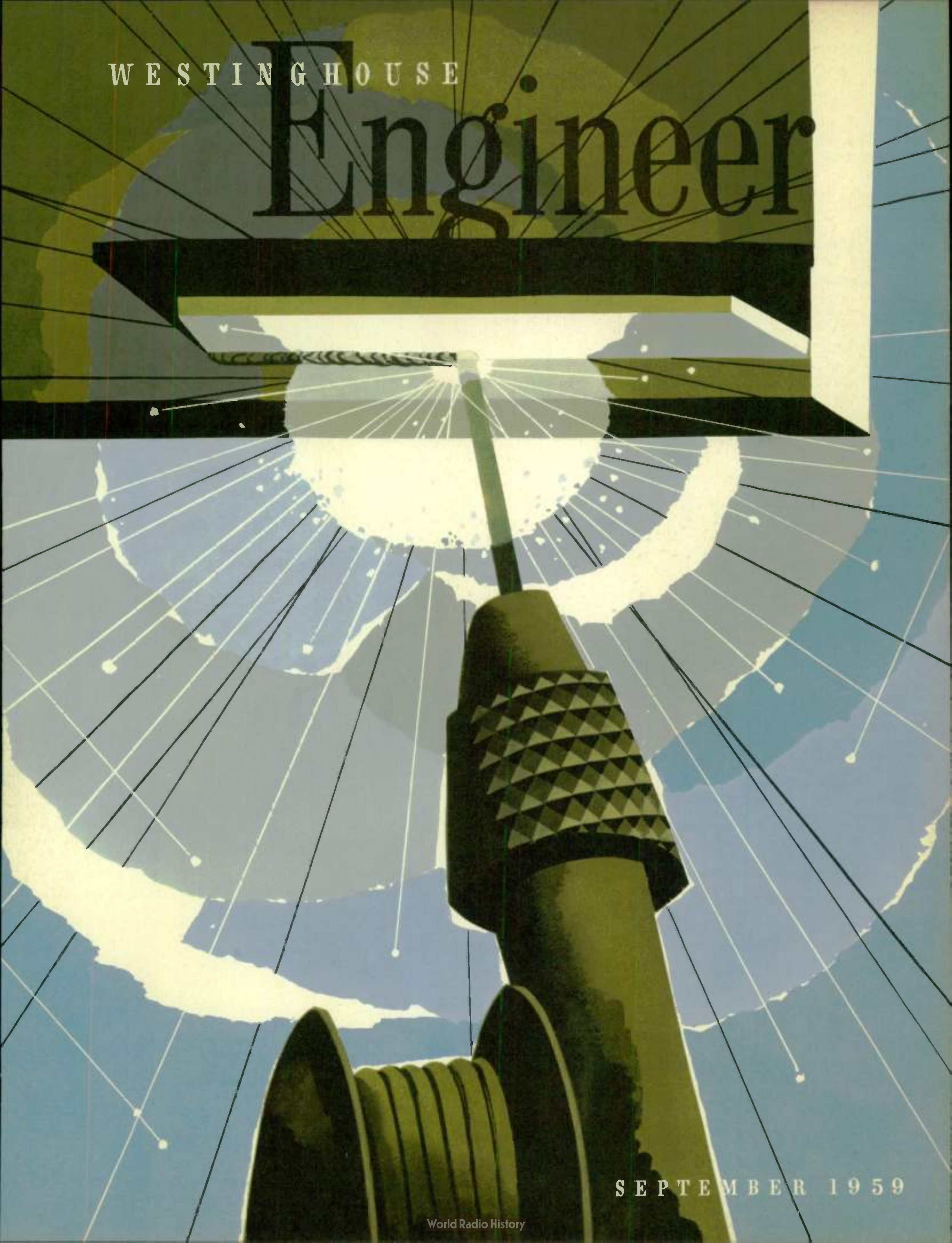
WESTINGHOUSE Engineer



SEPTEMBER 1959

Astronuclear Laboratory . . .

another step toward the horizon

Eleven years ago, the development of nuclear-powered submarines and nuclear generating stations seemed an extremely difficult and remote possibility. Even to the scientists and engineers given the responsibility of developing them, such power plants seemed to be somewhere on a distant horizon—difficult to even visualize, let alone put into the form of practical "hardware."

To explore this new frontier, a separate division was formed at Westinghouse in late 1948—the nucleus of the group that subsequently developed the power plants for the nation's first nuclear submarine, the Navy's first nuclear surface ships, and the first large-scale nuclear generating station. The success of this pioneering organization in turning a general concept into a practical reality is history; particularly impressive was the relatively short time required.

Much pioneering work remains to be done in nuclear plants of this type, but in the meantime whole new frontiers have opened in atomic power, many of which have yet to be explored.

Today, using nuclear power in outer space for exploration or military applications appears as distant on the horizon as did a nuclear-powered submarine in 1948, but fully as feasible. Such applications require the same type of development philosophy, organization, and scientific talent that was applied to the *Nautilus*—the nation's first nuclear submarine.

In recognition of this situation and its endless possibilities, Westinghouse has recently formed a new Astronuclear Laboratory, to undertake pioneering research and development projects in nuclear power. The new laboratory will be part of a newly-formed Atomic Power Division, which will also include the existing Atomic Power Department, whose function is the commercial application of atomic power, primarily for nuclear electric-utility plants.

The Bettis Atomic Power Laboratories, operated by Westinghouse for the Atomic Energy Commission, will continue its challenging research and development job, as the nation's foremost atomic reactor development center.

The hard core of the organization for the new Astronuclear Laboratory will include some of the key people who worked on the *Nautilus* and Shippingport generating station projects at the Bettis Laboratory. In basic knowledge and specific experience, this Astronuclear Laboratory will be unlike any in industry today. From it can conceivably come achievements as spectacular as the development of the *Nautilus*, and with far-reaching effect on the future of our country.

COVER DESIGN: Recent improvements in a constant-potential, constant-wire-speed power source (p130) have made consumable-electrode, inert-gas shielded metallic arc welding an extremely versatile and economic welding method. Cover artist Dick Marsh exhibits his version of this welding process on this month's cover.

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Published bimonthly (January, March, May, July, September, and November) by Westinghouse Electric Corporation, Pittsburgh, Pa.

SUBSCRIPTIONS: Annual subscription price in the United States and possessions is $2.50; in Canada, $3.00; other countries, $3.00. Single copy, 50¢. Address all communications to *Westinghouse* ENGINEER, P.O. Box 2278, 3 Gateway Center, Pittsburgh 30, Pa.

INDEXING AND MICROFILM: *Westinghouse* ENGINEER contents are regularly indexed in Industrial Arts Index. Reproductions of the magazine by years are available on positive microfilm from University Microfilms, 313 N. First Street, Ann Arbor, Michigan.

THE WESTINGHOUSE ENGINEER IS PRINTED IN THE UNITED STATES BY THE LAKESIDE PRESS, CHICAGO, ILLINOIS

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Developments in Arc Welding

Arc welding, an already important fabrication tool, is still finding new applications because of constant advances in the process.

G. E. COSSABOOM
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From kitchen sinks to atomic submarines, successful manufacture of many products often depends on whether or not metal parts can be joined. Frequently the solution is found in welding, and increasingly in electric arc welding.

Through welding, metal pieces can be joined almost as though they had never been separate. Simple pieces cut from plate, sheet, pipe, and other common shapes can be joined into complex forms, which otherwise would require specialized and expensive forming or casting equipment. The resulting joint can be made liquid tight, even gas tight; it can be made for strength, or pieces can be "pinned together." When required, the weld can be made metallurgically identical to the parent metal by subsequent heat treating. Probably the most important, though basic, attribute of welding is that a flush joint can be produced.

All these advantages plus speed, efficiency, and economy were recognized early. Accomplishing some of these potentialities has taken much longer.

coated electrode

The most significant of earlier arc welding developments was the chemical coating of short lengths of mild steel wire electrodes (Fig. 1). Heat from the arc dissociates the coating, and gases given off displace air near the arc and pool, thereby protecting the molten metal from oxidation. Other chemical constituents perform a fluxing, cleaning, and wetting action on the work piece. Still others contribute to arc stability. Lastly, the chemicals form a slag covering over the deposited weld, protecting it from the atmosphere during solidification.

Coated-electrode welding was applied mostly to mild steel at first, and only direct-current welding power supplies were used.

Before World War II, coatings were developed that allowed use of alternating current. Thus transformers could replace motor-generator sets with an attendant cost reduction. This development allowed extension of the process to higher currents and faster speeds. Also coatings were developed that permitted stainless steel and some alloyed steel to be arc welded.

Coated-stick-electrode welding still is used most widely because of its versatility and flexibility, though the process has some serious limitations. Quality, efficiency, and economy of the coated-rod process depend to a large degree on operator skill. Also, a practical coating has never been developed for most nonferrous materials, especially aluminum. The first of these limitations spurred development of semiautomatic and automatic processes using spooled continuous wire electrodes. The second brought about the inert-gas-shielded, nonconsumable electrode process.

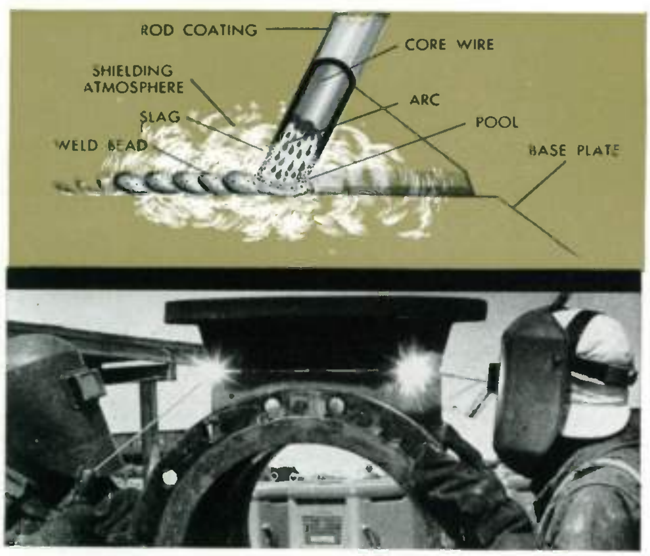


Fig. 1—(**Top**) Schematic diagram of the flux-coated stick-electrode welding process. This process (**bottom**), using mild steel, low-alloy, and stainless steel in light, medium, and heavy gauges, can be used on all common joint types and in all positions.

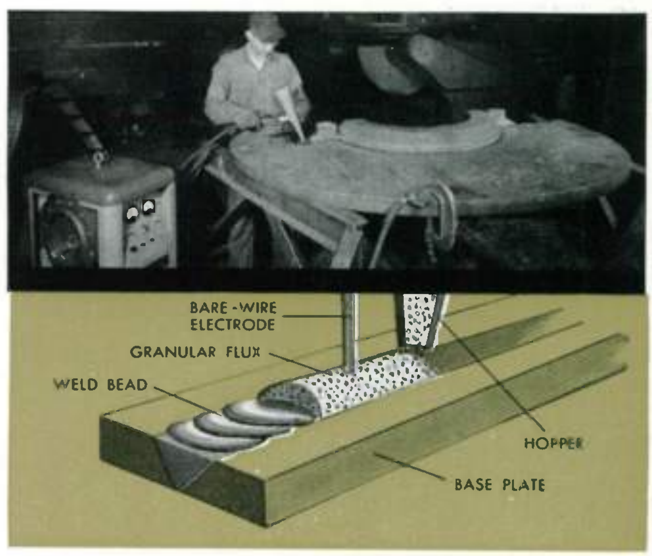


Fig. 2—(**Bottom**) Schematic diagram of the submerged-arc welding process. This process is used primarily in the down-hand position. The semi-automatic process uses mild steel, low-alloy, and stainless steel. The fully automatic process usually is used on thin, heavy, and (**top**) very heavy gauges.

continuous electrode—submerged arc

An uncoated wire is used in the continuous-electrode process. A granular flux, fed onto the weld joint, blankets the arc, and performs all functions of the stick-electrode coating (Fig. 2). This process is called "submerged arc."

As mentioned earlier, effectiveness of the stick-electrode process depends largely on operator skill. He must control the electrode feeding rate in two directions—into the arc and along the joint. In some cases, a weaving motion across the joint is also necessary. However, arc length must be kept constant to maintain consistent weld quality. But to produce a constant arc length, the electrode must be moved at different rates in each direction. The operator is faced with a problem similar to the old parlor game of patting the head and rubbing the stomach. Much practice is required. Obviously, if electrode feeding rates could be controlled automatically, much could be gained.

