in the driver; this, in turn, would decrease his alertness and probably increase his reaction time. Such opinions are, of course, highly speculatory, since no systems are presently available under which this effect could be evaluated. The continuous lighting of the Connecticut Turnpike may provide some of the answers regarding this particular point.

The manner in which the human eye actually sees has been a subject of considerable discussion. Certainly under a standard bidirectional system, seeing is provided by illumination that allows both direct discernment and silhouette discernment of the obstacle ahead. A unidirectional system that would aim its lights *against traffic*, has been proposed on the basis that normal seeing at low illumination levels is primarily by silhouette. Unfortunately, threshold discernment values, that is, the illumination level where direct discernment leaves off and silhouette vision begins, has never been adequately defined. Silhouette discernment is not preferable to direct discernment providing the latter can be economically attained. This is especially true when considering high-speed roadways, since depth perception is much easier under direct illumination. One major limitation of these systems would be the close spacing required. To maintain an adequate footcandle level on the roadway and the resultant pavement brightness, high candlepowers would result if these luminaires were extended beyond 150 to 200 feet apart. Obviously such "up stream" lighting systems cannot eliminate the luminaire as a potential glare source.

A third possibility, and perhaps the most promising, is a unidirectional highway lighting system aimed so that the *light is in the direction of traffic flow*. These luminaires would be installed on the left side of the roadway, that is, in the medial strip, aimed in the direction of traffic flow, and with little or no light coming back toward the driver.

A fourth possible system for highway lighting would be continuous fluorescent strips mounted on one side of the roadway. This would, in essence, provide a major amount of light directly across the highway, and if the mounting heights were properly chosen could provide good illumination. Based on the recent fog study at the Pennsylvania State University, such a lighting system may provide improved visibility under fog conditions. However, the cost, at least at this time, would be prohibitive.

glare considerations

The factor *disability veiling brightness* of disability glare is often used for comparing the effect of different light sources; in a general sense, this term is an indication of the amount of light striking the eye, and the angular displacement of the glare source from the normal line of sight. Also factored into this term is the effect of various atmospheric conditions on light transmission; the effect of several atmospheric conditions is shown in Fig. 1.

The three different lighting systems for superhighways are shown in Fig. 2. The roadway in each case is a divided highway with 36-foot roadways and a 32-foot medial strip. The observer is located 10 feet in from the edge of the roadway, and 100 feet from the first luminaire. System 1 is a typical bidirectional installation; system 2 is a unidirectional system with light aimed toward the driver; and system 3 is a unidirectional system aimed in the direction of traffic flow.

In calculating the glare effect for the different systems, two different methods were used. One represents an idealized condition (Table I), with a sharp cutoff of light both in the vertical and horizontal directions; for example, in this condition, it is assumed that the observer does not receive any light flux from luminaires in the opposite lane. In the second set of calculations (Table II), standard commercially available luminaires were used. In this case absolute cutoff of light is not feasible.

As shown in these tables, the mercury lighting in system 1 produces more glare from the closest luminaire than does fluorescent lighting; however, total glare is less for mercury. This is true because of the closer control of light possible with mercury lamps, which are, of course, a smaller light source. Therefore the glare from succeeding luminaires decreases with mercury, whereas it does not decrease as rapidly with fluorescent. The total glare from all luminaires visible to the driver is therefore greater with fluorescent lighting.

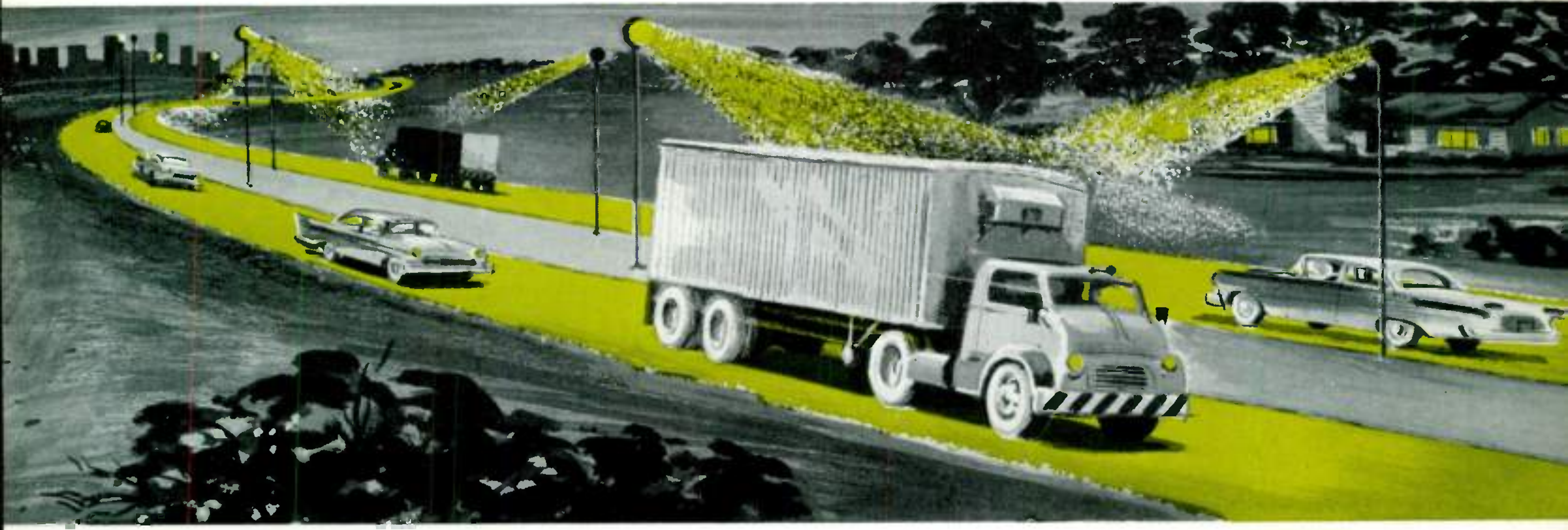


TABLE I—DISABILITY VEILING GLARE FROM IDEALIZED DESIGN

	System 1		System 2		System 3
	Mercury	1500 MA Fluor.	Mercury	1500 MA Fluor.	Mercury
Totals	.0718	.0422	.0718	.0422	0
Loss in Visibility	30.6%	24.7%	30.6%	24.7%	

TABLE II—DISABILITY VEILING GLARE FROM PRACTICAL DESIGN

	System 1		System 2		System 3	
Pole No.	Mercury	1500 MA Fluor.	Mercury	1500 MA Fluor.		Mercury
1	.07180	.0422	.07180	.0422	1	—
3	.00890	.0256	.00890	.0256	3	—
5	.00800	.0229	.00800	.0229		—
7	.00620	.0226	.00620	.0226	5	—
9	.00628	.0228	.00628	.0228	7	—
11	.00570	.0228	.00570	.0228		—
13	.00564	.0214	.00564	.0214	9	—
2	.014000	.0134	—	—	2	.00010
4	.000845	.0020	—	—	4	.00219
6	.000760	.0018	—	—		
8	.000595	.00183	—	—	6	.00511
10	.00078	.0024	—	—	8	.00995
12	.000510	.00185	—	—		
14	.000460	.00175	—	—	10	.01220
Totals	.13047	.20533	.11252	.18030		.02955
Loss in Visibility	38%	44%	36%	42.5%		21.2%

System 2, with its light aimed toward the driver, in effect uses half of the bidirectional luminaire, with the side facing away from the driver blacked out. In practice, the glare directed toward the driver would be greater if the luminaire were specifically designed for unidirectional lighting, since the light flux would be greater. In the idealized system of Table 1, this system produces exactly the same amount of glare as the bidirectional system. In Table 2, using the practical luminaire, the glare is also the same, except that luminaires in the opposite lane produce no glare component.

The third system, with light aimed in the direction of traffic flow, produces no glare with an idealized luminaire. This assumes that the cutoff of the luminaires in the opposite lane is perfect, so that no glare is received from this source. From a more practical standpoint, some glare would be visible from luminaires in the opposite lane, as indicated in Table 2. Even these low glare figures possibly can be reduced by further refinement in design.

Here then is a system that even in its practical state provides less disability veiling brightness than the idealized version of either the bidirectional system or the unidirectional aimed towards the traffic system. Until now, the design of streetlighting has paid more attention to the illumination produced than to the comfort of the motorist involved. Certainly the most important task of streetlighting is to provide visibility. However, a motorist may be subjected to long hours of driving under the visibility conditions produced by a highway lighting system, and thus comfort becomes a major factor. Visibility and comfort must be equally evaluated.

development of a highway luminaire

In choosing a design approach for a highway luminaire, many factors must be taken into consideration and many compromises made. The theoretical considerations of the way we see and the effects of disability and discomfort glare must, of course, be the basic motivating force behind a good decision. Other factors that must be considered are: cost, accessibility of the luminaire for maintenance, pole spacing, and pole location as a contributing factor in accidents. Because highway driving is a continuous process without appreciable environmental change, a design that achieves freedom from glare is of major importance. With poles at a uniform spacing and with the car traveling at a constant speed, the consistent flashing of a glare source at regular intervals into the eyes of the driver is believed to be one of the most serious problems in highway lighting.

This premise precludes the choice of a unidirectional system with the light source pointed towards traffic, as well as the use of a standard bidirectional luminaire. It also means that the luminaire must not be an offending glare source.

Visibility is the second most important factor. Automobile headlights produce a certain type of visibility. This visibility is the result of vertical footcandles, which serve to reveal an obstacle or object to the driver by means of reflected glint and direct discernment. A lighting system that depended for the revealing of any object on another type of visibility, namely silhouette discernment, when used in combination with high beam headlights would produce a lower overall visibility rating for the combination and would tend to confuse a driver

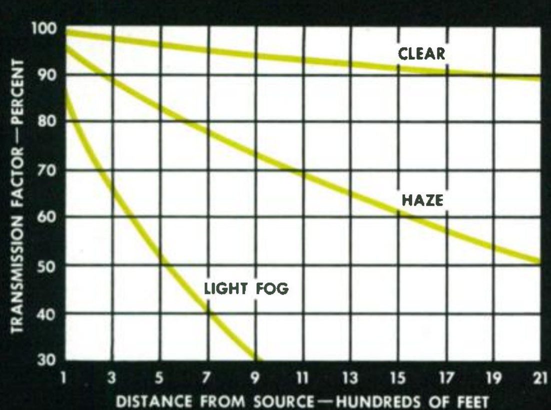


Fig. 1—Atmospheric Transmission

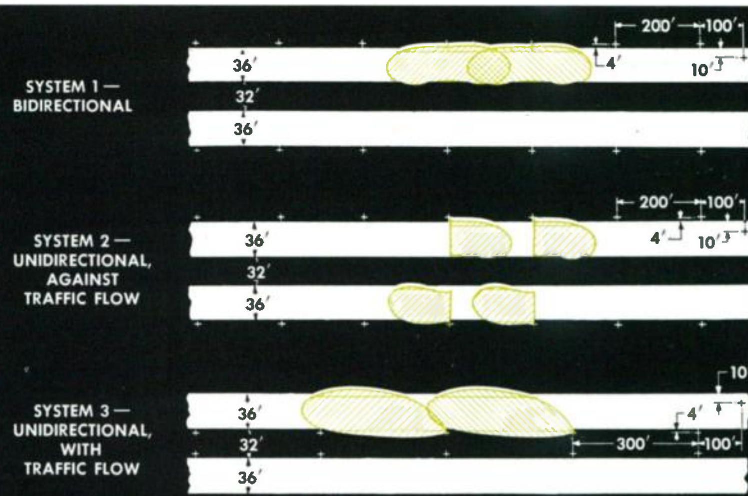


Fig. 2—Luminaire Arrangement for Glare Calculations

because his basis of judgment would not be constant. These factors all point to a unidirectional luminaire with maximum candlepower in the direction of traffic as the logical choice.

Luminaire Distribution—The factors of physical size, lumens per watt, and lamp life led to the selection of the 400 watt E-H1 mercury lamps as the most suitable light source for a luminaire to produce the required vertical footcandle level. To facilitate maintenance operations, the luminaire should be located off the actual roadway area so it can be serviced with a truck without blocking traffic. This indicated that the light distribution should be such that no light was directed straight downward from the luminaire, and the tentative specification of the luminaire mounting location from 5 to 6 feet outside the traffic lane was selected.

Working backwards from the criteria of one vertical footcandle, it was possible to construct an idealized candle distribution for the luminaire. This is shown as Fig. 3.

If such a highly idealized type of distribution could be obtained, the roadway would be uniformly lighted to a level of one footcandle vertically and with no light into the opposite roadway. However, a luminaire cannot be designed that will provide a main beam candlepower in the order of 100 000 and so cut off the beam to have zero candlepower immediately adjacent to this peak. Therefore, this idealized distribution must be modified. Such a distribution is shown in Fig. 4.

The initial considerations were based on luminaires being spaced approximately 300 feet on the left-hand side of the roadway with the poles located in the medial strip. The luminaire would be located 4 feet to the left of the edge of the high speed lane with the pole being located a minimum of 10 feet from the edge of this lane. Luminaire mounting height would be 30 feet. The luminaire would be aimed so that the axis of the parabolic section would intersect the pavement at the middle of the roadway directly opposite the next pole. This would result in an aiming angle of approximately 84 degrees vertical and 274 degrees lateral. Even with a medial strip of 32 feet in width, the adjacent curb of the opposite roadway is only 10 degrees laterally from the peak of the main beam. As the highway extends farther and farther away, both roadways tend to be asymptotic and will converge at 90 degrees vertical and 270 degrees lateral. Such a condition makes the cutoff requirements extremely critical. As can be seen from the proposed distribution, the peak candlepower of 120 000 must be reduced to 10 000 in 7 degrees to 1000 candlepower in 10 degrees and to 100 candlepower in approximately 20 degrees. These distribution requirements are tied in very closely to the glare calculations. Only with good lateral control can such low values of disability veiling glare be achieved.

Optical System—Since lateral control is of the greatest importance, the optical system design was based on achieving minimum lateral spread and with all possible accent on sharp cutoff to the left of the main beam peak.

As mentioned, the light source used in this luminaire would be a 400-watt E-H1 mercury lamp. The lamp would be mounted in a vertical position with the base up. The main body of the reflector is to be a parabolic section of revolution whose major diameter would be 20 inches. The rear section of the reflector essentially bypasses light around the arc stream in such a manner as to minimize spread. A prismatic lens would be utilized to further control this light. This prismatic lens would be divided into two major areas: one that would handle the light from the parabolic reflector, and the other that would handle direct light from the lamp (see Fig. 5).

preliminary evaluation

To prove that good visibility could be obtained from a highway lighting system that depended essentially on vertical footcandles to provide discernment, an experimental installation of three luminaires was made on a test street. These tests were conducted with a general purpose floodlight, and not with a luminaire designed specifically for unidirectional lighting. Nevertheless the tests indicated that the system provides a satisfactory level of illumination with good obstacle discernment and no offending glare. Further tests using the new experimental luminaire are now being conducted.

The need for a highway lighting system that provides good visibility and maintains driver comfort is clear. The work conducted thus far with a unidirectional lighting system, throwing light in the direction of traffic flow, indicates that the end result—a highway without glare—is attainable. ■

Fig. 5—An experimental version of a luminaire designed for unidirectional lighting.

