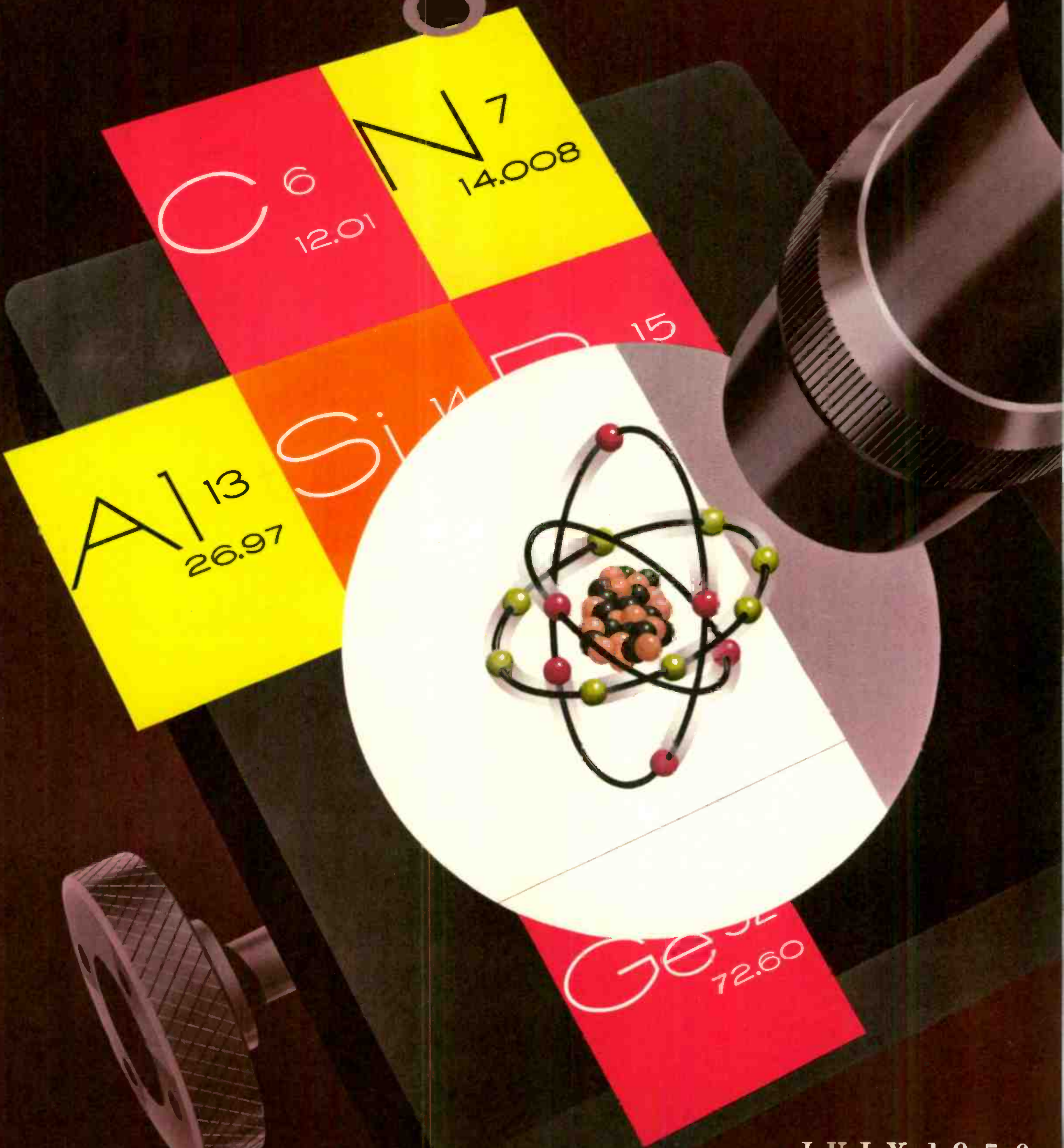
WESTINGHOUSE Engineer



JULY 1956

dURING THE PAST FEW MONTHS, a new phrase has appeared in our Company's advertising—"Watch Westinghouse." This open bid for your attention has a background that is deeply rooted in events that have taken place throughout Westinghouse during the past few years. In this period we have been devoting an unusual amount of effort toward the future. This effort is already beginning to produce results—results that will affect your plans as well as our own. The future we have been planning for is arriving.

This increased emphasis shows up in nearly every phase of Westinghouse activities. For example, our fundamental and applied research programs were stepped up several years ago. Some of the results of this effort are already appearing. For example, in the field of metals, our Research Laboratories have just developed a new alloy. This alloy not only has high-temperature strength, but also has a "built-in" ability to damp vibration. This means better steam turbines. Importantly, this new alloy may well be the forerunner of something new in metallurgy—the development of alloys by design rather than by cut-and-try methods. This is but one example; others are a few steps behind.

In 1952 and 1953 we set up special development groups in each of our product divisions; their primary objective was to look ahead and come up with ideas and designs for the long-range future—say five or more years hence. These groups, of course, supplement our regular development sections, whose efforts are largely devoted to product improvement for the more immediate future.

Together, these different groups are producing significant results. A few examples are Cypak systems, a control system that paves the way for automation; experimental designs of a motor control using transistors; a new technique for vulcanizing silicone rubber by bombardment with electrons; and the many exciting developments in the challenging new atomic-power field. As a result of the increased efforts in research and development, many other new concepts and new products—some revolutionary in nature—are rapidly approaching reality.

We are now better equipped than at any time in Westinghouse history to produce the products that research and engineering develop. A planned expansion of our laboratory and manufacturing facilities has given us tremendous new capacity to produce for the present and the future. In the past 10 years, 31 plants have been constructed or acquired. Most of the others have been modernized. New laboratories include an ultra-modern new central Research Laboratory, devoted primarily to fundamental and basic research, a development laboratory for steam turbines, and a pilot plant for new metals, all of which are now in full operation. Every major plant has its own laboratories for standardization and product improvement. Others are under construction, including a new jet-engine laboratory, transformer test facilities, and an electronics laboratory. Since 1945 Westinghouse has more than doubled its number of plants, and increased its total floor space by 81 percent.

This coordinated effort of research, development, and production-facility expansion has left Westinghouse in an enviable position—the future we have been preparing for is here, and with it the promise of the future is becoming an accomplished fact. New things *are* happening at Westinghouse. Watch for them.

Gwilym A. Price *CHAIRMAN AND PRESIDENT*

WESTINGHOUSE

Engineer

VOLUME SIXTEEN • NUMBER FOUR • JULY, 1956

In This Issue

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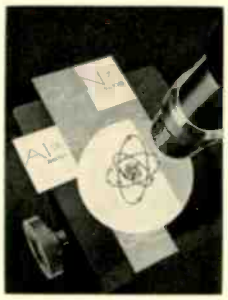
Magamp, Cypak, C S P

THE COVER

The test tube, the beaker, and the flask are probably the most widely used symbols of research. Forsaking this approach, artist Dick Marsh used a section of the periodic table, an atomic symbol, and a viewing tube to suggest that much of research is concerned with investigation of the elements.



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The increased emphasis on industrial research in this country engenders some important questions. Just what is the role of research in industry? What are its aims, and how are they accomplished? Here are some answers, pertaining to the Westinghouse Research Laboratories.

The Role of the Research Laboratories

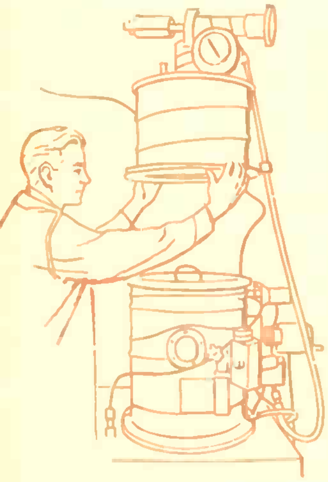
DR. CLARENCE ZENER

Acting Director, Westinghouse Research Laboratories, Churchill Borough, Pennsylvania

RESEARCH IS assuming an increasingly important role in American industry. The reasons are many. For one thing, the whole tempo of technical development in this country has been quickening. Research must keep abreast, or preferably a step or two ahead. Major "breakthroughs" are needed in several research areas. From a purely economic standpoint, no major company can afford *not* to do research, both applied and fundamental, if only for the reason that any major breakthrough by a competitor might have disastrous and long-lasting effects.

Research, particularly in industry, means different things to different people. Within Westinghouse this term has a clear interpretation.

What is Industrial Research?



One means of defining research in contrast to development is to pinpoint its role in technological advances. Each product-manufacturing division of Westinghouse not only has a development group that works on short-range improvements but also an advanced development group who concentrate their efforts on product designs of a long-range nature. These engineers can certainly be relied upon to improve current products and develop new ones. Every year hundreds of new engineers enter these divisions, bringing with them fresh ideas and viewpoints from engineering schools scattered all over the country. Also, other engineering departments contribute to the flow of new ideas and products. A Materials Engineering Department for example, concentrates on developing and testing new materials of all kinds. A New Products Department also contributes fresh approaches to product and systems design With this impressive array of men and facilities devoted to development work, where does the research laboratory fit in?

Manufacturing groups of Westinghouse have many problems in common. Many products would benefit, for example, from an insulating wire enamel that enabled higher temperature operation of a motor or a transformer. Several separate efforts to develop such an insulation would be highly inefficient. Rather, the interests are pooled in a research group who specialize in the insulation field. Frequently, a basic insulation developed by this group is adaptable to a wide variety of applications, sometimes with no modification, sometimes with minor alterations of its constituents or method of preparation. This research group, then, can explore the entire field of insulation, and delve into its fundamentals; the odds are more favorable for *major* improvement in insulation than they would be for a group whose limits were more confining.

Again, many fields are plagued by unwanted vibration. At the Research Laboratories a team of scientists and engineers devote themselves exclusively to a study of the origin of vibration and methods of alleviation. Because of their long and intensive training in this specialized field, they are more effective in eliminating vibration trouble.

Such examples could be multiplied manyfold. Whereas engineers concerned with a particular product are specialists in their product, the scientists at the Research Laboratories are specialized in the various disciplines of engineering and science. In essence, the various development laboratories work on problems where the basic principles are well established; the Research Laboratories, on the other hand, attack problems where the basic principles have yet to be discovered.

Another way of defining industrial research is to take a look at the people who are involved—the research scientists and engineers. Their interests and personal characteristics have much to do with the organization and function of any research laboratory.

What kind of a man is this research scientist? His distinguishing characteristic is a consuming curiosity about his field of specialty, but almost equally about most of the things that surround him. Most engineers have similar tendencies. A flicker of a television screen that is merely an annoyance to the non-technical viewer may well cause the electrical engineer to inquire as to its causes, and lead him to try and remedy the situation. The research man differs only in the nature and extent of his curiosity. The research scientist is more apt to probe more deeply, for a more fundamental reason for the television set's behavior.

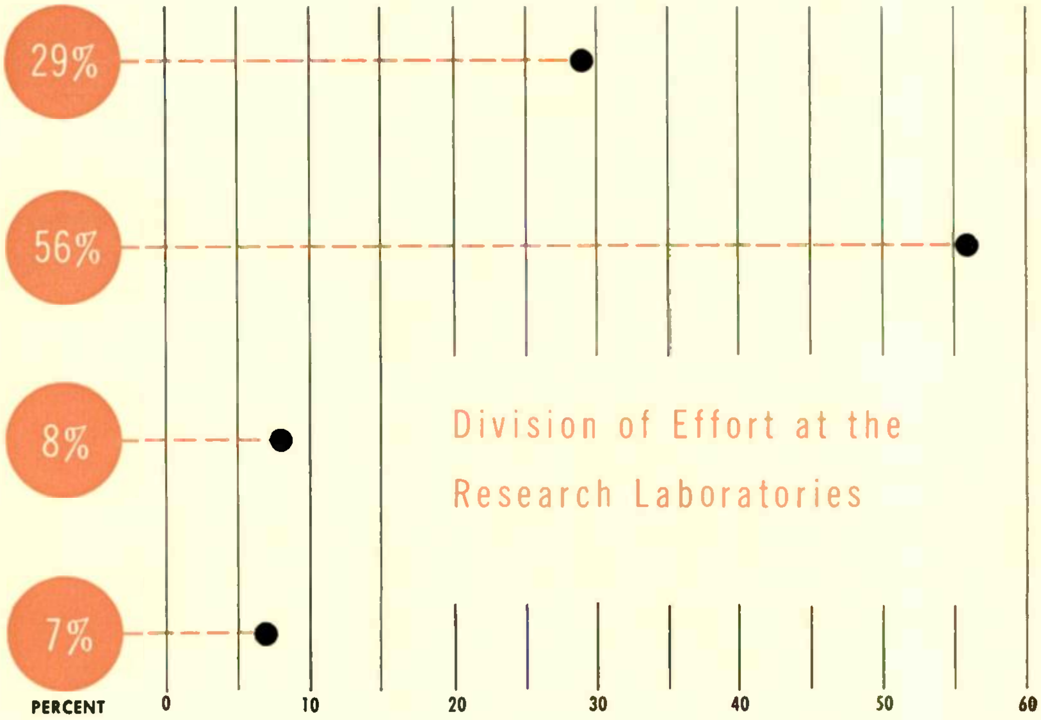
A second essential ingredient of the research scientist is his unbounded faith in man's ability to guide nature's forces to serve his will, and a desire to be a part of the history of man's efforts in this direction. His neighbor has never tasted the pleasure of creative work, of delving into areas that no man has ever explored before, of having thoughts never conceived before by others. In one sense this is the spirit of the explorer combined with that of the great painter or composer.

The increasing complexity of modern science and technology also means that the depth and breadth of the individual scientist's knowledge must be greater, as must his capacity for additional knowledge. This has meant that an increasing number of men joining the Research Laboratories have already acquired doctor's degrees. Of the men hired directly from colleges and universities in 1956, for example, 72 percent had doctor's degrees.

Although perhaps no group of people can be said to have a common, exclusive trait, the research man is nearly always a strong individualist, and likes to work unfettered by seemingly unnecessary restrictions. This, plus other characteristics, adds up to the fact that the environment of a research laboratory must be quite different than any other found in industry. In addition to the quite necessary facilities such as modern equipment and a good research library, the scientist must be burdened with as few limitations and restrictions as possible in the attainment of his goal. Factors that do not directly affect his project or area of research—such as administrative or organizational problems—must be kept to a minimum. At the same time, however, the scientist cannot be isolated from the potential end results of his research, i.e., the application of the new knowledge he will uncover. Research must have a direction, whether general or specific, and in an industrial research organization this is best accomplished by contact between research and engineering groups, so that each group is fully aware of the other's problems, and understands them thoroughly.

What Type of Research is Pursued?

The rapid expansion of science has been outpaced by an even more rapid expansion of technology. As a consequence, the time interval between a scientific discovery and its technological application has been shortening over the past few decades. To obtain valuable lead-time we must spearhead many of those fields of science basic to future developments in the electrical industry. Electrical properties of matter are obviously fundamental to such future developments. The Research Laboratories are therefore spearheading advances in understanding the electrical properties of materials under a wide range of conditions. Such conditions range from the very low temperatures approaching the absolute zero to near-solar temperatures found in arcs. The frequencies used range from the 60 cycles for power transmission to the hundreds of megacycles in radar systems. The electrical conductivity of interest ranges all the way from the truly infinite conductivity of superconductors through the good conductors used in power transmission, through the poor conductivity of semiconductors, to the essentially zero conductivity of insulating



Division of Effort at the Research Laboratories

This portion is devoted to investigations in fields of science basic to the electrical industry, but not directed toward a particular product development.

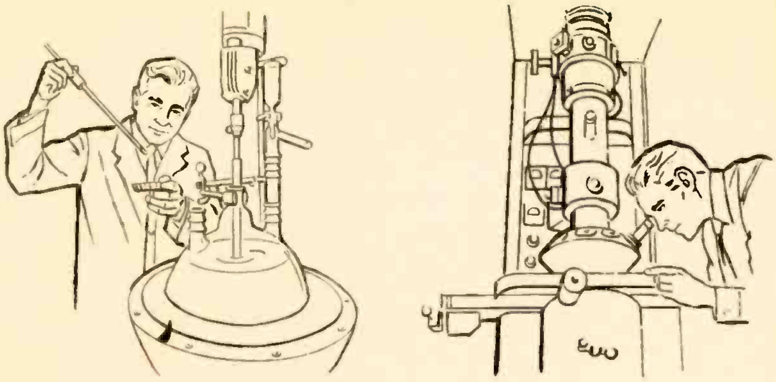
The largest percentage of effort is presently coordinated with long-range plans of product divisions. Much of this is fundamental research.

Government activity is about 8 percent of the total. Part of this effort involves loan of personnel to government laboratories.

Direct product development occupies but a small percentage of the total effort. Most of this is in highly specialized fields.

Westinghouse Research Departments

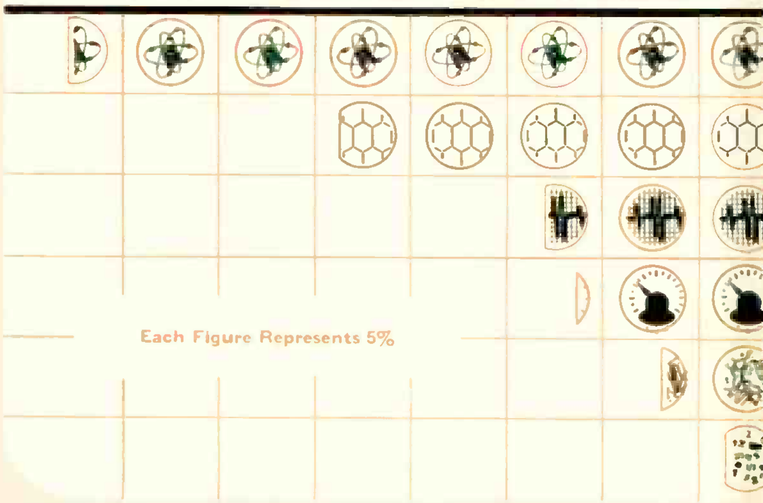
CHEMISTRY DEPARTMENT	. . . engages in studies in organic chemistry with special emphasis on plastics; on gas metal reactions; corrosion; electroplating; lubrication; inorganic coatings; and applications of radio-chemical techniques to special problems.
ELECTROMECHANICAL DEPARTMENT	. . . specializes in the development, design, and engineering of automatic-control systems. Gyro-stabilized systems have been an intense area of research.
ELECTRONICS and NUCLEAR PHYSICS DEPARTMENT	. . . carries out basic and developmental research in microwaves, optical physics, television, image translation, acoustics, and communication theory. Emphasis is on the study of physical phenomena underlying the operation of electronic devices, and on the theory of information handling involved in their use.
INSULATION DEPARTMENT	. . . conducts fundamental studies of the chemical, electrical, and physical properties of insulating materials. Basic work also is done on the mechanism of dielectric breakdown and the effect of corona on insulation.
MAGNETICS and SOLID STATE PHYSICS DEPARTMENT	. . . has a balanced program of fundamental research and development in magnetic materials and in low temperature physics.
MATHEMATICS DEPARTMENT	. . . is concerned with research in mathematics as it may be applied to new fields of interest. The department also acts in a consulting capacity on problems in mathematics.
MECHANICS DEPARTMENT	. . . carries on research in thermodynamics, combustion, fluid mechanics, vibration and impact problems, lubrication, mechanics of materials, dynamic systems, and stress analysis.
METALLURGY DEPARTMENT	. . . does fundamental research on metals, develops new alloys, studies the heat treatment of metal products, investigates welding problems, and conducts a broad program for the preparation, analysis, and testing of metals and alloys.
PHYSICS DEPARTMENT	. . . conducts a broad program of fundamental research in atomic physics, physical electronics, mass spectrometry, optical and electrical properties of matter, and electrostatic phenomena.
SEMICONDUCTOR and SOLID STATE PHYSICS DEPARTMENT	. . . does research in the preparation, purification, and growth of semiconducting materials. The department carries out studies of electrical, magnetic, and optical properties of metals, semiconductors, and phosphors.
TECHNOLOGY DEPARTMENT	. . . implements research progress at the Laboratories by providing professional technical services to all other departments. These include chemical analysis, x-ray crystallography, metallurgical processing, and others.



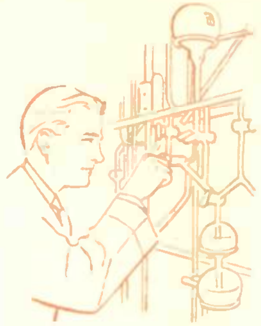
materials. Whereas some 29 percent of the effort at the Research Laboratory is currently devoted to such "blue sky" effort directed towards no particular development, the Laboratory hopes to raise this ratio to 40 percent.

A close understanding of long-range aims of manufacturing divisions is essential to an industrial research organization. Thus special effort is made to gain this understanding. Periodic meetings are held between research scientists and product engineers. In some special fields, standing committees are formed, which meet periodically; these committees include one on insulation, another on semiconductors, a magnetic amplifier committee, and one on high-temperature alloys. At a typical meeting between the Research Laboratories and the Steam Division, the following questions might be raised: What does a turbine designer think his equipment will be like ten or more years from now? What is a desirable evolution in turbine practice? This means the turbine designer, for example, must formulate a picture, or perhaps several, of what his equipment will be like in ten or more years. What are the roadblocks that prevent this design now? Will his present materials serve his needs indefinitely, or are there some definite barriers to much further progress? Does he, for example, foresee the need for a higher temperature blade material? If so, how high? And what must its other properties be? This sort of questions give the research scientist a reasonably definite area to work in without being confining. Importantly, these are not short-range problems; they are problems that require fundamental research; problems that have no immediately apparent solution.

At a 1952 meeting between the Research Laboratories and the Steam Division it was brought out that the currently used blading material would constitute a roadblock by 1957.



DISTRIBUTION OF PERSONNEL IN THE RESEARCH LABORATORIES



During the intervening five years the steam inlet temperature would be raised from 1050 degrees F to 1250 degrees F. But the then-used blading material would not withstand the required stresses at the latter temperature. Whereas alloys were known which would withstand the required stresses at such temperatures, none satisfied the additional requirement of high damping capacity. High damping is necessary to avoid excessive vibration build-up and hence ultimate failures by fatigue. The early recognition of this problem enabled the scientists at Research to embark upon a thorough and basic solution, unimpeded by pressure for a quick but perhaps not lasting solution. They first concentrated on understanding the fundamental mechanism of damping. This mechanism turned out to be intimately connected with the ferromagnetic characteristics of the material. Once this understanding was attained it was comparatively easy to combine, at least in small heats, the requisite magnetic characteristics with high-temperature strength. The skill of making large heats of this alloy is now being developed at the Westinghouse pilot plant at Blairsville. The new alloy will be available for turbines projected but in the design stage in 1957.

A close understanding by the Research Laboratories of long-range aims of the product divisions has been aided by the establishment of a Long Range Major Development Program in every product division. Some 56 percent of the effort at the Research Laboratories is tied in with these programs.

Whereas most product development takes place within the product divisions, some slight amount takes place within the research laboratory. Some research engineers are so skilled in certain practical areas that their aid is inevitably sought by the product divisions with problems in these particular areas. As an example, a group of engineers in the Research Laboratories is so skilled in the science of applying gyroscopes to control problems that product divisions with appropriate control problems always request this group to develop their controls. Some seven percent of the effort is devoted to such product development.

%	
38	PHYSICISTS
24	CHEMISTS
13	ELECTRICAL ENGINEERS
11	MECHANICAL ENGINEERS
7	METALLURGISTS
4	MATHEMATICIANS

In government work the Research Laboratories activity is relatively less than in most laboratories, corresponding to only eight percent of the total. This work consists of two distinct types. The first is sponsored through a division, which hopes thereby to obtain a product that it may ultimately manufacture for the government. The second type is in response to a new development in this country, namely the establishment by the government of large laboratories devoted to a specific secret goal. Since the developments in these laboratories represent potentialities to Westinghouse, close touch on these developments is maintained by lending personnel to these laboratories. This partial dispersal of personnel represents only one of the many ways in which research is continually adjusting its techniques to correspond to changing social and economic conditions.

How is the Laboratory Organized?