Since voltage across the arc is a function of arc length, circuits were developed to monitor voltage and adjust feeding speed of the continuous electrode. When this control is used, the equipment is termed *semiautomatic* but the operator still must control travel rate along the joint. Travel rate along the joint can be controlled mechanically by moving the work piece under a stationary welding head, or vice versa. This arrangement is termed *fully automatic*. Most of these developments followed the development of the submerged-arc process.

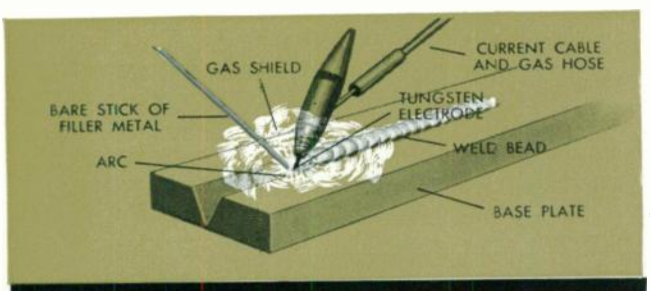
The process is versatile in that most all mild steel, alloy steel, and stainless steel can be welded by properly combining wire and flux. And both d-c and a-c power can be used. The process is most used now for heavy material thicknesses, for instance, seven-inch and thicker steel-walled pressure vessels, and high-current applications, even in excess of 1500 amperes. Even three-phase arrangements using two electrode wires have been applied.

Development of the submerged-arc process removed limitations of human control. Yet it, too, has at least one serious limitation. Because of loose granular flux, the weld joint must be kept in a nearly flat or downhand position. Thus massive equipment often is needed to rotate the part.

tungsten electrode with inert-gas shielding

Another major development of the 1930's and 40's, inert-gas shielding, is vastly different. In this process, the arc is established between the work piece and a high-melting-point electrode, usually tungsten (Fig. 3). The arc is used much like a gas flame. A weld bead is formed by introducing additional material into the molten pool. The unique feature of this development was the use of inert gas, usually argon or helium, to protect the molten metal from the atmosphere. This welding process made joining of aluminum practical, and was largely responsible for tremendous growth in aluminum usage during and after World War II.

In addition to success with aluminum, this process—often called TIG for tungsten-inert-gas—has been used extensively for welding stainless steel and many nonferrous materials, but it too has many limitations. High operator skill is required, and welding speed is relatively slow. Inert shielding gases are relatively expensive and welding equipment is somewhat specialized. Also, the tungsten electrode is not always "nonconsumable." If the electrode



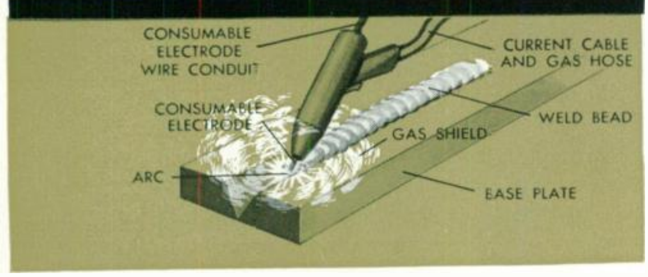


Fig. 3—**(Top)** Schematic diagram of the gas-shielded tungsten-arc welding process.

Fig. 4—**(Bottom)** Schematic diagram of the gas-shielded consumable electrode welding process.

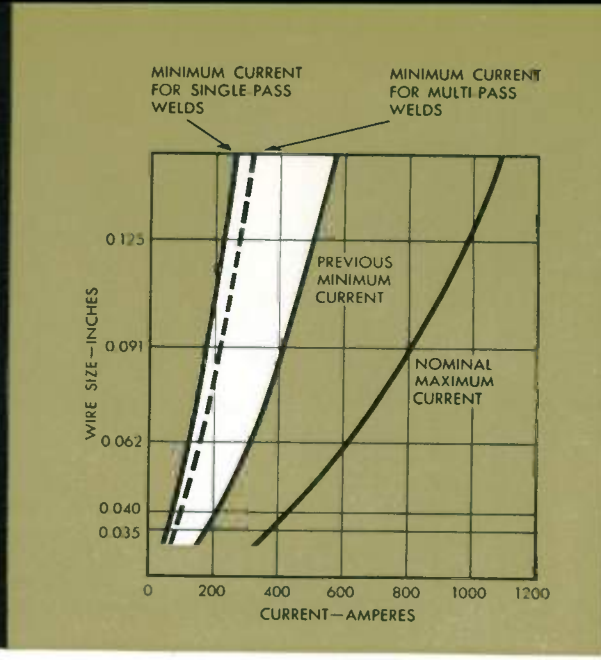


Fig. 5—(Left) A demonstration of the semi-automatic, CO_2-shielded welding process with a dynamic reactor in the circuit. **Right**—This graph of welding current versus wire size demonstrates the increase in versatility of a given wire size due to the dynamic reactor.

touches the work piece, a small but potentially troublesome speck of tungsten can be left to form a hard brittle inclusion in the weld bead. In aluminum particularly, this "foreign body" inclusion acts much like a notch, leading to stress concentration and crack initiation. In most applications, the electrode cannot be touched to the work piece for starting or restriking the arc. Instead, a source of high-frequency voltage is added to the main welding power supply. High-frequency voltage produces an ionized path across the gap, reducing the resistance and allowing welding current to follow. However, the high-frequency radiation often interferes with neighboring radio, tv, and other electronic equipment. Extensive and expensive shielding methods may be required in some cases.

continuous electrode with inert-gas shielding

Limitation of high-cost, low-speed, and specialized equipment fostered further development, and led to introduction in the 1950's of the next major welding process, combining the advantages and eliminating most disadvantages of the last two processes (Fig. 4). A continuous electrode (like the submerged arc process) is used, but shielded with an inert gas (argon or helium). Designated "consumable electrode, inert-gas shielded metallic arc welding," the name often is shortened to MIG welding (metallic-inert-gas). Eliminated are flux and resulting abrasive slag materials, which create cleaning problems. Also eliminated is the high-frequency voltage supply and its radiation problems. Since electrode material is compatible with the work piece, it can be touched to the work piece without creating contamination. And because the arc is visible, the joint can be followed more closely in an irregularly shaped piece.

The process has found increasing use in aluminum welding. Welding speeds are higher than with the tungsten electrode process, and as a result welding costs are lower. The process is well suited to semiautomatic and fully automatic applications and is being applied to other nonferrous materials and stainless steels.

Three different types of equipment have been designed for the MIG process: (1) drooping volt-ampere or constant-current type, (2) flat volt-ampere or constant-potential type, and (3) rising volt-ampere type. They differ mainly in the welding power source used.

A discussion of how and why each type is used becomes detailed and involved. The choice depends primarily on application. In general, the constant-current type is least expensive, but most limited in use. The rising volt-ampere type, on the other hand, is most expensive and least limited. The constant-potential, constant-wire-speed type, had been, until late 1958, a little less versatile than the rising volt-ampere type and a little more expensive than the constant-current type. But during 1958, an advance made it the most versatile type for the MIG process; and made the MIG process the most versatile and economical method.

Development of the process involved a simple modification of the constant-potential power source by adding a "dynamic reactor." Its creation stemmed from consideration of transient and dynamic phenomena of the welding arc.

With previous consumable-electrode systems, the arc is wild and unruly unless a minimum threshold value of current density is maintained in the welding wire. Thus, for welding currents of less than about 300 amperes, high-cost small-diameter electrode wires are used. In many cases, special and expensive wire-feeding arrangements are necessary for these small diameter wires. These factors limit the process mostly to medium and heavy gauge materials. Also, only skilled operators can handle weld positions where the pool is not vertically under the arc. For light-gauge materials and "out of position" welds where the joint is overhead or the joint axis is vertical, the threshold currents are too great. Due to the high temperatures produced, either a hole is burned in the base plate, or the molten metal cannot be kept in the weld joint. For use on steel, inert shielding gases are too expensive. Yet with carbon-dioxide shielding, which is feasible and inexpensive, the molten metal splatters on adjacent surfaces. This creates grinding and cleaning expense.

Study of dynamic arc conditions showed that for current densities above threshold value, the arc consists of a metal spray. Below threshold value, transfer is globular, and many momentary short circuits occur. With a constant-potential power source, short-circuit current is virtually unlimited. At each short circuiting, current rises so fast that the glob explodes instead of melting, creating a wild and uncontrollable arc with much spatter.

dynamic reactor extends continuous-electrode gas-shielded process

Some reactance, acting as the electrical equivalent of a flywheel, was needed to retard the rate of current rise during short circuits to allow melt-off to take place.

By inserting a reactance in the welding circuit, violence of the arc in a CO_2 gas shield vanishes. Spatter sticking to adjacent surfaces is eliminated. All mild steel welding now is economically practical with this process and shows a cost advantage over all other processes.

Current range of each commonly available electrode wire has doubled because current-density threshold is eliminated (Fig. 5). Minimum current for some diameters has been reduced by two-thirds. Small diameter wires are not needed, eliminating specialized wire feeding equipment for light-gauge applications. Also, "out of position" welds are no longer restrictions.

What evolves from elimination of these restrictions is one widely applicable metal-joining method, in most cases more economical to use than any other.

Mild steel of almost any variety, weld-joint type, joint orientation, and thickness now can be welded where the combination of these factors calls for a welding current between about 90 and 800 amperes. With available semi-automatic equipment, one common diameter of electrode wire, 1/16 inch, can cover the normally used diameter range of coated-stick electrodes (1/8 inch through 5/16 inch). Deposits are equivalent to those from the highest quality stick electrode—the low-hydrogen variety. Using CO_2 shielding gas, these low-hydrogen type, high-quality beads can be deposited two to three times faster than with stick electrodes. The result is a superior weld deposit at about one-half or less the cost per deposited foot.

Low-alloy, high-tensile steel in similar variety can be welded with much the same results. Already T-1 and HY-80 alloys are being welded successfully with the process.

Stainless steel of nearly every type can be welded. Travel speed, and therefore economy, is much improved over both the tungsten-arc and coated-stick electrode methods.

Aluminum applications of wide variety can use this welding method. Previously, only the tungsten-arc process could weld aluminum successfully. The consumable electrode method makes high-frequency power supplies unnecessary, increases welding speeds, and improves economy. It has already replaced much of the tungsten-arc process except in very thin gauge applications.

Magnesium, *titanium*, *copper*, and other nonferrous and alloyed metals have been welded both experimentally and in manufacturing applications with this consumable-electrode, gas-shielded method.

This listing indicates the versatility of the basic welding process. The equipment also is flexible because components can be combined in several ways with minor additions and modifications to fit a wide variety of manual and machine setups (Fig. 6). In addition, by including a timing circuit in the sequence controls, an extra operation can be performed. Two or more sheets of metal can be "pinned" together with access needed from only one side. With CO_2 gas shielding especially, the arc can be made so penetrating that it burns through the top sheet, fuses to the bottom sheet and deposits a plug of weld metal flush with the top surface. Often, the procedure presents a solution that would be impossible by resistance spot welding. The same timing circuit arrangement can be used for simple tack welding, or for short intermittent welds. And burn-through procedure can be extended to full lengths of bead.

This procedure has been used experimentally on automobile siderails. To follow accurately the edge of such pieces requires expensive tracking arrangements. Tracking need not be as precise when welding through overlapped surfaces instead of at the overlapped edge.

With the dynamic reactor, this single process is now almost limitless as to metal thickness, weld-joint type, and weld-joint orientation. In addition, some major drawbacks of earlier processes—coated short-length rods, a hidden arc, slag removal or bothersome high-frequency circuits—are eliminated. And both quality and economy of the deposited weld are improved also.

Through such developments, the arc-welding process has become one of the most widely used and important production tools in industry. ■

Fig. 6—A demonstration of the fully automatic gas-shielded consumable electrode process (the safety shields are removed for the photograph).

Radiation, Fields, and Electroluminescent Phosphors

Much of the attention given to electroluminescence in recent years has centered about a-c lighting applications. However, this phenomena has many other potential uses. Here are a few examples.

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Electroluminescent phosphors are best known for their ability to produce useful light when they are excited by an a-c field. This fact enables the construction of lamps in the form of flat sheets, which emit light when plugged into ordinary 110-volt household circuits. The phosphors —which resemble cake flour or talcum powder in appearance and consistency—convert electric power directly into visible light under the influence of the alternating field. At the present rate of development, electroluminescent lamps based on this effect may soon have a profound effect on lighting for American homes.