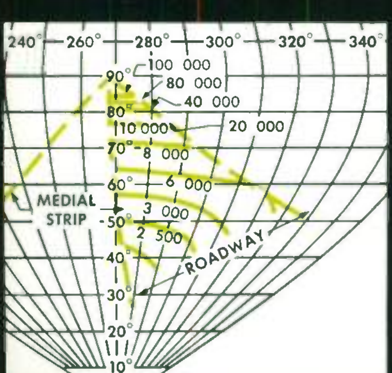


Fig. 3—Ideal Distribution

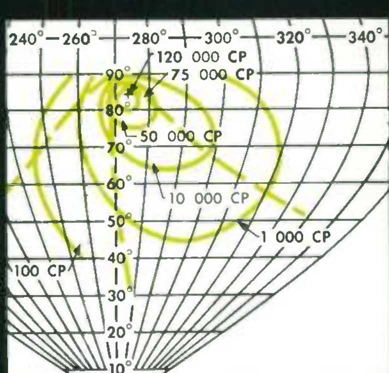


Fig. 4—Proposed Iso-Candle Distribution

SULFUR HEXAFLUORIDE — FOR ARC INTERRUPTION

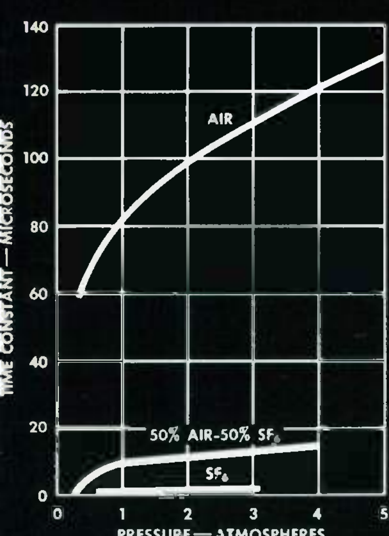
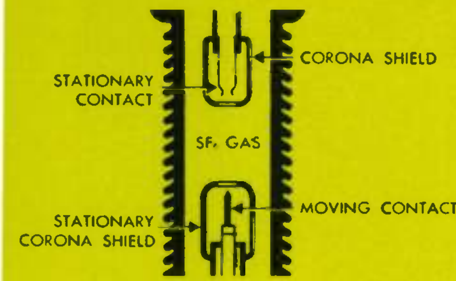
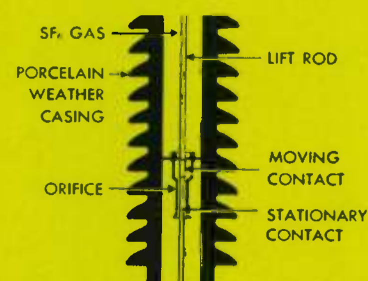


Fig. 1—Time constant curve for sulfur hexafluoride under plain-break conditions.

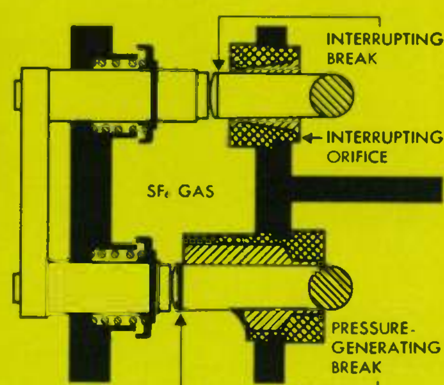
Fig. 2—The operating principles of four types of SF_6 arc-interrupters are illustrated by these simplified diagrams:



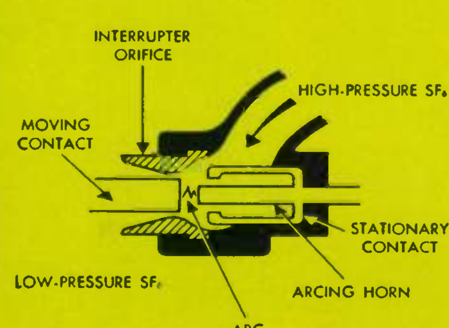
(a) A plain-break interrupter developed for the high-speed grounding switch. The contacts operate in SF_6 gas under pressure of about two atmospheres.



(b) A load-break switch employs a piston and Teflon orifice on the moving contact to force SF_6 gas through the arc formed during contact separation.



(c) A power circuit breaker interrupter uses two arcs formed in series in the chamber. Thermal expansion of the gas from the arc at the pressure generating break forces the flow of gas through the interrupting orifice as the interrupting contact opens.



(d) In the highest power SF_6 interrupter, high-pressure sulfur hexafluoride gas is forced through the interrupting orifice as the contacts separate.

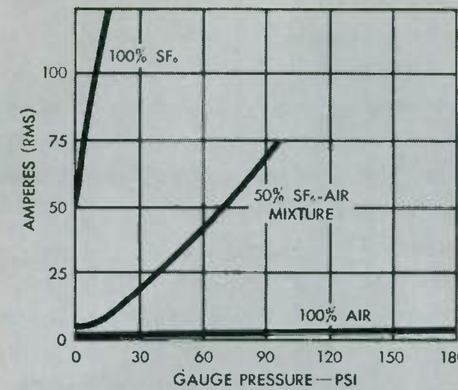


Fig. 3—Interrupting performance of a 3-inch plain-break gap in sulfur hexafluoride at 2300 volts.

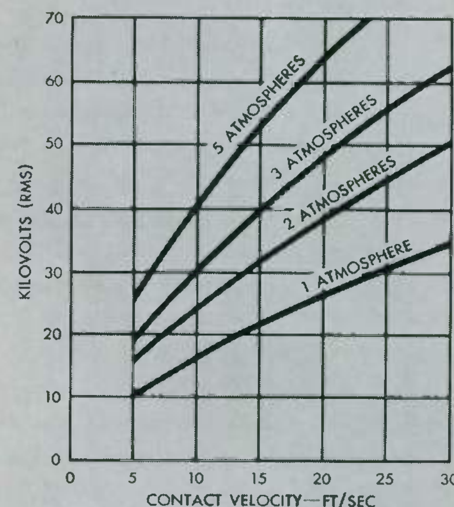


Fig. 4—Calculated voltage limits for restrike-free interruption by a plain-break arc in sulfur hexafluoride for capacitor switching at currents of 150 to 350 amperes.

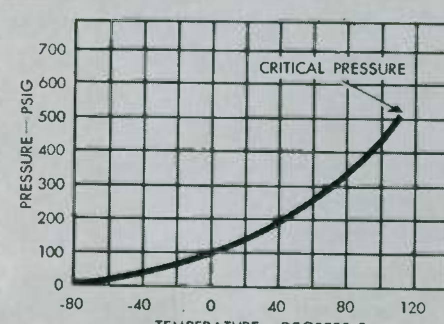
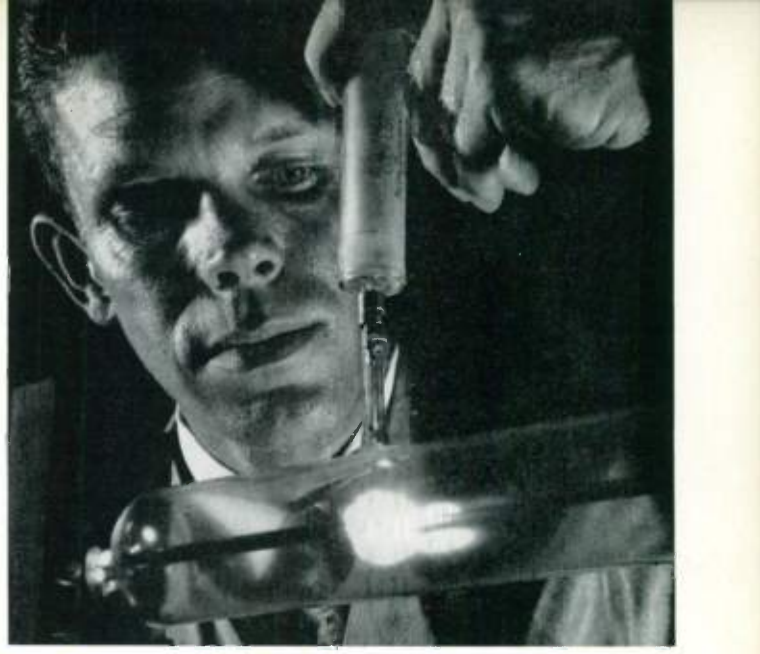


Fig. 5—Vapor-pressure curve for sulfur hexafluoride.

This newcomer to the circuit-interruption field promises to join oil and air to become the third major a-c arc-interrupting medium.

The requirements of a high-power arc-interrupting medium are difficult to fill. Only two mediums—air and oil—have proved universally acceptable over the first half century of circuit-breaker development. Sulfur-hexafluoride gas, long known to chemists but only recently exploited by circuit breaker designers, bids to become the third major arc-interrupting medium. Sulfur hexafluoride was first developed and applied as an insulating medium. At atmospheric pressure, the gas has a dielectric strength two to three times that of air, and its dielectric strength increases with increasing pressure; at three atmospheres, its dielectric value is approximately that of transformer oil. However, good as its insulating qualities are, circuit breaker designers feel that the real value of sulfur hexafluoride lies in its unique arc-quenching ability—under some conditions, 100 times better than air!



The effectiveness of SF_6 as an arc-quenching medium is demonstrated by this simple laboratory experiment. A high-voltage arc is readily drawn when the tube is filled with air, but is extinguished when a small amount of SF_6 is injected into the tube.

Sulfur hexafluoride is one of the halogen compound gases, is extremely stable and inert, and remains a gas down to a comparatively low temperature (-62 degrees C at atmospheric pressure). It is nontoxic and nonflammable. The gas is odorless and colorless, with a density approximately five times that of air.

Although a fundamental explanation for the a-c arc-quenching effectiveness of SF_6 gas still lags somewhat behind its application, significant progress has been made to develop an adequate theory. The phenomenon that apparently explains the superior arc-interrupting abilities of sulfur hexafluoride is the effect of negative ion formation by electron capture on electric discharges. Certain molecules offer an attraction for free electrons, and combine with the electrons to become negatively charged ions; gases made up of molecules with this electron-attracting characteristic are known as *electro-negative* gases. Sulfur hexafluoride is one of the best electro-negative gases. When the electrons are captured, SF_6 and SF_5 ions are formed, and both are massive and therefore relatively ineffective as current carriers. Both the insulating and arc-quenching abilities of SF_6 are strongly affected by this electron-trapping action; however, the mechanisms of electric breakdown and arc-quenching are so different in detail that the quantitative effects observed are quite different. Whereas sparking voltages in SF_6 are only about 2.4 times those in air, plain-break contacts drawing 60-cycle arcs in SF_6 can interrupt 100 times more current than in air at a given voltage.

The basic requirement of an a-c arc-interrupting medium is not primarily high dielectric strength, but rather, a high rate of recovery of dielectric strength; this requirement can be alternately expressed as a high rate of loss of arc-path conductance as the alternating current passes through zero. This rate of change in conductance is generally measured in terms of the *time constant* of the medium. The extremely fast capture of free electrons in the arc path through the electro-negative process is believed to explain the extremely low time constant of SF_6, only a fraction of that for air (Fig. 1).

arc interruption

The role of sulfur hexafluoride as an arc-interrupting medium can perhaps be best explained with a qualitative description of the arc-interrupting process. The phenomenon is rather complex, but can be most clearly described by dividing the process into two phases—an *energy-balance state* in the arc column immediately preceding a current zero, and a *dielectric recovery period* immediately following current zero.

In the energy-balance state, the arc must provide a low-impedance path for current flow until a normal current zero is reached. While the arc is a current-carrying conductor, it must operate in a relatively stable state; this means that current must be controlled by the connected circuit rather than by the arc. However, arc power should reduce at a rate approximately proportional to decreasing arc current. If the interrupting medium is to aid arc extinction, it usually serves to increase the rate of energy loss from the arc column. The ability of SF_6 to respond extremely rapidly to changing conditions makes it possible to reduce the arc diameter proportional to falling current magnitude with a relatively small flow of gas through the arc. The arc power should be reduced to a point where the arc loses stability just before a normal current zero. On the other hand, if arc stability is lost prematurely, thereby forcing a current zero (arc chopping), extremely high voltage transients can result in connected inductive circuits.

If the arc is to be quenched, the arc path must change quickly from a good conductor to an insulator to prevent restriking due to the rising voltage across the interrupter. In this period immediately following arc quenching, dielectric strength of the arc space is at first far below its ultimate value because of the high temperature and consequent low density of the gaseous arc residue. The ability to build up dielectric strength in this recovery period sets the upper voltage limit for breakers interrupting line-charging, magnetizing, or normal load currents where the rate of rise of circuit recovery voltage is relatively low.

However, when quenching high-current arcs, actual arc interruption depends upon the outcome of a continued dynamic energy balance after current zero. Some residual conductivity exists in the incompletely de-ionized arc space, through which the rising recovery voltage sends a small post-arc leakage current. If the arc is to be extinguished, the energy input into this path must not increase ionization and conductivity faster than the losses from this space can take energy away. The low time constant for conductivity change in arc spaces in SF_6 is a tremendous advantage in effectively quenching high-power arcs. After the leakage current disappears, the gap dielectric strength must still build up sufficiently rapidly to withstand the transient recovery voltage.

decomposition of SF_6 by arcing

Studies of the decomposition of SF_6 due to arcing indicate that even in high-power breakers, many interruptions at maximum short-circuit duty can be made without serious loss of gas through decomposition. At atmospheric pressure, more than a hundred high-power interruptions are required to decompose a cubic foot of sulfur-hexafluoride gas. The rate of decomposition is a function of arc energy, but is relatively low due to the fact that much of the decomposed gas immediately recombines to SF_6.

The gaseous decomposition products are chiefly lower fluorides of sulfur, such as SF_2 and SF_4. Although these gases are not toxic as such, they are unstable and easily hydrolyze in contact with atmospheric moisture to form sulfur dioxide and hydrofluoric acid. The highly toxic S_2F_{10} has never been observed in arc-formed decomposition products. Therefore, even though the presence of some air or even moisture does not appreciably effect the interrupting ability of SF_6, decomposition products formed during arcing can be minimized by using pure SF_6. In addition to using pure SF_6, a few pounds of activated alumina in the breaker chamber not only absorbs gaseous decomposition products, but also assures gas dryness.

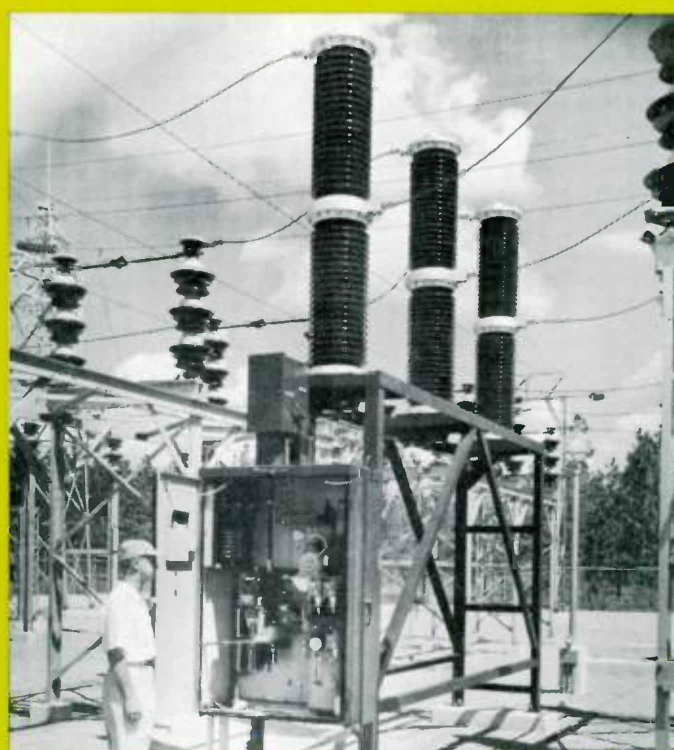
The fear of possible corrosive affects of the decomposition products has been a deterrent to the use of SF_6 for arc quenching. However, effective breaker sealing and the use of activated alumina has made the problem much less serious than might have been anticipated.