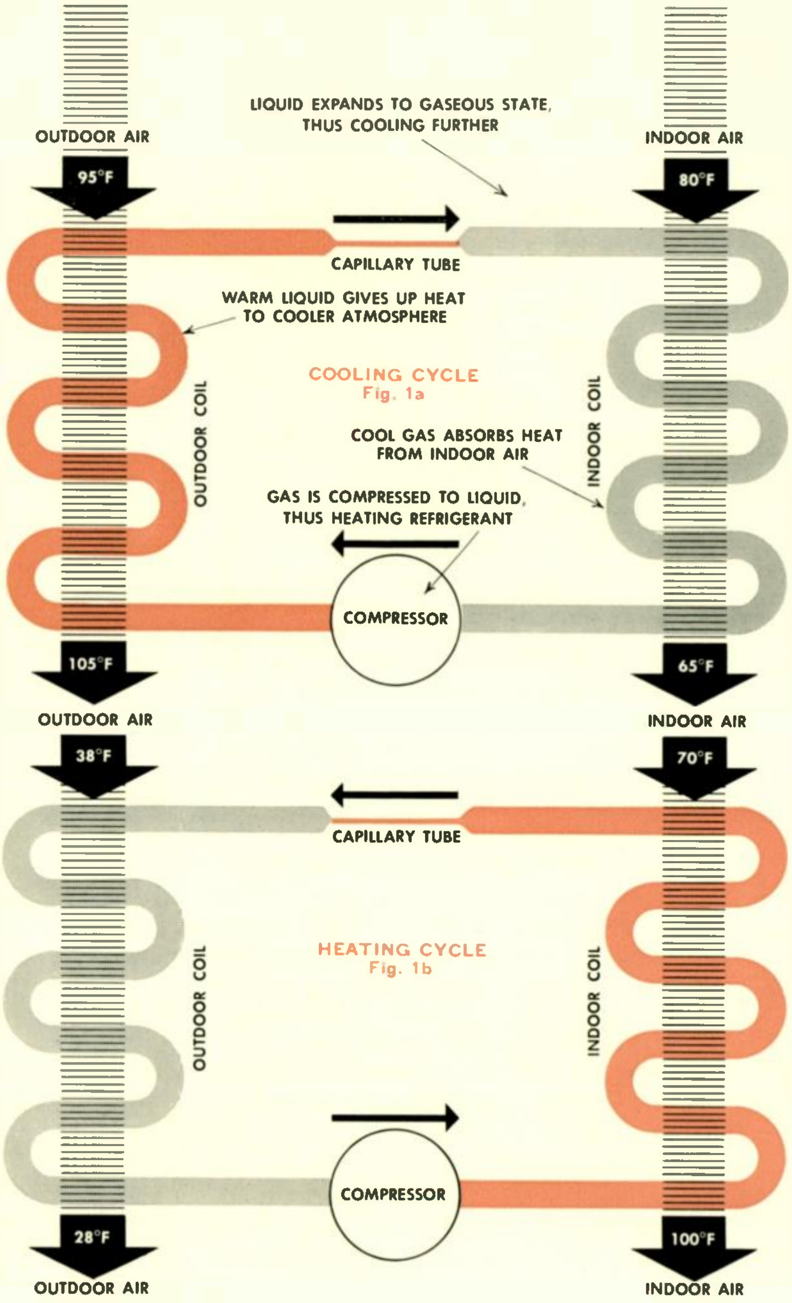
The departmental arrangement of the Research Laboratories is designed primarily to facilitate the translation of modern science and technology into application. These departments correspond rather closely to the various disciplines basic to the electrical industry: physics, chemistry, mechanics, metallurgy, mathematics, electromechanics, insulation, electronics and nuclear physics, magnetics and solid-state physics, semiconductor and solid-state physics, and technology. The diversity of backgrounds represented in the Laboratory is evident from the following distribution of personnel: physicists, 38 percent; chemists, 24 percent; electrical engineers, 13 percent; mechanical engineers, 11 percent; metallurgists, 7 percent; mathematicians, 4 percent.

In modern research, an increasingly important technique is the "team" approach. Many research projects today require more than a one-man approach, regardless of his individual ability. An investigation in the field of semiconductors for example, may well require the services of a physicist, a physical chemist, a metallurgist, and specialists in such things as x-ray crystallography and spectroscopy. Such teams may be temporary, loose associations, or in some cases a long-term group, but the team approach may be with us indefinitely.

The results of research are in various forms. In a few cases, the end result of research is a direct product. In such cases the new product is transferred to a New Products Department, entirely separate from the Laboratories, whose task is to engineer the product to the manufacturing stage. More frequently, however, the results are in the form of new information, or new materials, or products in the "test-tube" stage. New materials are usually transferred to the materials engineering group for development to pilot production. Other solutions are transmitted directly to development engineers in the product-manufacturing divisions concerned.

Several things are evident about industrial research. It cannot afford to leave fundamental research to others; thus a large part of the Research Laboratories is devoted to fundamental study. Conversely, however, it must keep an eye on engineering progress and make certain that it is applying sufficient effort to those areas where major scientific breakthroughs are needed. And last, it must be capable of supplying an additional helping hand in difficult development problems. The net result is a well balanced team, capable of spearheading scientific advance in nearly any direction. ■

Fig. 1—Simplified diagrams of the operation of the heat pump.



The heat pump is no longer merely an interesting novelty. Hundreds of installations have been made. Yet there are still many questions about its operation and application. Here are some of the answers.

The Heat Pump—
Its Principles and Applications

WALTER R. YEARY, Air Conditioning Division, Westinghouse Electric Corporation, Staunton, Virginia

■ THE HEAT PUMP was for many years considered an interesting engineering novelty—interesting, but not practical enough for widespread use. These opinions have been rapidly dissipated over the past decade, which has seen thousands of new heat-pump installations in both homes and industry.

At least part of the slow acceptance of the heat pump has resulted from a lack of clear understanding of its principles of operation and application. Actually, the principle of the heat pump is not difficult; nor is the equipment itself especially intricate. The lack of understanding is largely due to the fact that its concepts are not familiar ones.

The Principle of the Heat Pump

The heat pump, as its name implies, is merely a device for removing heat from one medium and "dumping" it in another. A refrigerator is a uni-directional heat pump, in that it removes heat from the inside of the box and dumps it outside. The basic difference between this and a residential or industrial heat pump is that the latter are reversible systems.

One stumbling block to the understanding of the heat pump is that many people tend to think of heat and cold as similar but opposite quantities. Once the concept is established that heat is the only real quantity, i.e., that cold is merely the relative absence of heat, the whole principle of the heat pump becomes clear. All matter—gases, liquids, and solids, contain some heat until they reach the temperature of absolute zero (−460 degrees F).

Heat will transfer from a warm object to a colder one even when the temperature difference is less than one degree. Thus a heat-exchange medium circulated through a properly designed system can absorb heat from the outdoor air—regardless of how low the temperature—and release it to the indoor air; or the cycle can be reversed for summer operation. All that is necessary is that the medium be at a lower temperature than the air it absorbs heat from, and at a higher temperature than the air it releases its heat to. This is accomplished by the heat-pump design.

How the Heat Pump Works

A typical-packaged heat pump is shown in Fig. 2a. This is the most common type—the air-to-air unit, which means simply that heat is absorbed from air at one end of the cycle and released to air on the other. The air-to-air heat pump is a typical air-cooled air conditioner during the summer cycle, with the outdoor coil serving as the air-cooled condenser and the indoor coil serving as the evaporator or cooling coil.

By proper control of the four-way valve, use of a reversible capillary tube and valve, and a combination cooling-heating thermostat, refrigerant flow is reversed in the circuit external to the compressor for heating purposes. The indoor coil becomes an air-cooled condenser and the outdoor coil becomes an evaporator or outdoor cooling coil.

Heating Cycle—The refrigerant circulated through the outdoor coil in winter is at a very low temperature—normally much colder than the outdoor air. Thus, obeying the law of heat transfer, heat contained in the outdoor air transfers into the refrigerant through the fins and tubes of the coil.

The capillary tube and valve (Fig. 2b) act as a restricting or metering device and the liquid refrigerant is forced to expand and lose pressure as it is fed into the larger internal area of the outdoor coil. The action of the refrigerant is the same or similar to that taking place when it enters the indoor coil during the cooling cycle. Because of the expansion and reduction in pressure, the refrigerant begins to boil and evaporate. Because of the evaporation, its temperature is reduced below the temperature of the outdoor air being circulated across the coil. Therefore, being colder than the outdoor air, heat transfers from the air into the refrigerant. The outdoor coil is thus functioning as an evaporator or cooling coil. The discharge air from the coil will be colder than the entering air because a certain quantity of heat has been extracted from it.

In the above action the liquid refrigerant is changed to a gas and is drawn toward the compressor by reason of the low pressure existing on the suction side of the compressor. Before entering the compressor, the gas must pass through the four-way valve, which serves the important function of directing the flow of the refrigerant.

During the heating cycle the position of the valve is such that it is open between ports A and B, and D and C (see Fig. 2c). Low-temperature gas enters the valve through port D and leaves through port C. High-temperature, high-pressure gas enters the valve through port A and leaves through port B. In the cooling position, the valve ports are open between A and D, and B and C.

After passing out of port C, the low-temperature, low-pressure gas enters an accumulator and from there it passes through a heat exchanger before entering the suction side of the compressor.

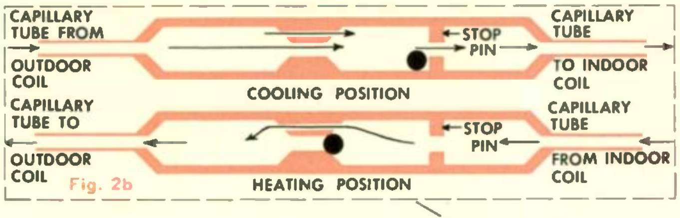
The refrigerant gas enters the compressor at the suction inlet, and in the case of most hermetics, travels through the compressor motor and up into the cylinder on the down-stroke of the piston. The up-stroke compresses the gas, and thus increases its temperature. This is where the equivalent energy of the electrical input to the compressor is picked up in the refrigerant stream. This additional heat is the heat of compression resulting from the work being done by the compressor as a result of the electrical input provided to the motor.

Heated refrigerant gas leaving the cylinder of the compressor is again directed through the four-way valve and then into the indoor coil. Due to the lower temperature of the air being recirculated across the indoor coil, the refrigerant releases its heat into the tubes and fins of the coil and finally into the recirculated air. It is then carried into the conditioned space by the air stream and, again because of a lower temperature within the space, is released into the space. Thus, heating is accomplished by the air-to-air heat pump.

The indoor coil is now functioning as a condenser because the cool air passing across it extracts heat from the refrigerant and condenses the gas to a liquid. The liquid refrigerant next passes into the capillary tube and valve, which is engineered to allow only the proper amount of liquid to enter the outdoor coil (or the indoor coil during the cooling cycle). Entering the outdoor coil the refrigerant is again evaporated, picking up

Fig. 2b—Capillary tube and valve operation.

Fig. 2c—(Bottom) Basic details of the 4-way reversing valve.



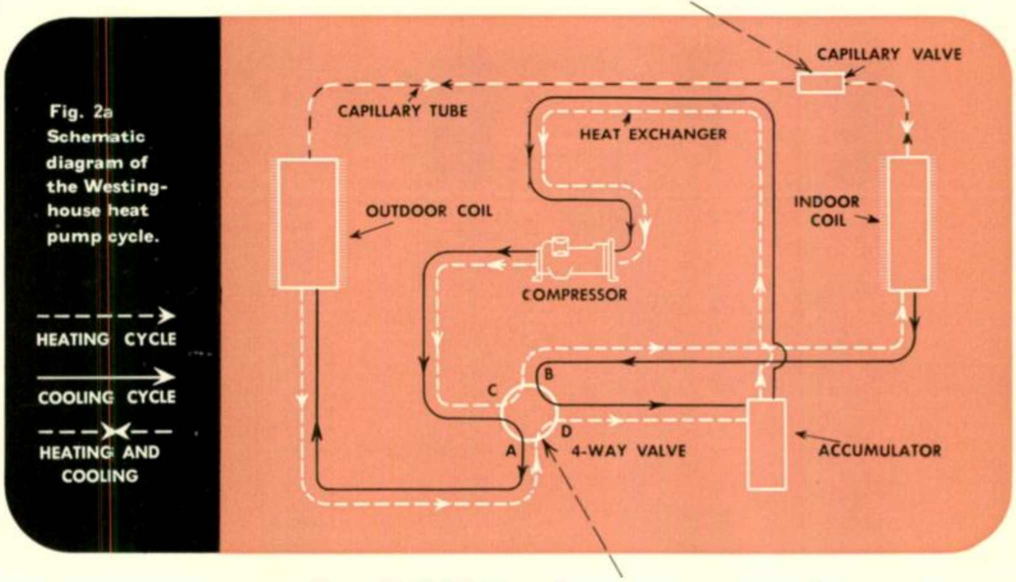
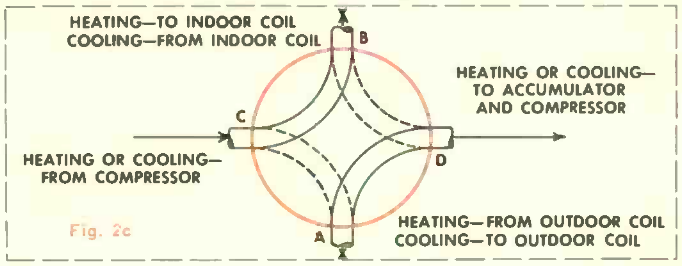


Fig. 2a Schematic diagram of the Westinghouse heat pump cycle.



heat, and continuing through the system, repeating the cycle.

Cooling Cycle—When the thermostat calls for cooling, the four-way valve automatically repositions itself so that ports A and D, and B and C are open to each other respectively. This changeover may be fairly quick with prompt response in the reversal from heating to cooling. During late spring or early fall the unit may reverse two or three times in a twenty-four-hour period yet maintain an indoor temperature so constant that occupants of the house may never recognize the changeover.

After the valve changeover the refrigerant flows as a liquid from the outdoor coil (now functioning as an air-cooled condenser), through the capillary tube and valve, into the indoor coil. Here its pressure is reduced due to expansion, and evaporation occurs, causing heat from the space to transfer into the colder refrigerant. The gas then leaves the indoor coil, passes from port B to port C of the four-way valve, to the heat exchanger, and into the compressor at the suction inlet. Compression again occurs, picking up the equivalent heat of the electrical energy input to the compressor, and the hot gas enters the four-way valve at port A, leaves through port D, and enters the outdoor coil and again condenses.

In the condenser the gas gives up the heat to the outdoor air being circulated across the coil. Leaving the outdoor coil, the liquid refrigerant enters the capillary tube in the reverse direction and the cycle is repeated.

Thus the air-to-air, self-contained heat pump is simply an air-cooled air conditioner, in which a reversal of the refrigerant flow in the circuit external to the compressor provides heating and cooling upon demand of the summer-winter thermostat.

Other types of heat pumps are common in this country. The basic principle is the same in each; the source of heat and the sink are the only major points of difference. Four other types (shown in Fig. 3) are: air-to-water, water-to-air, water-to-water, and earth-to-air.

Some industrial installations in this country use water-to-refrigerant-to-water-to-air systems. A few others use the same sequence of heat transfer except that outdoor air is the primary source of heat.

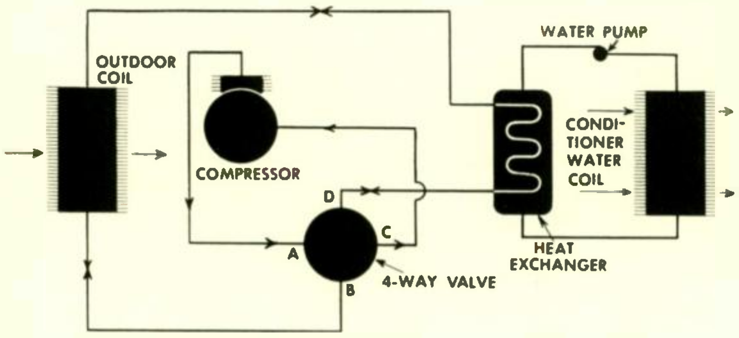
The three primary sources of heat are air, water, and earth. However, other sources might be used, such as solar radiation, sewage, process waste heat, and industrial flue-gas heat. Solar energy, while of tremendous potentiality, will probably be first developed as an auxiliary to the other three sources. Solar energy is used extensively in the lower southern states for domestic water heating. Considerable research is taking place aimed at full utilization of solar heat for heat-pump purposes, but it may be some time before this is accomplished. Waste heat, sewage and flue-gas heat have been used in some cases, but not extensively. However, flue-gas heat in industrial chimneys should be a prime source of heat since many boiler rooms operate 24 hours a day, which would be the condition most suitable for heat-pump use.

The operating efficiency of a heat pump is measured by the *coefficient of performance* or COP. The COP represents the ratio of total heat obtained at the indoor coil to the heat paid for in the form of electrical energy input to the unit. For example, if the heating capacity (Q_1) of a certain heat pump, operating at 35 degrees F outside air and 70 degree air entering the indoor coil, is 54 000 Btuh, and the value of the electrical input (Q_2) is 20 137 Btuh (5.9 kw) then,

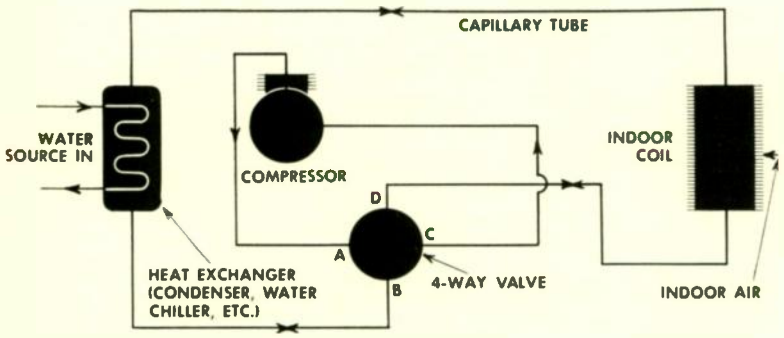
$$COP = Q_1/Q_2 = 54\ 000/20\ 137 = 2.9$$

which means that the amount of heat obtained is equal to 2.9 times the electrical energy applied to the heat pump.

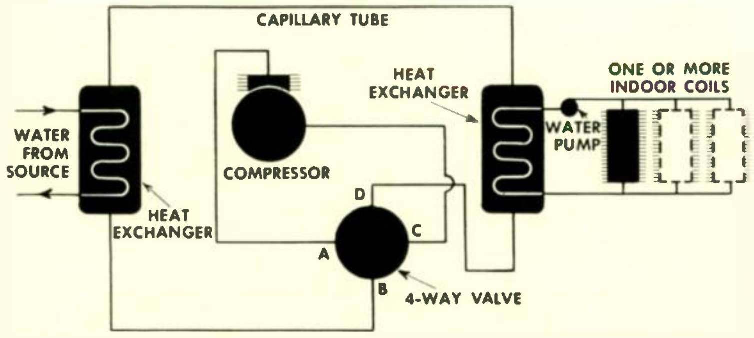
FIG. 3—HEAT-PUMP BASIC CIRCUITS



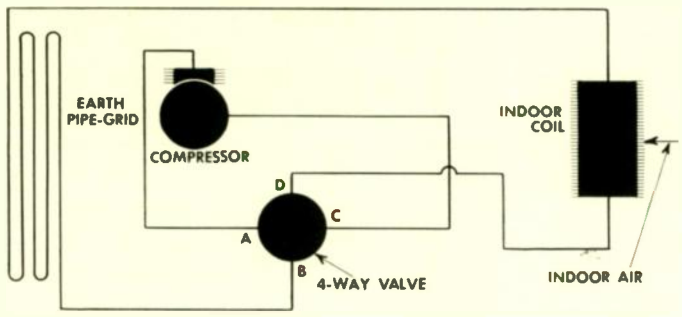
AIR TO WATER



WATER TO AIR



WATER TO WATER



EARTH TO AIR

The average coefficient of performance of most packaged-type units at the above temperature conditions is about 3.0, but may be either higher or lower. A COP as high as 4.0 or 5.0 is rare, and when it does occur, is usually only in large field-assembled systems. The coefficient of performance decreases as the outdoor temperature decreases.

In some areas of the country, supplemental electrical heating is needed. This heat is not included in the COP, since the coefficient is a measure of the heat pump's efficiency.

Application of Heat Pumps

The application of a self-contained heat pump is similar to that of conventional air-cooled air-conditioning equipment. Actually, it is physically simpler, since there are fewer components to install.

No water is needed for air-to-air heat pumps; the only piping necessary is a simple condensate drain. No fuel source is needed other than an electrical circuit of the proper size.

Heat pumps using water or earth as an outdoor source and sink require external water or refrigerant piping. Water-source units circulate either water or refrigerant through piping installed in a well, river, lake, or some other body of water. Ground-source units circulate refrigerant through a pipe grid buried in the ground below frost line.

Considerable difficulty has been experienced with ground-source heat pumps due to expansion and contraction of the pipes in the ground grid. Expansion tends to push the earth away from the pipes and, in many cases it remains in the outermost position. Consequently, overall direct contact of the pipe with the ground, which is necessary for highest efficiency, is lost.

For overall performance and minimum maintenance, air-to-air packaged units are the best choice for residential and most commercial installations. The outdoor coil of an air-to-air heat pump is usually an integral part of the complete assembly within the cabinet. Ductwork carries the inlet and outlet air.

Supplemental Heating—The heating capacity of the heat pump and the heat loss of the house determine the amount of supplemental heating required. The required kilowatts of heating are determined simply by comparing the house loss and pump capacity; if house heat loss is less than pump capacity no supplemental heating is required. If the house heat loss is greater than pump capacity, the difference in Btu is the amount of supplemental heating required (dividing by 3413 gives the kilowatt requirement).

Balance Points—When supplemental heater requirements are known, the next step is to determine when they will be energized, and how many will be turned on at any one temperature condition.

For the total heat loss of any particular structure a point exists on the heat-pump capacity curve where heat loss and unit capacity are exactly equal. This point may be above or below the outdoor design temperature, but usually lies above. This point of equality is known as the *first balance point* (see Fig. 4).

Supplemental heaters can be turned on all at one time, at a specific outdoor temperature; or they can be energized in steps. The first method is often employed where electric rates are based on a meter reading of the actual kwhrs consumed. An outdoor thermostat is arranged to energize all heaters at a point 3 to 5 degrees above the first balance point.

This method has the disadvantage of supplying more heat than is required at the first balance point and a decreasing excess down to the final balance point at design outdoor temperature.

The second method, i.e., energizing heaters individually, is the most popular. This involves determining succeeding balance points at which heaters are turned on. The method is shown in Fig. 4.

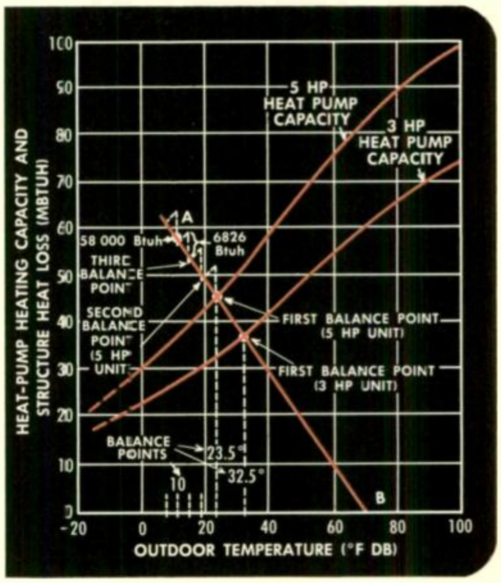
Heat-Pump Control

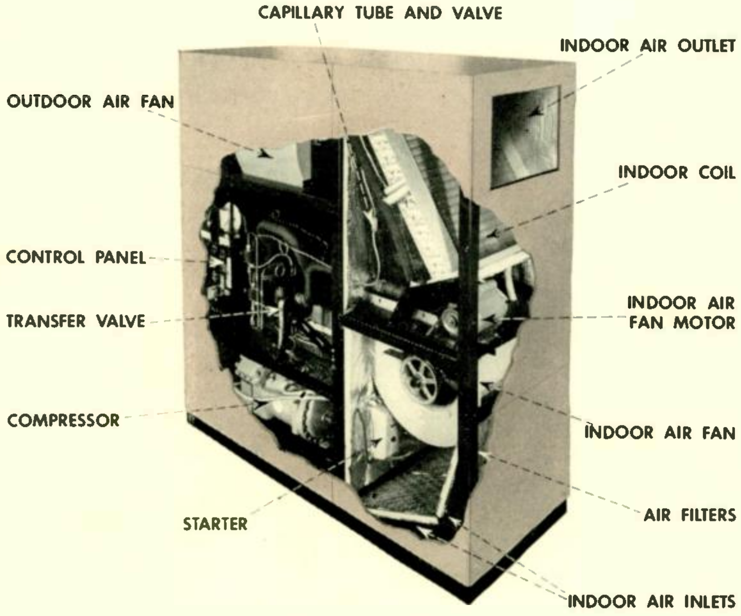
Heat pumps are provided with either two individual thermostats to control the heating and cooling cycles, or one combination thermostat that controls both functions. The combination type usually has one step or stage of cooling and two stages of heating, one for the heat pump alone, and another that energizes the supplemental heater circuit.