Important as it is, however, this is only one of the potential uses for these phosphors. The response to a-c voltages is but one aspect of their curious behavior. They are sensitive also to d-c fields and emit light if the phosphor layers are constructed to allow the flow of direct current. The phosphors are also very sensitive to radiation in the near-ultraviolet and blue regions of the spectrum; they emit strongly (photoluminescence) in the same bands that contribute to electroluminescence, and they are highly photoconductive.

As a result of this behavior, a logical question arises: Does anything interesting happen when these three exciting agents—a-c fields, d-c fields, and radiation—are allowed to act on the phosphor two at a time? The answer is an emphatic "yes." Each of the three possible combinations

(1) radiation plus a-c voltage,
(2) radiation plus d-c voltage, and
(3) a-c voltage plus d-c voltage (ac-dc electroluminescence)

leads to a strong interaction in the phosphor crystal, which under certain conditions leads to what can be called an "amplification" or "enhancement" of the light emission.

These interaction or enhancement effects can be conveniently discussed by defining the ratio

$$R=\frac{L_B}{L_1+L_2}$$

where L_1 is the light emission due to the first exciting agent acting alone, L_2 is the light emission due to the second agent alone, and L_B is the light emission when both exciting agents are acting simultaneously. If the means of exciting the phosphor crystals are entirely independent, then the separate emissions would simply add to form L_B and the ratio R will always be unity. What makes electroluminescent phosphor powders of added interest is that proper combinations of excitants, in any of the pairs listed above, lead to values of R substantially greater than unity and in some cases as great as 100 or more. Or, more directly, *the light output produced by the combination far exceeds the sum of the individual light outputs produced by the same excitants individually.*

While not yet all developed to the stage of practical application, the interesting enhancement effects caused

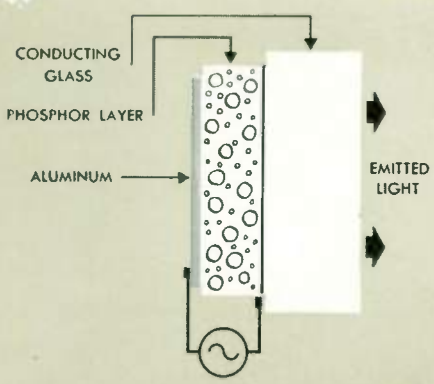


Fig. 1

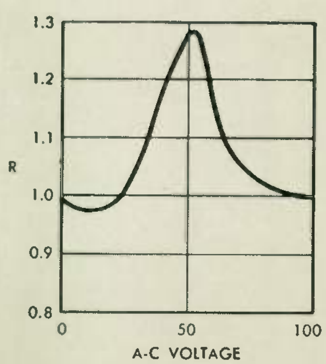


Fig. 2

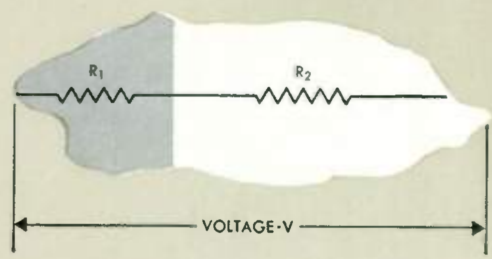


Fig. 3

by the three combinations of radiation and fields on the phosphor hold considerable interest for the future.

radiation plus a-c voltage

Electroluminescent phosphor powders are often mixed with an equal weight of plastic, sprayed on conducting glass, dried, and a back-electrode of vaporized aluminum applied (Fig. 1). This is, of course, the same construction used in conventional electroluminescent lamps. In this form most electroluminescent phosphor powders show this particular enhancement effect.

The normal way of operation is simply to apply an a-c voltage, as shown in the figure, and to measure the resulting light emission. Suppose, however, that no a-c voltage is applied, but the phosphor layer is exposed to radiation in the ultraviolet or deep blue region of the spectrum. The phosphor will glow in much the same way as if the voltage were applied; this is called photoluminescence. But now if radiation and voltage are applied together, and if the magnitude of each is adjusted properly, then the "combined" light emission is greater than the sum of the separate emissions. That is, the ratio

$$R=\frac{L_B}{L_{ac}+L_{uv}}$$

is greater than unity. This behavior is shown in Fig. 2 for a blue-emitting electroluminescent phosphor at a frequency of 10 000 cycles per second and with one microwatt per square centimeter of ordinary "black light" (ultraviolet radiation at 365 millimicron wavelength from a mercury lamp). The enhancement effect occurs over a wide range of frequencies, including 60 cycles, and a wide range of ultraviolet intensities. For each a-c voltage there exists an optimum frequency and radiation intensity.

While many electroluminescent phosphors emit about the same color of visible light whether excited by a-c voltage or radiation, the phosphor of Fig. 2 fortunately emitted blue with a-c voltage and green under ultraviolet excitation. Therefore, L_{ac} and L_{uv} could be sorted out in L_B by a spectrometer. This indicated that the electroluminescence alone is enhanced by the combination of field and radiation. In this particular phosphor, ultraviolet radiation that produces one unit of green photoluminescence, when

In a phosphor crystal, three different energy regions are assumed to exist: a *valence band*, filled with electrons, a *forbidden band*, which can be occupied by a few electrons, and if impurities are present, a *conduction band*, which is accessible to electrons, but normally does not contain many. Once in the conduction band, however, electrons can move freely; in the other bands, the electrons are more or less tightly bound.

A defect or impurity, called a luminescence center, must be present in the material for electroluminescence to occur. On the energy diagram, this luminescence center is located in the forbidden band.

When an alternating electric field is applied to the material, the energy of some electrons is raised sufficiently to place them in the conduction band, where they are free to move. Some of these electrons immediately fall back into a luminescence center; in this event the electron gives up part of its energy as radiation, which can be visible light. However, most of the effect of electroluminescence comes from those electrons that stay in the conduction band for a longer period of time.

To produce substantial amounts of light, each electron must produce more electrons; this happens when they are accelerated by the field and free other electrons, which are in turn accelerated, and so on. This "cascading" effect continues until the direction of the alternating field reverses; thereafter, many of the electrons fall back to luminescence centers, and light is emitted. As the field builds up in the opposite direction, the cycle repeats itself.

With a d-c field, the situation is quite different, as explained on page 137. Here the number of electrons "in circulation" is large, but because of the continual presence of the field, only a relatively few electrons fall back into luminescence centers; thus the light output is correspondingly lower.

The combination of alternating and direct current fields produces a third effect. During one-half cycle the effect of the fields is additive, many electrons are "boosted" to the conduction band, but little light output occurs. During the other half cycle the fields tend to cancel each other, many electrons are allowed to return to luminescence centers, and light is emitted.

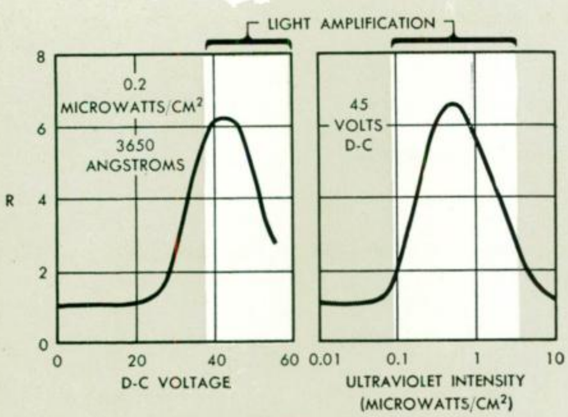


Fig. 4

Fig. 1—The usual a-c electroluminescent panel consists of a "sandwich" of conducting glass, a layer of plastic in which the phosphors are embedded, and a conducting layer of aluminum.

Fig. 2—When both ultraviolet radiation and a-c voltage are applied to an electroluminescent panel simultaneously, the resultant light emission is greater than the sum of the separate emissions. The factor R represents the ratio of the light emission when both exciting agents are acting simultaneously, to the sum of the light emissions due to each exciting agent acting alone.

Fig. 3—Each crystal (represented here schematically) has a volume from which electroluminescence originates (R_1), and a larger volume (R_2) where most of the radiation is absorbed and photoluminescence originates.

Fig. 4—When a combination of direct current and ultraviolet radiation is applied to certain phosphor powders, true light amplification occurs.

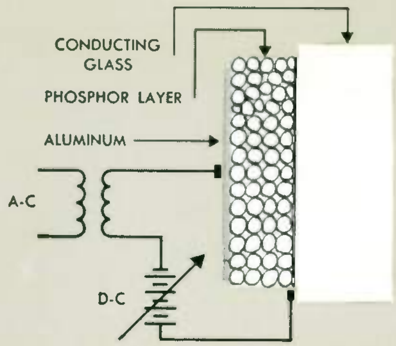


Fig. 5

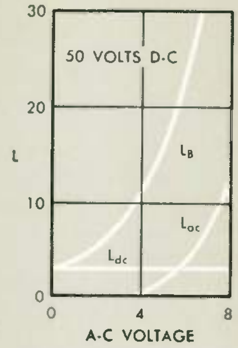


Fig. 6a

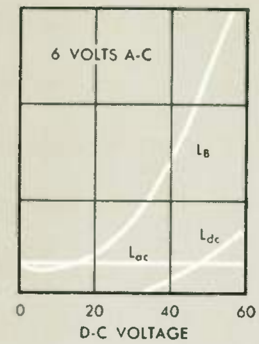


Fig. 6b

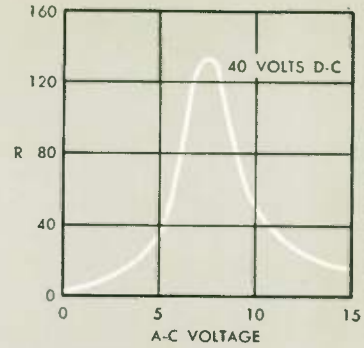


Fig. 7

added to a-c voltage that produces two units of blue electroluminescence, results in a combined emission of three units of blue electroluminescence and the same one unit of green photoluminescence.

The explanation of this interaction effect of radiation and field is a simple one, supported by many varied experimental observations. Each crystal, represented schematically in Fig. 3, contains a volume (resistance R_1) from which the *electroluminescence* originates, and a much larger volume (resistance R_2) where most of the radiation is absorbed and the *photoluminescence* originates. These crystals are photoconductive, which means that resistance R_2 is reduced by radiation. But since the applied voltage is constant, the "electroluminescence" voltage across R_1 thereby increases and the electroluminescence emission becomes greater.

When the day arrives that the efficiency of electroluminescence can compete with photoluminescence, as in the fluorescent lamp, then this enhancement effect may make the combination of the electroluminescent lamp and the fluorescent lamp a practical and valuable one.

radiation plus d-c voltage

If electroluminescent phosphor powders are sprayed with so little plastic binder that the crystals are mostly in contact, then after the usual vaporized aluminum back-electrode is applied the phosphor layer will respond to d-c as well as a-c voltages. The a-c response of these layers is similar, for example, to the Rayescent Safety Light, except that these special cells are considerably brighter at low voltages. With d-c excitation, they show a uniform glow, which increases rapidly in intensity with increase in d-c voltage; bright points of light are sometimes visible against the uniform field, and can be stable or intermittent. During d-c excitation, steady currents flow from one electrode through adjacent crystals to the other electrode, and visible light, or d-c electroluminescence, results.

The same phosphors that show strong a-c electroluminescence show the best d-c emission. The color of the d-c electroluminescence is generally shifted to somewhat shorter wavelengths than that of the a-c electroluminescence; that is, green a-c emission is likely to shift to blue under d-c excitation, yellow to green, and so on.

Some of the phosphor powders that emit a-c and d-c electroluminescence show a striking enhancement effect if radiation is added with the d-c voltage. This is shown in Fig. 4, where the ratio

$$R=\frac{L_B}{L_{dc}+L_{uv}}$$

is plotted against d-c voltage and ultraviolet intensity. Obviously this is a much larger effect than that resulting from the combination of radiation and a-c voltage.

In this d-c case the electroluminescence and photoluminescence can also be sorted out in the combined emission, and again the electroluminescence is the portion increased by the radiation.

In this case, however, the electroluminescence emission is increased as much as *twelve* or *fifteen times* by the radiation, rather than by fifty or sixty percent as in the a-c case. Furthermore, true light amplification occurs, as indicated in Fig. 4. In other words, the power in the visible light output (and subtracting L_{dc}, which would occur without the radiation anyway) actually exceeds the power input in the ultraviolet radiation. This then, is a light amplifier in which a weak input image can be amplified by d-c power to a strong output image.