In addition to the active gases, some metallic fluorides are formed from reaction with the breaker contacts during arcing. These fluorides, which distribute themselves as a fine powder throughout the breaker chamber, have high resistivity and therefore cause no electrical trouble. The breaker contacts are designed with a "wiping" action to pre-

1953

Sulfur hexafluoride first appeared as an arc-interrupting medium in this load-break (type VLB) switch, developed in 1953. The interrupter is similar to the type used in compressed-air designs, but surrounded by sulfur-hexafluoride gas. The whole is contained in a porcelain housing, permanently sealed to maintain the gas at about two atmospheres pressure, and mounted on a standard, outdoor air switch. Switches with the SF_6 interrupter are made for voltage ratings from 7.5 to 115 kv, and with a current-interrupting capacity of 600 amperes. They are suitable for interruption of transformer magnetizing currents, line-charging currents, and load currents.

1955



This is the first experimental gas-filled (SF_6) power circuit breaker. The 115-kv, 1000-mva breaker has a continuous current rating of 400 amperes rms, and will interrupt in 5 cycles and reclose in less than 15 cycles. The breaker is restrike free, which makes it particularly well adapted for switching capacitors, either single bank or bank against bank.

A porcelain housing is used for the enclosure, holding gas at 45 psig. The upper half of the porcelain-clad pole unit contains the interrupting device, and the lower half provides insulation to ground.

Three curved, double-armed, U-shaped moving contact castings are mounted on a rotating shaft and mate with six stationary contacts to provide a total of six breaks per phase. The short stroke and small amount of closing energy required of this breaker allows eleven successive closing operations without going below minimum closing pressure with the standard pneumatic operating mechanism.

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vent the accumulation of these insulating particles on the current-carrying surfaces.

The complete absence of carbon in sulfur hexafluoride is a major advantage for an arc-interrupting medium. For example, oil-breaker mechanisms must be carefully designed to avoid horizontal insulating surfaces where conductive carbon compounds can settle. The complete absence of arc-formed conductive compounds in SF_6 permits more freedom in structural design.

breaker design

Because of its cost, SF_6 is not discharged to atmosphere as in air-blast breakers. Instead, SF_6 circuit breakers are completely sealed and self-contained units. Although some sealing problems are introduced, the resulting benefits largely offset the added difficulty and cost of sealed construction. For example, an obvious benefit is the complete absence of flame, and also a considerable reduction of noise, even on high-power short-circuit interruptions. Sealed construction also avoids moisture-laden air and consequent moisture condensation, which would have deleterious effects of corrosion and increased electrical leakage over insulating surfaces.

The first breakers developed were porcelain enclosed. However, in the latest design, a 230-kv, 15 000-mva breaker, designers have gone to the all-steel, dead-tank construction of oil breaker designs.

Although pressure-tight sealing of SF_6 breakers was at first a problem, satisfactory solutions have been found. In the first commercial SF_6 interrupter, the type VLB load-break switch, only a few cubic feet of gas were contained in the arc chamber, so that even a small leak could reduce pressure rapidly. During the development of these interrupters, one of the most troublesome problems was diffusion of gas through gaskets and porous castings. The difficulty was eliminated by impregnating all castings with a thermo-setting resin, and sealing the breaker with a silicone rubber gasket. With this construction, the interrupters operated satisfactorily in the field for a number of years, but eventually some pressure loss was observed. This resulted in the development of a new gasket of low-temperature Neoprene compound, which has a permeability of less than one percent of the silicone gasket.

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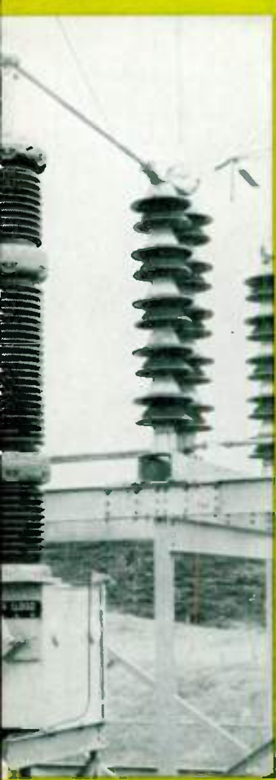
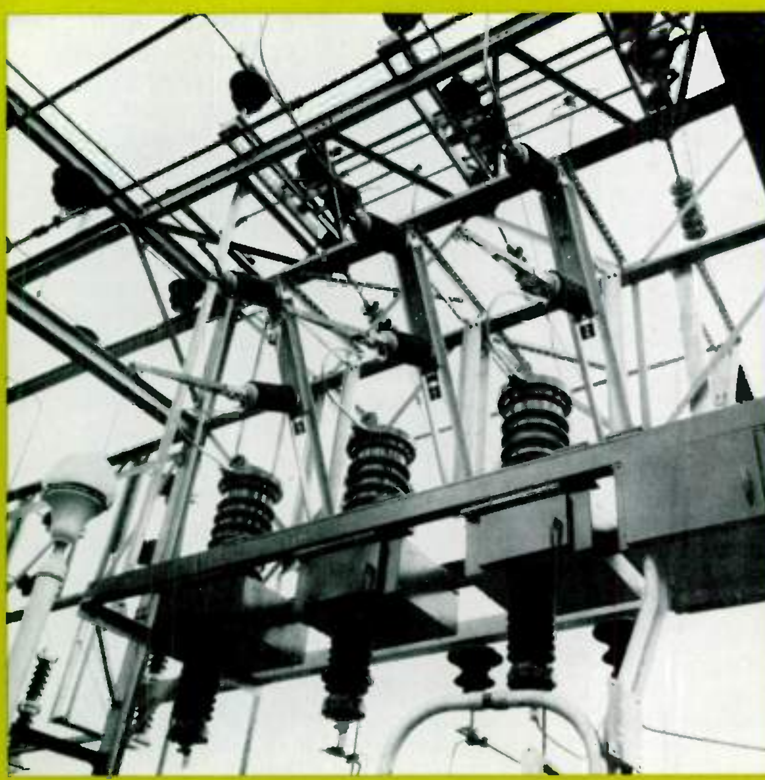


grounding switch uses a f the swinging blade em- ding switch designs. The oving contact, and the n enclosed in a porcelain n sulfur hexafluoride gas wo atmospheres. The gas e placed much closer to- ir. The small inertia and contact permit high oper-

1957



This 46-kv sulfur-hexafluoride circuit breaker for multiple reclosing duty has a minimum interrupting rating of 250 mva and an interrupting time much better than its specified eight cycles rating. The breaker and the associated relays are on a reclosing duty consisting of two reclosures and three trips with lockout occurring after the third trip.

Each of the three porcelain-clad pole units contains an interrupter and single bushing. A solenoid operating mechanism, mounted at one end of the supporting frame, operates the three pole units simultaneously through horizontal connecting rods.

Each interrupter assembly is a separate removable component consisting of the upper terminal, two-break interrupter, puffer, drive shaft, and moving contacts. One interrupter break generates pressure to force gas through the interrupting break orifice. The puffer, which is attached to the interrupter, operates during closing to force fresh gas into the interrupter chamber after each operation.

1958

This new 230-kv, 15 000-mva SF_6 breaker is the first of a line of high-capacity sulfurhexafluoride-filled circuit breakers. The unusual arc-interrupting ability of sulfur hexafluoride gas has made possible a breaker that combines the best features of insulating oil and compressed air designs. From oil breaker designs, the new breaker has borrowed dead-tank construction, positive mechanical connection between all contacts and operating mechanisms, and bushing type current transformers to provide overlapping relay protection. Like air breakers, the sulfur-hexafluoride breaker has lightweight, low-impact loading of foundations, and consequently light-foundation requirements.

interrupting mechanisms

Structural members of the interrupting mechanism can be of any material of adequate electrical and mechanical strength. However, organic insulation, such as fiber or Micarta should not be located in the arc path where it can be decomposed, to avoid diluting the gas with undesirable impurities. Interrupting orifices are usually constructed of Teflon, which is extremely resistant to arcing and produces negligible gas contamination.

The interrupting arrangements employed on sulfur-hexafluoride devices range from simple plain-break contacts to a gas-blast design. Because of the superior arc-interrupting ability of SF_6, the necessary gas flow in the interrupting orifice is relatively small. Generally, the required flow-producing pressures for arc extinction are only one-third to one-half the values required with air.

For low-power interrupting application, or capacitor switching, plain-break interrupters are effective; flow-type breakers are required for higher power interrupting duty. Gas flow can be produced by: a mechanical piston or puffer; thermal expansion of the gas by an auxiliary arc; or by discharging gas under pressure through the arc path.

A high-speed grounding switch employs a simple plain-break contact (Fig. 4a). Actually, this switch is a contact *making* rather than a *breaking* device, and SF_6 reduces arcing time during closing. A puffer technique was effectively employed in the SF_6 load-interrupting (type VLB) switch. The interrupting orifice is combined with a piston on the moving contact, so that gas compressed is forced through the orifice (Fig. 4b). For the 115-kv, 1000-mva and 46-kv, 250-mva circuit breakers, a double-break arrangement is used in which a pressure-generating break provides flow-producing pressure to force gas through the orifice surrounding the interrupting break (Fig. 4c). In the highest interrupting rating developed to date, a 15 000-mva, 230-kv circuit breaker, SF_6 at nominally 170 psi above tank pressure is discharged through the interrupting orifice (Fig. 4d).

economics and use of SF_6

Although SF_6 is normally a gas, it can be liquefied at moderate pressures and stored as a liquid at its vapor pressure, in much the same manner as carbon dioxide. The gas is stored and shipped in standard size steel cylinders, normally holding 100 pounds of SF_6. A 100-pound cylinder contains enough gas to fill a volume of about 250 cubic feet at one atmosphere of pressure at 75 degrees F. Vapor pressure, which is about 330 psig at 75 degrees F, varies with temperature as shown by the vapor-temperature curve (Fig. 5). Volume varies inversely as absolute pressure.

The cost of SF_6 is approximately $2 per pound, or about 75 cents per cubic foot per atmosphere. In general, the volume of gas required in an SF_6 breaker is considerably less than the volume of oil in a comparable oil-breaker design. For example, the total volume in all three phases of the 1000-mva circuit breaker is only about 15 cubic feet at a pressure of 45 psig, or about 24 pounds of gas.

Filling the Circuit Breaker—The sealed breaker is usually first evacuated and then filled directly from a high-pressure gas cylinder. Proper filling is determined from the pressure gauge on the breaker. Although a vacuum pump is generally used for removing air prior to filling, high vacuum is not required. The breaker is usually pumped down to a few millimeters Hg pressure; even this degree of vacuum is more than necessary, since an appreciable amount of air can be mixed with sulfur-hexafluoride gas before a noticeable decrease occurs in dielectric strength or interrupting ability.

A displacement method can be used for emergency filling on some designs if a vacuum pump is not available. The heavy SF_6 gas can be introduced at the bottom of the breaker tank, and will displace the air, which is exhausted through a port at the top of the chamber. The nonflammable property of SF_6 gas can be used to determine when the air has been completely displaced; by placing a flame before the escaping gas, the flame is extinguished when SF_6 begins to escape.

Any gas loss from a breaker is indicated by a pressure gauge. A simple low-pressure alarm system can also be readily installed. Should leakage occur, gas can be added in most designs even while the breaker is in service, through a filling valve located at ground potential. Except for some leakage experienced in the early VLB interrupter designs, no leakage problems of any consequence have been encountered. During the first year of service, the 1000-mva, 115-kv breakers lost, on an average, less than one pound of pressure. This represents a cost of makeup gas less than one dollar per year per three-phase breaker.

For small interrupters such as the VLB load-break switch, the cost of gas is negligible and is usually not worth saving when a switch is serviced. However, as larger breakers are built, reclaiming used gas becomes desirable. Many systems could be designed for removal and storage of SF_6. The particular system chosen will probably depend upon the breaker design. If pumps are used to circulate the gas from a low-pressure to a high-pressure chamber, the same pumps can be used to transfer SF_6 into storage chambers at relatively low pressure during servicing. If the breaker design does not include pumps, a portable system can be designed to pump gas from the breaker into a storage cylinder at a pressure sufficiently above vapor pressure to accomplish transfer in the liquid state.

Servicing Breakers—Servicing SF_6 breakers is simple, although a few precautions should be observed. Unarced SF_6 is extremely stable and nontoxic; proper use of activated alumina as an absorber should remove the small amount of gaseous decomposition products formed during arcing.

A breaker being serviced should first be completely evacuated; then the dust-like metallic fluorides should be removed by vacuum cleaning; and finally, the breaker tanks should be wiped with clean rags, and the alumina absorber replaced. Since operating and servicing the SF_6 breaker is different from oil or air breakers, operating personnel should be familiar with the properties and handling procedures of the new medium. However, although the procedures and equipment differ, servicing SF_6 type breakers is no more difficult than most air breakers.

in summary

Although SF_6 is new in the circuit-interruption field, several years of successful service experience have already been obtained. Load-break switches have been in service since 1953, and several 1000-mva, 115-kv circuit breakers have completed two years of service experience. Some 46-kv reclosing circuit breakers have recently been installed, and the first 15 000-mva, 230-kv breaker will be installed in 1960.

The favorable characteristics of SF_6—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. Sulfur hexafluoride has given circuit breaker engineers a new degree of flexibility in circuit breaker design. ■

SF$_6$ CIRCUIT BREAKER — A NEW DESIGN CONCEPT

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Joining ranks with oil and air as a circuit-interrupting medium is sulfur hexafluoride, whose arc-quenching abilities are outstanding.

The phenomenal arc-quenching ability of sulfur-hexafluoride immediately suggests the use of this gas in circuit interruption devices. Fortunately, SF$_6$ also has the other characteristics desirable for such applications, particularly stability, inertness, and excellent insulating properties. Beginning with investigations of the interrupting properties in the Research Laboratories, the gas has made rapid progress as an interrupting medium. After progressive development of low-power interrupting devices, sulfur-hexafluoride has now reached the point of application in a high-power, high-voltage circuit breaker, designed for 230 kv, 15 000 mva.

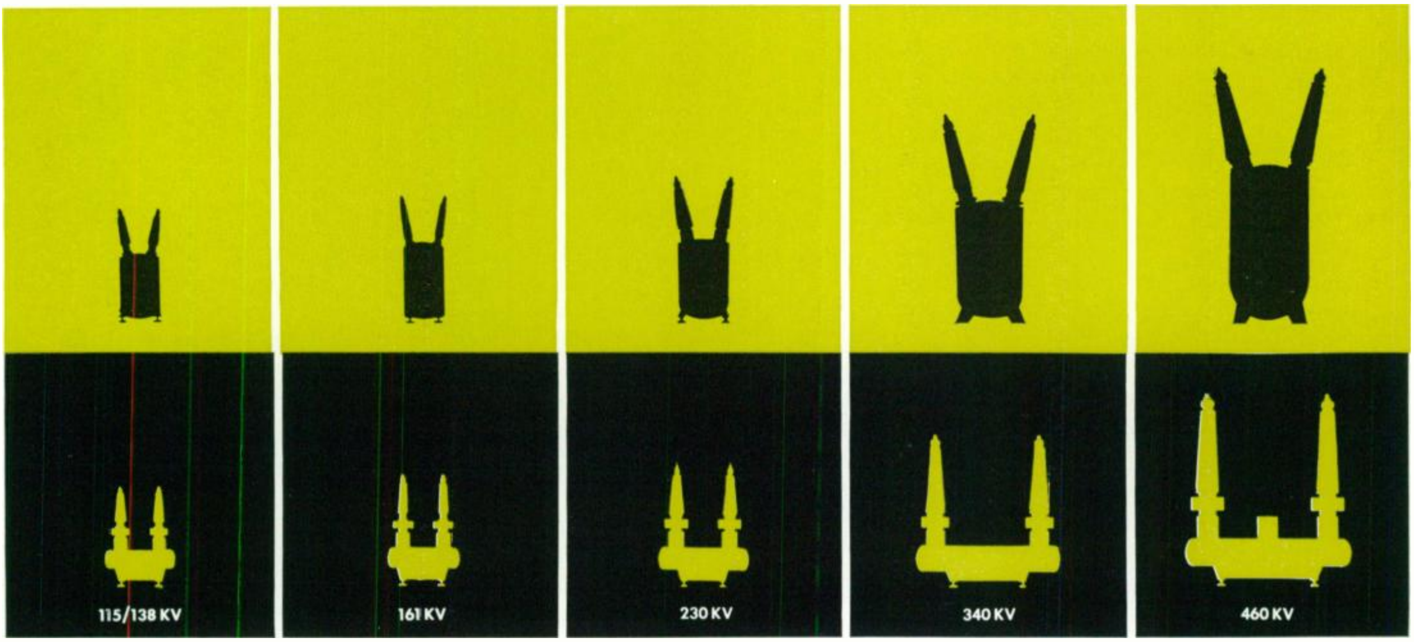
The first circuit interruption application of SF$_6$ was made in a load-break switch, developed in 1953. Subsequently, a 115-kv, 1000-mva power circuit breaker was developed in 1955; a 5-cycle grounding switch in 1956; and a 46-kv, 250-mva power circuit breaker in 1957. The new large breaker is the latest step in what will ultimately be a complete line of SF$_6$ breakers.