Heat-Pump Room Thermostats—The combination thermostat is the most common. The first heating contact energizes the compressor-motor starter magnetic coil, which closes the starter contacts and starts the compressor. As long as the heat pump alone is able to maintain desired room temperature, the thermostat operates on the first contact. If the outdoor temperature drops below the first balance point the sec-

Fig. 4—These are capacity curves for a 3-hp and a 5-hp heat pump. Assume a design outdoor temperature of 10 degrees F and a design indoor temperature of 70 degrees, and a house heat loss of 58 000 Btuh. To find the first balance point draw a line from the 10 degrees, 58 000 Btuh point to the 70 degrees F point on the temperature scale. The intersection of this line with the capacity curve is the point where capacity and house heat loss are exactly equal, i.e., the first balance point. In other words the unit will heat the house to 70 degrees F until the temperature drops to 23.5 degrees F (for the 5-hp unit) or 32.5 (for the 3-hp unit), below which temperatures supplemental heating will be required.

Additional balance points are needed to determine the points at which supplemental heaters will be turned on. Assume that 2-kw (6826 Btu) heaters are to be used and the 5-hp heat pump. Starting at the first balance point move up the temperature line (23.5 degrees) for a distance equal to 6826 Btu. From this point draw a line parallel to the capacity curve until it intersects the diagonal from A to B. The temperature at the point of intersection is the second balance point. Repeat the 6826 Btu vertical line from this point upward and again draw the parallel line. Repeat this procedure as often as necessary until point A is reached. Point A always represents the heat loss of the space to be heated.





This shows the components of the packaged heat pump.

ond set of contacts close, and energize a supplemental heater circuit relay. Supplemental heaters and their corresponding outdoor thermostats are all connected into this relay circuit. Once the second contact closes, supplemental heaters are energized according to the separate balance points to which the outdoor thermostats are adjusted.

Defrost Cycle—When outdoor temperature is near freezing the outdoor coil has a tendency to collect frost. Should this frost layer build up to the point where it interferes with the proper operation of the unit, the heat pump automatically defrosts itself. Actually the unit reverses its cycle from winter to summer operation for a few minutes to accomplish this. To prevent an indoor temperature drop during this defrost cycle, the supplemental heaters are energized when the cycle is initiated.

The point at which a defrost cycle should be initiated is determined by air pressure in the outside coil. With frost buildup on the air exit side of the outdoor coil, air pressure increases on the entering air side; by means of a pressure differential device this condition is sensed and the defrost cycle initiated.

Critical Unbalance

The ideal heat-pump installation is one in which the summer and winter requirements of the structure fall within the capacity range of the unit. The addition of one to eight kilowatts of supplemental heating is a near-ideal application.

If winter requirements exceed the capacity of the unit plus a maximum of eight kilowatts supplemental heating, a critical unbalance exists and the number of supplemental heaters must be reduced. This means reducing the load against which the unit must operate.

A critically unbalanced condition may be one in which, for example, the summer requirements are 35 000 Btu/hr and the winter requirements 75 000 Btu/hr at an outdoor design temperature of zero degrees or lower. A 3-hp unit will provide sufficient cooling for these conditions, but 16 kw of supplemental heating will be required for heating. A 5-hp unit will provide more than sufficient cooling capacity, and will be closer to the heating capacity. The 5-hp unit will furnish about 30 000 Btu/hr at zero degrees outdoor temperature, leaving a balance of 45 000 Btu/hr to be made up by supplemental heaters; this amounts to about 13 kw of heaters.

In some northern areas far more critical unbalanced conditions may occur. Obviously more heating and less cooling capacity may be necessary in northern Ohio or Michigan than would be required in a comparable house in Virginia or Kentucky. Critical unbalance is less likely to occur in the central and mid-southern states.

The unbalance often reverses in far southern states, and more cooling than heating may be necessary. This is not as much of a problem; the heat pump is merely selected to satisfy cooling requirements, and heating capacity is sufficient in most cases without supplemental heating.

A major factor in the reduction of critical unbalance is insulation. Better insulation, of course, not only reduces the load for both summer and winter, but also cuts operating costs, and in many cases the initial cost of the unit.

As an example of the effects of insulation, consider this example. With a temperature drop of 15 degrees across a 300 square-foot ceiling and roof with three inches of insulation, a gain of 3000 Btu/hr results. The same roof, uninsulated, will transmit approximately 4300 Btu/hr. In winter, with a 70-degree differential, this same roof insulated will have a heat loss of about 1900 Btu/hr; uninsulated it will transmit about 7300 Btu/hr loss.

Windows and doors are also an important factor. Single glazed windows conduct 3 to 12 times as much heat per square foot as a square foot of wall area. Double glazing, storm windows, and venetian blinds or other shades reduce this loss drastically.

Overall good insulation will do much to relieve any critical unbalance. In new construction especially, the extra cost of good insulation is well worth the effort.

Heat-Pump Costs

The initial cost of a heat-pump system is difficult to discuss in terms of averages. Variations in installation cost, freight rates, and labor cost are wide. As an example, a complete warm-air heating system for a 6-room house can be installed in City A in Pennsylvania for about $500. In City B in Virginia, the furnace alone may cost about $450, and the total cost may be over $800. Air conditioning costs vary in the same manner, thus making a nation-wide comparison with heat pumps next to impossible.

Conventional residential systems for year-round use frequently are more expensive than heat-pump installations. Costs in different areas determine which is most economical.

Operating Cost—Any operating cost analysis before installation is at best an approximate estimate. In any analysis assumptions must be made as to number of degree days, number of hours of operation, and use of the space. Such assumptions cannot be made with preciseness as long as weather remains an uncontrollable factor.

Power consumption and local cost of electricity are also large factors. Cost estimates are useful, however, as an approximation, and can be computed readily. Although direct comparison cannot be made for other localities, a general idea of the costs involved can be gained.

The Future of the Heat Pump

Much of the mystery of the heat pump is being dispelled, with the result that more and more new installations are being made. In considering the relative merits of the heat pump, all factors should be taken into account. Such consideration will often point to its use over conventional heating and cooling equipment. ■

CYPAK SYSTEMS

An Application of Logic Functions

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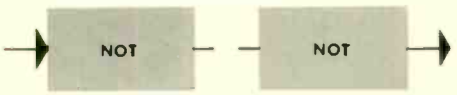
Fig. 1

In the AND unit an output occurs only when **all** inputs are received.

The OR element delivers an output when any **one** input is received.



The NOT unit delivers an output only when **no** input is received by the unit.

The MEMORY element produces an output after an initial input until a second input is received by the unit.

▪ THE CONCEPT of circuit design through logic functions has been relatively well isolated within the bailiwicks of a few very highly specialized scientists. Since the development of Cypak systems last year, however, this new concept has rapidly crowded its way into the industrial-control limelight.

Although the general principles are not as yet widely known, the proximity of logic-function design to the true fundamentals of control promises greatly simplified circuitry, as well as reliability compatible with industry demands.

The reliability benefits are immediately available. The only method that science has found so far to provide switching functions without moving parts is through the use of a logic-function type device. The increase in reliability is enormous, since perfectly static devices have an operational life that is limited only by the life, in terms of time, of the materials used in the device. This means operational life in terms of 20 to 30 years regardless of the frequency of operation. Consequently, the logic-function approach will likely dominate the industrial-control picture for switch-type controls.

What Are Logic Functions?

A logic function is a means of expressing a definite arrangement of information. Experience shows that any arrangement of information, regardless of its complexity, or even a set of movements can be described with four functions—AND, OR, NOT, and MEMORY* (see Fig. 1 at left).

These functions can be performed by relays; however a basic objective in developing Cypak systems was to find a static device for industrial service. Electronics, too, was bypassed in favor of magnetic and transistor devices. Transistors have many attractive features; they are fast, small, and simple. At present, however, transistors do not have the extensive reliability history demanded for industrial devices. Therefore, for the present, magnetic elements were chosen as the basis for Cypak controls.

The information processed by industrial controls, i.e., the signals, fall into two general categories, analog and digital. Digital signals are sharp and discrete, and of definite duration, i.e., a pulse. Analog signals, on the other hand are continuous and may vary in amplitude, frequency, or wave shape. The signal from a switch is digital; that from a tachometer generator an analog signal. Extensive field experience with magnetic amplifiers in many analog applications, such as paper-machine and steel-mill drives, indicates that their reliability is beyond question. Furthermore, the magnetic amplifier can be made to behave in digital fashion by so-called bi-stable circuits, in which the magnetic-amplifier is either on or off. One characteristic of the type of regulators used on analog applications is their relatively long time delay of perhaps two or three cycles. Assuming that it would be necessary to chain or cascade several logic-function devices to achieve the desired result, this time delay would become prohibitive. The circuitry trick in using magnetic-amplifier devices for logic-function purposes, then, must be to somehow speed up the operation. Cypak logic elements have accomplished this through the use of a special circuit.

A very high-grade magnetic material must be used so that a "square hysteresis loop" characteristic can be obtained. If a winding is placed on a core of this high-grade magnetic material and an a-c voltage from a low impedance source passed through that winding, the magnetic saturation of this core can be made to oscillate between a maximum negative and positive saturation. This circuit, of course, is of little use since no output can be obtained from the winding. However, if a

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*See "Cypak Systems," *Westinghouse* ENGINEER, July 1955, p. 114.

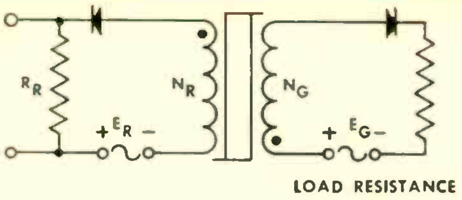


Fig. 2—A winding on a magnetic core with a self-saturating rectifier in the circuit and with a reset winding.

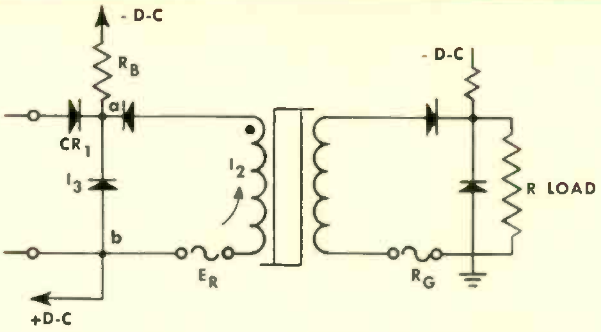


Fig. 3—The reset used in Cypak uses a d-c biased rectifier, which can serve as both high and low impedance when required.

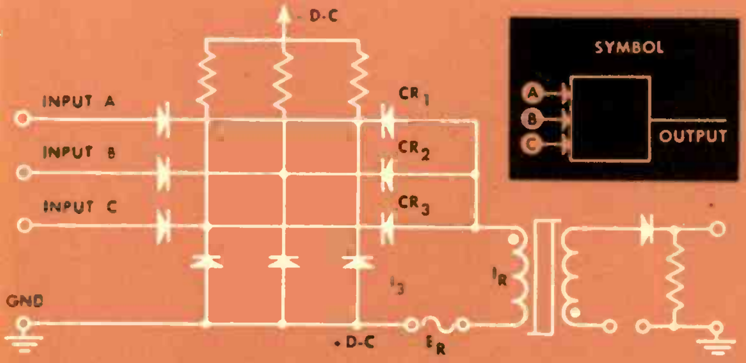


Fig. 4—The diagram for the AND element in Cypak. AND elements are built up in one, two, and three input styles and are used in conjunction with another input AND element when more than three inputs are needed.

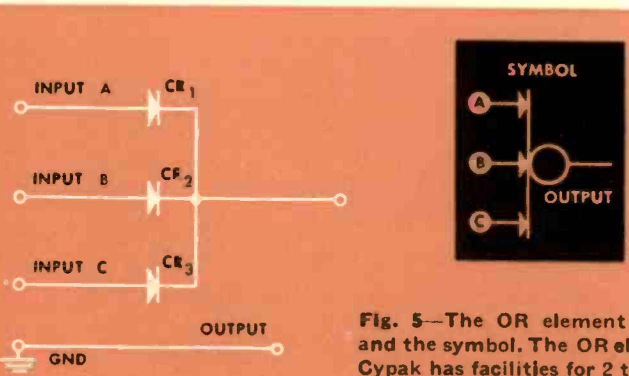


Fig. 5—The OR element diagram and the symbol. The OR element in Cypak has facilities for 2 two-input OR circuits and two voltage dividers.

rectifier is added to the circuit current can flow in only one direction through the winding. This means that the core saturates during the first half cycle of current through the winding. The next half cycle is blocked by the rectifier. The third half cycle appears as output, since the core is already saturated and will therefore absorb no more energy from the winding. With this circuit, then, a continuous output in the form of a half wave would be obtained after the first half cycle. This is not a *controlled* output; a reset winding is required. Also, one of the requirements of this logic-function device is that it be capable of acting on signals from other devices of the same nature. This requirement should be kept in mind. A reset winding circuit similar in form to the first (gating) winding could be added, as shown in Fig. 2. If the reset voltage is made to be 180 degrees out of phase with the gating voltage, the first half cycle results in positive saturation of the core due to the current in the gating winding, and the next half cycle results in negative saturation of the core due to the current in the reset winding. Thus the core is again made to oscillate between positive and negative saturation and no output is obtained. By stopping the reset current, however, an output could be obtained following the next gating half cycle. The most common method of doing this would be to place a low value resistor in series with the reset voltage, and then place a voltage of the proper magnitude and phase across this resistor, Fig. 2. However, because this circuit should be capable of being driven by similar units, a relatively high value of resistor should be used so that the preceding unit will not be overloaded and so that some gain per stage can be achieved. The compromise between these two opposed requirements is the use of a d-c biased rectifier so arranged in the circuit that it can serve as both a low and a high impedance at different times. This circuit produces a *controlled* output.

This circuit is the basis of Cypak circuitry and is more commonly known in the magnetics field as the Ramey amplifier. In practice, it is further modified by the addition of a rectifier in the gating circuit, Fig. 3, so that minimum output can be provided across the load when the gating circuit is not producing an output.

This circuit is already an AND element with one input. To make it a multiple-input AND, other paths are provided for the reset current so that all of the several paths must be blocked in order to completely block the reset voltage, Fig. 4. There is no practical limit to the number of inputs that can be provided to a Cypak AND element so far as industrial circuits are concerned. The theoretical value is probably about 10 000. This would be equivalent to 10 000 contacts in series.

Before the OR, NOT, and MEMORY circuits are described, some specific points common to all Cypak circuits should be emphasized. An estimated 80 percent of all the relay contacts used in industrial circuits are used exclusively for information processing, that is, transmission of signals. This condition prompted the development of a low-power device to do the information processing in industrial digital controls. With magnetic units, both cost and size are greatly affected by the power level of the device. Cypak elements were consequently designed to handle input signals as low as 10 milliwatts. More will be said later about the many advantages of this low-input power level. The elements themselves deliver in the order of 0.3 watts output, which is more than adequate power to do information processing. But what about power switching? Here, of course, the output of the Cypak logic elements must be amplified to the level required to either actuate the power device or to actuate another power-handling mechanism, such as a motor starter. This amplification can be accomplished through magnetic-type amplifiers that are digital in operation. In general, it is uneconomical to switch larger motors without an intermediate power-handling device, such as a motor starter, between the final Cypak output amplifier and the motor. The reliability penalty in this case is not great because of the comparatively low frequency

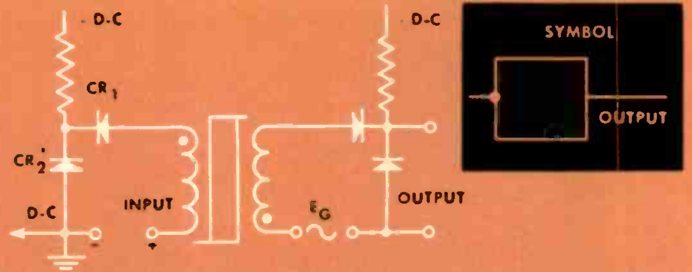


Fig. 6—The Cypak NOT element. There is one NOT circuit in each Cypak half-MEMORY element, plus a two-input OR circuit.

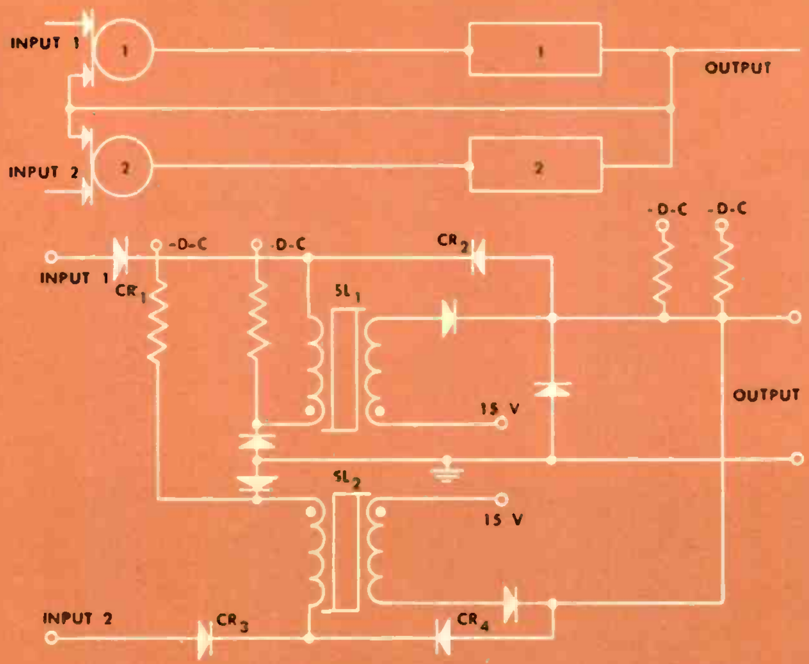


Fig. 7—(top) The schematic for the MEMORY, using two NOT's and two OR's; (below) The full diagram for the MEMORY element.

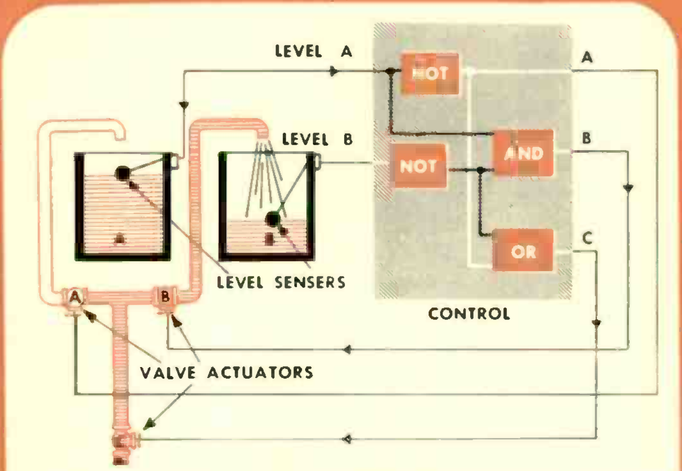


Fig. 8—The two-tank problem and its logic-function control.

of operation of the motor starter. Other means of accomplishing power switching are discussed later.

Another immediately apparent characteristic of the AND element just discussed is its phase sensitivity. The gating voltage and the reset voltage (Fig. 3) must be 180 degrees out of phase with each other. Also, a number of different voltages—for gating, reset, and bias—must be supplied. These characteristics are common to nearly all of the Cypak elements, but are not a disadvantage. All voltages of the proper phases are supplied from a single center-tapped transformer with an associated rectifier bridge to supply the bias voltage. Of course, the reset voltage, input voltage, and the reset bias voltage must all be of the same phase and opposite to the phase of the gate voltage and the d-c gate bias voltage. These points about Cypak magnetic elements take on a particular importance in circuit design.

The OR element is the only Cypak element that does not provide amplification within stage. It is a pure rectifier circuit, Fig. 5, so designed that any one of the inputs can produce an output but will still be isolated from the other inputs. Of course, the OR element is not sensitive to the phase of the incoming signal, and there is no limit to the number of inputs that can be provided.

The NOT element provides no reset current except during an input, thus producing an output at all times when an input is not present. As might be expected, this is accomplished by making the input voltage serve as the reset voltage, Fig. 6. Although the NOT element is generally used with a single input, there is no reason why several inputs could not be provided if isolated from each other to prevent feedback.

The function of the MEMORY circuit is to provide a continuous output once an input is provided and to stop that output when a second input occurs. This suggests that a train of pulses be kept circulating with a means for interrupting the train with a second input. This is exactly what is done with the Cypak MEMORY element. Two OR elements and two NOT elements made sensitive to opposite phase input signals are used, Fig. 7.

One other element in the Cypak family deserves some discussion. This is the TIME DELAY unit. Units have been designed for use as delay elements, where they produce maximum output for a specified time and then produce zero output; they operate in conjunction with a MEMORY element. Their principle of operation is much the same as any resistance-capacitance circuit that takes advantage of an RC time constant. In Cypak, these TIME DELAY units have been built in several ranges up to a maximum of 40 seconds.

This briefly describes the devices required for one method of accomplishing logic functions through magnetic principles. There are, of course, other designs of magnetic elements that provide the same functions. Few, however, can do so with a response of one-half cycle; and although most industrial digital controls of today find a half-cycle response (when using a 60-cycle supply) to be more than adequate, those of tomorrow may well be so complex that response time on switching units will become critical.

A higher supply frequency is, of course, a possibility. This would have the bonus advantage of permitting smaller cores, but would have the disadvantage of a high-frequency supply of some sort. This usually means higher cost. Also, at frequencies in the kilocycle range, the capacitance effect of dry-plate rectifiers becomes prohibitive. Considerable work is being done on the design of higher frequency units and important developments can be expected from this field.

How Are Logic Functions Applied?

The first clue on how to use logic function elements in circuit design probably comes from their name. Simple controls can be designed purely on the basis of logic.