This enhancement effect has been observed in blue, green, and yellow emitting electroluminescent phosphor powders and in sprayed areas as large as six inches square. As in the a-c case, radiation in the ultraviolet or blue region of the spectrum leads to enhancement. The explanation of Fig. 3 applies to this d-c case as well, and is further supported by actual measurement of the currents flowing in the presence of both radiation and d-c field.

ac-dc electroluminescence

Electroluminescent phosphor powder layers that contain only a few percent of plastic binder and therefore show d-c electroluminescence behave like conventional lamps with a-c excitation. A strong interaction, however, occurs when a-c and d-c voltages are applied simultaneously. This is easily done, for example, with the circuit of Fig. 5. The addition of an a-c voltage and a d-c voltage, each of which by itself excites visible luminescence, results in a light level considerably greater than the sum of the separate emissions. This effect is characteristic of electrolumi-

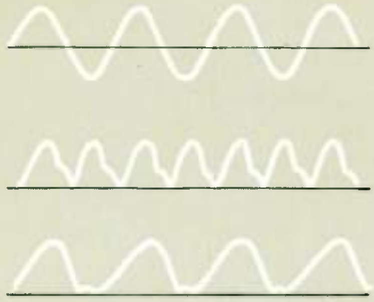


Fig. 8

Fig. 5—Simultaneous application of alternating and direct current to an electroluminescent cell produces a light output greater than the sum of the light outputs of the a-c and d-c acting alone.

Fig. 6—These curves show the effects of (6a) holding the direct current constant and varying the alternating current, and (6b) holding the alternating current constant and varying the direct current. They represent the response of a green-emitting phosphor.

Fig. 7—With a blue-emitting phosphor, the brightness with both alternating and direct current applied is about 250 times that with either voltage acting alone.

Fig. 8—The light output in ordinary a-c electroluminescence fluctuates with twice the frequency of the applied voltage. With ac-dc electroluminescence the light fluctuates at the applied frequency.

nescent phosphors in general. Its magnitude in some phosphors is such that, given a cell excited to visible output with an a-c voltage, addition of a d-c voltage can increase the brightness 250 times; at this point the light output due to the d-c alone is approximately equal to that due to the a-c alone. The maximum brightness obtained experimentally is as yet rather low, being limited by the d-c emission of the phosphor layers.

For each combination of a-c and d-c voltages, the quantities L_{ac}, L_{dc}, and L_B were measured; L_{ac} is the light output excited by the a-c alone, L_{dc} is the light output excited by the d-c alone, and L_B is the light output resulting from both exciting voltages acting simultaneously. The response of a green-emitting electroluminescent phosphor to a-c and d-c voltages and to their combination is shown in Fig. 6. When the d-c voltage is held constant, L_B increases rapidly with increase of a-c voltage from zero. L_{ac} does not become detectable until L_B is many times L_{dc}. In the voltage region where L_{ac} is about equal to L_{dc}, the ratio

$$R=\frac{L_B}{L_{ac}+L_{dc}}$$

reaches a maximum. Thereafter, because L_{ac} increases with voltage more rapidly than L_B, the ratio R decreases toward unity.

When the a-c voltage is held constant (Fig. 6b), the application of the d-c voltage results first in a quenching region in which output is reduced. Further increase of the d-c voltage is accompanied by a rapid increase of L_B, and the appearance of L_{dc}. At high d-c voltage, L_{dc} increases more rapidly than L_B, causing the ratio to pass through a peak and then fall off toward unity as before.

The dependence of the ratio R upon a-c voltage is given in Fig. 7 for a blue-emitting phosphor in which the ac-dc interaction is much stronger than in the green-emitting phosphor of Fig. 6. Since L_{ac} is about equal to L_{dc} near the peak in Fig. 7, the ac-dc brightness L_B is about equal to $2R$, or 250 times the brightness with either voltage alone.

Although the light output in ordinary a-c electroluminescence fluctuates with twice the frequency of the applied voltage, as shown in Fig. 8, the ac-dc light in the region of maximum ratio R fluctuates at the applied frequency because of the polarizing effect of the d-c voltage. This behavior is the key to the explanation of the ac-dc interaction effect: The d-c voltage sets up a steady electric field that causes electrons to be freed from luminescence centers and drift down-field, where they are trapped. As long as only the d-c field is present, these electrons cannot return and recombine with the empty centers and emit light. However, a steady current is flowing past these ionized or empty luminescence centers and occasionally one of the electrons in this current is caught by the center, recombines, and emits the light that is observed as d-c electroluminescence. This recombination is inefficient because of the high field at the centers, and the resulting light output is weak. When an a-c voltage is added to the d-c voltage, during half of the cycle the fields are in opposition and tend to partially cancel out. This allows part of the trapped electrons to escape thermally and return to the empty luminescence centers, where they recombine and cause the emission of the ac-dc light. During the other half-cycle this bucking action of the voltages does not occur and no light emission is observed. For this reason the ac-dc emission occurs only once per cycle and hence has the same frequency as the applied a-c voltage. In essence, the a-c field taps the reservoir of energy represented by the ionized centers and trapped electrons maintained by the d-c field.

Wide-range control of electroluminescence brightness with a d-c field is obtained when a moderate a-c voltage is first applied, according to Fig. 6b. Another interesting effect occurs when sufficient d-c voltage is applied to produce appreciable d-c electroluminescence and then a very small a-c voltage is added (operating region near the ordinate of Fig. 6a). The light output can be modulated by as little as a few a-c millivolts under these conditions, corresponding to an exceedingly low fluctuating field of about 10 volts per centimeter. Further, since the reservoir of ionized centers set up by the d-c field persists in part for some time after the d-c field is removed, the a-c field can be applied after the d-c field rather than simultaneously, and a characteristic but rapidly diminishing transient ac-dc emission is observed.

Several possible practical applications of ac-dc electroluminescence have been proposed, aside from the d-c control of electroluminescence light emission.

On-off indicator. This would be suitable for applications requiring control by very small a-c voltages and power. In ac-dc electroluminescence, the power is supplied principally by the d-c voltage and the few volts of alternating current needed to increase the light emission by large factors involves negligible added power.

Audio or d-c amplifier. The ac-dc cell, in conjunction with a photosensitive device, as shown in Fig. 9, can act as either a voltage or power amplifier with a-c or d-c input and a-c or d-c output. Although any phototube will serve as the light pick-up device, a two-dimensional photoconductive layer is shown, since the two components can then be very efficiently coupled optically. Since no electrical coupling is needed between the two components (not even a common ground) this arrangement can be considered a decoupling device. The frequency range of ac-dc electroluminescence is from zero to at least as high as 500 kilocycles, thus extending to frequencies above the audio region as well as allowing straight d-c amplification. With either a-c or d-c signal input, the other voltage can be used as gain control, determining the operating region on the response curve of Fig. 7; the response curve for constant alternating current and variable direct current is similar to that in Fig. 7. An aperture or iris can be inserted between emitting and receiving components of Fig. 9 as a gain control; other changes can be made by altering the optical path of the light between the components.

Switch and relay. The components of Fig. 9 can also be used as a switch or relay, with high impedance input and low impedance output, for example; and either input or output or both can consist of several independent units optically coupled but electrically independent, to form a solid-state equivalent of multi-pole and multi-coil relays.

Image amplifier. The ac-dc electroluminescent cell can perhaps remove one of the major problems in making large-area image amplifiers from double layers of photoconductive and electroluminescent material (Fig. 10). The conventional a-c image amplifier consists of an electroluminescent (EL) layer and a photoconductive (PC) layer back to back, and sandwiched between transparent conducting electrodes. The a-c voltage appears mostly across the thicker PC layer in the dark, and the EL layer emits very little light. If a spot on the PC layer is illuminated, that spot will become conducting and at that point the a-c voltage will appear across the EL layer, causing it to emit light by ordinary a-c electroluminescence. The conventional a-c image amplifier requires a PC layer that is much thicker than the EL layer, so that most of the a-c voltage will appear across the PC layer in the dark, or until the PC layer is strongly illuminated. Unfortunately, a thick PC layer prevents the light in the input image from penetrating completely through the layer, the layer does not become entirely conductive, and so the a-c voltage does not appear across the EL layer as desired.

In the ac-dc image amplifier the PC layer can be very thin so long as its dark resistivity is high enough that most of the d-c voltage appears across the PC layer in the dark. How the a-c voltage is distributed (most of it will appear across the EL layer if it is thick compared to the PC layer) is unimportant, since the ac-dc layer will emit strongly only when both a-c and d-c voltages appear across it; this occurs when the PC layer is illuminated and its d-c resistance is lowered.

conclusion

The highly sensitive phosphor powders, which have been developed for high-brightness, high-efficiency electroluminescence applications, are much more versatile than has been realized. Any one—or any combination—of a number of methods of excitation causes strong emission of light from these solid-state materials. For this reason it seems probable that many other applications in the field of control and amplification of light will appear. ■

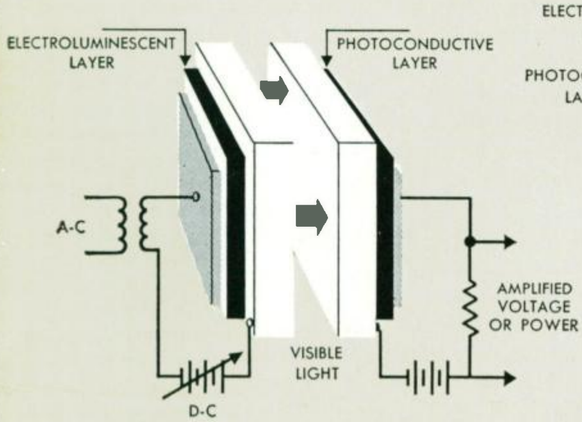


Fig. 9—The use of an ac-dc electroluminescent cell in conjunction with a photoconductor provides a voltage or power amplifier.

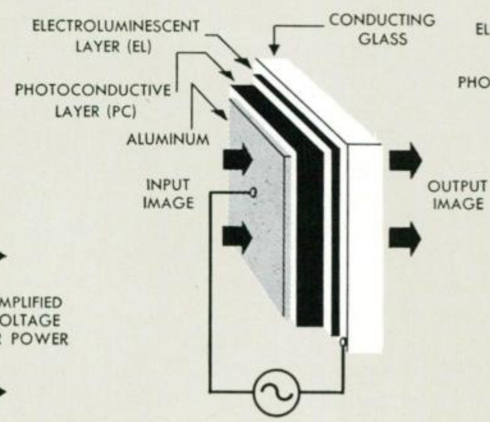


Fig. 10a—A conventional a-c image amplifier. The PC layer must be thick so most of the a-c voltage appears across it in the dark; this, however, prevents necessary light absorption throughout the layer.

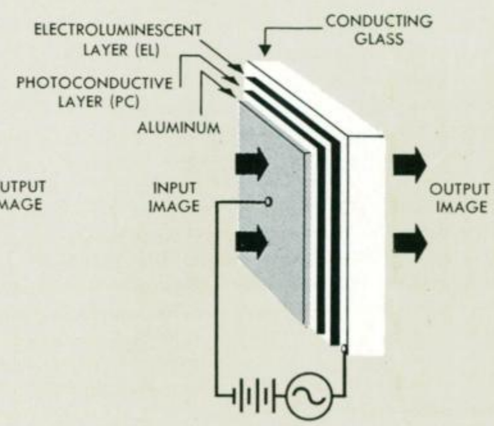
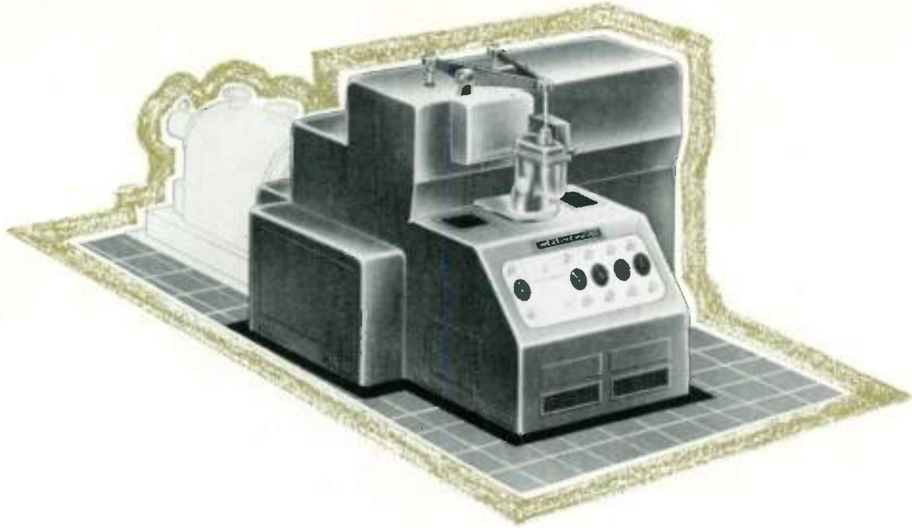


Fig. 10b—An ac-dc image amplifier. The division of the a-c voltage between the PC and EL layers is unimportant in this case; most of the d-c voltage appears across the PC layer in the dark and transfers to the EL layer upon illumination.