The new breaker was designed to combine the best features of other breakers utilizing interrupting media such as air or oil. Among these features are the established and well-accepted dead-tank construction, including the provision for bushing-type current transformers, and the mechanical interconnection of all contacts with the circuit breaker operating mechanism.

The new SF$_6$ breaker design overcomes some of the shortcomings inherent in established oil or air circuit breakers. Among the inherent advantages are quiet operation, elimination of any possible fire hazard, light foundation requirements, minimum auxiliary equipment, and the elimination of any porcelain under high pressure. This design provides a breaker of both low initial cost and low maintenance and outage times coupled with ease of maintenance.

general description

The SF$_6$ breaker (see Fig. 1) contains many of the design elements characteristic of the dead-tank oil breaker. Basically the unit consists of three cylindrical steel tanks mounted horizontally and parallel to each other. Each tank contains sulfur-hexafluoride gas at a pressure of approximately 30 psig. A multi-break interrupter is mounted coaxially within the tank and supported from the inner ends of two bushings, which project upward from the ends of each tank. Associated with the bushings are through-type current transformers, which are mounted externally to the breaker tank and can be passed over the bushing for mounting in position.



Line of SF$_6$ circuit breakers compared with similar line of oil circuit breakers.

Each tank is mounted on a common sub-frame. At one end this sub-frame supports a housing containing the operating mechanism and the equipment for handling the gas. A standard pneumatic mechanism closes the contacts and compresses the springs that provide the energy for opening the breaker. Operating rods between the pole units are connected to the contact operating linkage to mechanically tie the contacts together and insure the synchronous operation of the pole units. This insures that relaying difficulties will not be caused by contacts in each pole making at different times.

Mounting the tank in the horizontal position reduces overall height, which provides advantages in shipping and also permits special features for servicing. The development pole unit, ready for mechanical tests, is shown in Fig. 2. The 230-kv, 10 000-mva production oil breaker located next to the pole unit suggests the reduction in height accomplished with this design. Swinging doors on each end of the tank provide access to the interrupter at a convenient working height from ground level.

pole unit tank

The excellent insulating properties of sulfur-hexafluoride make possible minimum clearances between electrically live parts within the tank and ground. At the normal gas pressure of 30 psig the clearances within the tank are adequate to support the 60-cycle withstand voltage of 425 kv and the BIL test of 900 kv. Even at atmospheric pressure these clearances are adequate to support approximately twice normal line-to-ground system voltage.

The tank is adequately designed and constructed to meet pressure vessel requirements. A rupture disc located in one door of each unit protects against any possible overpressure. To minimize the gas leakage, unique gasketing arrangements are used. Static seals in the locations disturbed during servicing, such as the doors, use a double "O" ring seal. This arrangement not only provides double protection against leakage but also a quick means for checking for any leakage past the inner "O" ring. This can be done by unplugging a small vent located between the two rings. The gasket material is of a specially compounded neoprene recently developed for SF_6 applications. This material is designed to be effective over a wide range of ambient temperatures. Mechanical motion is transferred from the outside of the tank into the tank through a rotating shaft, which is sealed by Teflon "V" rings.

interrupter

For breakers with extremely high kva rating, a dual pressure system with an axial-flow type of interrupter seemed more suitable than a cross blast or puffer type of arrangement. Storing the energy in the gas at high pressure over a period of time—as compared with a puffer arrangement, which depends upon a flow of gas produced by motion of the contacts—has the advantage of greatly reduced mechanical operating energy requirements.

The interrupter is a three-break, double-pressure structure. The essential elements, shown in Fig. 3, are: a high-pressure gas reservoir; single blast valve; insulating tubes for conducting the gas flow from the blast valve to the interrupters; and three orifice-type interrupting units. A stationary member of each interrupter unit is mounted on insulating bars, which extend the full length of the interrupter, providing the main structural member of the interrupter assembly.

Each interrupting unit, as shown in Fig. 4, consists of the stationary current-carrying fingers, arcing horn, moving contact, and orifice. The moving contact members of each interrupting unit are mounted on a pair of insulating rods in a "ladder" type of construction, which is actuated to the open position by the spring assembly located at the one end of the interrupter. A stationary finger arrangement transfers the current between the moving and stationary contact members.

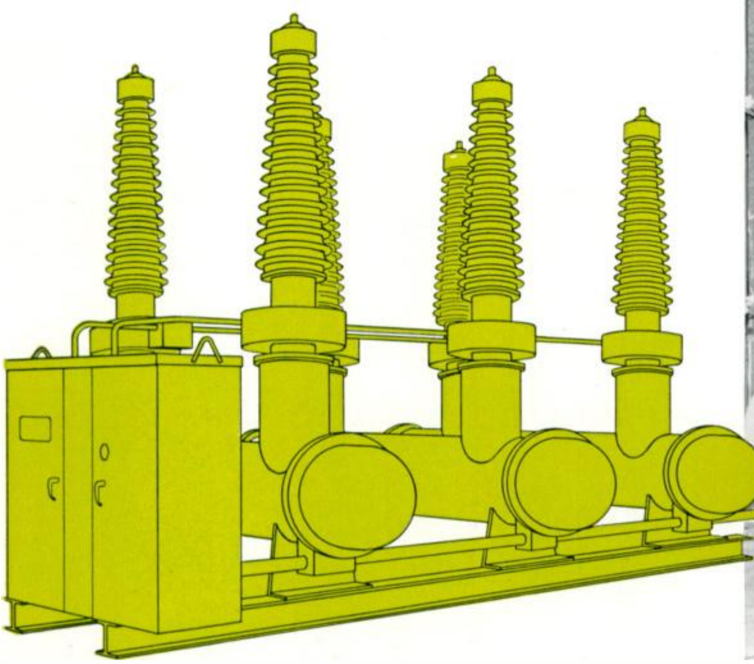


Fig. 1—Perspective sketch of 230-kv, 15 000-mva sulfur-hexafluoride gas circuit breaker.

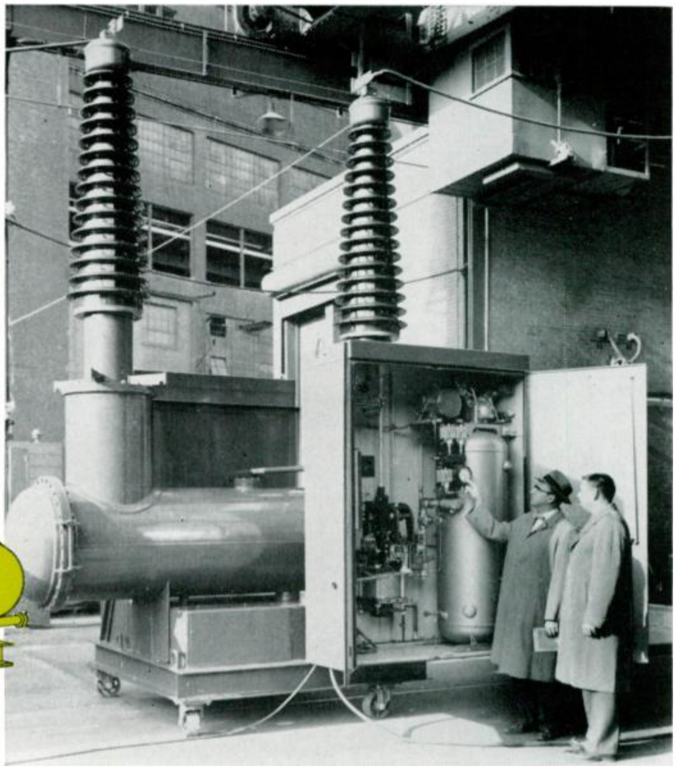


Fig. 1a—A photograph of one pole of the 15 000-mva sulfur-hexafluoride circuit breaker.

Contact construction is such as to minimize erosion due to arcing on the portions that conduct current in the closed position of the breaker. In the closed position the current path is through the sidewall of the moving contact into a set of fingers. An arcing horn located within the finger cluster projects a short distance beyond the end of the fingers and into a cavity in the end of the moving contact. Upon opening, the arc quickly transfers from the end of the finger cluster to the centrally located arcing contact and to the end of the moving contact; both surfaces are faced with arc resistant material. This contact arrangement has been tested in the experimental single-break interrupter and subjected to large numbers of interruptions in the High Power Laboratory.

The interrupting function is performed by a high velocity flow of SF_6 gas through the orifice. During normal operation the high-pressure gas reservoir is maintained at approximately 200 psig and the low-pressure area at 30 psig. At the start of contact motion on an opening operation, the pilot valve is opened mechanically. The pilot valve exhausts the gas from the region behind the blast valve operating piston, thereby opening the blast valve. Opening of this valve allows high-pressure gas to flow through insulating tubes to the interrupting orifice, thereby extinguishing the arc as the contacts move to the open position. As the contact linkage moves to the open position, the latches operating the pilot valve are released, allowing the pilot valve to close by spring force and gas pressure. This, in turn, closes the main blast valve and conserves gas for the next operation.

Uniform distribution of voltage across each of the three breaks is obtained by capacitor assemblies. These units are tapped in across each of the several breaks. Electrostatic shields around the metal portions of the assembly provide for control of the electric field between interrupter and tank.

The accessibility and ease of handling of the interrupter unit for inspection and service is indicated in Fig. 5. A pair of aluminum rail channels in the upper portion of the tank extend out one end to provide tracks for trolleys that carry the interrupter out of the tank. One man can easily perform this operation. The low tank height permits this and other operations upon the tank to be done by personnel working at ground level. The assembly used to remove the interrupter reduces the time required for this operation to approximately 15 minutes for a pole unit.

gas system

After each interruption, the gas discharged into the tank is recompressed by a compressor and delivered to the high-pressure reservoir of the interrupter. Thus the system is closed, with no discharge of gas outside the breaker. Quiet operation is therefore inherent, as opposed to some breakers that discharge compressed gas to the atmosphere.

On the three-pole breaker the auxiliary equipment for handling the gas is located in the same housing as the pneumatic operator, although a separate housing was provided on the development pole unit. This equipment consists of a filter for removing the small amount of gaseous arc decomposition products in the gas; a compressor for circulating and storing the gas; a relief valve for maintaining the high-pressure system within the requisite limits; and hand valves and various control and indicating instruments for maintaining the proper pressure relationships. In addition an auxiliary reservoir is located in this housing to provide sufficient gas for several breaker operations between compressor operations. Since the gas at 200 psig liquefies at approximately 42 degrees F, a heating arrangement is provided around the reservoir to keep

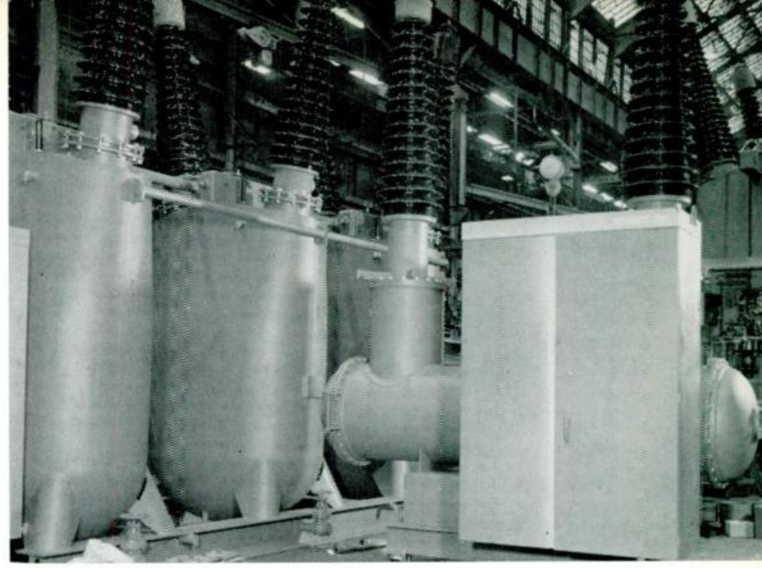
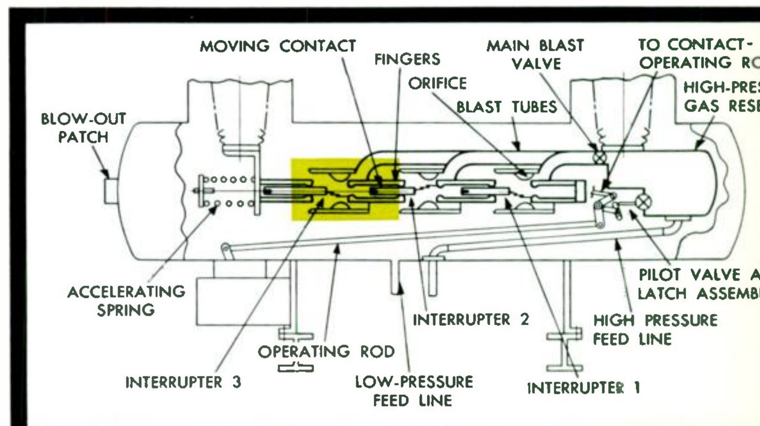


Fig. 2—Development pole unit of 230-kv, 15 000-mva SF_6 gas circuit breaker compared with 230-kv oil circuit breaker for size.



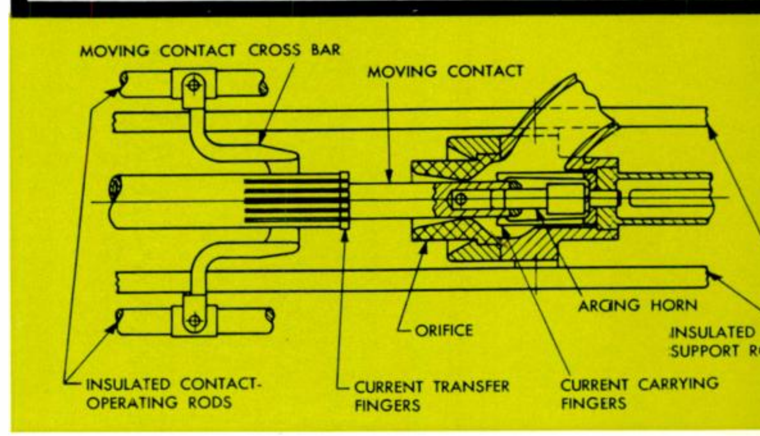
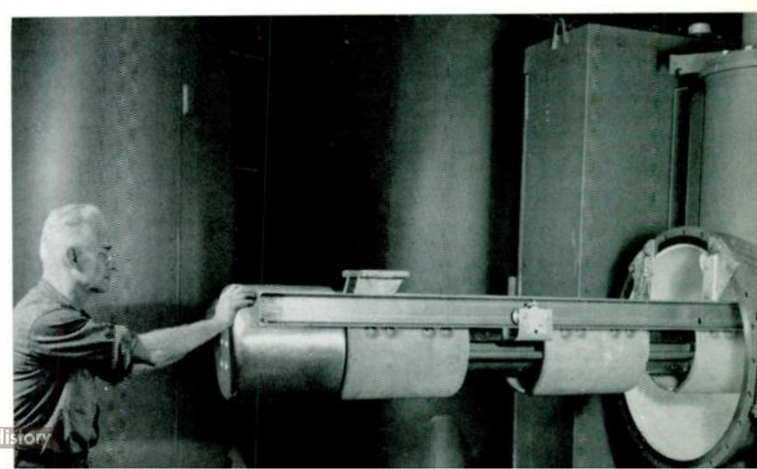


Fig. 3 (Top)—SF_6 interrupter and tank for a 230 kv breaker.
Fig. 4 (Bottom)—Cross section of interrupter unit.
Fig. 5 (Below)—Low tank height permits easy access to interrupter for removal, inspection, and assembly.



the temperature above this point. These heaters are controlled by a thermostat located on the reservoir. A schematic diagram of the gas system is shown in Fig. 6.