For example, take the problem of two tanks, Fig. 8, which must be filled in a specific sequence. A stipulation is that tank "A" must be filled first and tank "B" can be filled only

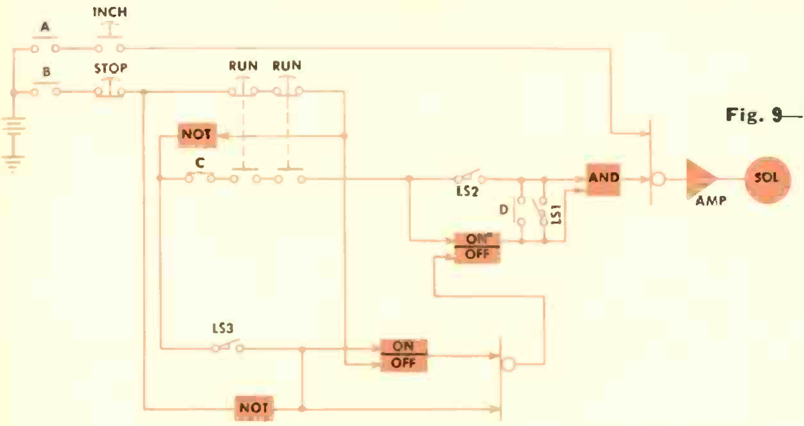
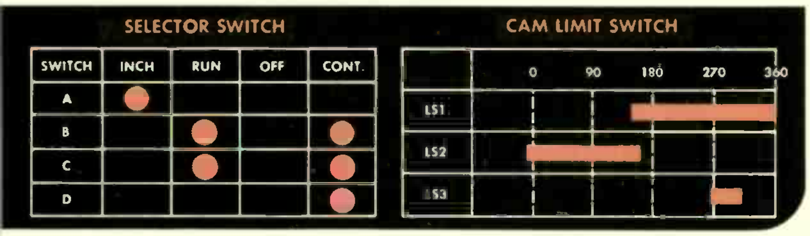
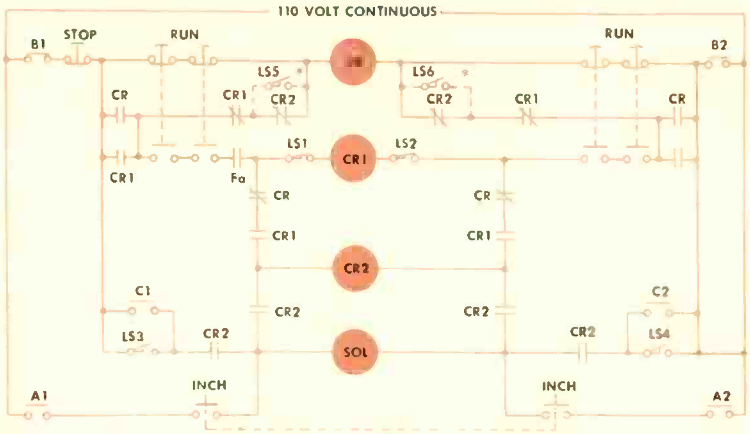


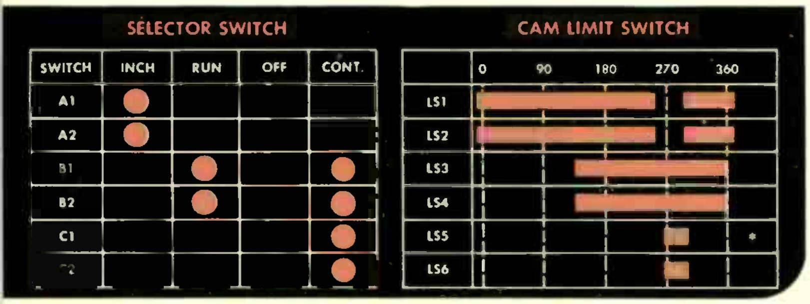
Fig. 9—The logic diagram counterpart of the punch-press control.



SELECTOR SWITCH

SWITCH	INCH	RUN	OFF	CONT.
A	●			
B		●		●
C		●		●
D				●





SELECTOR SWITCH

SWITCH	INCH	RUN	OFF	CONT.
A1	●			
A2	●			
B1		●		●
B2		●		●
C1				●
C2				●

*Jumper or Limit Switch Required if "ON HOP" Operation Is Desired

Fig. 10—A relay diagram for a punch press.

if tank "A" is full. The sensing elements are level sensers in both tanks that deliver an output when the tanks are full. Immediately, the characteristic of the level sensers suggests that a NOT element be used to detect when the tanks are not full. Hence, the inputs from the level senser should be fed to two separate NOT elements. But the stipulation is that tank "B" be filled only when tank "A" *is* full and when tank "B" is *not* full. Hence, the output from the NOT element associated with tank "B," and the output direct from the level senser for tank "A" should be put through an AND element. This part of the controls says if "A" is full *and* "B" is not, "B" will be filled. A common valve is also added, which will operate when either "A" *or* "B" is empty. This, of course, means an OR element fed by outputs of two NOT elements.

This example, of course, was an easy problem to solve; most industrial digital controls are far more complex. Nevertheless, many controls can be designed by a "logic" process. Sometimes this is not the most efficient method. In the case of a punch-press control, Fig. 10, for instance, the direct translation from control requirements to logic circuit becomes more involved. The logic circuit, Fig. 9, can be designed by translating from the relay diagram. By considering the relay equivalents of AND, OR, NOT, and MEMORY, a logic diagram can be derived and later modified.

The question arises, "What about the control that is too complex to permit a translation by a logic method?" Not only are there many circuits in this category but their number is increasing as machines and controls become more complex.

This increase in control complexity, particularly in the data-processing field, has revived interest in a form of mathematics developed by a British mathematician in the 19th century to mathematically express the processes of logic. Boolean* algebra, sometimes called contact algebra or logic algebra, is presently used to reduce control requirements to a mathematical expression that is directly translatable to the circuit design required. This turns out to be not only a convenient method of designing circuits with logic functions but also a positive method of reducing the control to the least number of components.

Application Considerations

The low input power level of Cypak presents opportunities. Unusual input devices can be employed with Cypak that will permit heretofore unheard of reliability. One of the bad trouble spots on the majority of digitally controlled machines in industry is the limit switch. Part of the maintenance difficulties with limit switches is electrical and part is mechanical. The contacts pit and erode much like relay contacts to cause the majority of the electrical trouble. The breakdown of mechanical parts due to the arm action of the limit switch is, of course, responsible for most of the mechanical failure. The ideal limit switch, then, would have no contacts and no moving parts. A limit switch that fulfills these requirements will be forthcoming in the immediate future. Both a push-button and a limit switch that have no contacts have already been developed.

Other possibilities for much more reliable input devices look at least inviting. Phototransistors, whose outputs are dependent upon the impingement of light or higher frequency waves, show considerable promise. The object with this type of device would be to mount a small, rugged light source or a radioactive source on the moving part of the machine, and mount the phototransistor on the non-moving portion so that it develops a voltage across its load when the light source passes it.

These unusual input devices are not absolutely necessary to the operation of Cypak. Standard input devices can be used. Code requirements make it necessary to use 110-volts across contact-making input devices, since this is considered the minimum voltage that will burn through the grease and corrosion on the contacts. Cypak operates on input signals of about 12 to 15 volts. The stepdown is accomplished through a voltage divider that picks off 15 volts for the Cypak element. These voltage dividers are often used in con-

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*"An Investigation of the Laws of Thought, on Which are Founded the Mathematical Theories of Logic and Probabilities," George Boole, Dover Publications, Inc. (British)

junction with rectifiers to prevent feedback through the input device.

The best uses for Cypak systems are those that involve sequencing and interlocking to some degree. Of course, the greater the amount of sequencing and the higher the duty cycle, the greater the advantage. Many early applications have been in the machine-tool control field (Fig. 11).

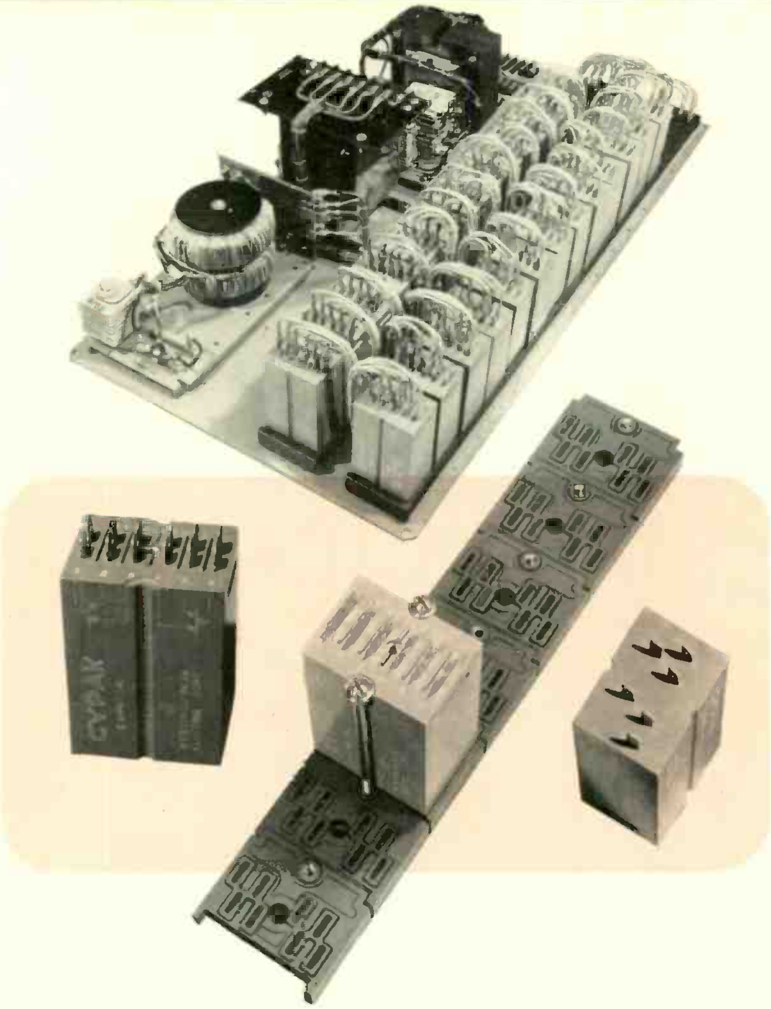
The increase in complexity in machine-tool controls, brought about by the increasing stronger move towards full automation, seems to be culminating in numerical control schemes. Numerical control is the storage, in terms of numbers, of the complete specification for a desired metal shape, and then the translation of those numbers, through a control system, into position information for servomechanisms that control the relative position of the work and tool. Various machine tools—milling machines, lathes, boring machines, cam machines, drilling machines, and punch presses—have already been, or could be, numerically controlled. Numerical control differs from automatic-sequence control in that a variety of temporary programs can be used to change the control functions to suit the part being machined.

The general principles of numerical control can also be applied to other areas of automatic control. A specific example can be cited in the steel-mill industry. Schemes have been worked out for the automatic charging of blast furnaces, where the proper amount of stone, ore, and coke are delivered to the furnace at the proper times according to a pre-selected schedule. The information is either fed in manually through pushbuttons or automatically through read-in devices, such as a punched-card reader.

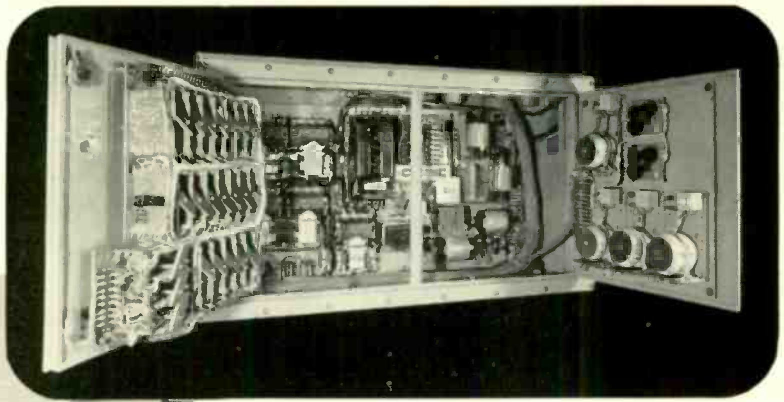
The use of numerical control in the field of process control also appears attractive. Because of the large amount of information processed, both manually and automatically, in such enterprises as oil refining, pipeline operation, and chemical processing, numerical control may eventually be used widely in these areas.

Although a Cypak system for numerical control is far more flexible in its function and in general more complex than one for automatic-sequence control, the system elements are the same. Because of the greater complexity, reliable operation is of even greater importance.

A complete tabulation of the potential applications of Cypak systems is impossible. This brief discussion, however, indicates directions in which its possible uses lie. ■



The redesigned Cypak elements are built up in plug-in type, completely encapsulated modules. Power connections are made through a power channel. The phase is determined by the way the module is plugged into the channel. Power connectors are unsymmetrically arranged about the axis of the module. The only direct wiring required is on input and output terminals. This new module is more rugged than previous designs, easier to wire and install, and even more reliable.



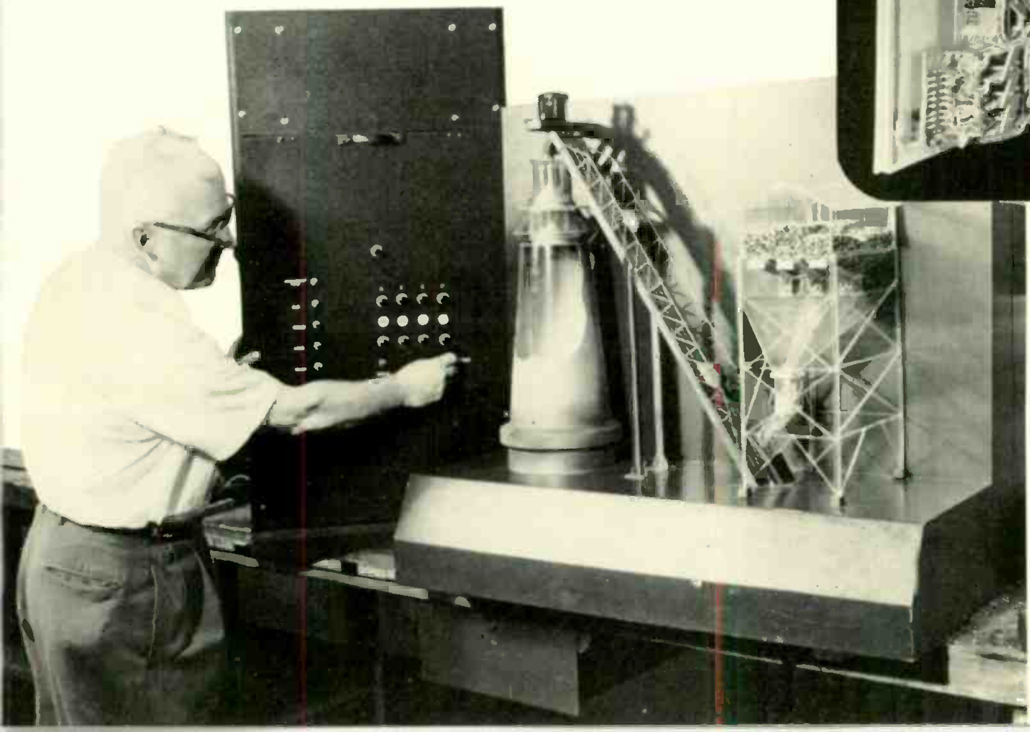
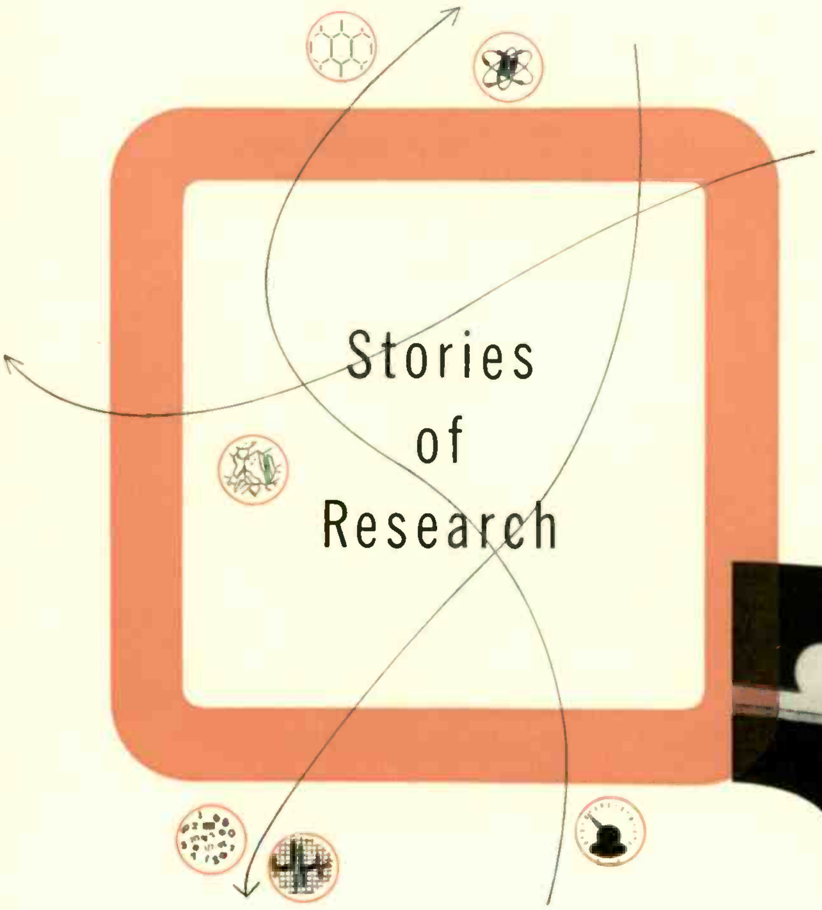


Fig. 11—Above, a Cypak control for a turret lathe. The control is mounted as an integral part of the machine. Each of the six turret faces has five modes of operation. At left, a skip-hoist model is an example of Cypak control use in numerical controllers. All this model needs is a read-in device to make it completely automatic.

Stories of Research



Roadblock for Arcs

RESISTANCE TO ARCING is an important requirement of electrical insulation. A new technique, developed at the Research Laboratories, increases the arc resistance of molded electrical insulation as much as 1000 percent. The technique consists of inserting "electrical roadblocks," in the form of submicroscopic particles of an inert material such as silicon dioxide.

Among the few molding compounds that meet the requirements of low cost and basically good electrical and mechanical properties are those made from phenolic resins. However their comparatively low arc resistance has limited even greater use. A study of the nature of phenolic insulating materials shows that this susceptibility to arcing is due to their chemical structure. Their molecules contain chains of carbon atoms that tend to unlink under heat or strong electrical discharge, forming simpler chemical substances that conduct electricity. These substances then act as a path for an arc. In the new technique small non-conducting particles of an inert material are inserted between the molecules of the molding compound. These effectively block the path of the electric arc.

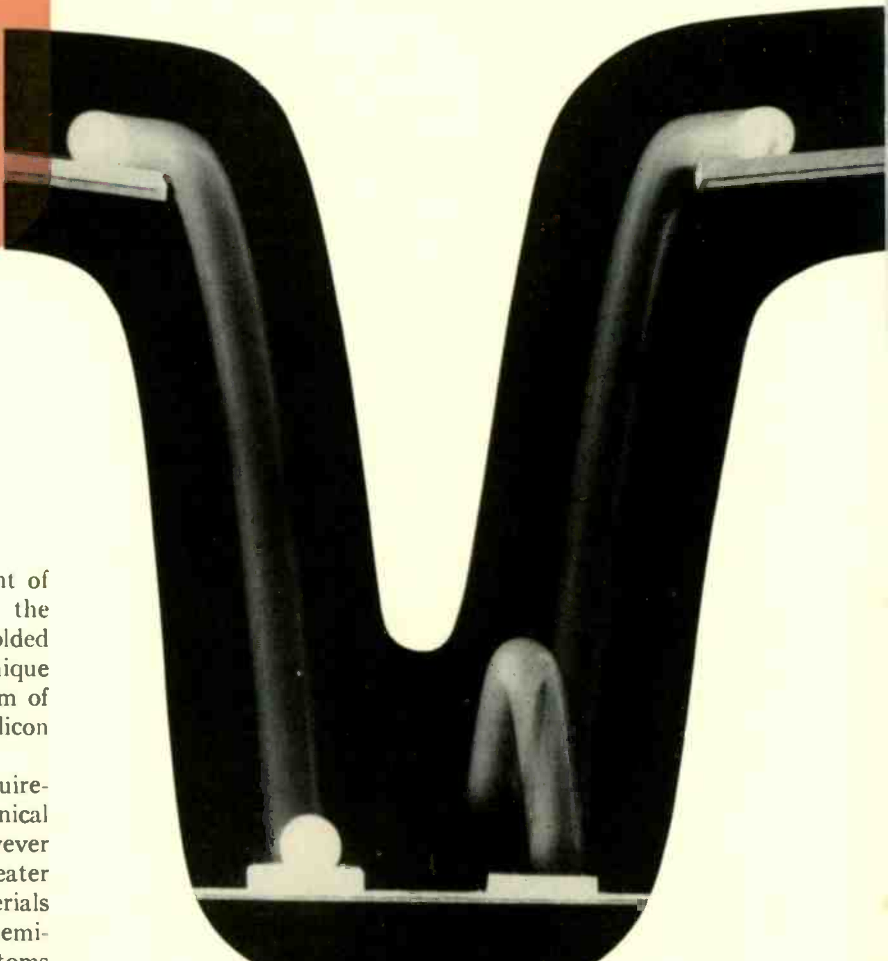
Other substances than silicon dioxide can also be used. Oxides of such metals as aluminum, titanium, and zirconium have been used successfully, with as little as one percent by weight showing beneficial results.

This new technique was investigated at low levels of power where ASTM standard arc resistance tests are applicable. Corresponding standardized tests at high currents and voltages have not yet been adopted. ■

Presto—Vulcanization

SILICONE RUBBER can be vulcanized by an irradiation technique in a fraction of the time taken by conventional methods. A new process, devised by engineers of the materials engineering department, beams two-million-volt electrons at a silicone gum, and almost instantly converts it to silicone rubber; the new technique produces a better rubber in two seconds than conventional vulcanizing methods yield in several hours. While not yet ready for commercial application, irradiation with high-energy electrons may ultimately become an important method of vulcanizing silicones. It duplicates all the good features of chemical vulcanization without introducing chemical agents that remain in the rubber and spoil some of its desirable properties.

Another advantage of this new technique is the ease and precision with which it can be controlled. Curing of rubber is accomplished at room temperatures—no heat, no pressure, and no chemicals are required. Control of the process consists merely of regulating the voltage and governing the length of exposure time.



High-energy electrons can be obtained from a standard electrostatic generator. Vulcanization takes place when the speeding electrons smash into the silicone molecules and cause them to rearrange into new patterns. This process changes the silicone from a non-elastic, putty-like mass into a solid with the bounce of natural rubber (see photo above). ■

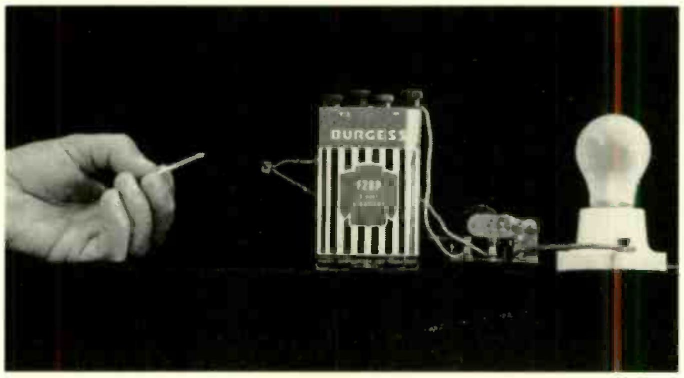
New Technique for Transistors

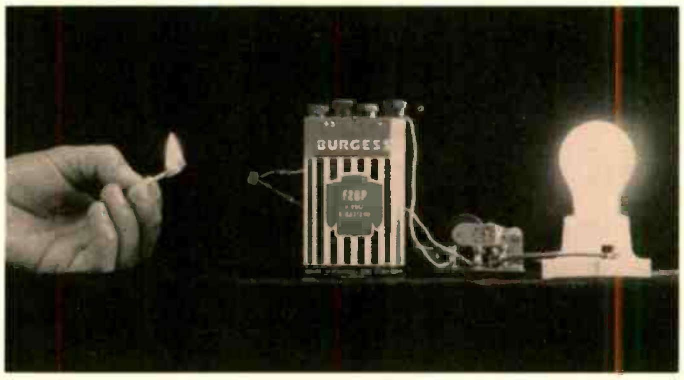
▪ CONVENTIONAL METHODS of making transistors rely on delicate temperature control to achieve quality and consistency in the finished product. Ordinarily a thin slice of n-type germanium is placed between two layers of the metal and heated. The metal atoms dissolve inward through the germanium forming two outside layers of p-type germanium and leaving a thin n-type layer between them. The thinner and more uniform the n-layer, the better the performance of the finished transistor. Too high a temperature causes the thin layer of n-type germanium to melt away completely, leaving the transistor worthless. Too low a temperature leaves the n-layer too thick, giving a transistor with poor performance.