Applying Turbine Drive to Boiler Feed Pumps

The steam turbine boiler feed pump drive shows increasing promise in the larger electric utility turbine cycles. Particular plant requirements and overall cycle evaluation will determine its suitability.

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The boiler feed pump—a key element in the electric utility turbine cycle—is becoming the subject of increasing investigation. The larger capacity feed pumps required for larger turbine generator units are placing a greater economic premium on obtaining the optimum drive for a particular application.

The three fundamental feed pump drives are: *electric motor*, *steam turbine*, and *generator shaft*. From these three basic drives, a number of successful systems have evolved; the choice depends upon whether half- or full-size equipment is used, the different interrelations with the feed-heating cycle, and the particular plant arrangement. The steam turbine drive has gained rapidly in popularity during the past few years, but the selection of a turbine drive should be determined by a thorough application analysis, and the design reliability of the turbine.

The turbine drive has several advantages: (1) Capital investment can be decreased and plant layout simplified by eliminating the largest power-plant auxiliary motor and its associated equipment, such as breakers, ducts, and control equipment. (2) Rated pump speed can be chosen for maximum efficiency and optimum physical design because turbine and pump speeds are the same, eliminating need for gear and coupling devices. (3) The variable speed inherent in a turbine drive will coincide with the operating pump speed for maximum efficiency at part loads, which eliminates throttling losses and poor hydraulic coupling efficiency at part loads. (4) Generated output is not reduced by the power required by the pump motor. (5) The trend toward larger steam turbine generator unit sizes and higher initial pressures mean increased pump power requirements and, hence, more economic justification for investigating the possible advantages of a turbine drive.

variables affecting evaluation study

The relationship between load, heat rate, and cost must be calculated for each individual boiler feed pump drive application. The following factors will affect this relationship: (1) main turbine type, steam conditions, and capability; (2) number of extractions from the boiler feed pump turbine; (3) boiler feed pump turbine exhaust pressure and exhausting zone in cycle configuration; (4) efficiency difference between motor and turbine drive for a given load; (5) variation of change in enthalpy across the boiler feed pump over the load range; (6) variation of pump, motor, and gear efficiencies over the load range; (7) feed-heating cycle configuration (extra components and accessories); and (8) one- or two-pump operation.

The above list indicates that the variables must be definitely stipulated to arrive at a justified conclusion. An

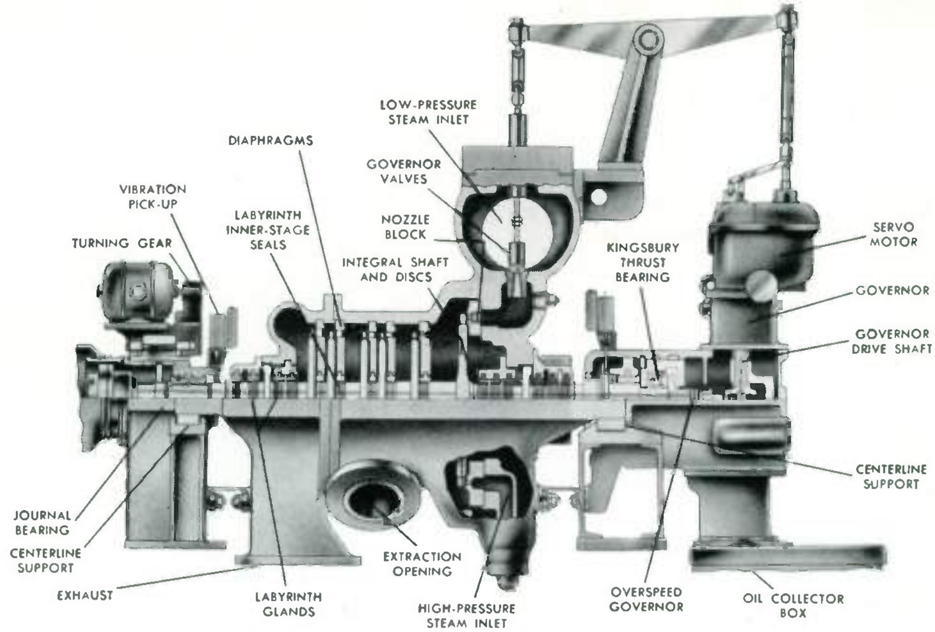


Fig. 1—Cutaway view of boiler feed pump turbine, of non-condensing type, with two nonautomatic extraction openings.

example of an important variable often overlooked is item (5), the change in enthalpy across the boiler feed pump. About ten years ago, this factor was usually neglected in calculating heat balances; today, common practice is to calculate a value at full load and use this same value across the entire load range. However, now that utilities are taking a closer look at feed pumps, the trend is to include pump performance curves with the thermal data of the main turbine. This is important in sizing and correlating the pump, and computing performance of the overall heat balance, as well as the individual components in the feed-heating cycle.

In studies involving the application and integration of the boiler feed pump turbine into the turbine cycle, solutions to individual applications have varied from condensing to non-condensing single-, double-, and triple-extraction units.

over-all cycle evaluation

A comparative analysis was conducted recently for a particular application of a turbine-driven boiler feed pump. The turbine generator unit under consideration was rated at 300 mw and designed for operating steam conditions of 2000 psig throttle pressure, 1000 degrees F initial steam temperature, 1000 degrees F reheat temperature, with an absolute exhaust pressure of 1.5 inches of mercury.

The turbine-drive was rated 9000 hp at 5000 rpm. The three turbine inlet conditions considered were: main-turbine throttle steam; cold reheat steam shifting to steam supplied through a reducing station from ahead of the throttle at low loads; and cold reheat steam shifting to a combination with main-turbine throttle steam at low loads by use of dual steam chests. The turbine exhaust varied from the highest pressure heater to the condenser.

Heat balances were calculated at full and part loads for a number of boiler feed pump locations, within the six-heater feed-heating cycle. Heat rate, cost of equipment, and cycle complexity were considered in determining the most economical location, for justification of the turbine drive. A synopsis of this over-all cycle evaluation study at full load is tabulated on page 142–3.

mechanical features of a boiler feed pump turbine

If the analysis justifies a turbine application, the requirement of maximum design reliability of the turbine drive itself must be satisfied. Therefore, the turbine is patterned after large main-unit turbines, designed for similar

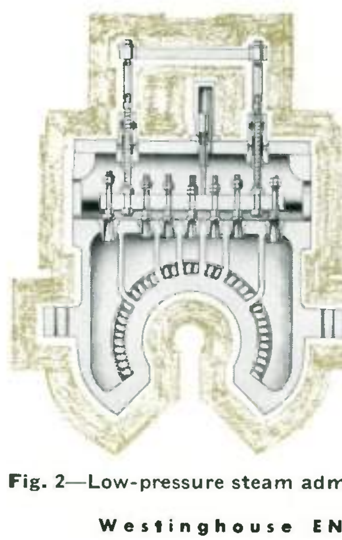


Fig. 2—Low-pressure steam admission.

pressure and temperature conditions, to give a uniform standard of reliability for the complete unit steam cycle.

The boiler feed pump turbine has several noteworthy features. A typical longitudinal section through the modern boiler feed pump turbine is shown in Fig. 1. This turbine is arranged for direct connection through a flexible coupling to the boiler feed pump. The most significant features of the turbine are the dual separate steam chests, consisting of a low-pressure unit and a high-pressure unit.

The low-pressure steam chest, located in the turbine cover, admits cold reheat steam to the turbine. The structural simplicity and sturdy construction of the steam chest and multi-valve assembly are illustrated in Fig. 2. The nozzle chamber is partitioned so that each valve admits steam to a single group of nozzles. The two end valves feed nozzle groups that extend down into the base of the boiler feed pump turbine.

The high-pressure steam chest, located in the base of the turbine, admits high-pressure and high-temperature steam directly from the boiler to the turbine for starting and for low-load operation. The detail design construction of the high-pressure inlet pipe and nozzle chamber assembly supported on the turbine base cylinder is shown in Fig. 3. Note that the admission ports are suspended in the turbine casing in a way to minimize distortion due to rapid temperature changes.

The transition section between the high-pressure nozzle chamber and turbine casing is designed to provide flexibility for relative expansion between high-temperature inlet parts and the lower-temperature turbine casing. This turbine arrangement eliminates distortion of the nozzle face under temperature and pressure transients. A steam baffle is used to prevent the turbine governing stage casing from being subjected to wide and rapid temperature fluctuations when the turbine is operating in the range where the high-pressure steam control valve is alternately opening and closing.

Both the high-pressure and low-pressure turbine ends are sealed by step-type labyrinth steam seals. The seal system of the feed pump turbine is combined with that of the main turbine.

The turning gear for the turbine and boiler feed pump is located on the exhaust bearing pedestal. It is capable of starting and rotating the combined units from standstill. The turning-gear device also has an arrangement for remote manual engagement from the control room. An indication is provided when turbine and pump have reached a sufficiently low speed to permit safe engagement of the turning gear.

The turbine casing, shown in Fig. 1, is ruggedly supported to resist strains that can be imposed by the connecting piping. For smooth operation over a wide speed range, the turbine has centerline supports that allow freedom of expansion and contraction of the cylinder casing.

lubrication and control system

Main and auxiliary oil pumps, oil reservoir, strainers, and coolers are mounted on a bedplate as an oil supply unit, and located apart from the turbine. This unit supplies all oil requirements for the turbine, and bearing oil for the boiler feed pump.

Controls for the boiler feed pump turbine have the same rigid specifications as the main unit, to give dependable reliability to the power cycle.

The turbine has a governing system that operates on signal pressure from the feed-water controller to vary steam flow to the turbine, thereby matching turbine output and its connected pump to controller requirements. Feed-water flow is controlled entirely by variable-speed operation of the turbine and pump.

In the absence of gears, cams, and complex mechanical linkage, both high-pressure and low-pressure control valves, actuated by hydraulic servo motors, respond to the same hydraulic signal from the governor. Thus, control valves of both steam chests are tied together. Through this hydraulic tie, the high-pressure control valve opens in sequence following the opening of the last low-pressure governor valve.

The high-pressure control and stop valves are a single unit, located on the side of the cylinder, as shown in Fig. 4. A high-pressure pipe connects the stop valve and control valve unit to the high-pressure inlet in the turbine cylinder base. With this arrangement, any external forces in the high-pressure system are transmitted directly through the valve body to the turbine cylinder and main turbine supports without affecting the high-pressure nozzle block.