Although most of the decomposition products of the arc recombine immediately upon extinction of the arc, a small percentage remains. This remainder is removed by an activated alumina-containing filter.

bushings

The bushings are of a new design. They consist simply of a lead, a mounting-flange arrangement, a pair of insulating porcelains, and a compression spring assembly at the upper end located within a sealed cap housing. The springs provide compression loading on the porcelains for sealing purposes. This arrangement is shown in Fig. 7. A small opening at the upper end of the conducting lead allows passage of SF_6 from the bushing to the breaker. This arrangement greatly minimizes the effect of any pressure changes within the breaker upon the region within the bushing porcelain. This type of bushing construction is free of any possible damage to organic insulation. As on conventional condenser-type bushings, a voltage tap connection is provided by an electrically floating metal cylinder in the region of the mounting flange with an insulated connection brought to the outside.

Extensive tests were made in the High Voltage Laboratory to verify this design. To determine the proper clearances, impulse and 60-cycle voltage tests were made on prototypes with variable clearances and at various gas pressures. The clearance between lead and the ground flange is more than sufficient to withstand the specified 60-cycle test voltage of 425 kv and the BIL test voltage of 900 kv at normal pressure, and twice line-to-ground system voltage at zero gauge pressure.

The bushing-type current transformers used are embedded in Fosterite contained within a metal shell, and the entire assembly is supported around the bushings by projecting arms mounted on the flanges. Conventional accuracy is obtained with these 2000-5 multi-ratio transformers.

experimental single interrupter

The design parameters for the basic interrupter unit were obtained in the High Power Laboratory by tests on the structure. The interrupting unit consists of the same elements previously described for the three-break unit. During much of the testing, a tube was inserted between the blast valve and orifice to simulate the relative position of the blast valve and the third interrupter of the 3-break interrupter assembly.

Fault interruptions have been made on this single-break interrupter at voltages of 13.2, 22, 44, 66, and 88 kv involving currents ranging from 380 to 66 000 amperes. During these tests several factors have been investigated such as: (1) differential pressure between the high-pressure chamber and low pressure, (2) orifice shape and size, (3) blast valve size, (4) duration of blast valve operation, (5) relative positions of high-pressure chamber and interrupting contacts, and (6) sensitivity to the rate of rise of recovery voltage.

Fault interruption arcing times on the final configuration ranged from 0.6 cycles to 1.3 cycles (Table I). The short arcing time obtained permits 3-cycle breaker performance. A representative fault interruption is shown in Fig. 8.

Several tests were made to determine the effect of the rate of rise of the recovery voltage on the interrupting ability of this interrupter. The rates of rise associated with faults on the

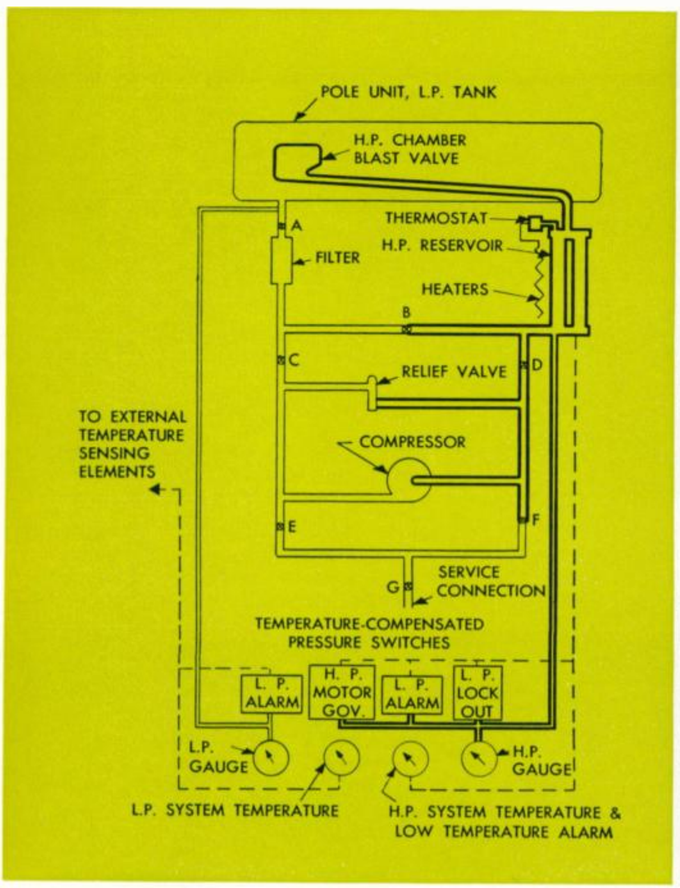


Fig. 6—Schematic diagram of gas system for SF_6 gas breaker. High-pressure system is indicated by heavy outline.

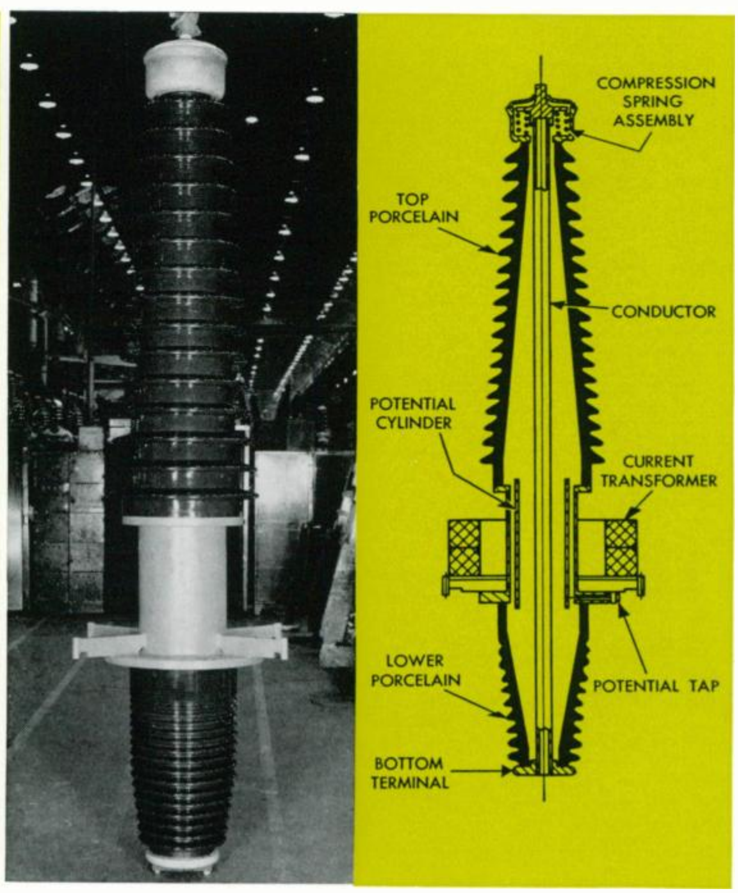


Fig. 7—Cross section of 230-kv gas-filled bushing, and a completely assembled bushing.

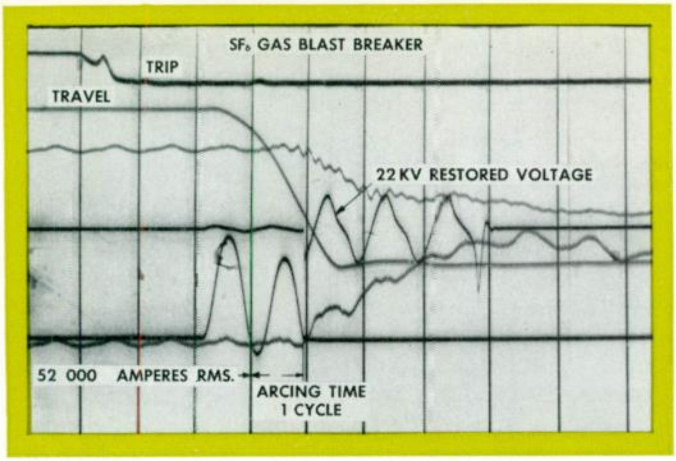


Fig. 8—Oscillogram of interruption of 52 000 amperes in 1.0 cycle arcing time.

line were also kept in mind. A summary of these tests appears in Table II, which compares the characteristics of the first cycle of the transient recovery voltage of the test circuit with the similar characteristics of a 230-kv 15 000-mva system. This comparison shows that the test interrupter is capable of handling rates of rise of recovery voltage and peak voltages in excess of the requirements of the transmission system. These tests indicate that the performance of SF_6 breakers, like oil breakers, are not critical to rate of rise of recovery voltage. Charging current and magnetizing current interruption tests were also made with equal success.

extension of design to a line of breakers

The SF_6 interrupter unit provides a building block for a line of breakers. Such a line is illustrated on page 51, and for comparison a similar line of oil breakers is shown. By varying the number of interrupter units, the length and diameter of the pole unit tank, and the size of the entrance bushings, breaker ratings from 115 kv to 460 kv, and even higher can be built. For the extremely high-voltage rating it is visualized that a mechanical supporting member will be necessary for the longer interrupter structure associated with that rating. This can be provided by a simple porcelain unit mounted midway in the length of the tank, as shown in the extreme right unit on page 51.

The SF_6 breaker combines many of the best features of other types of breakers and eliminates many of their disadvantages; it can thus be expected to assume a major role among circuit interruption devices. ■

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TABLE I— FAULT INTERRUPTION TEST ON SINGLE BREAK INTERRUPTER HIGH PRESSURE—200 PSIG

Test No. 86249	Test Voltage KV	Interrupting Current Amps	Interrupting Time Cycles(1)	Arcing Time Cycles(2)	Corrected Interrupting Time of a 3-Pole Breaker
KK	22	360	4.3	1.0	2.8
KL	44	720	4.2	1.0	2.8
KM	44	720	4.1	0.9	2.7
KN	44	5 000	4.4	1.2	3.0
KO	44	720	4.2	0.9	2.7
KP	44	5 000	3.8	0.6	2.4
KQ	44	5 000	4.1	0.8	2.6
KS	44	5 000	4.0	0.8	2.6
KT	44	10 000	4.4	1.1	2.9
KU	44	10 000	4.1	0.9	2.7
KV	44	13 750	4.0	0.8	2.6
KW	44	18 750	4.2	1.0	2.8
KX	22	1 440	4.3	1.1	2.9
KY	22	18 750	4.2	1.0	2.8
KZ	22	30 000	4.1	0.9	2.7
LB	22	40 000	3.9	0.7	2.5
LC	22	37 500	4.1	0.9	2.7
LD	22	1 440	3.8	0.6	2.4
LE	22	40 000	4.3	1.1	2.9
LF	22	44 000	3.9	0.6	2.4
LG	22	40 000	4.0	0.7	2.5
LH	22	38 500	4.6	1.3	3.1
LI	22	42 500	4.3	1.0	2.8
LJ	22	52 000	4.0	0.8	2.6
LK	22	51 000	4.2	1.0	2.8
LL	22	31 000	4.1	0.9	2.7
LM	22	30 500	4.0	0.8	2.6
LN	22	29 000	4.4	1.2	3.0
QD	13.2	2 400	3.8	0.4	2.2
QE	13.2	12 000	3.8	0.4	2.2
QF	13.2	11 700	3.8	0.4	2.2
QG	13.2	11 700	4.1	0.7	2.5
QH	13.2	11 800	3.75	0.35	2.2
QI	13.2	31 000	4.7	1.3	3.1
QK	13.2	30 000	4.5	1.1	2.9

(1) Interrupting times appear excessively long because of the long time between energizing of trip and contact part on this experimental unit.

(2) Arcing Time—interruption time—contact part time.

TABLE II— ABILITY OF SF_6 INTERRUPTER TO WITHSTAND FIRST PEAK OF TRANSIENT RECOVERY VOLTAGE EXPECTED ON A 230-KV 15 000-MVA TRANSMISSION SYSTEM

Current Interruption Amps	% Interruption Capacity of 230 KV, 15000 MVA System	Rate of Rise of Recovery Voltage		Voltage of First Peak	
		Test Circuit Referred to 3 Unit Interrupter (1) Volts/microsec.	230 KV 15000 MVA System (2) Volts/microsec.	Test Circuit Referred to 3 Unit Interrupter (KV)(1)	230 KV 15000 MVA System (2) (KV)
5 000	13	4600	1000	505	390
10 000	26	4800	2100	335	328
20 000	50	6600	4200	335	186
30 000	75	9000	6300	100	93
39 000	100	2400	2100 (3)	250	230 (3)

(1) Determined from tests obtained in High Power Laboratory.

(2) Rate of rise of recovery voltage calculated for faulted transmission line. Recovery voltage characteristics based on a system with a 15 000-mva source consisting of five lines.

(3) Recovery voltage based on source side only.

STEREOPHONIC SOUND ON RECORDS

Fig. 1—The 45/45 method of cutting two channels into one groove.

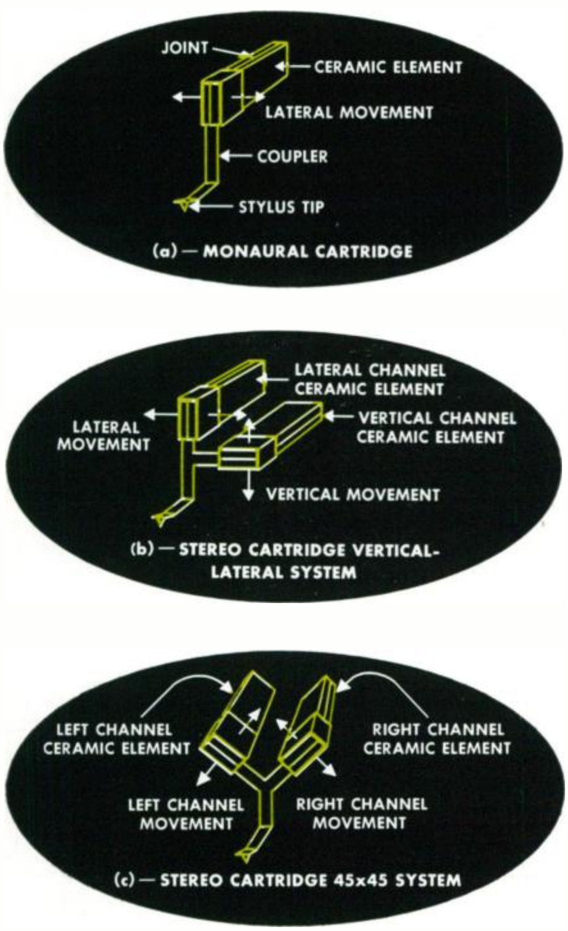


Fig. 2—A ceramic element is formed by two thin pieces of ceramic cemented together. Bending the element laterally creates a stress at the joint, which produces a voltage. If the element is bent in a vertical direction, no joint stress is produced, and no voltage is developed. Hence, the ceramic element is sensitive to only one direction of movement, and can be mounted in a phono pickup to respond to lateral movement for monaural cartridges (a). Two elements, mounted 90 degrees apart, are used in the vertical-lateral cartridge (b), or the 45/45 cartridge (c).