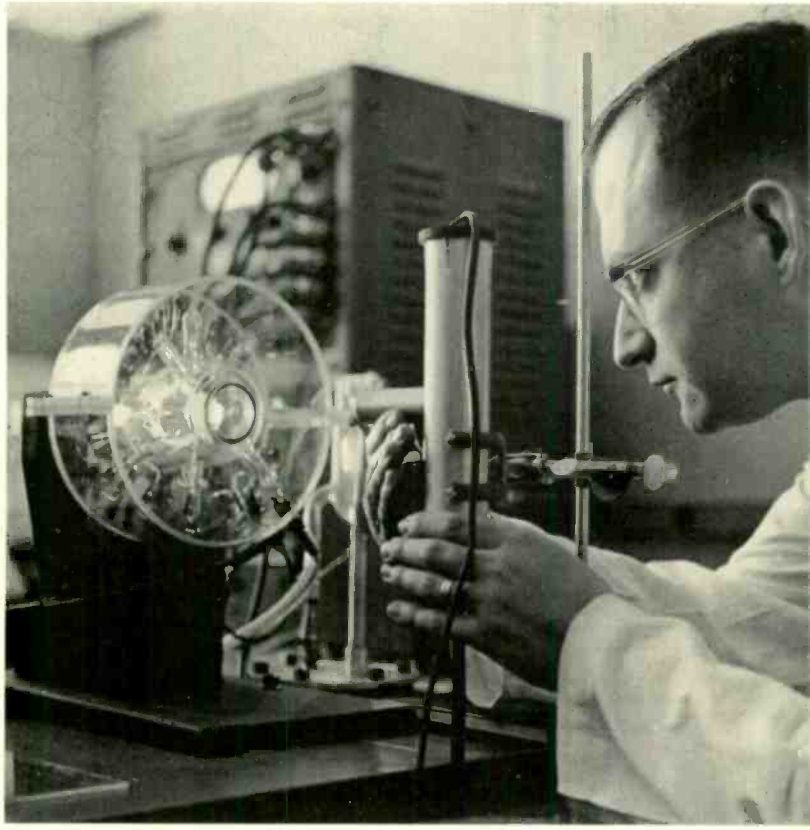
A new technique developed at the Research Laboratories can allow the temperature to be virtually uncontrolled, which means the process inherently produces transistors more consistent in quality from unit to unit. Key to the new process is a cooling-off period during the heating of the transistor sandwich, which allows the critical n-layer to build up to the desired thickness and uniformity.

The transistors produced in the laboratory by this process have unusual performance. One transistor, for example, can amplify current of much higher frequency than the usual junction-type transistor. Thus high-frequency electronic equipment, including home television sets, may soon be fully transistorized.

The new technique has also produced transistors that are super-sensitive to light. These photodiodes use the energy of light to control electric currents, like an ordinary photoelectric cell. However they are at least 10 000 times more sensitive to light, and one of them can control as much current as 100 typical photoelectric cells combined. The new photodiode operates on a voltage as low as that from a 1½ volt dry cell or 6-volt storage battery, yet operates a standard relay without amplification. One potential application for such a photodiode might be as an automatic headlight dimmer. ▪







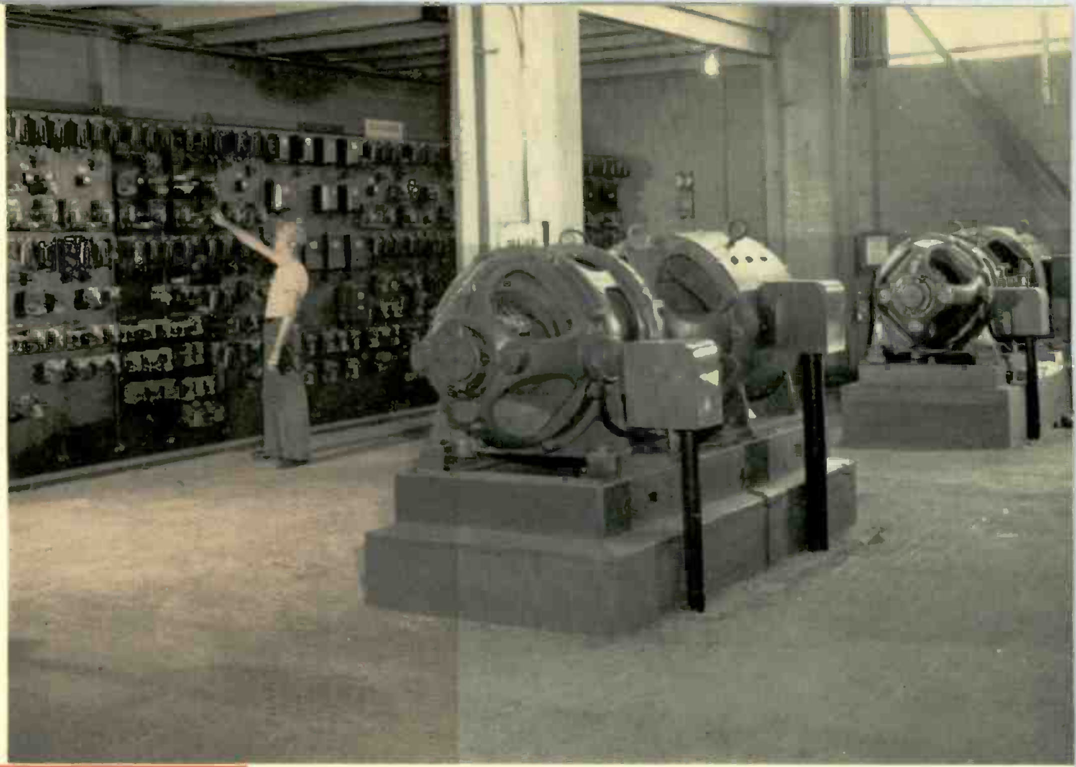
High Speed "Stop Watch"

▪ "SPLIT-SECOND TIMING" has a new degree of meaning as a result of a new electronic tube that can time atomic events down to less than one billionth of a second. In fact, scientists at the Research Laboratories who developed the photo-multiplier tube don't yet know the exact top speed of this new "stop-watch," and won't until better laboratory techniques are developed to measure it experimentally. However, this will give an indication: light travels at a rate that can carry it more than seven times around the world in a single second; during the shortest interval measured by the new electronic stop watch, light can travel but a few inches.

A photomultiplier tube strengthens radiations by a chain reaction of electrons. In a conventional tube, an electron striking a metal plate causes several electrons to be given off from the other surface of the plate; several such stages give a multiplying effect. In the new tube, an exceedingly thin nonmetallic film replaces the plate. The thin film that supplies the emitted electrons is a layer of material chemically similar to table salt and but two millionths of an inch thick. This film is evaporated in a vacuum onto an even thinner film of glass-like material, which lends strength to the salt film. Between these two films is deposited a third film of gold, some 200 times thinner than the salt film itself. This three-layer sandwich is mounted on the surface of a round copper screen, its mesh so fine that the holes cannot be distinguished with the naked eye. The complete sandwich on the face of the screen is so thin that a stack of about 1000 would about equal the thickness of the average sheet of writing paper.

In a conventional tube electrons are guided through a number of complicated paths in their passage through the tube. In the new tube the electron avalanche moves straight ahead, which shortens the path of the electrons and speeds their travel time through the tube; this gives the tube its precision and speed. ▪

Typical adjustable-frequency supply consists of a three-phase generator, driven by an adjustable-speed d-c motor.



Adjustable-Frequency A-C Drives

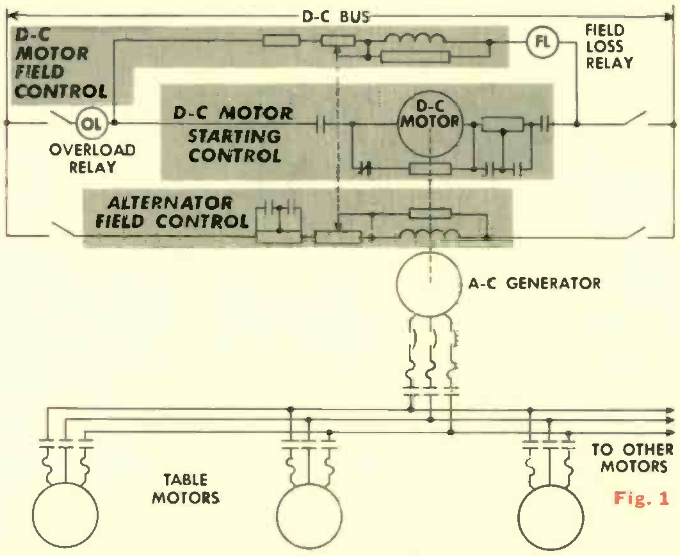
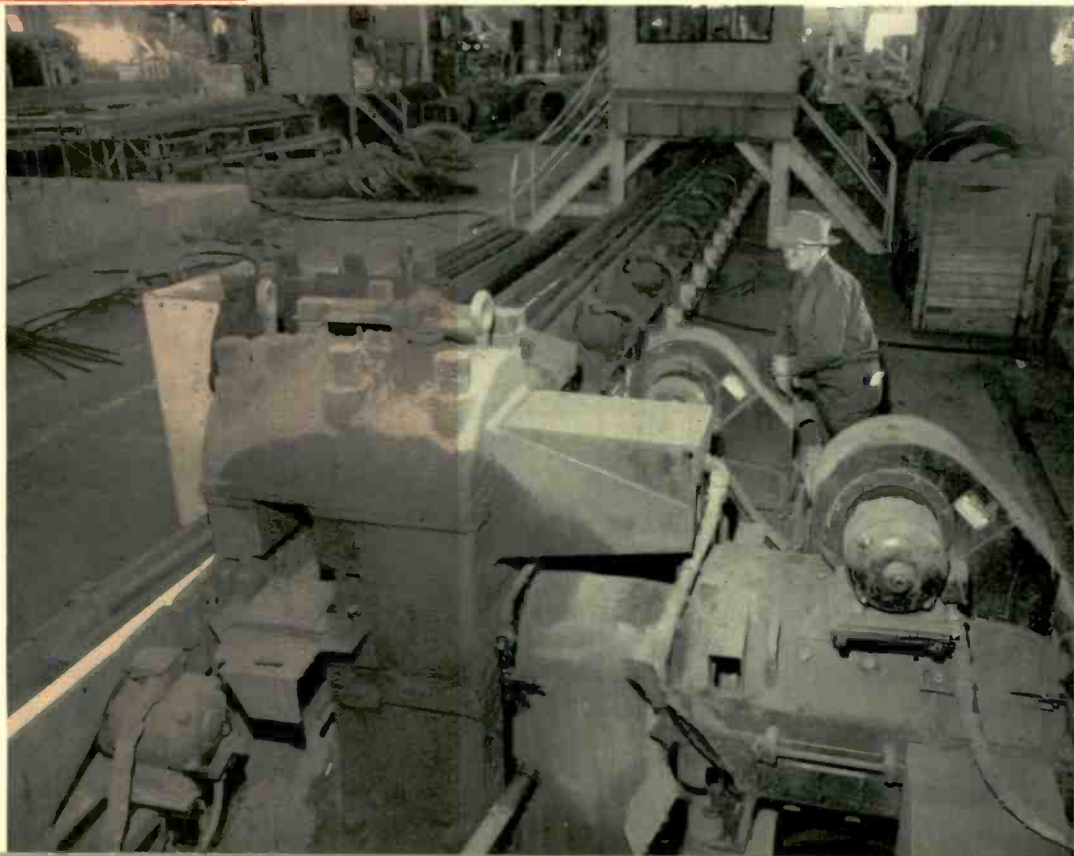


Fig. 1



The rod-mill run-out table carries rod from the mill to the cooling beds. The long rod, in a red-hot state, must be prevented from buckling or stretching.

When many motors are required for a single drive, and must operate closely together over a speed range, the adjustable-frequency drive is often the most practical answer.

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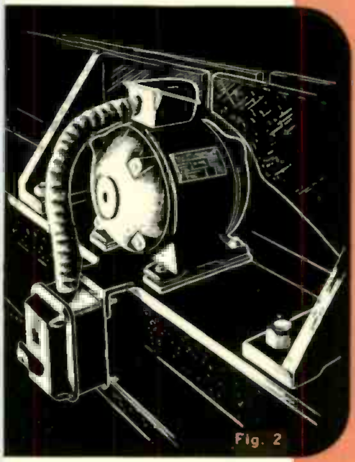


Fig. 1—Simplified control schematic of an adjustable-frequency drive for a run-out table for a rod and merchant mill application.

Fig. 2—An individual motor drive on each roll with a common adjustable-frequency supply maintains uniform roll speed on rod and merchant mill run-out table.

■ THE SQUIRREL-CAGE MOTOR is undoubtedly the workhorse of American industry. More machines are driven and more work is done by this motor than any other single type. Its ruggedness, low cost, and reliability are well-known features. Widespread use of the squirrel-cage motor is made in spite of the fact that it is essentially a constant-speed machine, hence relatively inflexible from that standpoint.

Essentially constant speed—but not necessarily! If the supply frequency is adjustable, these motors can be made to operate with most of the flexibility of the d-c machine. In fact, an adjustable-frequency system has many advantages over a d-c drive. Group drives, for example, can be made to operate together closely over a wide speed range without special adjustments. Starting, acceleration, and switching of single motors in a group drive can be done easily with the a-c system, but require special treatment with d-c motors.

The added cost of an adjustable-frequency supply is partly offset by the savings afforded by the simplified squirrel-cage motor construction. But to be an important factor, many motors must be involved. For this reason, adjustable-frequency drives have been used most often for such applications as steel mill run-out tables, or spinning machines for man-made fibers, where hundreds of small motors may be required for a single drive.

Further justification for the separate power supply is the elimination of brushes, slip rings, and commutators, all of which contribute to maintenance costs. This is a very real limitation for certain high-speed applications. High-speed spinning devices, for example, must operate from 8000 to 10 000 rpm, speeds that would destroy brushes and commutators in a very short time.

In locations subject to adverse atmospheric conditions, such as acid or water mists, hydrogen sulfide, or occasional steam vapors, the a-c adjustable-frequency drive shows to even greater advantage because there are no brushes, commutators, or slip rings on the a-c motors that are mounted at the machine.

Another timely example is the "canned" motor-pump used widely for nuclear-power installations, where no connection is permitted between stator and rotor. In this case, adjustable-frequency control of even a single motor was the only practical scheme.

The basic elements of an adjustable-frequency drive are shown in Figure 1. This system is used for a merchant and rod-mill run-out table in a steel mill. All of the table motors are energized from the adjustable-frequency a-c generator, which in turn is driven by a d-c motor energized from the plant bus. The d-c motor is started at full field by armature-resistance control, and its speed is controlled by field weakening. The motor-operated rheostat for the motor field has a rheostat plate for the a-c generator field also, which provides for over-excitation at the low-frequency end of the range to provide more torque. The a-c table motors are started at low frequency across the line. At the same time the generator field is over excited momentarily to provide the additional excitation needed to take care of starting conditions.

Speed changing after the motors are running is accomplished by manipulation of a master switch that controls the motor-operated rheostat. When stopping the drive, the motors are brought to low speed by frequency control and then coast to rest after the a-c line contactor opens. Other drive systems having more precise methods of control are commonly used but these represent refinements of the basic system shown here.

Drive Motors

When an adjustable-frequency power supply of the proper characteristics is provided, squirrel-cage induction and synchronous motors will operate over a wide speed range with essentially constant torque capability. This permits the simple construction of the squirrel-cage or similar synchronous motor to be combined with the flexibility of an adjustable-speed drive. The maintenance-free operation of squirrel-cage induction motors and reluctance-type or permanent-magnet synchronous motors have permitted machinery designers to lay out machines for greatest operator convenience and efficiency. Regular maintenance requirements are reduced to a minimum since there are no brushes, slip rings, commutators, or contacts. By the use of switches or plug connectors, individual sections may be removed from production for repairs or replacement without costly unscheduled shutdown of the rest of the machine.

Synchronous motors are required where all sections must run at exactly the same speed, and where precise speed control is required. Synchronous motors lock into step with the supply frequency and at steady loads there is no speed error. The slip of the induction motor introduces a speed error that is dependent on the load and will exist even though the control of frequency is perfect.

Adjustable-frequency drives using induction motors are desirable when various driven-machine sections need not be driven at exactly identical or precisely controlled speeds. The inherent slip of induction motors provides excellent load division between sections of a machine tied together by the machine or the product.

Adjustable-Frequency Supply

In all but very special applications, the adjustable-frequency supply consists of either a synchronous generator, or an induction frequency changer, driven by an adjustable-speed drive. The drive may be a d-c constant- or adjustable-voltage drive, mechanical or hydraulic adjustable-speed drive, or an a-c adjustable speed drive. Other types of drive may also be used, the selection depending upon speed range, horsepower requirements, torque characteristics of the load, regulation and control requirements, and other such considerations as space, maintenance, efficiency, and installation cost.

A synchronous generator is desirable when the adjustable-frequency system must start from rest as a complete unit and accelerate together. Also, a synchronous generator is most economical and practical for obtaining low frequencies in the range of 40 cycles and lower. Excitation for a synchronous generator comes from a d-c supply. The generator field is excited at a relatively fixed value, and therefore the voltage generated is approximately proportional to the speed; frequency is exactly proportional to speed.

Since a wound-rotor induction frequency changer has an output frequency at standstill equal to primary frequency, it is less suitable than a synchronous generator for starting drives by variable-frequency control. The induction frequency changer is generally best applied to drives operating above constant line frequency where the motors can be started at the operating frequency. The induction frequency changer is excited from the available a-c power supply; the output voltage and frequency result from the added effects of transformer action and rotation of the rotor. With fixed a-c excitation on the primary of the wound-rotor machine, the output voltage and frequency vary with speed of rotation, or slip.

Characteristics of Adjustable-Frequency Drive Equipment

All of the a-c machines in an adjustable-frequency system are capable of operating at essentially constant flux, over a frequency range. The voltage generated in the armature winding of an a-c motor or generator is proportional to flux and frequency. Therefore, if the iron is worked economically at a fixed value of flux, the generated voltage will be proportional to the frequency. The ratio of generated volts per cycle is the same at high or low frequency for constant flux. The terminal voltage of a motor is higher, and that of a generator is lower, by the amount of the internal impedance drop of the machine. Except for limitations due to reduced ventilation at low speed, the machines are capable of carrying the same load current over a wide frequency range. With fixed flux and constant load current, constant torque capabilities are obtained from the machine.

It is a characteristic of induction and synchronous motors that line and primary-winding impedance drops tend to limit torque at low frequencies. If the voltage is raised slightly at low frequency to overcome the IR drop in the primary winding and leads, an increase in torque is obtained. This voltage boost is readily obtained on the synchronous generators used for low-frequency applications. At frequencies above 60 cycles no boost is required.

The volts per cycle usually need not be raised more than 15 percent for minimum frequencies above 15 cycles. And for low-inertia loads, little or no boost is required. The minimum boost necessary to insure satisfactory operation should be used, since a raise in volts per cycle will adversely affect generator size and performance.

Although no standards exist for variable-frequency drive equipment, the inherent constant-torque and constant volts-per-cycle characteristics of motors and generators offer a sound basis for standardization. While the maximum and minimum frequencies vary widely with the application requirements, motors can all be rated on the basis of one of the standard motor voltages at 60 cycles—preferably 220/440 volts at 60 cycles, but possibly based on 55 or 110 volts at 60 cycles if voltage must be limited. Voltage limits may be imposed by safety considerations or by the voltage rating of distribution apparatus.

Standardization of volts per cycle for generators is basically the same as that for motors—1, 2, 4, or 8 volts per cycle. This allows the use of basic 60-cycle generator designs, which in the case of large generators with a small number of turns per coil is a real advantage, since these designs are somewhat inflexible. The generator voltage rating should be slightly higher than that of the motors to offset line drop. Standardization of kva per cycle is not proposed because the requirements of various types and sizes of machines are so different.

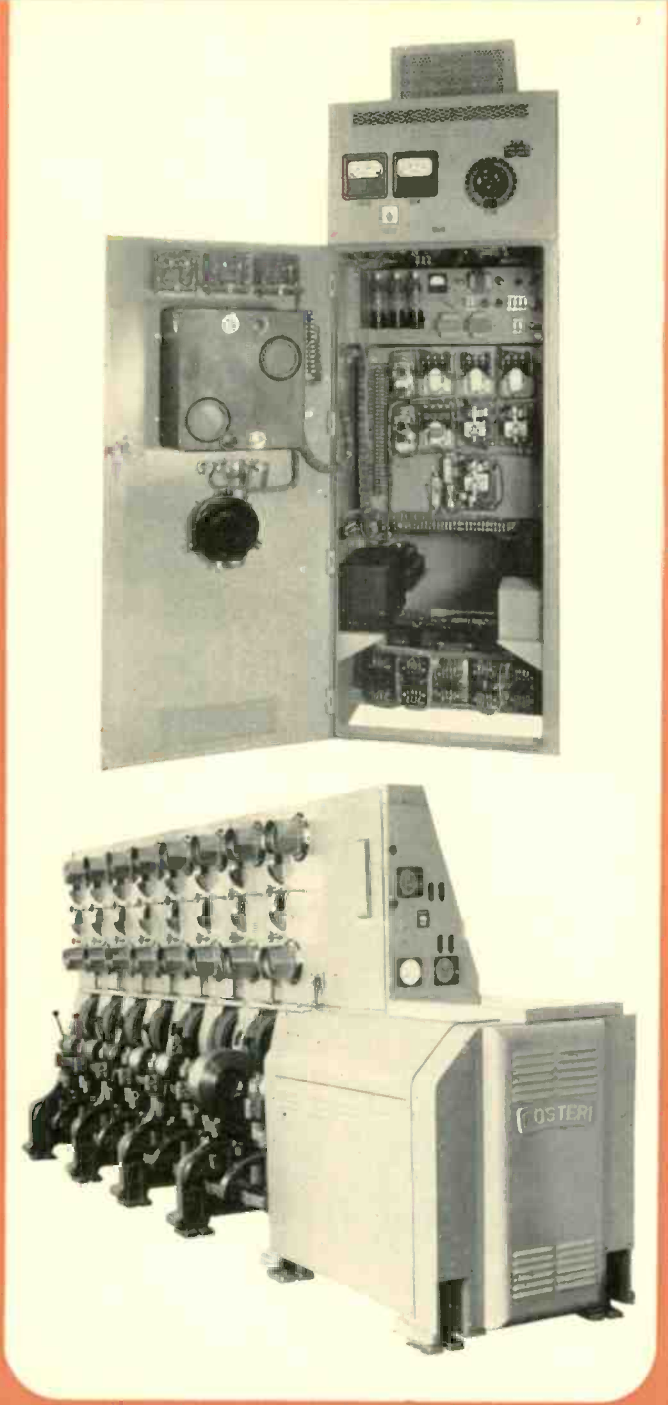
A 15-percent boost in volts per cycle requires no major change in generator electrical design. Field heating is the limitation in operating over a speed range because of the reduced ventilation at low speeds and greater losses due to volts-per-cycle boost at low speed. Except on some rotating-armature generators, forced ventilation is required for cooling at speeds below about 600 rpm.

Similarly, since both induction and synchronous motors have constant-torque characteristics, the horsepower capability will vary with the frequency. Selection of motor horsepower rating on a basis of the equivalent capacity at 60 cycles is desirable. For example, if a section of a machine requires 4.3 horsepower at 3850 rpm, the equivalent 4-pole, 60-cycle motor capable of the same torque output would be rated 2 hp at 60 cycles and 1750 rpm. The frequency at top speed would be 130 cycles, and the voltage would be 477 volts, corresponding to 220 volts at 60 cycles.

This rating method permits use of standard 60-cycle induction and synchronous motors and reduces the special design work required for an adjustable-frequency drive, which ultimately results in savings to the user and quicker deliveries. Generators for the higher frequencies must, of course, be checked for mechanical strength to withstand the higher centrifugal forces at higher speeds.

Starting Methods

The motor-starting method for an adjustable-frequency drive system depends on the particular requirements of the application, and the limitations of the power supply. The available starting methods commonly used are (1) adjustable-frequency starting, (2) across-the-line starting at any frequency, or (3) reduced-voltage starting at any frequency. Since reluctance synchronous motors have greater starting torque and current than squirrel-cage induction motors of the same horsepower rating, the size of the a-c generator for line-starting a reluctance motor must be greater than for induc-



Two basic elements of a nylon spinning-machine drive: the control cabinet (above, left) for the adjustable-frequency drive contains an electronic regulator panel for precision frequency control; the eight-position winder (below) has each feedwheel individually motored and regulated by the adjustable-frequency supply.

tion motors of the same horsepower. However, since the reluctance-motor starting and accelerating torque is high at rated voltage, reduced-voltage starting can be used even when full-load or higher torque is required to break away from static friction of the load.