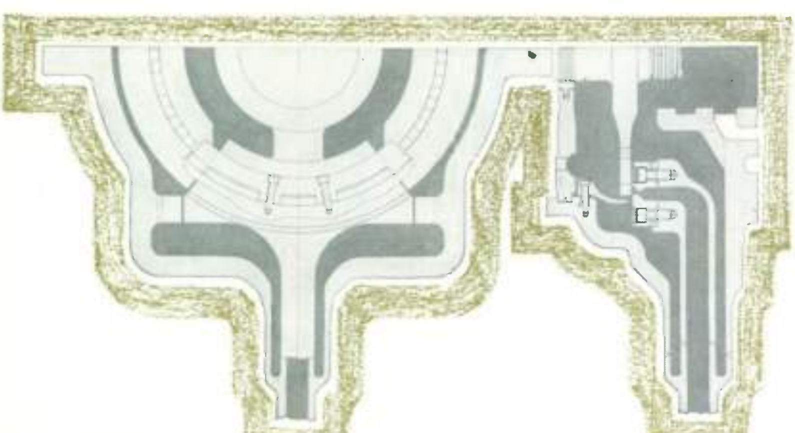
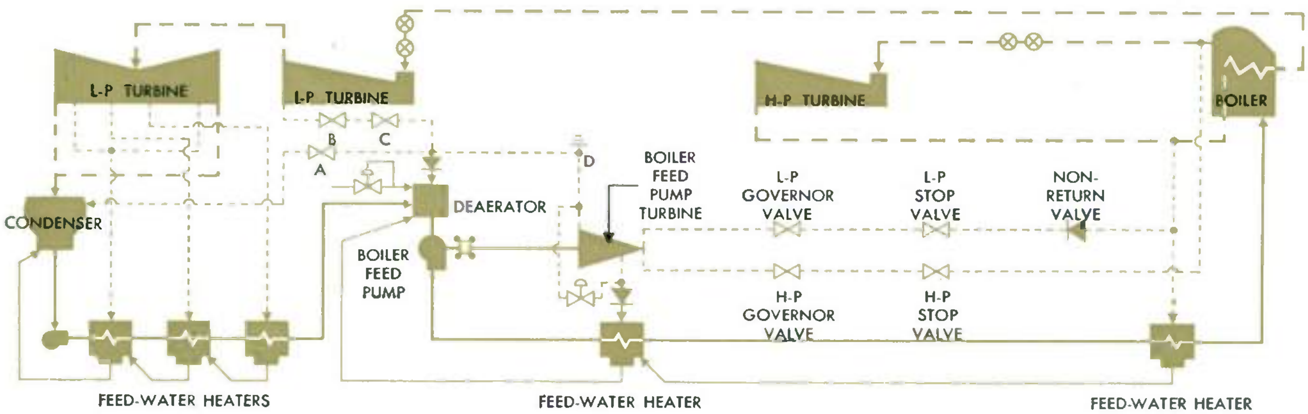


Fig. 3—High-pressure steam admission.

Fig. 4—High-pressure stop and control valves.

The unit shown in Fig. 1 is a multi-stage Rateau-type turbine with multiple-extraction openings for extracting steam for intermediate feed-water heaters of the main-steam cycle. Sufficient steam is extracted from these openings to satisfy requirements of connected intermediate feed-water heaters. The turbine exhaust is connected to a main cycle feed-water heater during normal operation, but suitable piping and valves connect the exhaust to the condenser during startup and periods when the low-pressure heaters are by-passed.

The rotor and discs are constructed as an integral unit from a solid rotor forging to provide maximum dependability. The rotor blades are constructed of corrosion-and erosion-resistant materials with specially proportioned inlet contours to insure satisfactory operation with high-pressure steam and cold reheat steam over wide speed range.



OVER-ALL CYCLE EVALUATION

This table contains a synopsis of a cycle evaluation study for a 300-mw turbine generator unit, with operating steam conditions of 2000 psig throttle pressure, 1000 degrees F initial steam temperature, 1000 degrees F reheat temperature, and an absolute exhaust pressure of 1.5 inches of mercury. The boiler feed pump turbine drive is rated 9000 horsepower at 5000 rpm.

Several plans were studied, but for purposes of comparison, plan 5 was selected as a base, and all other heat rates and equipment costs are listed as positive or negative values in

PLAN NUMBER	BOILER FEED PUMP TURBINE LOCATION IN CYCLE	BOILER FEED PUMP TURBINE CONDITIONS				
		THROTTLE FLOW—LB/HR	EXTRACTION FLOW—LB/HR	INLET PRESSURE—PSIA	INLET TEMPERATURE—°F	EXTRACTION PRESSURE—PSI
1	Throttle to No. 1 Heater	202 500	—	2015	1000	—
2	Throttle to No. 3 Heater	103 500	—	2015	1000	—
3	Throttle to Condenser	50 440	—	2015	1000	—
4	Cold Reheat to No. 3 Heater	196 250	—	567	672	—
5	**Cold Reheat to No. 3 Heater with Extraction**	**240 230**	**104 800**	**567**	**672**	**241**
6	Cold Reheat to No. 3 Heater with Extraction (Uses Reducing Station)	240 230	104 800	567	672	241
7	Cold Reheat to No. 3 Heater with Double Extraction (Uses 7 Heaters)	231 260	53 960 52 040	567	672	241 179
8	Cold Reheat to No. 3 Heater with Extraction (Floating Heaters)	204 800	83 190	567	672	171
9	Cold Reheat to Condenser	66 920	—	567	672	—
10	Motor Driven Boiler Feed Pump	—	—	—	—	—

The stop valves of both the high-pressure and the low-pressure steam chests can be manually tested without affecting turbine operation.

Many of the safety devices are built into the front bearing pedestal. The turbine is equipped with an emergency overspeed governor, arranged to trip the stop valves at a predetermined overspeed. Means are provided for periodic checking of the overspeed governor without attaining tripping speed or interfering with normal turbine operation.

conclusion

A turbine drive for the boiler feed pump may or may not be the most economical choice. Only a thorough analysis of the individual situation can provide this answer. However, the possibility of economic improvement makes the analysis worthwhile. ■

CONTROL ELEMENTS OF TYPICAL TURBINE-DRIVEN BOILER FEED-WATER PUMP

The over-all steam cycle diagram for the evaluation study is shown at left, with the boiler feed pump turbine located per plan 5. Basic operation of the cycle is as follows:

A motor-driven booster pump is started to establish a boiler pressure of 200 psig. When steam pressure is established, the pump turbine is started. The first valves to open are the low-pressure control valves, which supply steam from the cold reheat line. Since there is no steam available in the cold reheat line, the high-pressure steam valves open to admit steam directly from the boiler to the feed pump turbine. A nonreturn valve is provided in the low-pressure steam supply to prevent back flow of steam to the cold reheat point.

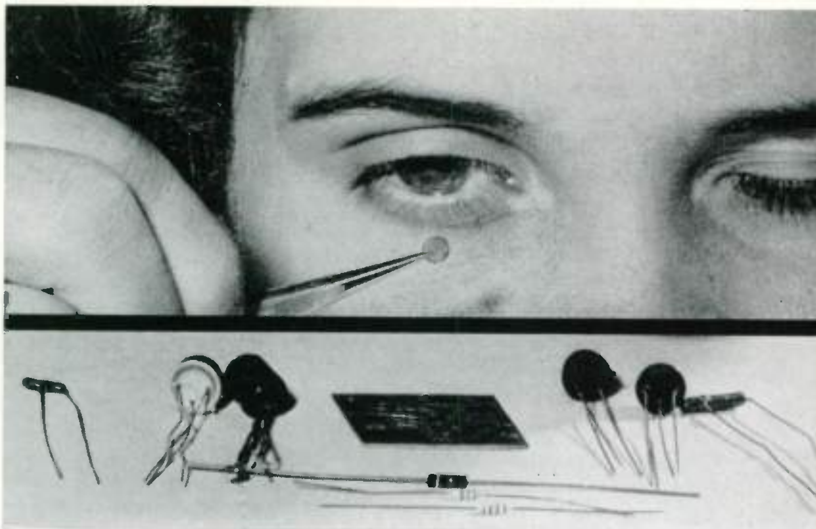
During the starting period, exhaust steam from the boiler feed pump turbine is admitted to the condenser through condenser exhaust valve *A*. Exhaust valve *A* will normally be open to loads of 20 percent of rating or less. If condenser vacuum is lost, the exhaust valve *A* will remain closed and relief valve *D* will dump the exhaust steam to atmosphere.

During normal load operation, greater than 20 percent load, the pump exhausts to the number 3 heater (deaerator). At full load, steam in excess of that available from the pump turbine is required by the heater, therefore the additional steam is supplied from the main turbine unit. At partial loads above 20 percent of rating, the excess pump turbine exhaust steam is returned to the main unit through *B* and *C*. Valve *B* is closed for 20 percent load or less. Valve *C* is a power-operated valve, which will close when the main unit is tripped.

relation to this base. The over-all steam cycle diagram for plan 5 is shown above.

In calculating equipment costs, only the cost of the boiler feed pump turbine and the price addition for extracting steam from or returning to the main unit were considered. The cost of valves, piping and controls were not considered as they come under the scope of the user's plant analysis. Notably, in plan 6, the cost of the reducing station and desuperheater were not included, and in plan 7, the cost of the additional feed-water heater was not included. The motor-driven boiler feed pump data are included in the tabulation for comparison.

EXHAUST PRESSURE—PSIA	MAIN UNIT NET LOAD DIFFERENTIAL—KW	NET HEAT RATE DIFFERENTIAL —BTU KWHR	TURBINE COST DIFFERENTIAL —DOLLARS	REMARKS
567	+4770	+21	+176 900	Continuous high-temperature, high-pressure steam conditions.
120	+2320	+22	+92 900	Same as Plan 1 except for lower flow.
0.75	+3010	+36	+43 300	Same as Plan 2 except exhausting to condenser.
120	+200	+21	−9 000	Dual steam chest—heat rate gains favor Plan 5.
120	**Base**	**Base**	**Base**	**Dual steam chest—This plan shown in diagram above.**
120	0	0	−25 000	Dual steam chest—Reducing station complicates reliability.
120	+480	−7	+10 000	Dual steam chest—Lowest heat rate but customer heater evaluation caused rejection.
90	−1400	+23	+8 000	Dual steam chest—Unstable governing operation and performance at all loads.
0.75	+2640	+35	+98 000	Dual steam chest—Similar to Plan 3 exhausting to condenser.
—	−1500	+5	—	Reduces net load output as well as having poorer heat rate than Plan 5.



Strikingly small even in comparison to the eye, this slice of silicon crystal performs all the functions of its best commercially available counterpart—a miniature transistor oscillator, the components of which are shown below—but with increased reliability because of the simplicity of the structure.

Such experimental "hardware" is being produced for infrared, reconnaissance, communications, telemetry, flight-control, and other military applications under a contract from the Air Force. The contract was preceded by four years of experimental study that showed molecular action of certain materials performs the same basic functions of conventional electrical circuitry in about 0.001 the material volume and with increased reliability.

WHAT'S NEW IN ENGINEERING

Shown in final stages of winding is a 97-ton rotor for a 330-mva, 45-psig, 16.5-kv turbine generator. This 1800-rpm inner-cooled generator, the largest unit of this speed ever built, will be installed in the Consolidated Edison Company's Indian Point nuclear plant now under construction near Buchanan, New York.

Steam conditions for the turbine are 355 psig, 1000 degrees F, and 1-inch Hg absolute. At maximum load, the turbine will pass 2 200 000 pounds of steam per hour. Because of the large volumetric flow to the turbine exhaust, double-flow, 44-inch long, low-pressure blades are used.

Hot-Metal Detector . . .
Steel Worker Par Excellence

In metal-working mills, a major aim is reduction of operator fatigue, which, in turn, leads to a maximum of usable product from the mill. A silicon hot-metal detector, a device that can sense high-temperature materials, can go far in achieving this goal. These detectors, located throughout a mill, can detect hot steel or metal and the detection signal can be used to perform various operations that would otherwise have to be done by the operator.

When a mill has a wide variety of schedules, hot-metal detectors are especially important. In a West Coast merchant bar mill, where 3/8- to 4-inch rounds, bars, squares, shapes, and even flats up to 5 inches wide are rolled, operators are not apt to make a mistake when switching from one schedule to another, because many routine operations are initiated by hot-metal detectors.

Progress in the field of thermoelectric power generation is visibly demonstrated by this 100-watt thermoelectric generator, TAP-100 (terrestrial auxiliary power, 100 watts).

Weighing only 40 pounds, the generator is pound for pound the most efficient and compact device developed for other than laboratory use, and has ten times the electrical output of any previous thermoelectric generator built in the United States.

The version at left, which operates at a temperature of 850 degrees F, is heated with propane gas. However, with modification of the nonthermoelectric portion of the generator, other fuels such as gasoline and kerosene can be used. Already, an advanced version of TAP-100 is being developed, which will be heated by a long-lived radioisotope. Development of the generator was sponsored by the Air Research and Development Command's Rome Air Development Center at Griffiss Air Force Base in Rome, New York.

When rolling rods or small-diameter rounds, the billet passes through four in-line stands. As the billet approaches each set of rolls, a hot-metal detector produces a signal that causes fingers to rotate the billet 90 degrees; this process maintains a uniform cross-sectional size as the billet passes through successive stands. The billet is then sent through eight looping stands. As the rod emerges from each stand a repeater, which is a curved deflector, bends the rod around in the opposite direction into the next stand. During the time the rod is in both stands, the loop grows in size, and the repeater must be removed. A hot-metal detector initiates a signal when the rod has nearly completed the loop. And due to a time delay, the repeater is removed the moment the rod enters the next stand. Hot-metal detectors located ahead of each looping stand also operate fingers to rotate the rod 90 degrees.