The newest and most dramatic development in sound listening — stereophonic sound from disc recordings — can transport the listener into the recording studio or concert hall. The listener is enveloped in sound that has true dimension, direction, and depth.

what is stereophonic sound?

The human hearing system recognizes both depth and direction. If the sound source is directly in front of the listener, sounds travel an equal distance to each ear. If the object moves to one side, the sound will travel a longer distance to one ear than the other, and the listener's mind quickly notes the difference in sound at each ear, and detects depth and direction. Human hearing is thus a two-channel system, relaying to the mind through two different paths the sounds that envelop the listener. Because the sound signal at each ear differs, sound perspective and realism is obtained.

stereophonic sound on records

Until the advent of stereophonic disc recording, all commercial discs had the recorded sound condensed into a single sound channel (monaural sound). Music of the recording musicians, seated at divergent points on the stage or in the studio, was recorded as if it came from a single sound source.

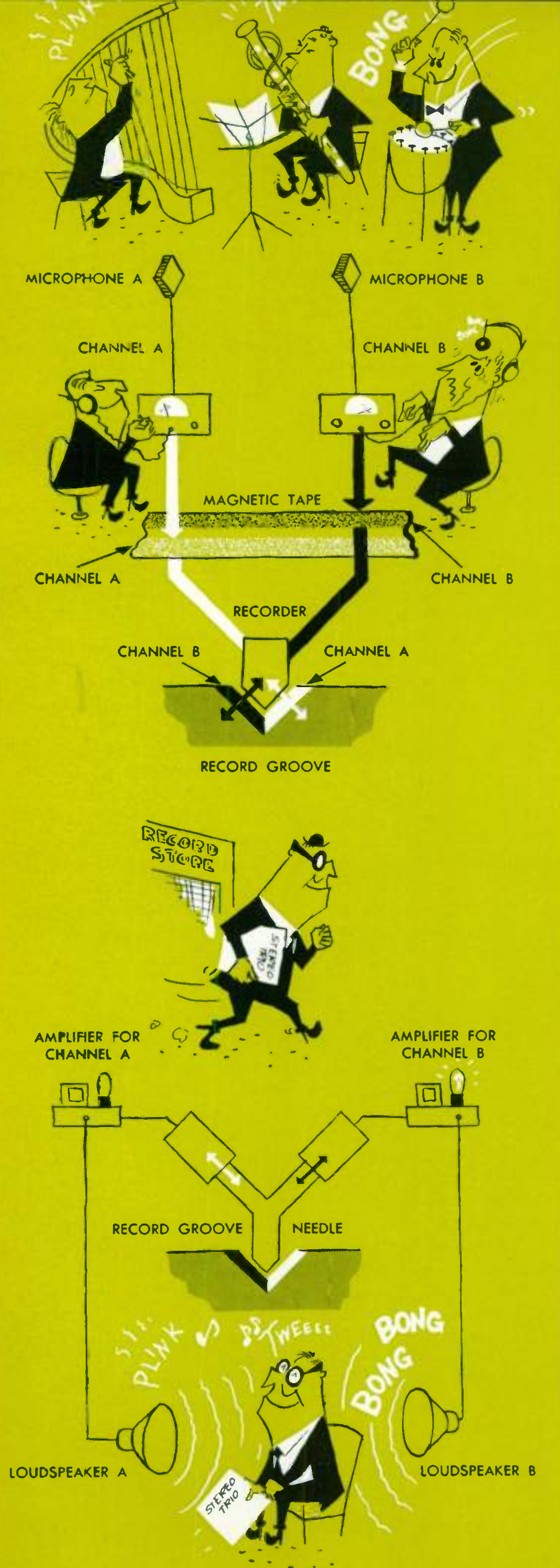
The development of the single-groove stereophonic recording technique has made dual-channel sound on a record commercially practical. Although the original ideas for cutting two sound channels into a single groove are better than 20 years old, 1958 marked the year of their commercial introduction to the public.

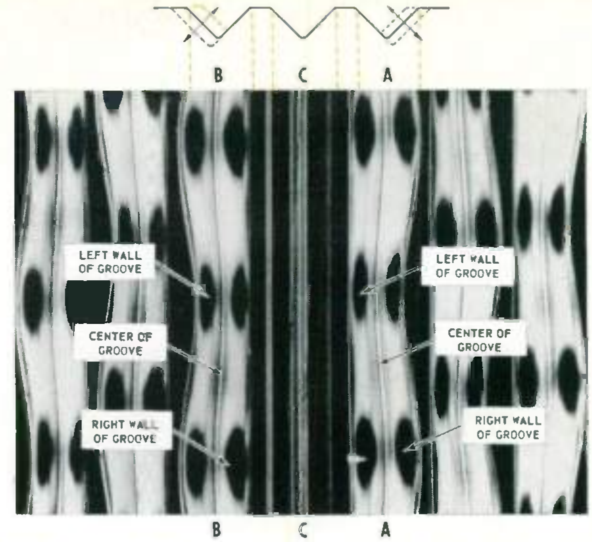
The system approved by the Record Industry Association of America is known as the "45/45." Each wall of the groove is inclined 45 degrees from vertical (Fig. 1) and a separate channel is recorded in each wall of the needle groove. A specially designed stereo cartridge (Fig. 2c) detects and separates the signal from each channel. A ceramic or magnetic element is sensitive to movement in only one direction, so that two of these elements, offset 90 degrees from each other, will pick up each channel separately.

A similar system, used by a few European record manufacturers, is called the "vertical-lateral" system (Fig. 2b). However, the 45/45 system offers one major advantage over the vertical-lateral method: each channel is of identical sound quality, something that the vertical-lateral method cannot achieve due to inherent quality differences between the lateral and vertical methods. Such stereo records can be safely played on monaural systems whose cartridges have sufficient vertical compliance. Compliances lower than 1×10^{-6} cm/dyne may damage the record.

The operation of stereophonic sound, from musician to listener, is shown symbolically in the sketch at right. The stereophonic disc recording is made by placing two separate microphones, separated from 10 to 30 feet, in front of the recording artists. The separate sounds picked up by the microphones and amplified in separate amplifiers are recorded on magnetic tape, and then transcribed to the record master by the stereophonic disc recorder.

The listener plays the disc through a high-fidelity system designed for stereophonic operation. The stereophonic cartridge separates the sounds from the two channels, which are fed to separate amplifier-speaker systems. By properly placing himself in front of the speakers, the listener hears sound that seems to come from definite points in the room, behind the speakers, or between the speakers. The stereo listener can have the best seat in the concert hall. ■





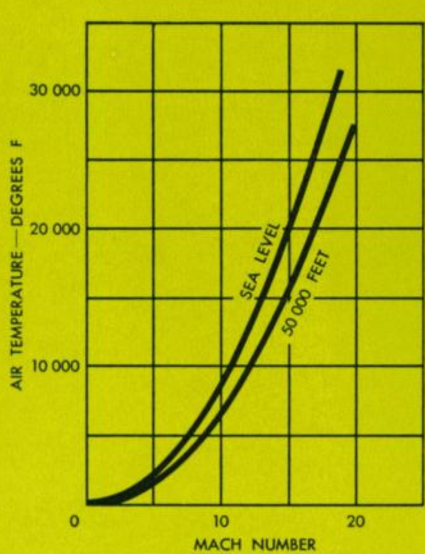
Enlarged view of the grooves on a stereophonic disc recording. *Courtesy of Westrex Corp.*

These shelf-size amplifier-speakers are companion units for Westinghouse stereo-fidelity phonographs. Model at left has two 6-inch speakers, plus amplifier; the model at right has 8- and 4-inch speakers, plus amplifier.

This stereophonic amplifier-speaker console carries 12- and 4-inch speakers and a 10-watt amplifier. This unit and the shelf-size units are connected to Westinghouse Stereo-Fidelity phonographs by a low-capacity cable with a standard phono plug.

HIGH TEMPERATURE TEST FACILITIES

ARMIN BRUNING
Marine, Transportation,
and Aviation Facilities
Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania



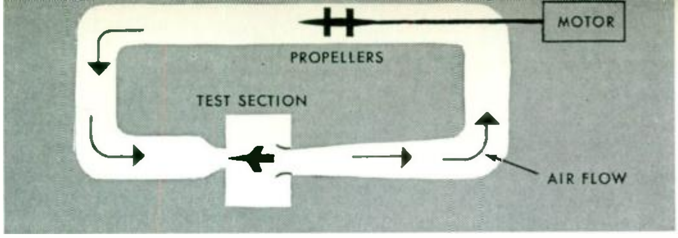
The high temperatures produced at supersonic speeds require that a thorough evaluation be made of missile and jet aircraft equipment, structural configurations, and surface shapes during all design and manufacturing stages. This can in part be accomplished with tests that in some way simulate the heating effects, aerodynamic forces, and chemistry of the air at supersonic speeds. Herewith are some of the various methods and facilities used to perform these tests.

With the sound barrier no longer a serious problem, aircraft speeds have been increasing at phenomenal rates, only to be confronted with another obstacle—the heat barrier. Because of the high heats generated by air friction and compression at supersonic speeds, structural configurations, metals, and other factors must be carefully determined before an aircraft or missile design is decided upon.

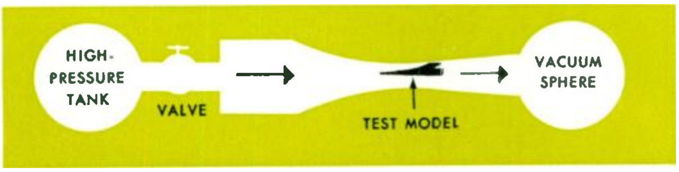
During the flight of an aircraft, the skin temperature rises until the heat radiated by the skin equals the heat absorbed due to air friction over the skin surface. Although no generalization can be made, certain configurations and finishes can lead to skin temperatures approaching that of the air boundary over the surface of the vehicle. For high-speed jet aircraft, the heat generated by air friction can considerably reduce the structural strength and fatigue resistance of structural members. Another serious, but not quite so obvious, problem arises from the fact that depending upon the altitude, temperature, and the velocity of the plane, air particles actually bounce over the surface of the plane at a certain frequency. Should the natural frequency of vibration of the skin equal that of the air, dangerous vibrational modes result that can weaken the structure of the plane. As the speed of the plane and therefore the temperature of the surface changes, so does the natural frequency of vibration of the skin and structure. The problem, then, is to design a structure that will not have a resonant frequency equal to that of the air particles over the speed range of the plane. Also, for high-speed jet aircraft, the amount of heat absorbed must be established beforehand, since air-conditioning equipment must be able to keep the ambient temperature at comfortable limits for the crew under all conditions.

Missiles must also be designed to operate in the searing heats produced by air friction, but the problems are somewhat different than encountered in jet aircraft. For instance, when a missile re-enters the atmosphere, different areas are subjected to different temperatures—the nose cone being the hottest. Since the temperature builds up so quickly and the flight time is so short, the heat is not evenly distributed, resulting in high temperature gradients along the surface and structural members. The gradients produce different rates of expansion, giving rise to severe stresses in the skin and structure. The metal, of course, must have a high enough melting point to withstand these temperatures, but beyond this, structural design should be determined to reduce internal stresses to a minimum.

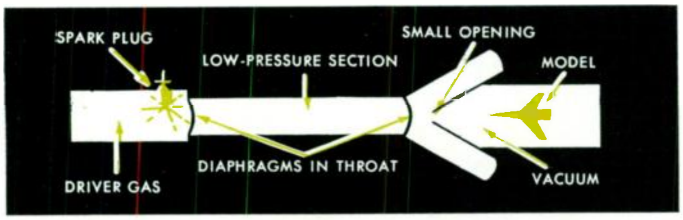
Many tests have been developed to determine the fatigue resistance of metals and limitations of equipment at elevated temperatures, but all are lacking in some respects. Mathematical analysis of missile and aircraft heating is sometimes subject to large errors because each of the many metals used has a different coefficient of diffusivity, and further, each coefficient varies differently with temperature. Other problems arise from the different coefficients of expansion and con-



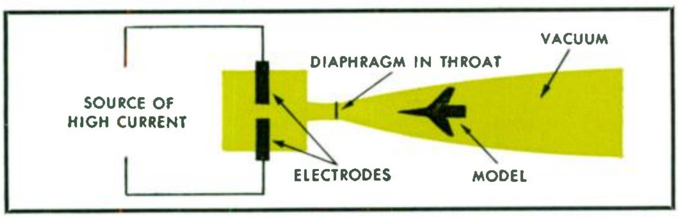
CONTINUOUS-FLOW TUNNEL—Tests scale models or components. Temperatures to 4500 degrees F. Speeds to Mach 7. Simulates heat-transfer mechanisms and aerodynamic forces.



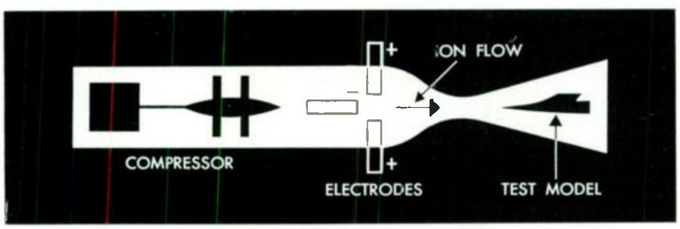
BLOWDOWN TUNNEL—Tests scale models or components. Temperatures to 4500 degrees F. Speeds to Mach 7. Simulates heat-transfer mechanisms and aerodynamic forces.



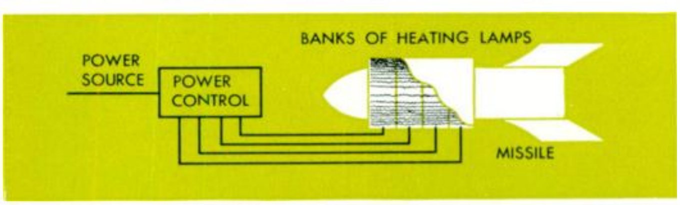
SHOCK TUBE—Tests scale models or components. Temperatures to 15 000 degrees F. Speeds to Mach 50. Simulates aerodynamic forces, but not heat-transfer mechanisms.



HOT-SHOT TUNNEL—Tests scale models or components. Temperatures to 15 000 degrees F. Speeds over Mach 10. Simulates air chemistry, but temperatures are difficult to record.

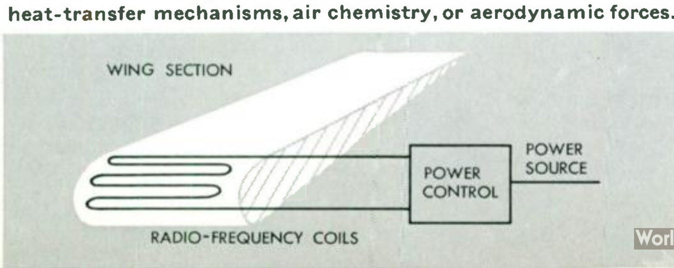


ELECTRIC-ARC TUNNEL—Tests scale models or components. Temperatures to 100 000 degrees F. Speeds to Mach 1. Does not simulate heat-transfer mechanisms or air chemistry.



RADIANT HEATING—Tests full-scale airframes. Temperatures to 4000 degrees F. Simulates transient heating, but not heat-transfer mechanisms, air chemistry, or aerodynamic forces.