A typical situation illustrating two methods of starting is a machine having several tandem components, each driven by synchronous motors powered from the same source. When starting such a machine, all sections should be started together and brought up to an initial speed suitable for threading or other operations preliminary to steady operation. As the generator speed increases, the voltage and frequency also increase until the synchronous motors develop enough ininduction-motor torque to break away static friction of the load. The motors then gradually accelerate, lagging behind the generator speed by an amount sufficient to develop the necessary torque, until a high enough voltage and frequency are attained to cause the motors to pull into step. This must occur below threading speed in order that the machine sections run at the proper exact relative speeds suitable for the preliminary operation. Earlier speed differences during acceleration to preliminary operating or threading speed are not a disadvantage at that stage.

Adjustable-frequency starting of the entire machine is the most economical. No increase in generator kva or kw rating is required over running requirements and no increase in generator drive size is required to take care of this starting method. Across-the-line starting, even if it could be used, would require a bigger generator and drive.

After all motors are running in synchronism at threading speed and all preliminary operations have been completed, speed is gradually and smoothly raised to production speed. The a-c generator field is over-excited during acceleration to provide increased voltage and pull-out torque.

The second method of starting is illustrated by a situation that may prevail in certain kinds of tandem-driven equipment. For example, given a machine consisting of two sections, it may be desirable to keep the first section operating at production speed while cleaning or adjusting the second section. The second section can be shut down with the multiple synchronous-motor drive. After the interruption, this part of the machine can be restarted at production speed and frequency. Motors of 20 percent of total horsepower are started across the line, with the generator field over-excited to minimize voltage drop. Starting inrush is greater than full load on the generator and causes an appreciable impact speed drop on the system, which is not objectionable in this application.

Recent drive systems have included single-step primary reactor starters to limit current, and particularly the watts inrush upon starting the motor. A reactor has the desirable characteristics that its reactance varies with frequency and that its power factor is low. The impedance drop is approximately in phase with motor voltage under locked conditions at any frequency. A reactor selected to limit starting current to a given value at the high-frequency end of the speed range inherently allows approximately the same inrush current to flow at lower frequencies.

A resistance starter, on the other hand, provides a voltage drop in proportion to the current, and results in greater limit-

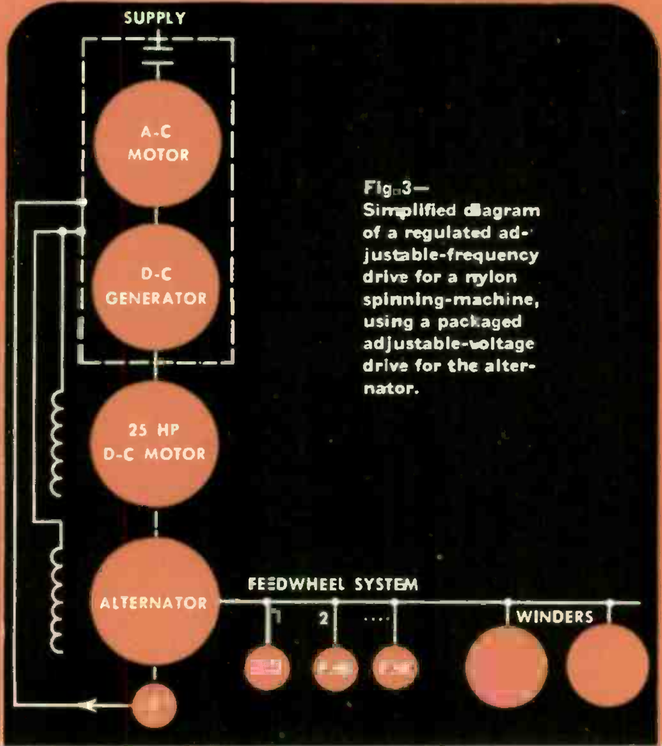


Fig. 3— Simplified diagram of a regulated adjustable-frequency drive for a nylon spinning-machine, using a packaged adjustable-voltage drive for the alternator.

ing action at low frequency. Furthermore, the addition of resistance to the primary circuit of a motor for reduced-voltage starting may actually increase the watts drawn from the line and thereby make the impact speed drop worse rather than better.

Another method of starting employs a motor driven by a continuously adjustable autotransformer. The motor is connected to the autotransformer at zero volts and the motor voltage gradually increased until the torque is sufficient to start the load. The voltage continues to increase until the motor is transferred to the line at 100-percent voltage. In special cases the voltage may be raised above line voltage for pulling high-inertia loads into synchronism and then reduced to line voltage for running continuously. The motor-driven autotransformer is used principally on drives where the impact speed drop must be limited to an extremely small value.

A fixed-tap autotransformer can also be used for motor starting at any operating frequency on an adjustable-frequency system. It has the advantage of lower kva demand than a reactor, but has the disadvantage of requiring more elaborate switching. A reactor starter inherently provides closed-circuit transition. When synchronous motors are used, regardless of the starting method, full voltage is required when pulling into synchronism. Reluctance-synchronous motors exhibit the characteristic that pull-in torque varies as a power between the square and cube of applied voltage. A 10-percent reduction in voltage at the motor can, therefore, cause a 25-percent reduction in pull-in torque. During pull-in, the motor may draw three times full-load current so that any impedance drop in the generator, motor, and motor leads will be accentuated. At low frequencies, the line drop and motor-winding IR drop is a greater percentage of applied voltage than at high frequency. The volts per cycle at the low-frequency end of the speed range is usually raised to overcome the IR drop and provide full synchronizing torque. Such loads as pumps having lower torque requirements at low speed require little or no boost in volts per cycle at the motor.

Braking Methods

Since squirrel-cage induction and reluctance synchronous motors are most commonly used on adjustable-frequency drives, dynamic braking for quick stops can be obtained by applying d-c excitation to the motor windings from a low-voltage rectifier or other source of direct current. For example, in the tandem-driven machine referred to above, the second section is stopped quickly from any production speed in an emergency by d-c dynamic braking. Very high braking torques can be obtained by sufficient d-c excitation, and there is no tendency to reverse or coast. The d-c excitation is removed by a timing relay after the motor has had time to stop.

If the entire adjustable-frequency drive must be braked to a stop, it is sometimes convenient to use regenerative braking, which is achieved by reducing the supply-voltage frequency rapidly. This is done by braking the supply generator drive. The braking method employed depends on the actual conditions and requirements. The adjustable-frequency drive system lends itself to a variety of braking methods.

For starting, running, and stopping, the adjustable-frequency drive has many advantages to offer for group drives. Machine layout and operator convenience are often simplified by motorizing individual machine sections, and integrating their operation by means of frequency control. As industry continues toward more coordinated drives, adjustable-frequency finds more and more usage as the most practical method of system control for group drives. ■

The reluctance motor can be satisfactorily applied to either constant- or adjustable-frequency operation. It is ideally suited to applications where many small synchronous motors can be operated from a common-frequency supply; motor speed is set by adjusting the supply-voltage frequency.

Reluctance Motors for Adjustable Frequency Drives...

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THE PHENOMENAL GROWTH of the man-made fiber industry in the past ten years has given great impetus to the use of small synchronous motors for adjustable-frequency drives. The reasons for this are fundamental. A machine spinning fiber of a given denier may have a great number of positions, each producing many filaments composing a strand of yarn. Each position must operate at exactly the same speed to obtain uniformity of yarn. Many gears, shafts, clutches and other mechanical parts would be required to hold each position speed the same mechanically. To accomplish this electrically, many small synchronous motors can be operated from a common frequency supply to drive the various loads, such as feedwheels, pumps, and winders. Since different spinning-machine speeds are necessary for the various deniers of yarn, the supply alternator frequency is adjusted to set different synchronous speeds for the motors.

The most prevalent type of synchronous motor used for this application is the reluctance motor. Thousands of these motors have been used because of their inherent ruggedness, simplicity, and low cost. In addition, the reluctance motor is practicable for ratings ranging from small fractional horsepower ratings up to 10 hp. Even larger ratings can be built, but the size and cost may make an excited salient-pole type more economical.

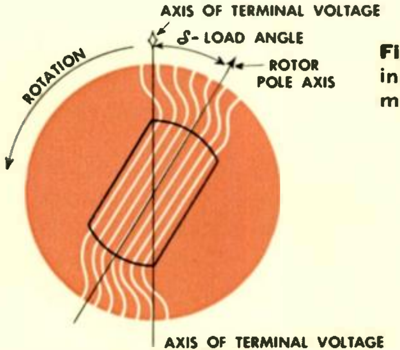


Fig. 1—Sketch illustrating how the reluctance motor develops torque.

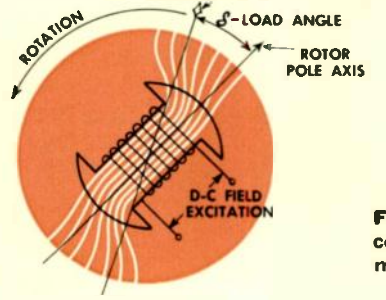
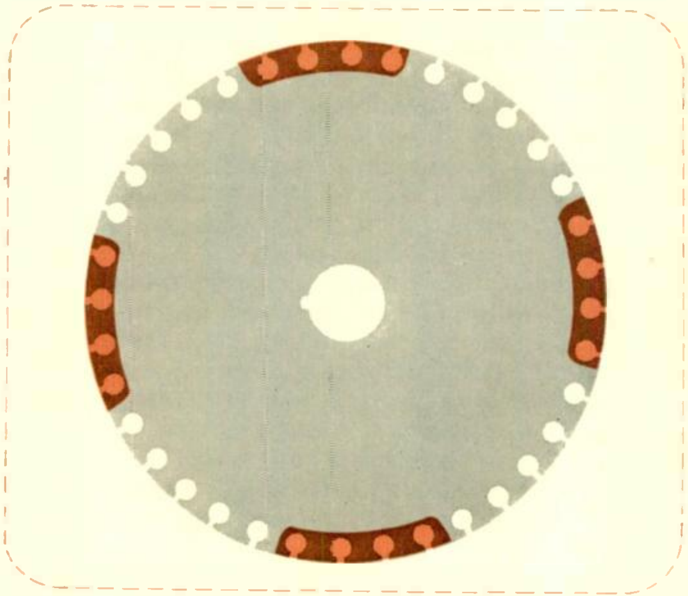


Fig. 2—Sketch shows how conventional synchronous motor develops torque.



Typical rotor lamination for a reluctance motor can be derived from an induction-motor punching by cutting away colored areas to form salient poles on the uncut surfaces.

The physical appearance and construction of the reluctance motor is essentially the same as that of a standard squirrel-cage induction motor, except that the reluctance motor is often somewhat larger for a given rating. The appearance of the stator, its winding, and the external appearance are the same as that of a squirrel-cage motor. The fundamental difference lies in the rotor design. Salient poles are created on the reluctance-motor rotor by removing some of the iron. Actually, a squirrel-cage rotor can be converted to reluctance operation by a very simple machining operation. If a standard squirrel-cage rotor is milled to give flat sides corresponding to the number of stator poles (above, right), the motor will run as a synchronous reluctance motor. The machining of "flats" on the rotor, in effect, forms salient poles at the unmachined surfaces. At these poles, the reluctance of flux to cross the air gap is substantially *less* than at the "flats," where the air gap is much larger. The result is that the magnetic flux crossing the air gap gathers at these poles, tending to lock the rotor poles in synchronism with the stator field. When an external load is applied, the rotor drops back in angular position with respect to the stator field, just as with a conventional synchronous motor. This produces a net pull with a tangential component which is effective in producing torque at the motor shaft (Fig. 1). Of course, this is not a particularly efficient design, and as a result the motor rating will be substantially reduced.

Perhaps a comparison of this operation with that of an excited-field, salient-pole motor will be helpful. When direct current is applied to the field winding of a synchronous motor, the reaction of the rotor and stator flux components that produce torque is as shown in Fig. 2. If the d-c field is strong enough to supply more than the necessary motor excitation requirements, the motor returns magnetizing current to the power supply at a leading power factor. Under these conditions the torque capacity of the motor is high. However, if the d-c field is weakened to the point where it will not supply all of the necessary motor excitation, then additional excitation is drawn from the a-c line at a lagging power factor. Under these conditions, the torque capacity of the motor is greatly reduced. If the field is weakened still further, and removed entirely, then all of the excitation must come from the a-c line at lagging power factor. Now the motor can carry only a small load torque. The torque thus developed is caused by the "reluctance" torque described previously. Such a reluctance motor will have a relatively small torque rating for a given frame size, and will operate at relatively low power factor.

In practice the motor designer can select certain design factors to produce improved performance over that just described. The fact remains however, that reluctance motors seldom operate at power factors exceeding about 60 percent;

with high-inertia loads, and especially when used for adjustable-frequency operation, the motor power factor may go below 40 percent.

Application Factors

The problems of applying reluctance motors are essentially the same as for ordinary synchronous motors with d-c field excitation. Since reluctance torque is much weaker than torque developed with rated d-c excitation, the requirements of each particular application must be well known. Some of the most important factors that should be considered are (1) load inertia, (2) pull-in torque, (3) pull-out torque, and (4) motor full-load torque.

Load inertia and *pull-in torque* are closely associated because both influence the synchronizing operation of the motor. Pull-in torque of a synchronous motor is the maximum constant torque under which the motor will pull its connected load into synchronism, at rated voltage and frequency. The speed to which a motor will bring its load depends on the power required to drive the load; whether the motor can pull the load into step from this speed depends on the inertia of the revolving parts. Thus the pull-in torque cannot be determined without knowing the load inertia as well as the load torque. The transition to synchronous operation from squirrel-cage operation is important and deserves close attention. During half of the angular motion of one rotor pole relative to a pole of the rotating field, the reluctance torque aids acceleration of the rotor. During the other half of this relative motion, it opposes the acceleration. The load must be accelerated into synchronism with the magnetic field during the torque-aid portion of this angular motion.

When the motor runs close to synchronous speed, even as an induction motor, the relative motion between poles is slower. This affords more time during which the poles are favorably aligned, and facilitates synchronism. Also, the required increment of speed-up to synchronism is smaller, thereby requiring less accelerating torque. By the same reasoning, a large inertia requires more pull-in torque to synchronize within the same time interval. The relationship between pull-in torque and load inertia can be seen from Fig. 3. For example, consider a motor designed for 170-percent pull-in torque based on its own rotor inertia of 0.33 lb-ft^2. If this motor must drive a load whose inertia (reflected to the motor shaft) is 2.0 lb-ft^2, the ratio of total inertia to motor inertia is 6.0. From the curve, the reduction factor is 0.41. The net pull-in torque developed by this drive is expressed by the relationship:

$$\begin{aligned} \text{P. I. T. with external inertia} &= \text{Reduction factor x P. I. T.} \\ &\qquad \text{without external inertia} \\ &= 0.41 \text{ x } 170\% \\ &= 68\% \end{aligned}$$

If the application requires that 100 percent of full-load torque be pulled into synchronism, then this motor will not be adequate. On the other hand, if the load is a machine that can be started at light load or no-load, then a 68-percent pull-in torque is suitable.

Pull-out-torque is the peak load torque that the synchronous motor can carry without losing synchronism. For steady loads such as many types of pumps, the required pull-out torque will be essentially full-load torque. Other loads may require high pull-out torque compared to their running torque. The pull-out torque must be sufficiently large to prevent loss of synchronism. In contrast to pull-in torque, load inertia has little effect on pull-out torque, since a change of load speed is not involved.

The *running-torque* requirements of the load must also be known. The closer a motor can be applied to pull-out, the better will be the power factor and efficiency. With an ordinary squirrel-cage motor, power factor and efficiency drop off substantially as the motor is unloaded. As shown in Fig. 4, the effect is even more pronounced with reluctance motors.

To summarize, low inertia, low pull-in torque, and low pull-out torque all help keep motor size small and performance good. For example, compare two 0.33-hp reluctance-motor designs, one for 170-percent pull-in torque and the other for 200 percent. The first has a power factor and efficiency of 45 and 72 percent respectively, while the second has 35 and 67 percent respectively. These figures are based on

Fig. 3

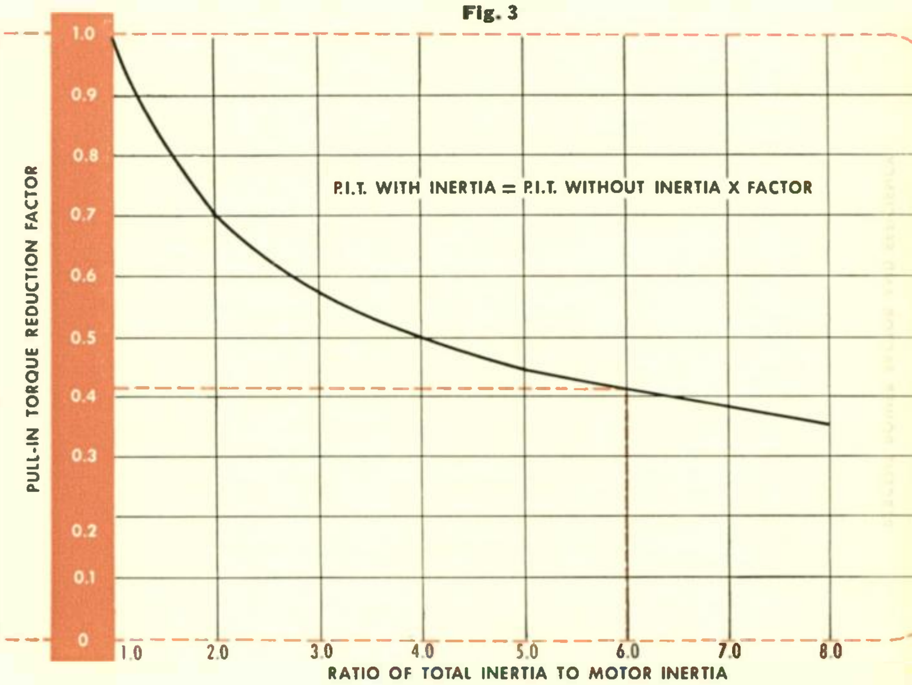


Fig. 3—This curve shows the relationship between the load-inertia effect and the reduction in motor pull-in torque.

Fig. 4—These curves show the variation of power factor and efficiency of a reluctance synchronous motor with loading.

Fig. 5—Motor-terminal voltage should vary almost directly with frequency.

negligible external load inertia, since in this particular case, a large gear reduction was involved. Without the gear reduction, the reflected load inertia would have been appreciable and a larger motor frame size would probably have been required to develop sufficient pull-in torque for synchronizing. This would have resulted, not only in a larger motor, but in a reduced power factor and efficiency as well.

Adjustable-frequency Factors

The considerations discussed previously are general ones pertaining to normal application of reluctance motors. These principles apply to both adjustable-frequency operation and constant-frequency operation. For the adjustable-frequency case, however, two additional points should be examined—torque and thermal capacities.

Torque capacity depends on the motor excitation or flux density. This is easily visualized since a greater flux density at the rotor poles means a stronger pull to keep the rotor turning. If the motor can be made to operate with the same flux density at all frequencies, then the torque capacity is unchanged. Translated into application factors, this is accomplished by keeping the volts-per-cycle approximately the same for all frequencies. For ranges up to 3 or 4 to 1, this results in keeping the flux density about constant. Thus if a motor is designed for 220 volts at 60 cycles, it should be operated at 330 volts at 90 cycles, or 110 volts at 30 cycles, with proportional voltages for intermediate frequencies as shown in Fig. 5. This can be inherently achieved by maintaining constant d-c excitation on the alternator which supplies the adjustable-frequency power.

If a wider range of frequencies is to be employed, especially a range extending to quite low frequencies, special refinements are necessary. Constant volts-per-cycle is no longer adequate to develop constant torque because of the effect of

This reluctance synchronous motor is being tested for vibration or noise prior to use.

Fig. 4

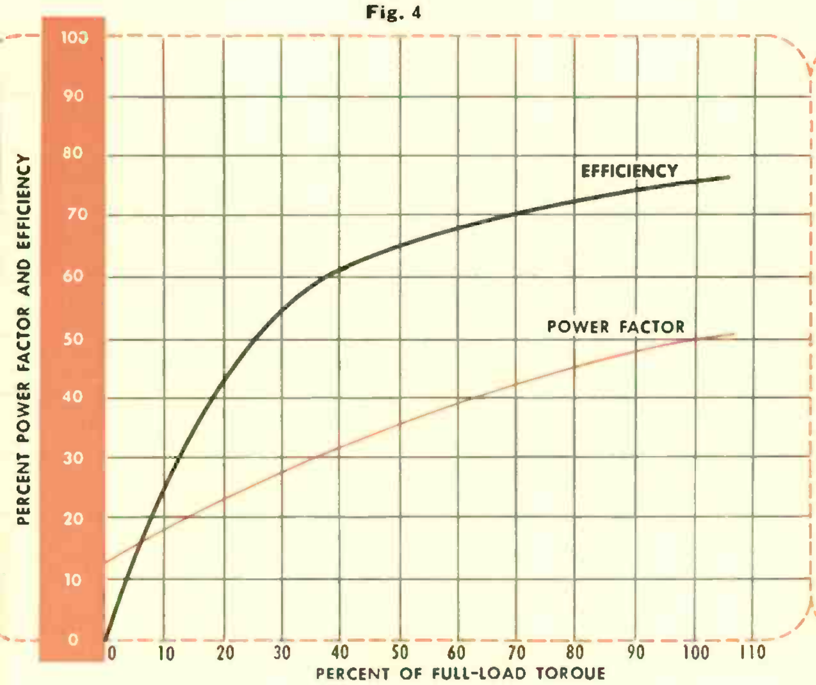
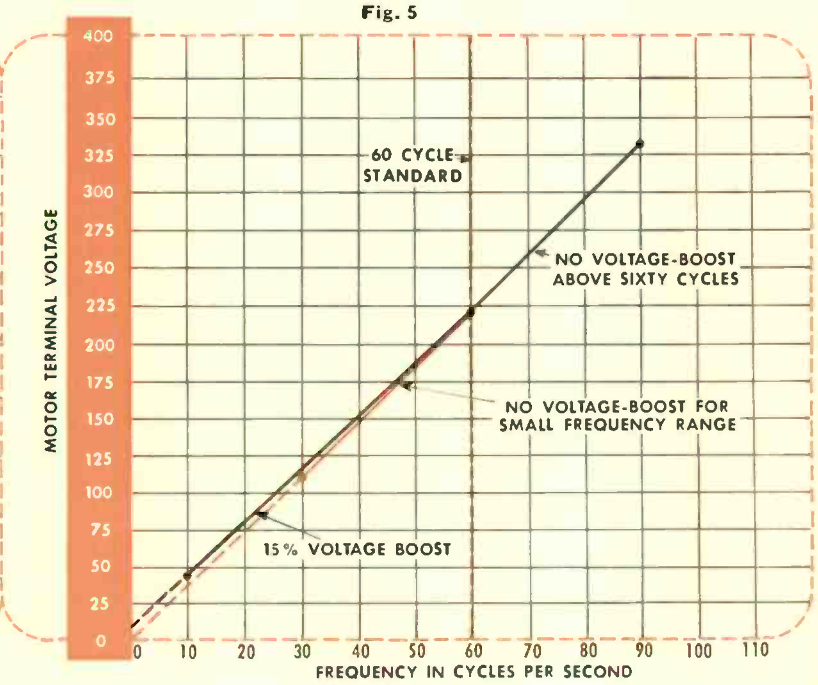


Fig. 5



voltage drops, which become appreciable at the lower voltages. Normal voltage drop in motor leads may reduce the motor terminal voltage below the proper value. If frequency and voltage are already low, then a few volts of line drop can be an appreciable percentage of the total. In addition, the high synchronizing current drawn by a reluctance motor will cause an internal voltage drop in the motor, which can be sufficient to affect the pull-in process. This, too, is most pronounced at low frequencies where the applied voltage is low.

To overcome both of these difficulties, the volts-per-cycle ratio can be boosted at the lower frequencies (Fig. 5). A voltage boost of 10 to 15 percent is common for drives covering a range of 7 to 1 or more. This amount is sufficient to overcome voltage drop and to provide a margin of excess torque for synchronizing. However, the extra voltage results in additional exciting current, which in turn reduces power factor and efficiency somewhat. Therefore, judgment must be used to determine a proper compromise. If the load torque requirements are less at low speeds than at higher speeds, then little or no voltage boost will be required for frequencies down to about 10 cycles or more.