A hot-metal detector and two coilers at the end of the line assure continuous coiling of rod. When the end of a rod approaches the coiler, the detector produces a signal that stops the coiler and deflects the guide pipe to the other coil, which is started for the next rod.

Large size stock that cannot be looped is sent straight through the in-line stands onto a transfer table. The table then moves the stock down to the looping stand after receiving a signal from a detector. Also, the turners in front of each stand are operated by hot-metal detectors.

Large size stock is usually sheared at the end of the line. A hot-metal detector after the shear starts the cutting operation. After the cut section passes by, the front of the next bar is also sensed, maintaining a constant length of stock. To prevent a false cut, should the end of the bar lie between the hot-metal detector and the shear, another hot-metal detector on the other side of the shear allows a cut only if the bar extends beyond the shear. ■

22 000-Kw Gas Turbine

A 22 000-kw gas turbine for "peak shaving"—supplying power for short periods when electrical system loads are unusually high—will be used by the Philadelphia Electric Company as a pioneer application in meeting the ever-growing peak demands that face electric utility systems.

Although the concept of using gas turbines for peaking has been proven through many years of service on smaller units both here and abroad, this installation has a gas-turbine generator combination specifically designed for this type of service. ■

New Use for
Static Proximity Limit Switch

A static proximity limit switch, designed to detect magnetic metals one-half inch away, has been used to advantage in many conveyor and material-handling applications. The absence of moving parts, such as contacts and lever arms, makes possible a long life as compared to conventional mechanical limit switches.

However, the device has another advantage in that it does not disturb flow of material. For instance, limit switches have been applied to a tin-can sealing applicator to maintain height of an incoming stack of can lids.

The machine applies sealing compound to the rim of the tin can lid so that a hermetic seal can be made between the lid and the can wall. Lids are dropped onto a stack guided by four vertical rods. Since the lids are taken from the bottom of the stack and the sealing compound is applied to the inside surface of the lid, the lids should all be stored identically in the stack. However, if the stack is too low, incoming lids may flip over before landing. Thus the height must be detected and maintained.

While a mechanical limit switch would make contact and disrupt the flow or even turn over the lids, the static proximity limit switch does not touch the stack and therefore does not impair the flow. If the level of the stack falls below the sensing element, a time delay is started, allowing for normal fluctuations. If after the time delay, the stack does not return to its correct height, fingers clamp the bottom of the pile, preventing the lids from entering the machine. When the stack again reaches the sensing element, the fingers are released.

The sealing machine is manufactured at the Cambridge, Massachusetts plant of the Dewey and Almy Chemical Division, W. R. Grace and Company. ■

Trends in Assembled Switchgear Design

Increasing use of aluminum, extension of circuit breaker ratings, improved insulation materials, and a protected aisle for maintenance of outdoor metal-clad are some recent design trends in assembled switchgear.

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Metal-enclosed switchgear, both indoor and outdoor, is finding ever increasing application. These self-contained units, with air circuit breakers, are ideally suited for unit substations, powerhouse auxiliary switchgear, and industrial plants. With increasing application, continual detail product modifications are to be expected. And although any one improvement can rarely indicate a trend, collectively these changes can be interpreted as contributing toward a new development or an important basic change in design A review of recent progress in assembled switchgear designs will help identify these trends.

use of aluminum

Since the world supply of copper is insufficient to meet the expected increase in demand for conductor material, the present trend is toward replacement of copper by aluminum wherever possible. Aluminum buses and connections have been used for several years by manufacturers of 600-volt metal-enclosed switchgear. This was a logical starting point since this switchgear has sufficient space to accommodate the larger size bars required; furthermore, the buses are bare, thus presenting no problems in redesign of insulating tubings, compound boxes, and other forms of insulation. With the entirely satisfactory performance of aluminum in low-voltage switchgear, its application has been extended to 5- and 15-kv metal-clad switchgear, station-type cubicle switchgear, metal-enclosed rectifier switchgear, and isolated-phase bus.

The present practice is to use the high-strength aluminum alloy (designated 6101) for switchgear primary conductors. This extruded, heat-treated alloy has a conductivity of 55 percent of the International Annealed Copper Standard, and a minimum tensile strength of 29 000 psi. This strength is comparable with that of hard-drawn copper, so that aluminum requires no more mechanical bracing against the forces of short circuits than does copper. This aluminum alloy has been tested up to 150 000 amperes, in series with copper bus, and the deflections and deformations were entirely comparable.

Several satisfactory methods for joining aluminum to aluminum, or aluminum to copper have been developed. The accepted practice for aluminum primary conductors in switchgear apparatus is to use silverplated joints, with heat-treated steel hardware. Several joint compounds are available that also provide satisfactory electrical characteristics in bolted joints for extended times when properly applied, but silver-plating has an advantage in that no further surface preparation is required.

Several applications have also been made of unpainted aluminum for outdoor switchgear housings (Figs. 2 and 3). These have been in service for several years in different sections of the country with highly satisfactory results. Elimination of periodic cleaning and painting of outdoor switchgear is an important economic factor in favor of aluminum enclosures.

magnetic air circuit breaker ratings extended

As loads on utility and plant substations grow, so must the interrupting capacities of the circuit breakers that serve these loads. Increased interrupting capacity in itself does not indicate technical accomplishment. It is relatively easy to build an air circuit breaker for any conceivable interrupting rating, both in mva and voltage, provided

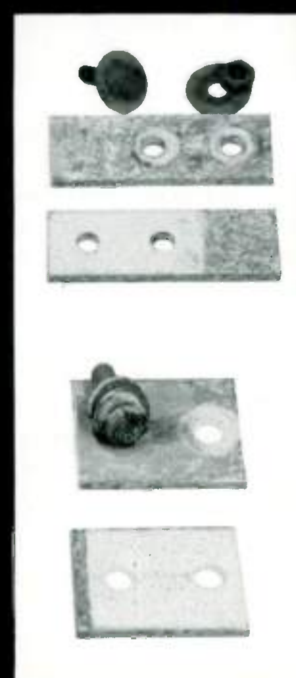


Fig. 1—(Near Right) The security of silver-plated aluminum joints has been established by laboratory testing. The sample on the above right was tested in a 100-percent atmosphere for six months; the lower sample was exposed to a salt spray for 200 hours.

Fig. 2—(Center) Unpainted aluminum enclosures have been successfully installed outdoors near Pittsburgh.

Fig. 3—(Far Right) In addition to its corrosion-resistant properties, aluminum is economical for use for high-current conductor housings.

that no particular space limitations are imposed on the design. The essence of the science (and art) of circuit breaker development consists essentially in designing to meet economically acceptable space requirements.

Most of these new higher-rated breakers are physically interchangeable with their lower-rated predecessors. Five new ratings of magnetic air circuit breakers have been developed by Westinghouse within the last five years. Three of the five increases are in the 5-kv class: a 75-mva rating, a 3000-ampere/350-mva rating, and a 2-cycle total interrupting time breaker with a 30 000-ampere interrupting ability. Two breaker-rating increases are in the 15-kv class —a 750-mva and a 1000-mva circuit breaker.

75-Mva Breaker—The 75-mva breaker, used on the lowest capacity systems, was obtained by modifying the arc chute, thus increasing the interrupting capacity of the previous 50-mva design. These circuit breakers are now provided with ratings of 75 mva at 4160 volts, and 50 mva at 2400 volts.

350-Mva, 3000-Ampere Breaker—The 350-mva, 3000-ampere magnetic air breaker was developed in response to electric utility requests. Today's larger generators require more auxiliary power, and boiler feed pumps in particular have required a continuous breaker rating of more than 2000 amperes.

This higher capacity demand also influences the size of station service transformers. A 2000-ampere secondary breaker current rating limits transformer capacity to 14 000 kva, whereas 20 000-kva transformers are being applied to 200 000-kw generator applications.

Momentary rather than interrupting current ratings may have greater significance on 4.16-kv auxiliary systems. This results from induction motor feedback during the first half cycle of the fault condition. Frequently a 2-to-1 ratio instead of the standard 1.6-to-1 ratio exists between momentary and interrupting current.

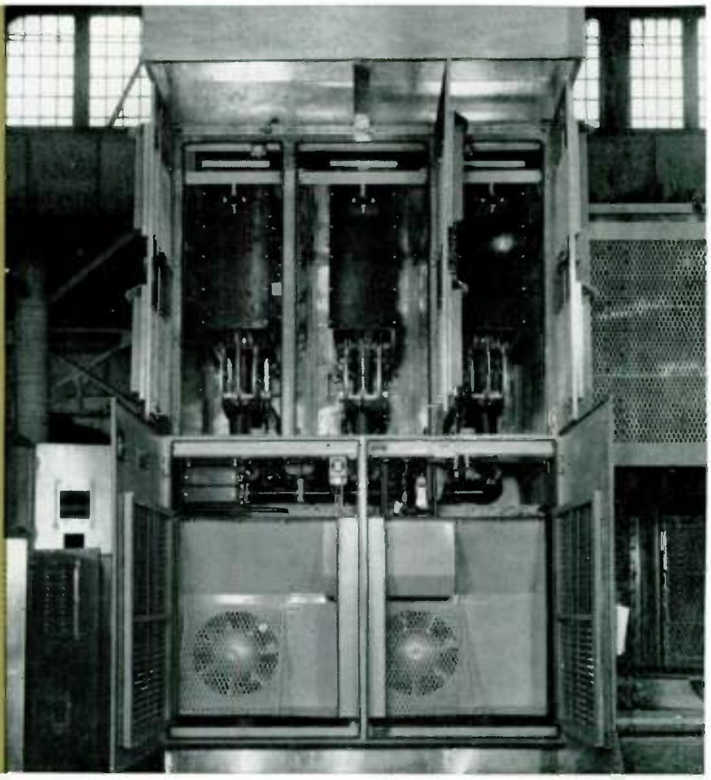
It is apparent from the foregoing that the 3000-ampere current-carrying rating and the 80 000-ampere momentary rating in this new 350-mva breaker are its most important features. Such a breaker will be of real help in the design of satisfactory and economic auxiliary power systems at 4.16 kv, or supplying a particularly heavy 4.16-kv load from a transformer substation.

Unit substations using these breakers and having equivalent transformer capacity, either single or double ended, will be available.

Two-Cycles Total Interrupting Time—The magnetic two-cycle breaker was developed for distribution circuits, where a fast interrupting time can minimize annealing and burndown of overhead distribution-circuit conductors.

Although there has been much discussion concerning the need for high-speed breakers during the last three years, the actual total clearing time required is still in question. Since clearing time is a function of the current value to be interrupted, Westinghouse switchgear engineers set some practical limits for a design goal: two-cycles was chosen as an economic limit for maximum clearing time for currents above 3000 amperes, and slightly more than two-cycles for currents down to 600 amperes.

Because of the fast interrupting time of two-cycles or less from trip-coil energizing to fault-current clearing, most interruptions will be on the asymmetrical portion of fault-current envelope. The usual 1.6 ratio between interrupting current and momentary current cannot be maintained.



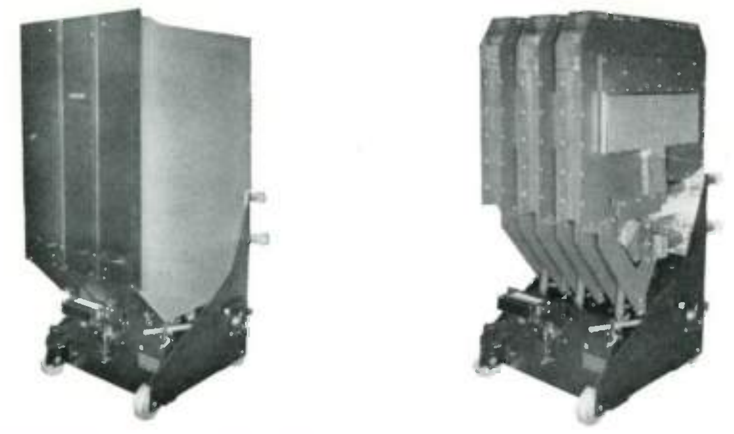


Fig. 4—(**Left**) 1000-mva, 1200-ampere, 13.8-kv magnetic air circuit breaker completely assembled for insertion into metal-clad switchgear; (**right**) same breaker with main barrier removed.

Therefore, the breaker was assigned an interrupting rating of 30 000 amperes at 4.16 kv rather than the usual kva interrupting value.