INDUCTION HEATING—Tests full-scale airframes. Temperatures over 4000 degrees F. Simulates transient heating, but not heat-transfer mechanisms, air chemistry, or aerodynamic forces.



ductivity of each metal and the multitude of connections made between the structure and the skin. Even actual temperature tests of completed missiles in flight are somewhat unsatisfactory due to the difficulty in gathering data and recovering the missile. Scale-model tests cannot be extrapolated with any degree of accuracy because the scale factors for stress, temperature, diffusion, and aerodynamic characteristics all have different relationships to the mass and size of the missile or plane.

continuous-flow tunnel

Ideally, ground testing can be accomplished by subjecting a model or airframe sections to wind tunnel tests where the air velocity, density and temperature are equivalent to actual flight. However, the first major obstacle is the cost of making a tunnel capable of producing air velocities equal to those encountered by missiles; and secondly, the airflow simulates high temperatures of high-speed flight, which creates a problem of cooling the walls, nozzle, and compressor of the wind tunnel. At present, most tunnels in daily use are limited to temperatures of 1500 degrees F, but experimental tunnels have been built that can operate with stagnation temperatures of nearly 5000 degrees F. Because of temperature limitations, the continuous-flow tunnel can only pump air with the correct Reynolds number and enthalpy up to about Mach 7. Above this limit, reduced gas temperature must be used.

electric-arc tunnel

To circumvent these problems, several alternative test methods are used—the simplest is to heat a model in an electric-arc tunnel. In this method, an electric discharge between two electrodes creates air temperatures in the range of 100 000 degrees F. A compressor then blows the heated air over the model. At this temperature, the air becomes highly ionized, and as a result the test does not accurately simulate actual in-flight heat-transfer mechanisms; structural loading, especially as related to surface erosion; or chemistry of the air in contact with the specimen. Also, air speeds are limited to Mach 1 with present designs.

hot-shot tunnel

At present, in the range of Mach 10 and air densities representative of high altitudes, tunnels using short-time air flows are most used. The "hot shot" tunnels, while they can produce a realistic airflow at 10 to 15 thousand degrees F for 10 to 15 milliseconds, require extremely refined instrumentation. Also the desired flight conditions cannot be programmed into the test equipment. Another limitation inherent in the hot-shot tunnel arises from the basic definition of temperature. Temperature is a parameter that indicates the amount of energy contained in a material; this energy affects mechanical characteristics of the material and the ability of the material to transfer its energy. This energy can exist in a substance by virtue of many different mechanisms: translation, vibration and spin or rotation of the molecules; ionization of the molecules into atoms; excitation of atomic electrons; and free electrons in vibration and spin liberated from the atoms. Under normal conditions, these energy states are in equilibrium, so that, for example, measurement of radiant energy, directly related to the electron energy of the atoms, also gives a measure of the other energies. Unfortunately, for a certain set of conditions, each mode of storage requires a certain time to absorb or dispense its energy; no complications usually arise as the difference between these times is so short. However, hot-shot testing techniques are hard to interpret because in the transient air flow, lasting only a few milliseconds, these modes of energy storage are not in equilibrium, as they would be in actual flight.

shock tube

In another short time test, "the shock tube," a supersonic wave front is generated through the gas by an explosive driving mechanism. By using rapid repetitive cycles, fairly long test periods can be obtained, which allow the use of low enthalpy, i.e., the amount of heat per unit mass is low. Here, as in all air flow techniques, helium is usually used above Mach 7 to prevent the gas from liquefying after exit from the supersonic nozzle; using helium, speeds up to Mach 50 can be produced. This method, like the hot-shot tunnel, suffers from the variation of energy distribution in the wave front.

radio-frequency heating

Radio-frequency induction heating is capable of producing heat fluxes high enough to simulate heat generated during the re-entry of missiles. Induction coils set up currents in the metal to produce the heating required. Banks of these coils can be arranged to test a complete missile, and with separate control channels, different areas of the missile can be subjected to different temperatures. The tremendous amounts of electrical energy required for this type of heating usually prevent the entire missile from being heated at one time. A serious disadvantage in many instances is that different materials heat at different rates, due to differences in electromagnetic permeability, thereby giving thermal gradients that do not duplicate aerodynamic heating. Accurate simulation of aerodynamic forces is also difficult.

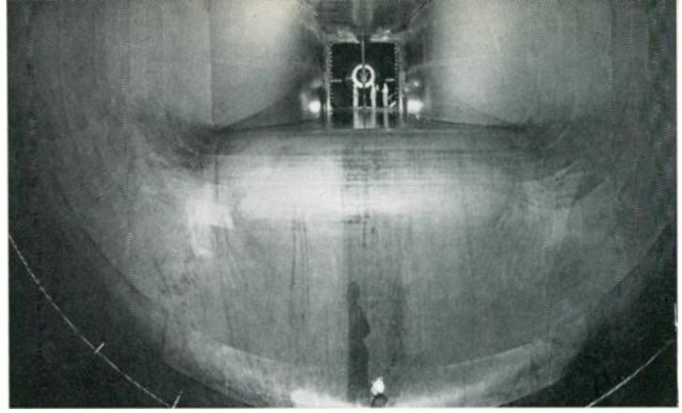
radiant-lamp heating

Electronic and air-conditioning equipment can be simply tested by placing a section of the airframe in a pressure vessel and reducing the pressure to correspond to the desired altitude. Banks of tungsten-filament quartz-enclosed lamps then maintain desired temperatures on various areas of the plane or missile. Power levels to the lamps are controlled with temperature controllers in conjunction with ignitron-contactor power controls. This system cannot develop heat fluxes high enough to simulate re-entry of missiles; it can be used to test some interesting portions of the flight of intermediate-range and intercontinental ballistic missiles.

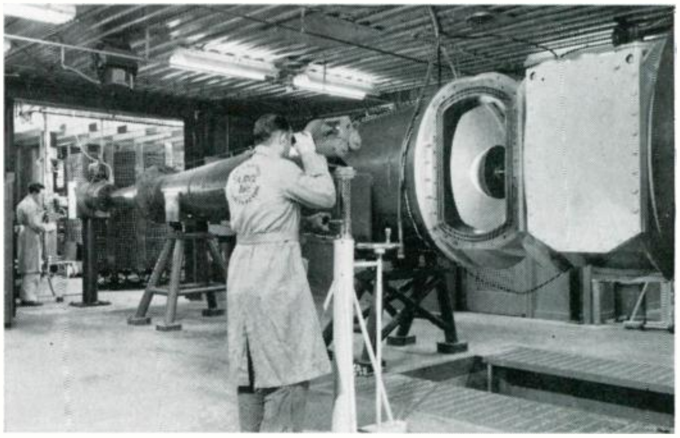
Before making such tests, either the structure-temperature or aerodynamic heat-transfer characteristics must be predictable over the entire vehicle. Because these are ground tests, the aerodynamic and "g" loadings must be simulated by a pointwise approximation, such as by pulling on the structure with piano wires. The mechanisms of heat transfer in such tests are radically different from those in actual flight.

However, of all high-temperature test facilities, the "hot body" or radiant lamp technique is most used. In this method, the heating lamps can be controlled to accurately reproduce the temperature rise encountered in the transients of actual flight. The temperature can be made to rise at 1000 degrees F per second to approximately 3000 degrees F. Since full-scale missiles or planes can be tested by this method, different designs can be directly compared, without any scale factors as required for test models. Also, the radiant lamp technique is relatively simple and inexpensive to use.

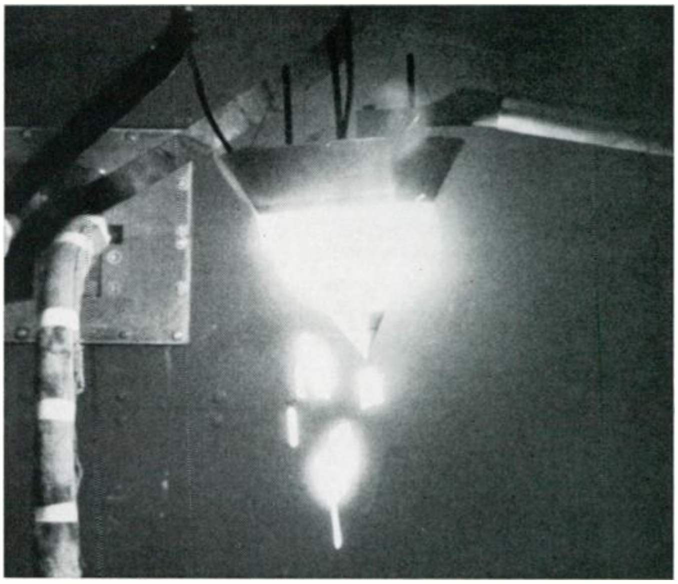
Test Program—Two approaches are made in controlling the radiant lamps to simulate the temperature rise encountered by a missile. The simplest from the equipment standpoint utilizes a precalculated curve of skin temperature versus



Downstream view through the sidewalls of the flexible nozzle shows the 40-foot long transonic test section of the Propulsion Wind Tunnel at the Arnold Engineering Development Center. The flexible sidewalls are adjusted by motor-driven jacks to create test velocities up to 1100 mph.



Runs exceeding escape velocity last but one-tenth of a second in Tunnel Hotshot II, which is part of the Gas Dynamics Facility at the Arnold Engineering Development Center. Longer runs would damage or destroy components or the tunnel.



Radio-frequency coils were placed inside this steel cone to demonstrate the effectiveness of radio-frequency induction heating. This demonstration was performed at the Mechanical Branch of the Aeronautical Research Laboratories, Wright Air Development Center, Wright Patterson Air Force Base, Ohio. The bright spots below the cone are melted steel droplets.

time. The skin-temperature signal, after comparison with a feedback signal indicating the actual temperature of the missile, is used to regulate the system. This type of control is hard to apply in that it presupposes the temperature of the missile skin (T_s) as a function of time, Fig. 1.

The skin temperature must be calculated from the heat equation, but because of the complexity of aerodynamic heating, radiant cooling, and internal structure cooling, an analytical solution is difficult to obtain. In addition to the analytical difficulties, the physical constants such as conduction across metal-to-metal joints are highly variable and difficult to ascertain.

The other approach uses a heat signal, representing the net heat influx through the skin, to control the power level of the lamps. This signal is equal to the heat absorbed from the air boundary minus the heat radiated by the skin, as expressed in the following equation:

$$Q = h(T_e - T_s) - \epsilon k T_s^4$$

where h is the heat-transfer coefficient, T_e is the effective temperature of the air boundary, T_s is the skin temperature, ϵ is the emissivity of the skin, and k is the Stephan Boltzmann constant.

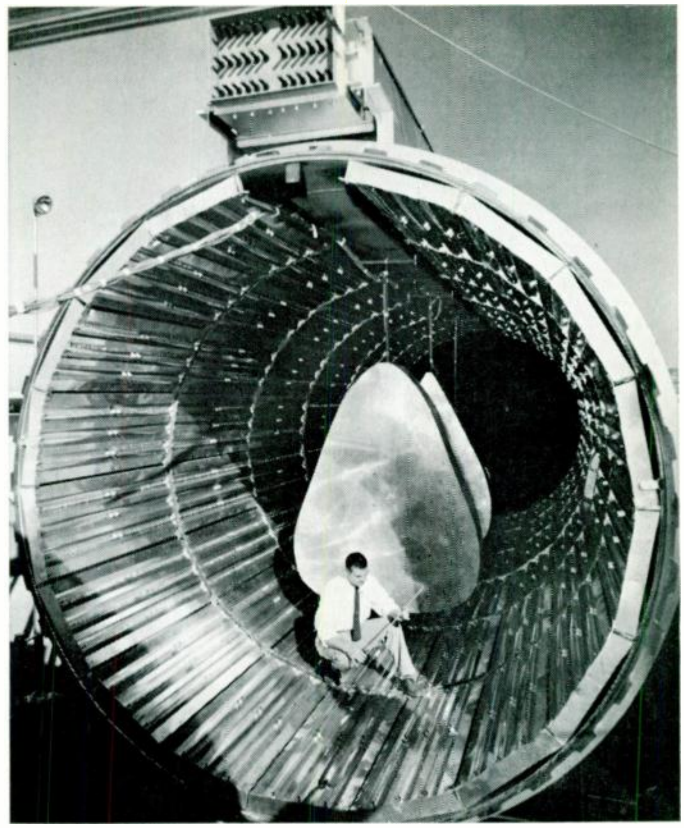
The value of Q is continuously calculated in a computer during the test and used to control the power level of the radiant lamps, Fig. 1. Where the skin temperature (T_s) is precalculated in the first method, the effective air temperature (T_e) must be calculated or determined from wind tunnel tests as a function of time in this approach. This is much easier to determine as only the speed, altitude, and relative size of the plane and roughness of the skin must be known. The heat transfer coefficient, h, must also be calculated, but this is also more easily and accurately determined than T_s.

Both T_e and h are fed into the computer-regulator from function generators. At the start of a test, the effective air temperature is equal to the air temperature at the launching platform. Then the function generator sends a new value of T_e into the computer-regulator, simulating the effective air temperature of the boundary layer shortly after launching. With this new value of T_e, a new value of Q is produced, raising the power level of the radiant lamps and consequently raising the skin temperature of the missile. The temperature of the skin, T_s, as detected with the thermocouples, plus new values of T_e and h are used by the computer to generate a new value of Q. The process is continuous.

To assure that the actual value of heat entering the skin is equal to the calculated value, a feedback loop is inserted. A measure of the actual heat applied is obtained by two methods. The first uses a correlation factor between the electrical energy applied to the lamps and the heat entering the skin surface. However this correlation or efficiency factor is difficult to determine. In the second method, the net heat influx is found by taking the derivative of the skin temperature signal (T_s).

While the missile is run through a temperature test, mechanical loads are simultaneously applied to simulate aerodynamic forces; the stresses set up in the skin and structure are then recorded. This gives engineers a fairly accurate idea of how the structure will withstand the shock of thermal and aerodynamic loads in actual flight.

In view of the ever increasing speeds of missiles and the accompanying heats they produce, a particular design should be completely tested before it reaches the production stage. The ultimate goal is a ground test that would completely simulate the heating mechanism, air chemistry, and aerodynamic forces of high-speed flight. ■



The efficiency of air cooling equipment is tested in this pressure vessel. A section of an airframe with cooling equipment is placed in the vessel; the pressure is reduced to simulate high altitudes while the lamps heat the airframe to simulate temperatures produced by air friction. The facility is owned and operated by the Convair Division of the General Dynamics Corporation in San Diego, California.

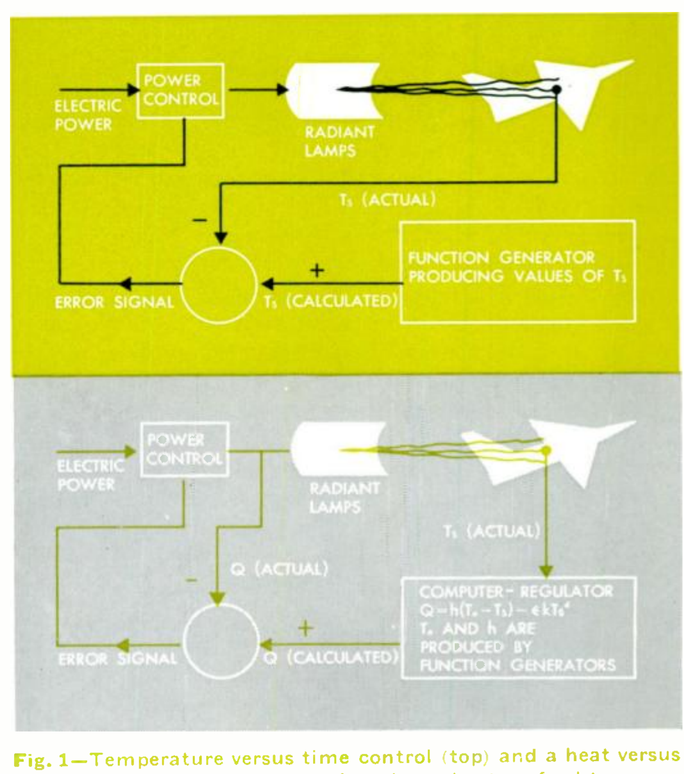


Fig. 1—Temperature versus time control (top) and a heat versus time control (bottom) for a radiant-lamp heating facility.