The thermal considerations of adjustable-frequency operation involve two points: (1) the ability of the motor to dissipate heating losses at different speeds, and (2) the magnitude of losses generated at different frequencies. The ability of the motor to dissipate heat depends both on the enclosure and the amount of ventilation available. Ventilation of an open motor falls off rapidly with speed because of the decreased fanning action. A totally-enclosed motor, on the other hand, will dissipate about the same heat at all speeds since there is negligible cooling due to convection. Because of the reduced amount of total heat dissipation for this enclosure, totally-enclosed non-ventilated motors are seldom used except where atmospheric conditions make it imperative. Even then, fan-cooled motors are usually recommended for drives operating well above 60 cycles since the cooling action is good at high speeds where the core loss is high. At very high speeds, a fan-cooled motor tends to lose efficiency because of the excessive fan loss that is incurred.

Internal losses generated by the motor include mechanical loss, stator copper loss, and iron loss. The mechanical loss, which includes friction and windage, usually drops off rapidly with decreasing speed. For a constant-load torque, the stator copper loss is approximately constant for all speeds since the motor current is relatively constant. This loss may be increased at low frequencies if substantial volts-per-cycle boost is employed. In adjustable-frequency operation, the iron loss usually falls off rapidly with decreasing frequency.

To determine the thermal capacity of a motor for adjustable-frequency operation, a balance between heating losses and cooling ability must be made. A check of the high and low operating points will usually be sufficient. If the top frequency is much over 90 cycles, core loss may be so great as to present the limiting condition.

For most applications, however, the low-frequency point is the critical one, because motor cooling falls off more rapidly than do the losses. Thus, from the standpoint of both heating and torque considerations, the low-speed condition is a very important case.

Conclusions

A thorough knowledge of the load to be driven, including inertia and torque requirements, can result in a satisfactory application of reluctance motors to either constant- or adjustable-frequency operation. While conservatism is prudent, it can also be expensive when selecting reluctance motors for an adjustable-frequency drive. Using a motor that is larger than necessary will result in low power factor and efficiency, and will increase the size of the variable-frequency supply alternator. Also, the size of the drive equipment for adjusting alternator speed will be increased.

Wherever possible, load tests of a particular application should be made; the cost of the investigation can be paid for many times by savings in initial cost of the drive equipment. Where load tests are not possible, there is no substitute for good judgment. And a knowledge of the influencing factors in the application of the reluctance motor will make it easier for the user to determine his needs. ■

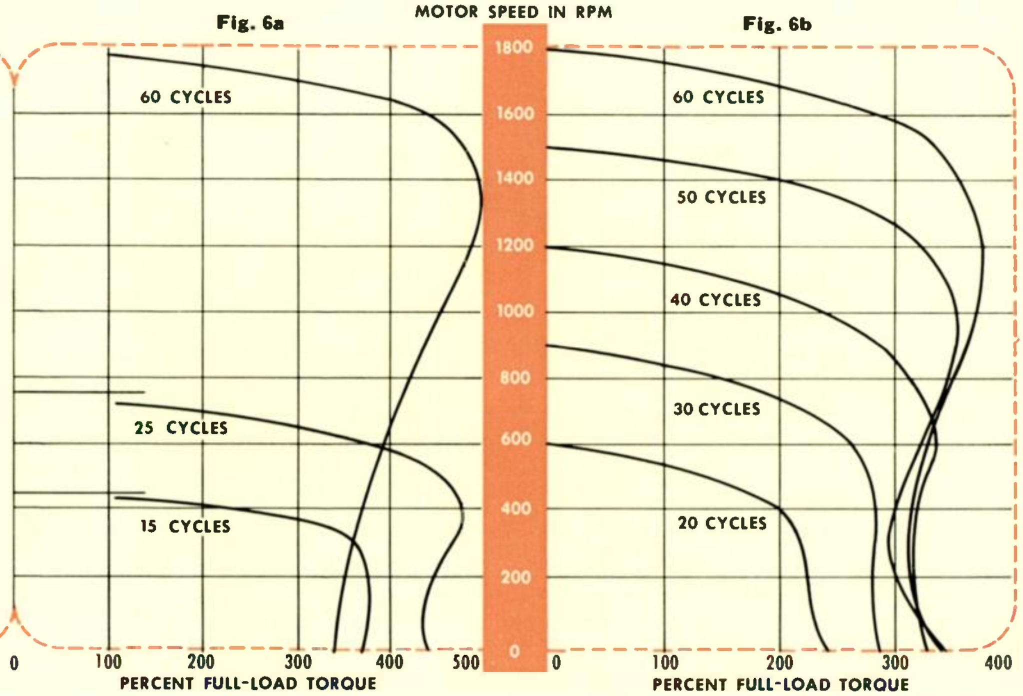


Fig. 6a—Synchronous reluctance motor speed-torque curves for different operating frequencies.

Fig. 6b—Induction motor speed-torque curves shown for five different operating frequencies.

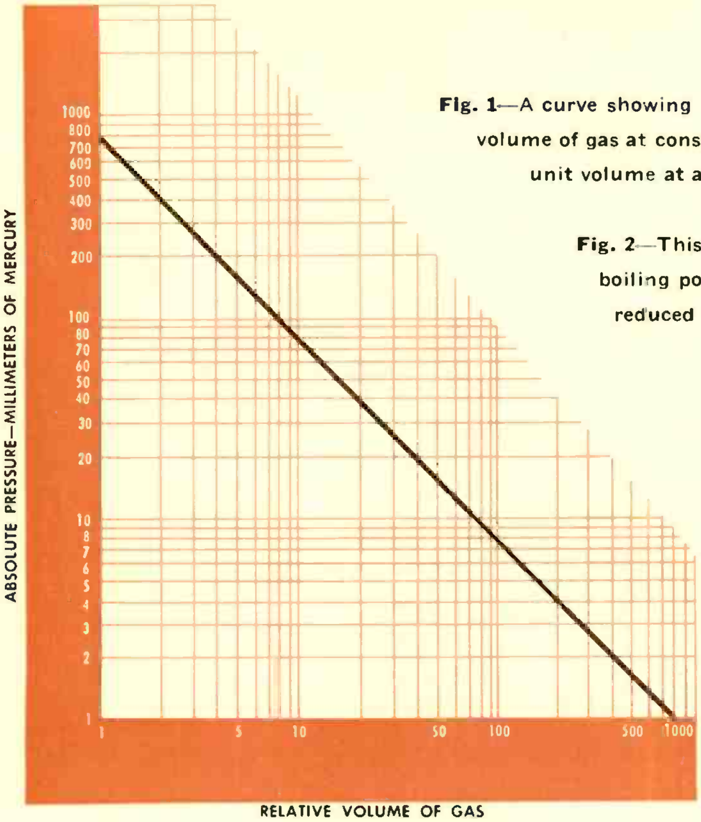


Fig. 1—A curve showing absolute pressure and relative volume of gas at constant temperature based on unit volume at atmospheric pressure.

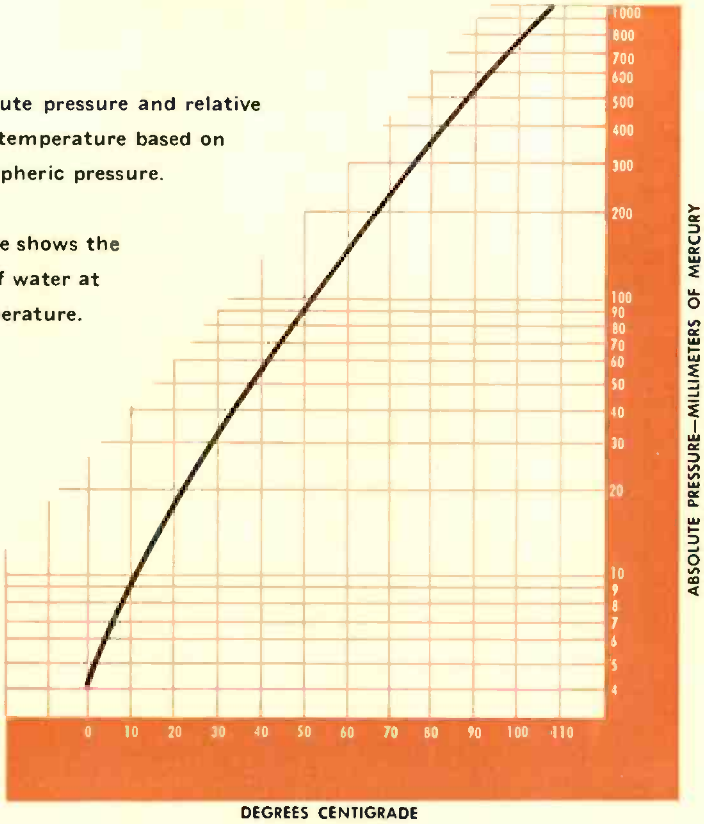


Fig. 2—This curve shows the boiling point of water at reduced temperature.

The transformer tank serves as the "oven" for vacuum drying in this new method. It is suitable for either field or factory use. Here's how it works.

Vacuum Drying of Large Power Transformers

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■ ALL POWER TRANSFORMERS must be vacuum dried before being filled with oil, to rid the core and coils of moisture and gases occluded in the insulation. Until recently, the conventional method was to oven dry the core and coils and then place them in the tank for vacuum oil impregnation. A new method is to vacuum dry the complete transformer in its own tank; this method, first applied in manufacture, has now been adapted for use in the field.

The new method provides one answer to the growing problem of adequately drying larger and larger units in the field and in repair shops. It is faster than the conventional method, and also results in considerable reduction in insulation power factor and an increase in insulation resistance.

Theoretical Considerations

The primary purpose of vacuum drying is two-fold: to remove moisture, and to remove as much occluded gas as possible at a reasonable cost. The transformer is heated to store heat in the insulation, the coils, and the punchings. This stored heat provides heat of vaporization for the water removed during vacuum drying and increases the water-vapor pressure, thus accelerating the vacuum-drying process.

Removal of the gas occluded in crevices among insulation fibers is essential for thorough oil impregnation, in the short time available for oil penetration before dielectric tests are made. The expansion of gas in these small spaces assists in extracting moisture. The curve in Fig. 1 shows expansion of gas with reduction in pressure based on unit volume at normal atmospheric pressure. In normal vacuum drying and filling operations, the maximum absolute pressure is 10 millimeters of mercury. This corresponds to an expansion of 75 times the original volume at atmospheric pressure. The normal finishing range of the pressure is five to six millimeters with corresponding expansions of 125 to 150 times the atmospheric volume.

The reduction in pressure produces a corresponding reduction in the boiling point of water, thus expediting the drying. The relationship between pressure and boiling point is shown in Fig. 2. Thus, at 10 millimeters absolute pressure the boiling point is only 12 degrees C, while at five millimeters it is only 1.75 degrees C. Obviously, by maintaining the vacuum for a sufficient period, with room temperatures of about 20 degrees C, the desired amount of water can be removed.

Considerable cooling takes place as the vacuum drying proceeds, and can present a real problem if the transformer is not preheated. The amount of water extracted by vacuum application may be as much as 20 gallons. This would be approximately 190 000 Btu of heat removed by the vaporization of the water alone. Other sources of heat loss contributing to the reduction of temperature are the radiation and convection from the tank, and the heat removed in the air pumped from the transformer.

Condensation, or the deposition of water, can occur under two conditions of primary interest in drying transformers and the associated problem of keeping them dry after they have been properly processed. The condition most familiar to everyone is that occurring when moist warm air comes into contact with a cool dry surface. The moisture condenses from the air and appears as a fairly uniform film over the cold surfaces (see supplement to article, below).

The second condition arises when air is cooled rapidly to below the dew point, at which time moisture condenses causing fog or dew on surfaces that may be warmer than the surrounding air. This could happen in a transformer when the vacuum is relieved (see supplement).

Ambient air must therefore be prevented from entering the transformer to relieve the vacuum. The transformer can be filled completely with oil and a sufficient quantity of oil drained from the unit after the vacuum is relieved to obtain the proper oil level. However, the most satisfactory method to relieve the vacuum is to admit dry nitrogen to equalize the pressure in the gas space with that of the ambient atmosphere.

The vacuum, to be effective for initial impregnation of fibrous insulating material, should be high. An absolute pressure below ten millimeters of mercury is essential.

The Method

In the new field drying method, transformers are heated by circulating hot air through the winding and insulation using an external air heater. The tanks are then sealed and a vacuum of 10 millimeters of mercury or less absolute pressure is drawn. After drying and before relieving the vacuum, the transformer is filled with oil.

Typical heating time is from 40 to 50 hours followed by vacuum applied for a minimum of 42 hours.

Drying Equipment

A forced-air system is used with steam-to-air heat exchangers. The temperature of the air leaving the heat exchanger is controlled by a simple on-off thermostat and a solenoid valve in the steam supply. Massive volumes of air are introduced through all openings in the bottom of the tank and allowed to vent through the manhole. The fan air delivery can be estimated as 15 cubic feet of air per minute for each square foot of transformer tank surface. This includes the top

Some Pertinent Facts About Moisture Condensation

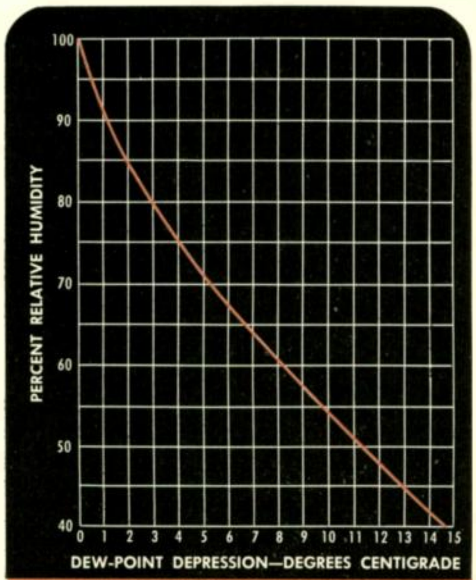

Fig. 3

Curve showing dew-point depression in degrees Centigrade (range from 10 degrees C to 45 degrees C) vs. percent relative humidity. Dew-point is equal to ambient temperature in degrees centigrade minus dew-point depression.

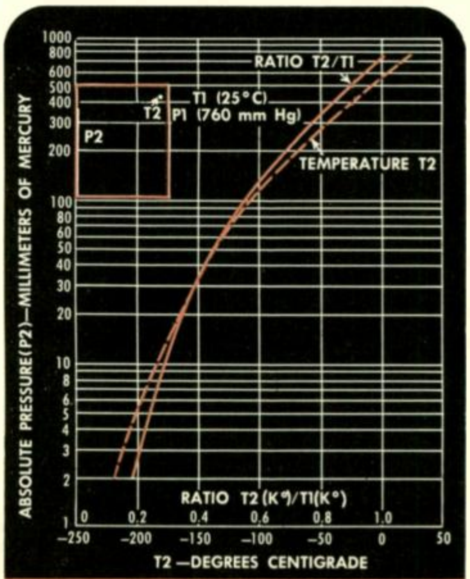

Fig. 4

This shows the adiabatic expansion of air from normal pressure to lower pressure, or air temperature variation when vacuum is relieved on transformers with ambient air at 25 degrees C and 760 mm mercury.

THE PHYSICAL CONDITIONS resulting in moisture condensation from the air are simple and fairly common. Whenever moisture-laden air is cooled below the dew point, water condenses on all adjacent or surrounding surfaces. The condensation takes place regardless of whether the surface is cooler, the same temperature, or warmer than the air, unless the surface temperature is maintained high enough to heat the air layer adjacent to the surface above the dew point. If dew does form on a warm surface, it may disappear rapidly due to the heating of the air layer by the warm surface. The dew points for various relative air humidities and temperatures encountered are shown in Fig. 3. The range of the curve is from 40-percent to 100-percent relative humidity and from 10 degrees C to 45 degrees C ambient air temperature.

With a typical example, consider the first condition that may give trouble in the spring or fall seasons. The nights are cool and the days are warm and humid. A transformer has been standing without excitation for several days so that it is following the ambient air temperature. During the night the unit has cooled to 10 degrees C but the air temperature at 9 a.m. is 20 degrees C with 65 percent relative humidity. The transformer has warmed up to 15 degrees C. The conditions are: ambient air 20 degrees C, 65 percent humidity, dew point of, say, 18 degrees C. If this unit is opened, the warm moist air entering the gas space is cooled to 15 degrees C, or 3 degrees below the dew point, and moisture condenses out of the air and bottom areas but not the surface in cooling equipment.

The power required to heat the transformer can be estimated as 60 watts or 3.4 Btu per minute for each square foot of tank surface. These values are minimum and can be exceeded as the volume is self-limiting and the air-temperature is controlled.

The heat source must provide sufficient heat-transfer surface. It may consist of electrically-heated elements, providing the element temperature is low enough to prevent any accidental ignition of oil vapors. The maximum temperature of the heating elements should not exceed 150 degrees C. Electrically-heated elements are controlled by a contactor operated from the thermostat instead of the solenoid valve.

The air is heated at the blower or fan entrance to provide more uniform air temperature at the point of air delivery to the transformer. The thermostat bulb for temperature control is located between the transformer and the delivery side of the fan. The fan delivery is distributed from a plenum chamber by ducts constructed of domestic hot-air-heater distributing pipe.

Drying Procedure

The drying procedure is based both on theoretical knowledge and experience gained from field and factory drying.

First the transformer is heated until the insulation resistance values are the same for four consecutive measurements, two hours apart. Temperature of the hot air entering the transformer is limited to 115 degrees C average, but not over 120 degrees C maximum for dry insulation. This temperature is reduced to 100 degrees C average, not over 110 degrees C maximum for oil-soaked insulation. The lower temperature for oil-impregnated insulation is necessary to prevent spontaneous combustion, for which the threshold temperature is 120 degrees C. Good temperature control must be available to work safely as high as 110 degrees C maximum.

Second, the tank is sealed and a vacuum applied. The stored heat in the transformer structure furnishes the heat of vaporization for the water driven off. Absolute pressure in the transformer tank is reduced rapidly to below 10 millimeters of mercury. Pumping is continued until four consecutive measurements of insulation resistance, at two-hour intervals, are essentially the same. The transformer is then considered to be dry without unnecessary dehydration and consequent deterioration of the insulation.

And third the oil supply is connected and the transformer filled while an absolute pressure of 10 millimeters or less is maintained. The oil is sprayed in from the top of the tank in order to deaerate and dry the oil. The oil level should be raised a few inches above normal before the vacuum is relieved to compensate for the oil-level drop as the tank resumes its normal volume.

This method of drying has been applied a number of times in the field. In addition to the excellent results obtained, its use is attractive because of the relatively inexpensive and portable components, all of which are readily available. ■

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on the internal parts of the transformer. If the humidity had been lower or the transformer only 4 degrees C warmer no condensation would have occurred. Thus, the only safe rule to follow in opening sealed transformers is: a transformer should not be opened when its temperature is lower than the surrounding air; preferably, the transformer temperature should be higher than the air.

The first condition as described may give occasional difficulty, but precautions are generally used to prevent water condensation. However, since this is a question of humidity and temperature, if the conditions are known it is sometimes safe to open transformers when they are a few degrees below the ambient air temperature.

The second condition is more puzzling to most men installing or drying transformers using high vacuum. A typical experience is as follows:

The transformer has been heated to about 90 degrees C by circulating hot air through the windings. The air has been shut off and vacuum applied to the tank for 50 hours. The tank has cooled to 28 degrees C and the ambient air is 26 degrees C with a relative humidity of 80 percent. The transformer, according to insulation power factor and resistance measurements, is quite dry. The unit is filled with oil at 25 degrees C to the normal oil level. The vacuum of 25 millimeters of mercury absolute pressure is relieved and the manhole opened. Drops of water are observed on the inside of the tank cover and walls. The tank walls have been cooled to 25 degrees C by the oil—only one degree below the ambient—so the presence of the water seems very unusual.

The physical conditions resulting in condensation are not mysterious. The dew point is 26 minus 3 or 23 degrees C. The oil has lowered the tank wall temperature to 25 degrees C leaving only a 2 degrees C decrease in temperature necessary for water precipitation. In relieving the vacuum, the air expands essentially adiabatically into the gas space. The initial expansion could cool the entering air down to minus 160 degrees C, and then as the pressures equalized, the temperature of the expanding air would increase until the pressures are equal with only a small difference in temperature. However, the air in the tank is perhaps 10 degrees C cooler than the ambient air at 26 degrees C. This is 7 degrees C below the dew point so moisture is condensed out of the air onto all surrounding surfaces. The result is water droplets generally covering the inside of the tank walls.

The temperature variation of air expanding adiabatically into an evacuated vessel is shown in Fig. 4. As an example, if air at 25 degrees C was expanded into an enclosed space where no heat was added to the air and the expansion started at 10 millimeters absolute pressure in the vessel and ended when the ambient pressure and the vessel pressure were equal, the initial air just inside the expansion orifice would be at minus 185 degrees C. The average air temperature in the vessel at the end of the pressure equalization would be in the neighborhood of minus 30 degrees C. The final low temperature of the gas represents the work done in pumping the vacuum initially. In actual transformers, however, the tank wall and oil warm up the air. A 5 to 10 degrees C depression is the most that may be expected.

This depression of temperature means that relative humidities above 55 percent in the entering air may give trouble due to condensation when the vacuum is relieved by admitting ambient air. Condensation may be only a momentary condition since with humidities up to 75 percent the rate of moisture reabsorption by the air can be fairly rapid. The water may evaporate before the tank can be opened and all evidence is gone. On the other hand, relative humidities 80 percent or higher do not give rapid evaporation and the water droplets may persist for a long time. Thus, in some cases water is observed, causing some anxiety on the part of the man in charge of drying or filling the transformer.

The total moisture deposited in the above example would be 0.05 pounds per 100 cubic feet of gas space. This is about one fluid ounce of water and although it looks bad when distributed over the tank surface, perhaps not more than one-sixth of a fluid ounce is introduced into the oil. The water on the tank wall is evaporated by the air, particularly if some air is circulated in the gas space by a fan. The appearance of this water does not necessarily indicate that the transformer is wet.

An Engineering Personality

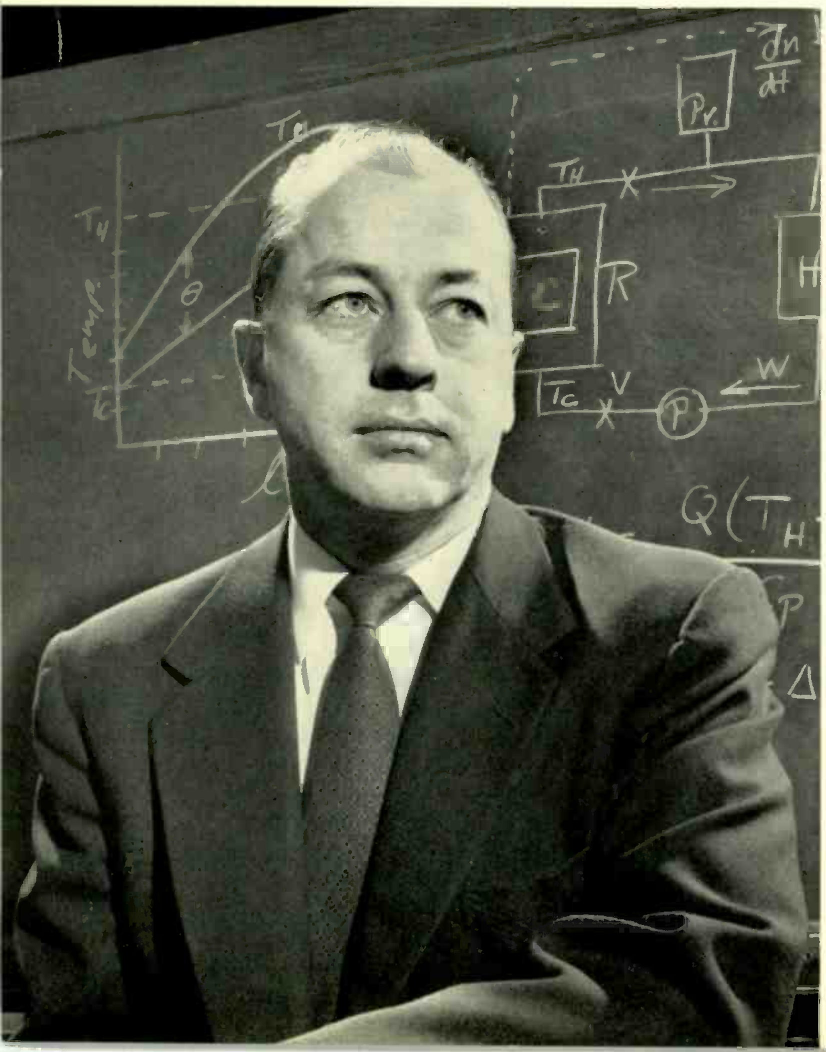
P. N. Ross

■ At the present stage of development, nuclear-reactor projects demand specialists from nearly every field of science and engineering. But to achieve the best results from such a diverse group of technical talent, there must also be others to formulate clear overall concepts of the systems and to balance and coordinate the efforts in the specialized fields. Such has been the job of P. N. Ross.

Phil Ross is one of the engineers from industry who got into the atomic-energy field on the ground floor. He was one of the group who worked and studied at Oak Ridge in 1946, where the early concepts for nuclear power reactors were being formulated. When the Westinghouse Atomic Power Division was formed in 1948, Ross was one of the first handful of men selected; he became the assistant director of research.

In 1950, the submarine project was getting well underway, and Ross was made manager of the general engineering subdivision, whose function was to develop the concepts of the power plant as a whole, including specifically the overall physical arrangement of the equipment in the submarine hull, and detailed design of all of the fluid system.

In 1951 Ross became manager of the newly established Project Department, which coordinated the entire submarine project. Here he had responsibility for the project engineering of the submarine prototype, and later for the early work on the *Nautilus* plant. In 1952, he became manager of the reactor department, which was responsible for the development and design of the reactor as a physical entity. This included responsibility for the thermal, mechanical, and hydraulic design of the reactor core, and design and procurement of the reactor vessel, control-drive mechanism, and fuel-handling equipment. During this period the design, manufacture, and installation of the reactors for both the prototype and the submarine were completed.



By 1954, other reactors were under development by Westinghouse and were established as separate projects, each with its own departments for reactor, power plant, physics, and materials development. Ross then became assistant manager of the LSR (Large Ship Reactor) the job he now holds. Here he has full technical responsibility for the entire project, with all the technical departments associated with the project reporting to him.

Ross, a native of Massachusetts, came to Westinghouse from Harvard University, after earning his BS in electrical engineering in 1938, and his master's degree in 1939. After completing the Graduate Student Course, he joined the electric utility engineering group at East Pittsburgh. When the war broke out he was sent to Washington to help the Navy with shipboard electrical systems, where he served until 1945.

By his quiet, modest demeanor, Ross might easily be typed as a careful and deep thinker, which he is. But on many occasions he has demonstrated that he is also a man of action. One incident related by associates bears this out. The occasion was the assembly of two large, precisely machined parts of a reactor, being fitted together for the first time since their manufacture. These were critical and expensive parts. As a crane lowered the smaller into place, the assemblage of scientists, engineers, and technicians were dismayed when it apparently stuck, part way into place. The dilemma was clear: shall we try to force the part as gently as possible, or try to withdraw it—possibly causing damage in either event and delaying the project. While the question was being pondered by others, Ross climbed down to get a closer look. Noting the trouble he picked up a nearby hammer, rapped a piston ring smartly back into alignment, and the two pieces glided neatly into place. The sigh of relief was heard throughout the building. As a memento of this auspicious occasion, the hammer was appropriated, chrome-plated and mounted, and presented to Ross.

In the past, Ross's outside activities have been varied. He was an enthusiastic yachtsman, and has won several trophies in yachting events; he also has been a tennis and golf enthusiast. At one time he designed and built his own house, doing much of the carpentry work himself. The press of his atomic power project has greatly reduced these activities at present. Every spare moment, he spends with his family. At least one of the boys shows a marked leaning toward Ross's profession; he has designed and built a model nuclear reactor, which he hopes to enter in a forthcoming science contest.

The nuclear power projects with which Ross has been associated have succeeded because they were team efforts of people with varied backgrounds and experience. No individual can be given credit for any project. However it is abundantly clear that Ross's clear concepts of reactor systems, and his ability to coordinate and balance the efforts of the engineers and scientists in achieving these systems, were important factors in their ultimate development. ■

what's NEW!

Look—No Contacts!

Two NEW MECHANICAL switches without contacts have been developed specifically for Cypak applications. Both work on the principle of a change in reactor-coil impedance caused by the presence or absence of a magnetic material in the proximity of the coil field. Hence, when the reactor core is unsaturated, the coil has high impedance; when saturated, the coil has low impedance. This impedance change is sufficient to provide a change in signal capable of operating Cypak control elements.

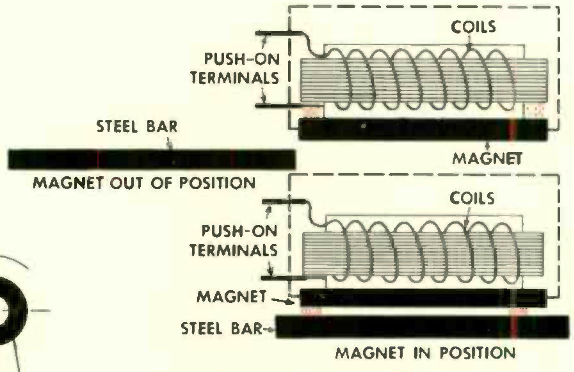


Fig. 1

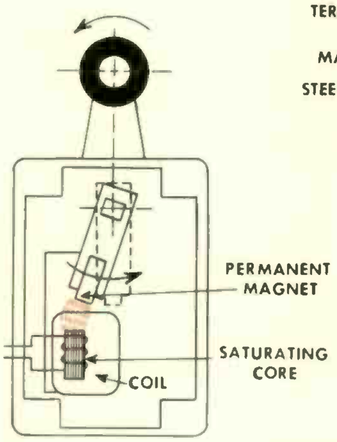


Fig. 2

The "proximity" switch (type CPP) is entirely free of moving parts, Fig. 1. It consists of an encapsulated core, coil, and magnet. The core is normally saturated by the presence of the permanent magnet housed in the same enclosure, but loses this saturation when an external steel bar moves in close to the pole face of the switch. This loss of saturation occurs because the flux is shunted away from the coil assembly by the steel bar. This unit is applicable to machine tools with rigid, accurate machine ways, such as planer beds or drill heads.

The second contactless switch (type CPL) is arm actuated, and does not require an accurate relationship between the switch and the moving member. It consists of a core and coil as the stationary part of the switch, and the permanent magnet as the moving part, Fig. 2. When the magnet is in its normal position, the core is saturated; when the arm is moved, the magnet is moved out of position and the core becomes unsaturated. This switch has only two points subject to possible wear, the main and roller bearing. The CPL switch should be particularly satisfactory for such applications as conveyors.

Both types offer practically unlimited life compared to the conventional electrical-contact switch. ■

New Liquid-Metal Pump

A MECHANICAL, liquid-metal pump has recently completed a successful 500-hour performance test run at more than 1000 degrees F—the highest temperature at which a pump of this type has ever operated for an extended period. Intended for use in nuclear-power plants, chemical process lines, and other applications requiring high-temperature heat-transfer mediums, the pump is designed to circulate liquid sodium and sodium-potassium alloy in capacities up to 5000 gallons per minute for fluid temperatures as high as 1600 degrees F.

The centrifugal-type pump has a hermetically-sealed canned-rotor that contains pump and motor rotor in one integral unit. Pumped fluid and all rotating parts are thereby isolated from the field windings and outer atmosphere. There are no external shaft seals in these pumps, and suction and discharge nozzles are designed to be welded into the pipeline. Although pumped fluid is allowed to fill the motor cavity, it is excluded from the rotor and stator windings by sealing jackets in the magnetic gap. All surfaces in contact with pumped fluid are made of corrosion-resistant alloys—austenitic stainless steel and Inconel.

An external supply of coolant is the only auxiliary requirement. Double walls are provided between the coolant and the sodium at all points of the integral heat exchanger.

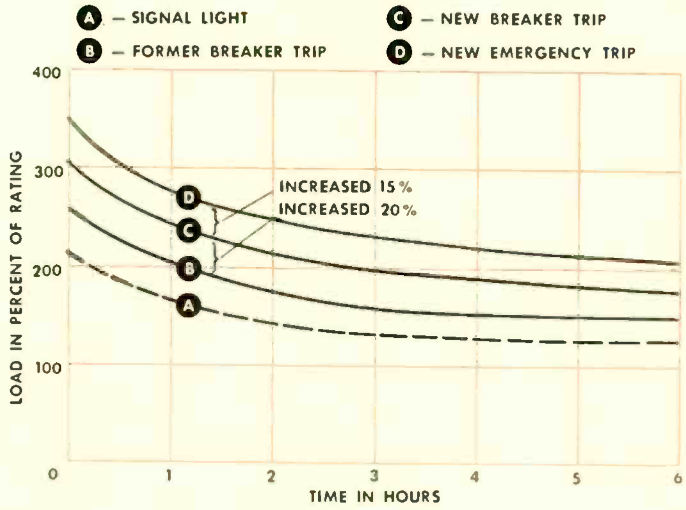
The bearings, lubricated by the pumped fluid, are made of sintered carbides to withstand the corrosive effect of sodium. Good lubrication is assured by keeping the temperature of the sodium in the region of the bearings between 275 and 400 degrees F regardless of the temperature of the pumped fluid. To provide for thermal expansion, a unique "thermal-flex" mounting system has been applied to the radial bearings. Supported from the mid-points of a series of leaf springs, the bearings are self-aligning. ■

Breaker Trip Settings Raised on CSP Distribution Transformers

HIGHER BREAKER TRIP settings for CSP distribution transformers will boost normal overload capacity of the transformers by about 20 percent, and emergency overload capacity by about 15 percent.

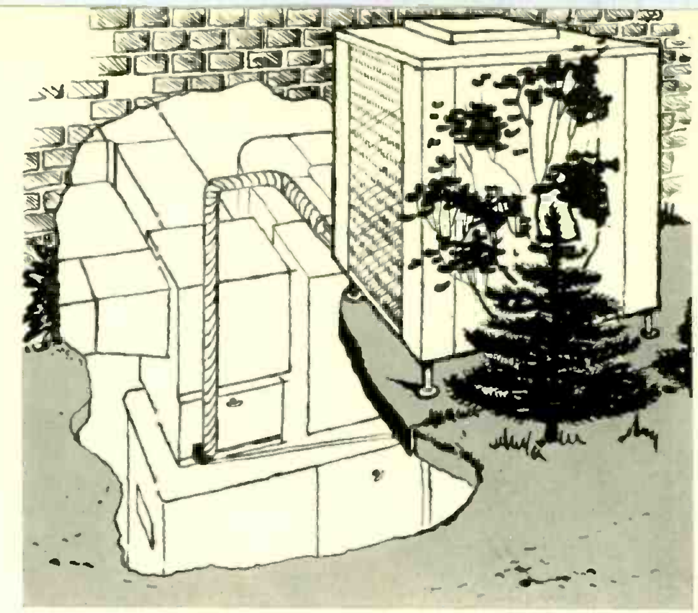
These new and higher trip settings are based on the results of more than 18 months of laboratory functional life tests and have been confirmed by two years of field experience with the higher breaker settings. Several utilities have cooperated extensively in accumulating this field experience.

LOAD-TIME CURVES FOR CSP TRANSFORMER FOLLOWING 75 PERCENT LOAD, 35 DEGREES C AMBIENT



For the electric-utility industry, the higher breaker trip settings make possible greater use of a utility's investment and offer a reduction in emergency service calls. For example, a 25-kva transformer with present breaker settings trips off the line in 90 minutes when carrying about 47 kva under severe initial conditions. The same transformer set for the new higher trip levels will carry about 56 kva for 90 minutes under the same conditions (see performance curves). This additional overload capacity can be carried without sacrifice in service life.

In addition to reducing the breaker trip-outs, increasing capacity for sustained overloads, and raising the level of emergency capacity, the new breaker trip settings will give utilities greater flexibility in scheduling transformer replacements. Although the breaker trip settings will be raised, the setting at which the overload signal light operates will remain at the standard ASA setting. With this increased band-width between overload signal operation and breaker trip, a greater time can elapse before transformer changes are necessary. ■



Waterless Air-Conditioner

THE PROBLEM of short supply and high cost of water for residential air conditioners is eliminated with a new waterless air conditioner.

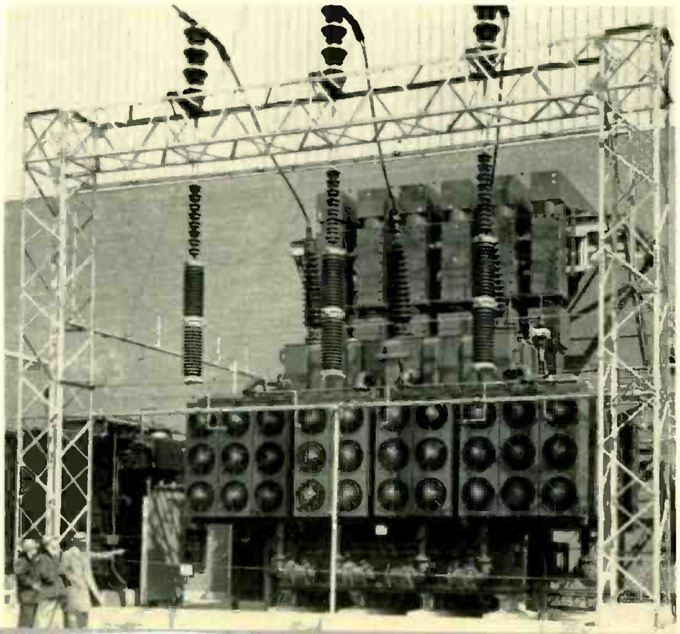
Heart of the new unit is an air-cooled condenser that makes possible for the first time installations and conversions in areas where summer water shortages exist or water rates are high. The air conditioner (ACU) consists of a large-capacity, multi-row condenser coil, a double-inlet centrifugal fan, and a fan motor and drive assembled within a weatherized metal cabinet (see artist's drawing). The same unit without a compressor (CAC) can be used to convert existing air conditioning units from water to air cooling.

New installations in homes with forced-warm-air furnaces consist of inserting an evaporator coil (cooling) unit in the duct above the furnace. This coil is connected to the air-cooled ACU unit located in car port, crawl space, attic, or behind shrubbery next to an outside wall.

In homes already equipped with a conventional water-cooled air conditioner, conversion to waterless operation is quick and simple. A CAC air-cooled condenser is installed in any convenient location inside or outside the house and connected to the existing compressor in the old air conditioner, eliminating the previous water-cooled condenser from the cooling cycle.

A feature of the air-cooled condenser is vertical air discharge, which takes advantage of warm air's natural tendency to rise. Thus shrubbery is protected from hot-air blasts and there is no detrimental effect of "bucking" prevailing winds.

Both the ACU air conditioner and the CAC air-cooled condenser come in 2-, 3-, and 5-ton capacities. ■



This 315 000-kva, 17.3/129-kv generator transformer, largest ever installed, is the first of two identical units being built for the No. 1 and No. 2 units of the Detroit Edison Company's new River Rouge power plant. The second will be installed by late 1956. The three-phase, forced-oil-to-air-cooled transformer, weighing 325 000 lbs, was shipped upright in a one-piece tank less bushings and cooling equipment. The installed unit weighs 448 000 lbs and is about 24½ ft high from the foundation to bushing tips, 16⅔ ft wide, and 26 ft long. Westinghouse also has under construction a 360 000-kva generator transformer for the plant's No. 3 unit.

personality profiles

Dr. Clarence Zener • *Walter R. Yeary* • *Paul Evans, Jr.* • *A. T. Bacheler and C. G. Helmick* • *J. P. Baker*

• *Dr. Clarence Zener*, now acting director of the Research Laboratories, will be remembered by many readers as the subject of a Personalities in Engineering article in the Engineer about two years ago. A native of Indiana, Dr. Zener spent most of his career up to World War II in college classrooms and laboratories. During the war he carried on research and development on projectile design and armor penetration at Watertown Arsenal. The war over, he became a professor in the Institute of Metals and the Department of Physics at the University of Chicago. From this post he came to Westinghouse in 1951.

• *Walter R. Yeary* has viewed the business of heating and cooling from more than one angle. Prior to World War II he was a contractor, specializing in electrical work, refrigeration and air conditioning, and heating. Since 1950 he has been associated with the application of Westinghouse equipment for air conditioning and similar purposes.

Yeary joined Westinghouse as a sales engineer for the Sturtevant Division, and was located in the Washington office. In 1952 he transferred to the headquarters of the division as an application engineer. In 1954 he was made training supervisor, and later that year moved to Staunton, Virginia with the newly formed Air Conditioning Division.

In his spare time, Yeary has diverse interests. He has his own amateur radio station (K4ABL). He writes for various technical publications. He's a confessed gadgeteer and "do-it-yourself'er", and likes to tinker with things electronic. The latter inclination likely derives from his wartime service as an officer in the Signal Corps. About this time of year, however, most of Yeary's time is spent in the outdoors, where he is determined to make Kentucky bluegrass grow in the Virginia red clay around his house.

• *Paul Evans, Jr.* is the author of this month's article on vacuum drying of transformers. A native of Ohio, Evans graduated from Ohio Northern University in 1937 with a BS in EE, then went on to Purdue University to earn his master's degree in 1938. Evans joined the Transformer Division in 1939, and except for a six-month interval, has been there since. Here he has been mainly involved with large power transformers, which has provided him with ample background for his article in this issue.

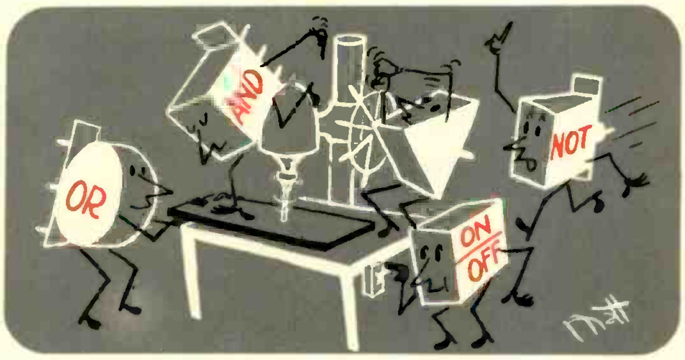
Most of Evans' spare time has been spent in further study as a quick glance at his record shows. Since 1943, he has been pursuing greater knowledge of his field at the University of Pittsburgh, which he hopes will lead to a Ph.D. degree.

• *A. T. Bacheler* and *C. G. Helmick* form the battery for both ends of the double-header in this issue—the opener on adjustable-frequency drives, and the nightcap on the use of reluctance motors for adjustable-frequency drives. This is the "opening day" appearance on these pages of this winning combination.

Bacheler graduated from Tufts Engineering School in 1941 with a BS in EE and came directly to Westinghouse on the Graduate Student Training Program. He went to work in the general mill section of the Industry Engineering Department in 1942, where he remained until 1950 when he transferred to the Motor and Control Division. Here, he has concentrated on the application of motors and control to the textile, synthetic fiber and film, rubber, and lumbering industries.

Helmick came on the Westinghouse Graduate Student Training Program from the University of Michigan after obtaining his BSEE and MSEE in 1951. He, too, went to the general mill section of Industry Engineering. Here, he concentrates on applications in the man-made fiber industry.

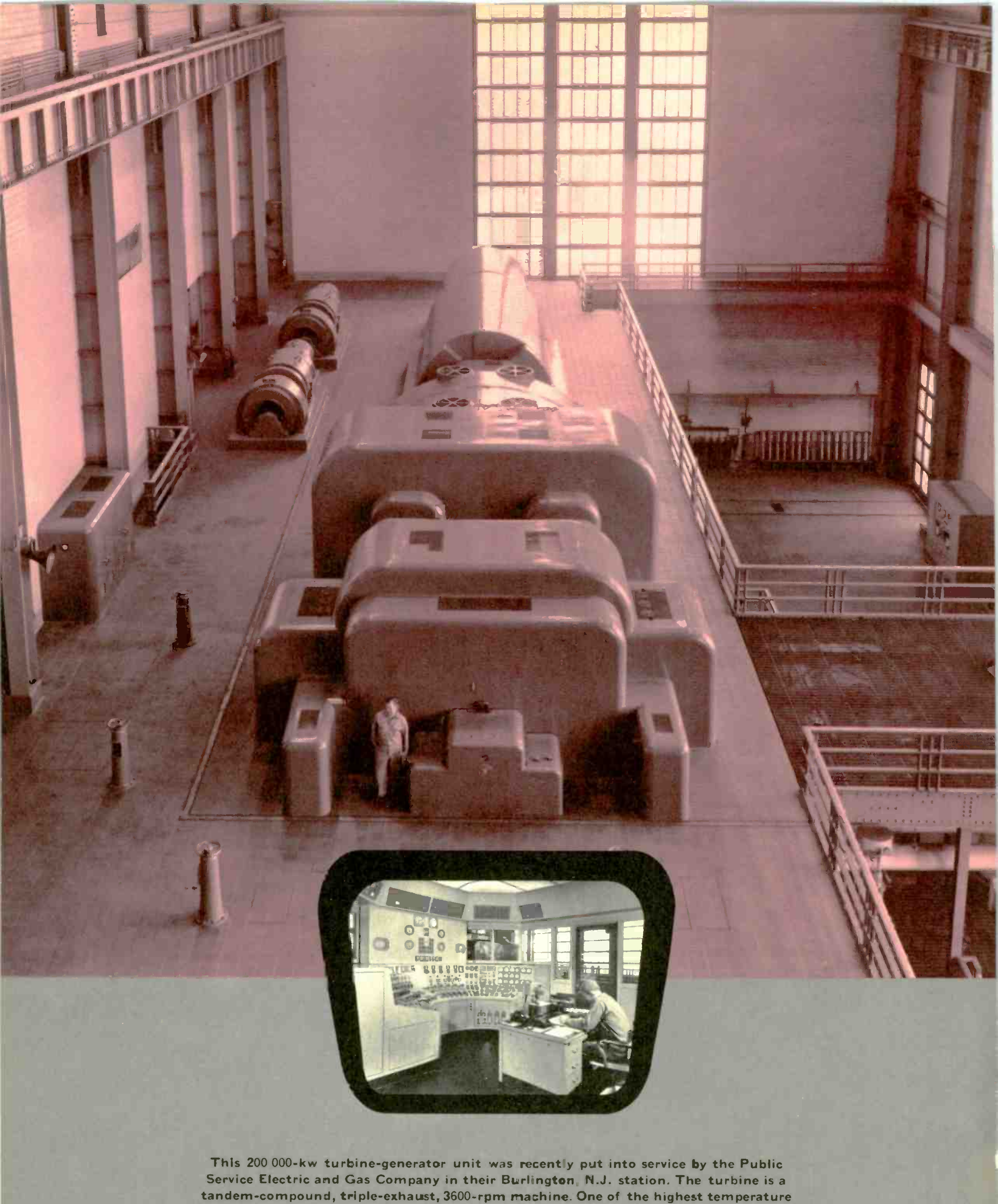
• For about four years, *J. P. Baker* occupied an office a short eraser's throw from the Engineer staff, where he was a member of the Technical Publicity staff. Here his function was to seek out technical articles from engineers in the company's product divisions, edit them, and place them with technical journals. He also frequently collaborated on material for the Engineer. Among other things he edited the first stories on Cypak systems early in 1955, the same subject he discusses in this issue.



Now the shoe is on the other foot. Joe is still writing, but now he's a member of a division himself, submitting articles to his replacement in Technical Publicity. In 1955 he transferred to the Director Systems Department, which manufactures Cypak systems. He is now in the Magamp section of that department.

Baker is a graduate of South Dakota State College, where he earned his BS degree in physics in 1949. After graduation he worked as a physical chemist until joining Westinghouse on the Graduate Student Course in 1951. Later that year, he was assigned to the Technical Publicity group.

In one sense we have Joe Baker in somewhat of a predicament. During his years in Technical Publicity he, of course, learned many techniques of gently prodding engineers to write articles. When he left this assignment, his techniques remained, so he may find us using them on him. Now, about that next article, Joe . . .



This 200 000-kw turbine-generator unit was recently put into service by the Public Service Electric and Gas Company in their Burlington, N.J. station. The turbine is a tandem-compound, triple-exhaust, 3600-rpm machine. One of the highest temperature machines in service today, inlet steam temperature is 1100 degrees F, reheat temperature 1050 degrees F. The generator is hydrogen-cooled, with the rotor inner-cooled by hydrogen flowing through hollow field conductors. From the curved console (inset), the operator has complete control of the boiler, turbine-generator unit, and other auxiliary machinery.