WHAT'S NEW IN ENGINEERING

A new static control combines a Magamp regulator and a transistorized power amplifier.

FUEL CONTROL SIMULATOR FOR JETS

Aviation gas turbine engineers have designed and built an electronic analog device, a *fuel control simulator*, that controls fuel flow for extensive testing of new jet engines to obtain necessary engine data for ultimate fuel-control design. A variety of fuel schedules and fuel control constants can be set to obtain optimum engine acceleration and deceleration as well as steady state operation for the full operating range of the engine (i.e., altitude, temperature, and flight speed). Since the steady state characteristics and the programmed acceleration and deceleration fuel schedules of the fuel control simulator can be changed by simple manipulation of dials, engine limit curves can be rapidly generated.

A jet engine fuel control must protect the engine at all times, regardless of pilot power lever manipulation or load changes. Therefore, the increase and decrease of fuel flow as a result of these changes must be carefully scheduled to prevent compressor stall and/or turbine overtemperature during accelerations, and to prevent "lean flameout" during decelerations. These transient maximum and minimum engine fuel flow limits must be determined for the full operating range of the engine before the fuel control design can be finalized. This engine range includes 0 to 100 percent rpm, compressor inlet pressures from several atmospheres to less than one-tenth of an atmosphere, and compressor inlet temperatures ranging from furnace heat to arctic cold. All these variables affect the permissible transient fuel flow. Generating schedule curves to adequately describe the limits for all possible combinations within the operating range of the engine is a titanic task.

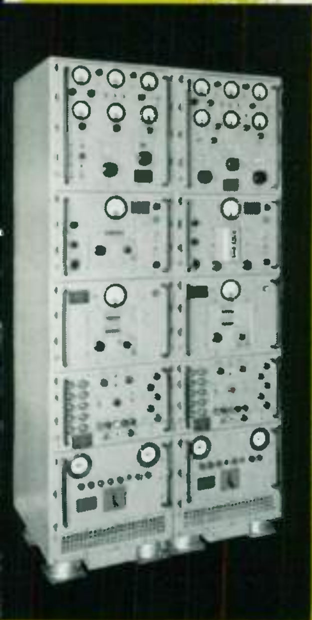
Using the fuel control simulator, adequate engine mapping can be accomplished with approximately 50 hours of engine running, while conventional testing to acquire equivalent data would require about 200 hours of engine running. This saving in engine test time is, of course, compounded by engineering time, facility time and cost, and maintenance and operating personnel time and cost. Once these limits have been determined, the engine fuel control can be designed to obtain optimum engine operation, both transient and steady state, which will permit the utmost in aircraft maneuverability.

The transient fuel flow schedule and steady state characteristics for the new J34-WE-46 jet engine were determined with this new computer. For high-altitude operation, the engine was tested in the altitude test chamber of the Navy Aircraft Turbine Test Station in Trenton, New Jersey. Use of the fuel control simulator resulted in an optimum fuel control design for this engine in a minimum time, thus decreasing overall engine development time and cost.

Future applications of this unit will further decrease development time and costs, and allow better matching of fuel control designs to individual engine designs. ■

NEW BI-STABLE MAGAMP REGULATOR

Another step toward completely static control was made with the marriage of a bi-stable Magamp regulator and a transistor power amplifier. In addition to its static components, this unit features operating improvements over previous Magamp-regulator relay combinations. A more sensitive magnetic amplifier has been used that can operate on signals of only 0.01 microwatt; but after amplification in the transistor stage, the signal is raised to 8 watts of power at 24 volts. This allows the unit to directly control relays, solenoids, or other static power amplifiers. Also because of the fast response time of the transistor amplifier, the unit can react to signal changes in 20 milliseconds. ■



A new Navy transmitter (AN/WRT-1 and 2) for shipboard use.

The Radometer, a new device for measuring x-ray dosage to a patient during fluoroscopy, spot-film radiography, or cineradiography.

MORE USEFULNESS FOR MICARTA

Micarta, the laminate of paper impregnated with phenolic resin, has proved valuable as an electrical insulation, a structural substitute for metal, a decorative paneling and many other uses. This year, engineers have further improved its characteristics, and extended its usefulness.

Until now, different grades of decorative Micarta have been made for standard flat applications and for curved post-formed uses. A new universal grade can serve both purposes equally well; and in the process the wearability and other features have been improved. The new Micarta laminate is made possible by a new Kraft paper, which is combined with laminating varnishes.

A permanent decorative finish and a specially constructed insulating core have been combined in a new wallboard, called Panelwall. The new wallboard is prefinished and is structurally stronger than similar wallboards. Because of its solid compressed paperboard core, the new wallboard also has excellent sound and thermal insulation properties.

Micarta has also taken to the highways, replacing a cast iron gear for the camshaft timing sprocket for a new automobile engine. The outstanding features of the sprocket gear are its high temperature capabilities (it retains its strength at 300 degrees F) and its inherent self-lubrication. The new gear is quieter and has longer life than the metal gear it replaces. ■

SHIPBOARD TRANSMITTER

Westinghouse is manufacturing for the Navy a new shipboard medium and high-frequency communications transmitter. It will be used primarily for transmitting from ship-to-ship, and from ship-to-shore. The new transmitter replaces pre-war designed equipments, and more recent transmitters having considerably greater complexity.

The Navy transmitter is an outgrowth of a Westinghouse-sponsored development of a stabilized communications transmitter. A new frequency generating system is employed, which provides a new high in performance with a tube reduction over previous equipments of four to one. The mechanical design of the transmitter is such that it will go through a submarine hatch, eliminating the necessity for the usual practice of cutting a hole in the submarine during large equipment installations.

The new shipboard radio, designated AN/WRT-1 and 2, is made in two frequency ranges: the first is in the medium frequency range from 300 to 1500 kc; the second is in the high-frequency range from 2 to 30 mc, and employs single sideband techniques to increase communications channel capacity and message reliability. ■

FOR MEASURING X-RAY DOSAGE

The Radometer is a new device developed for measuring x-ray dosage to a patient. The device consists basically of an ion chamber, a capacitor, and an electronic electrometer and meter-relay, with the necessary power supplies. The ion chamber is placed between the x-ray tube and the patient. The ionization produced in the chamber by x-rays is proportional to the radiation dosage to the patient; the ions produced in the chamber are collected and applied to charge the capacitor. The charge on the capacitor is transformed by the electrometer circuit to a reading on the meter-relay. The meter-relay has a pointer that can be set to any spot on the meter scale by an external knob. When the x-ray dosage causes the indicating needle to reach the pointer, a contact is made that energizes an alarm and, if desirable, terminates the x-ray exposure.

While no new concepts are involved, this is the first device

This video tape recorder makes it possible for radar design engineers to conveniently test and evaluate developmental radar circuits under airborne conditions without leaving the ground. The video tape recorder is used to recreate an airborne environment in the laboratory. Specifically, radar returns from clouds, cities, mountains, oceans, flatlands, passive countermeasures, etc., are tape recorded from the video output of an airborne radar receiver. The tapes are played back in the laboratory, where the video tape output modulates an i-f carrier; the resulting signal is fed into the front end of a radar receiver and then into radar control circuitry. Converting the tape recorded video to an i-f signal effectively enables the closing of a range-track AGC loop around the recorded video. This technique provides a means of analyzing not only range-track circuits, but also target acquisition circuits in the presence of both natural and man-made interference.

Video tape "flight testing" has been used by Air Arm Division engineers for the past 2½ years. The technique of video tape recording for laboratory evaluation of radar developmental circuits was unique at its inception, and represents a triumph over numerous technological problems.

of its type to be placed on the market. In the past, radiographic and fluoroscopic x-ray dosage has been estimated by the doctor from x-ray tube voltage and current, and the exposure duration. However, in recent years, fluoroscopic brightness stabilizers and photoelectric exposure timers make these factors more difficult to determine, so that the Radometer can give a more accurate measurement. The device can be applied in any case where fixed x-ray tube-to-patient distances are used, such as fluoroscopy, spot-film radiography, and cineradiography. ■

ULTRASONIC SEAM WELDER

An ultrasonic seam welder that can weld sheets of dissimilar metals continuously has been developed by engineers of the Westinghouse Materials Engineering Department. This welder brings to seam welding the advantages of ultrasonic welding: it makes dissimilar metals weldable, and eliminates the need for surface preparation prior to welding. Although the welder is still in the development stage, with some refinements it could have great practical value.

The continuous ultrasonic welder works something like this: Sheets of metal to be welded are passed between two wheels vibrating at 20 kilocycles per second. The peripheries of these wheels press against the metals on opposite sides of the sheets. At the point of contact, the wheels break up the oxide coating on the metal surfaces and by a kneading action weld the metal lattices on the surfaces, of the metals themselves. No electric current is passed through the spot being welded although in appearance the ultrasonic seam weld is similar to an electric weld. A variable-speed drive moves the metals through the unit as the weld is completed by means of the vibrating wheels.

The center of the vibrating wheel is attached to a transducer assembly, which is used to convert electrical energy to the high-frequency mechanical vibrations. This assembly consists of a magnetostrictive transducer, a coupling bar, and an enclosure for water cooling.

In operation, electrical power causes the transducer to vibrate longitudinally. The vibration is passed down the coupling bar and enters the wheel, causing it to vibrate as a solid disc with a free circumference. This action causes the center of the wheel to be pulled in and out and causes flexural vibrations to move radially out from the center of the wheel to its circumference.

The wheel surfaces in contact with the work move in opposite directions by having the transducers work in opposition to each other.

With the experimental welder that has been developed, two sheets of aluminum 0.010-inch thick have been seam welded continuously at a rate of 15 inches per minute.

Investigation is continuing on the ultrasonic seam welder to increase the welding speed, and to increase the thickness of the metals that can be welded. ■

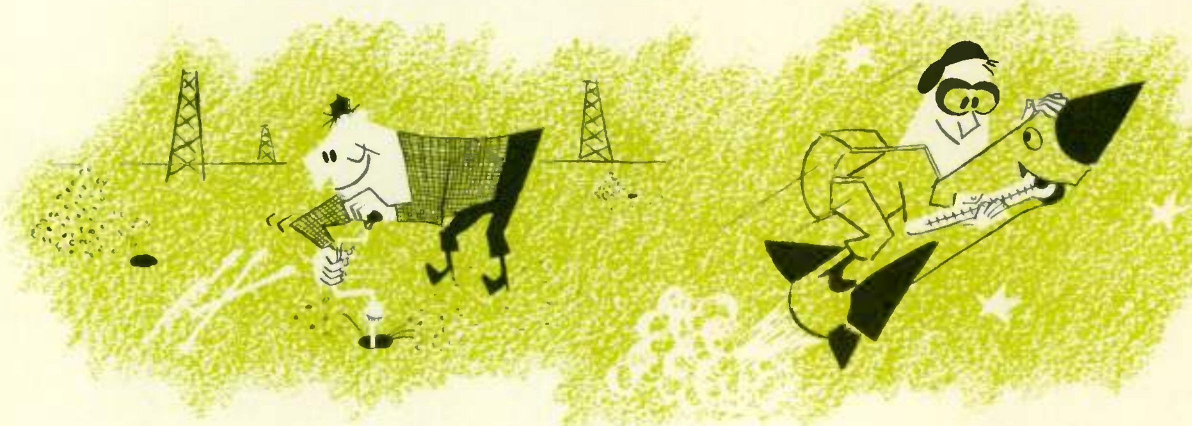
The pen of E. E. HOGWOOD has been busy. Since September 1958, when he co-authored with J. K. Howell, "Electrification of Petroleum Production," he not only prepared this article on electric drilling rigs, but wrote an AIEE paper for the Petroleum Industry Conference on "Electric Drilling Rigs—Application and Operation."

"In addition to his writing," he has been applying a-c and d-c equipment on rigs, where the merits of each are required. He has also assisted in the adaptation of heavy traction motors, generators, and controls to drilling rigs. He recently participated in the development of a new static control and excitation system, which improves the performance of this electrical equipment.

W. M. WALDBAUER is the second generation member of his family to work for Westinghouse. His father, now a manufacturing engineer at the Lighting Division, has worked for the company since 1923.

Waldbauer joined the company in 1953 at the Lighting Division in Cleveland. He is a 1950 graduate of Case Institute of Technology, where he earned his BSME. Since joining the Lighting Division, Waldbauer's assignments have included work on searchlights and on aviation, floodlighting, and street-lighting equipment.

Aside from work, Waldbauer's primary hobby is philately; he is also extremely active in YMCA activities in the Southwestern Greater Cleveland Area.



R. E. FRIEDRICH, who describes the new SF_6 high-power circuit breaker, is a native Pittsburgher and a graduate of the University of Pittsburgh. He obtained a BS in Physics and Engineering in 1940, and an MS in Physics and Engineering in 1953. After a short stay with the Mellon Institute, he joined the Westinghouse Graduate Student Course late in 1940, and was assigned to the Switchgear Division in 1941.

Most of Friedrich's work with circuit breakers has been in the realm of development engineering. He worked with the oil multi-flow grid development, and the tubular grid for the 345 kv, 25 million kva oil circuit breakers.

Friedrich was made a Supervisory Engineer in 1954, and a year later Section Manager of the standard development section of power circuit breaker engineering. Here, he has worked with both oil and SF_6 designs. He has accumulated 59 patent disclosures, with 20 patents issued or pending.

R. N. YECKLEY graduated from the University of Michigan in 1951 with a BSME, and came immediately on the Graduate Student Course. After joining the Switchgear Division, he attended Design School. Most of his work for the next two years (before the Army took his services in 1954) was connected with the operating mechanism for the 345 kv, 25 million kva breaker.

Upon returning from the Army in 1956, Yeckley was assigned to SF_6 breaker design. He first worked on the 46-kv reclosing circuit breaker, and then the high-power breaker, which he joins Friedrich in describing in this issue.

ARMIN BRUNING started his engineering career by enrolling in Johns Hopkins University in 1944. His objective was momentarily thwarted when he was summoned to serve in the Army for a year and a half. However, as Armin puts it, "This setback was made less painful when I was put in charge of ten Wacs at Fort Belvoir." After his stay with the Army, Armin returned to Johns Hopkins, graduating with a Bachelor of Engineering Degree in 1949.

He started out designing electrical controls for aviation gas turbines, and then after a brief stay with the Public Service Commission of Indiana, he came with Westinghouse in the marine, aviation and transportation section of the Industry Engineering Department. Here, Armin has enjoyed a wide variety of engineering problems. He has designed the control system for the radiant-lamp heating facilities, now used widely for temperature testing of missiles and aircraft. He has also worked with the application of pulsed power, such as in sonar; starting motors on large generators; and variable frequency power supplies, as applied to canned motor pumps.

In March 1958, Armin was made engineer in charge of the advanced development group of the Marine, Transportation and Aviation Facilities Department. This group was formed to study and solve electrical and mechanical problems of the marine, transportation, and aviation industries.

Armin obtained a MS in applied mathematics from the University of Pittsburgh in 1956, and is now taking courses for a PhD in electrical engineering.

The Westinghouse Testing Reactor, shown below as it appeared in late 1958, will go into operation in the near future. The primary purpose of WTR will be to subject materials and nuclear fuels to radiation conditions similar to those encountered in an operating power reactor. Photograph at right shows the top portion of the nuclear core for WTR. The core has been undergoing tests since mid-1958.