750- and 1000-Mva, 15-Kv Breakers—Magnetic air circuit breakers, as a general class, give the user the maximum economy in installation, maintenance, and flexibility of operation. These qualities are particularly desirable in distribution substations. As the size of the substation increases, the advantages of the magnetic interrupter become still more apparent. The fast growth of metropolitan substations thus led to the recent development of the 750-mva, 13.8-kv magnetic breaker for use in metal-clad switchgear. The interrupting rating of 500 mva had been the maximum available magnetic air breaker rating in metal-clad switchgear for many years. However, in the short period from 1956 to 1958, the 750-mva rating became inadequate to meet the increasing needs of the industry, and a 1000-mva, 13.8-kv magnetic air breaker was developed (Fig. 4).

The 1000-mva breaker fits into an indoor metal-clad cell of the same width as that required for the previously developed 13.8-kv ratings of magnetic breakers, and an increase of only 4 inches in depth is required over the depth of 750-mva rating. This is true for both of the continuous-current ratings of 1200 and 3000 amperes.

metal-clad insulation

Insulation materials that are both flame retardant and track resistant have been developed and applied to metal-clad switchgear during the last few years. The introduction of porcelain bus supports satisfies the demand for track-resistant, flame-retardant insulation. Plate insulation and other molded parts, used where porcelain is not practical, are now a glass polyester material, which is both flame re-

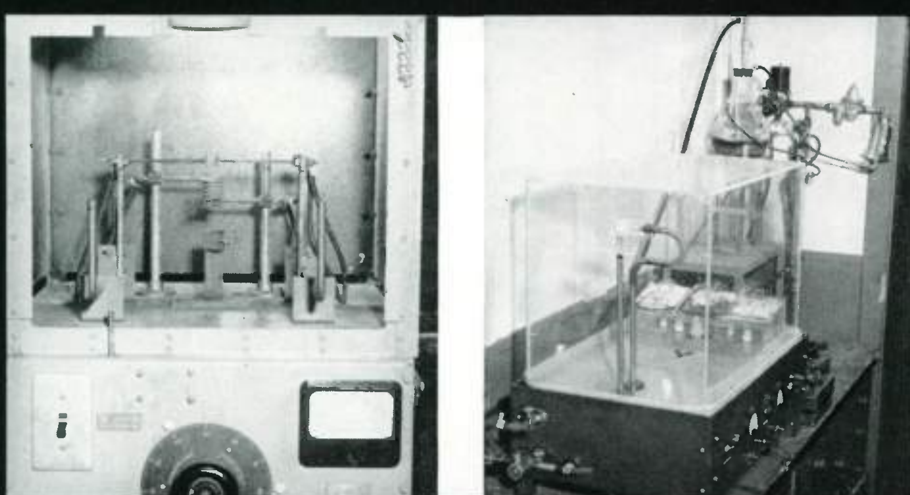


Fig. 5—Apparatus for testing (**left**) flame resistance and (**right**) track resistance of insulating materials.

tardant and highly resistant to tracking. Glass polyester is also more resistant to arc burning than most other organic materials. These new glass polyester laminates have replaced the flame-retardant phenolic paper laminates that were used previously.

The insulation for bus conductors is made with an improved binder that greatly increases the flame-retardant qualities of bus insulation.

Effectiveness of flame resistance is measured by the new NEMA flame-testing method, based on Federal Specification L-P-406b. The device for making the test is shown in Fig. 5. A conditioned specimen is surrounded by a heating coil, adjusted to give a coil temperature of 860 degrees C, ±5 degrees. Electrodes that provide a continuous spark discharge are placed adjacent to the sample to ignite any flammable gases given off. The test starts when power is applied simultaneously to the electrodes and to the heating coil, and the total elapsed time before the specimen ignites is the *ignition time*. Application of power is continued for 30 seconds after ignition. The time elapsed from turning power off until all flame is extinguished is the *burning time*. Using this test method, a typical sample of an insulation that is not flame retardant may take 80 seconds to ignite and then burn until it is consumed. A good flame-retardant insulation may take about 150 seconds to ignite, and burn for about 60 seconds.

Insulation under conditions of moisture, contamination, and continued electrical stress will sometimes develop conducting carbon tracks. For evaluation of track resistance, material samples are dusted with a synthetic dust and placed on an inclined rack surrounded by a transparent housing (Fig. 5). The samples rest on a grounded sheet of copper, and three copper electrodes are placed on their surface. The two outer electrodes are grounded, and the center electrode is energized at 1500 volts, 60 cycles. Test sample surfaces are kept continually moist by a fog supplied from a fog nozzle. The time required to track is taken as a direct measurement of track resistance.

miscellaneous metal-clad improvements

Spring Stored-Energy Closing Mechanism—Where a number of breakers must be closed simultaneously, such as a bank of breakers through which power is fed to a large network system, the spring stored-energy closing mechanism can minimize control power requirements. Closing energy is stored in a compressed spring at a relatively low rate, and released for breaker closing at a high rate. In the Westinghouse system, a motor and reduction gear compress the spring in 5 to 10 seconds, and latch a retaining linkage. The breaker is closed by releasing the retaining linkage, either electrically or manually.

The control circuit of the mechanism is such that, immediately upon breaker closing, the motor runs and compresses the spring. Thus, a first reclosure can be made instantaneously, but if the breaker immediately trips open after the first reclosure, a time delay is required for the second reclosure to allow time for spring compression. If the breaker is tripped open in the absence of closing power, the spring is compressed immediately upon restoration of closing power. In the absence of electrical closing power, the spring can be compressed by a hand crank.

Panel Hinge Wiring—New and improved wiring methods are used throughout assembled switchgear to improve appearance, increase wire life, and reduce manufacturing time. Stranded wire, with its improved flexibility and life, is used throughout. Wiring is carried to the hinged front panel by use of a loop, as shown in Fig. 6. This loop is subjected to relatively minor twisting rather than bending (as with the previous design). With this construction, 30 000 operations have been performed on a typical sample without failure.

Through-Type Current Transformers—For many applications, through-type current transformers are now used (Fig. 7). These possess several definite advantages over the wound type—better strength to resist short circuits, better insulation, increased flexibility with multi-ratio taps, and easier replacement.

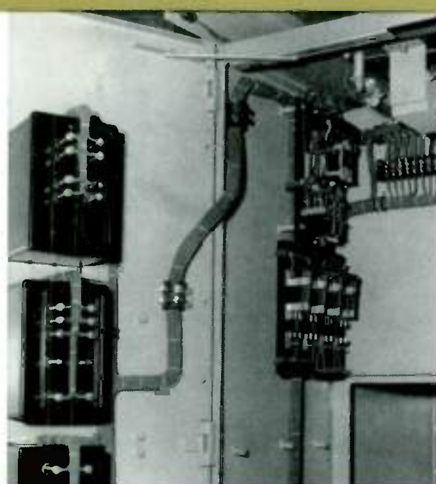


Fig. 6—(Left) Loop used to carry wires to hinge front panel.

Fig. 7—(Right) Through-type current transformers permit greater ratio flexibility, are easier to replace, and are stronger on short-circuit than the previous wound types.

weather-protected aisle for outdoor metal-clad switchgear

An important change in outdoor metal-clad switchgear is the introduction of the protected aisle for operation or maintenance. Users of outdoor metal-clad equipment are greatly concerned over the inconvenience associated with bad weather. System troubles are most frequent during storms, and these storms provide the most difficult "trouble shooting" conditions. One Eastern utility solved the problem by erecting a large enclosure that could be rolled on a track, for transporting breakers to a position where maintenance could be provided. Another utility used a truck that could be parked beside the equipment to provide temporary shelter.

These inconveniences prompted switchgear engineers to design a shelter that eliminates maintenance problems on outdoor metal clad. The design introduced in 1957 (Fig. 8) is an outdoor metal-clad construction that provides the facilities of an indoor metal-clad installation, but does not require a building. The design permits shelter for operation and maintenance of breakers, relays, and control equipment (Fig. 9). It is flexible in application and retains all of the advantages of metal-clad switchgear. The design has been named, because it provides sheltered maintenance, Shelterfor-M.

The aisle is provided for maintenance, operation, and exercising all of the features of metal-clad equipment, such as the ability to draw a breaker out and replace it with another breaker so that maintenance and test operations can be performed. The same full-height instrument panel is provided as on indoor equipment. This panel completely protects the operator from the breaker with steel isolation.

Because a common aisle is used for both operation and breaker drawout space, Shelterfor-M equipment can often require less space than the present designs. The previous outdoor metal-clad equipment required an aisle on one side of the gear for the operating panel and on the other side for breaker drawout space. In Shelterfor-M, the two functions are combined in one space and, although the aisle provided is far larger than the recommended minimum aisle space required for the previous design of unit, the total overall dimension can be less.

Another advantage is in construction of the foundation. Here, since the structure underneath the Shelterfor-M unit is self-contained, it is necessary only to support the foundation steel. With the superseded equipment, it was necessary to provide a "true and level" pad for transporting the breaker. The new type of foundation also permits elevating the switchgear on a supporting structure. This has been done in flood-hazard areas (Fig. 10).

All of the circuit applications that have always been available in metal-clad units are still possible. Actually, the ultimate arrangement that is possible with Shelterfor-M, and cannot be obtained with the former design, is the double-row common-aisle installation. In this case, dimensions are further reduced because the aisle serves two rows of switchgear. This arrangement is especially suitable for double-bus, single-unit transfer schemes. Here, the breaker drawout locations are immediately opposite across a seven-foot aisle. This contrasts with the superseded metal-clad design where breakers must be drawn out on the far sides of two rows of equipment and transported completely around the station before being inserted.

summary

Several trends can be implied by the course of recent design changes in assembled switchgear:

One of them indicates the increased use of aluminum, both in conductors and structural members. Aluminum bus joints can be properly silverplated and will remain sound. As enclosure material, aluminum offers good corrosion resistance and is more economical than other nonmagnetic materials.

Another very clear trend is toward an extension of present breaker ratings. Magnetic air breakers have recently had their kva rating extended to 1000 mva, their continuous rating to 3000 amperes, and interrupting times as short as two cycles are available.

Metal-clad insulations will continue to improve. The recent introduction of porcelain bus supports and glass polyester insulation provides a landmark in this progress.

Outdoor metal-clad switchgear will find more and more application now that it provides all of the features of indoor units with the same operating and maintenance facility. ■

Fig. 8—(Left) 5-kv Shelterfor-M installation.

Fig. 9—(Center) The aisle is large enough to permit complete interchangeability of circuit breakers.

Fig. 10—(Right) Foundation construction of Shelterfor-M switchgear permits pier support.

AN ENGINEERING PERSONALITY *W. R. Harris*

If one were passing by the *Walter R. Harris* residence late some Friday evening, the strains from a Dixieland combo might be heard, coming from within. This would not be a loudly playing hi-fi set, but a group consisting of Harris and several friends participating in a musical jam session, all for their own amusement. In the midst of the din would be Harris, normally a quiet, soft spoken West Virginian, "taking off" on tenor sax.

However, this is not the biography of a musician. Much as he loves music, there has never been any doubt in Harris' mind as to his chosen profession. When Harris was a junior in high school in Welch, West Virginia, a civics teacher assigned the class an essay on "What I Want to Do." The project included interviewing three people already in the chosen profession. Harris picked electrical engineering, and has never varied from his choice. A few years later, he was enrolled at the University of West Virginia, studying electrical engineering. But he was helping defray college expenses by playing in dance bands on Friday and Saturday nights. Harris recalls several occasions when he had a textbook packed with his music, in hopes of getting a few minutes to study between sets. The effort paid off, and Harris graduated with a BSEE in 1937, at the top of his engineering class.

After coming on the Westinghouse Graduate Student Course, Harris decided on application engineering as his field, and was placed on the Engineering and Service training program, in preparation for placement in a district office. However, a training assignment in the General Mill Section of Industry Engineering turned out to be a permanent one, and Harris spent seven years as an engineer in this section. During this period, his chief concern was with paper mill drives and control applications. He was in at the beginning of the application of rotating regulators, and helped solve many of the initial application problems. His ability along this line was such that he was given several special assignments on rotating regulator application and development. On one occasion, he was placed on a special assignment to study arc furnace regulating problems, and was one of the first men in Westinghouse to make a complete mathematical analysis to predict the behavior of a rotating regulator system.

Harris was transferred to the Metal Working Section in 1946, where he changed his field from paper mill to steel, aluminum, and brass mill drive and control applications. In 1948, he was made manager of the section.

Harris has had extensive experience in the application of system drives to large and complex mills and process lines. He is an authority on the use of feedback regulating systems, and on the selection and coordination of the characteristics of the d-c rotating machinery involved. He has accumulated 19 patents in this field, and has written about 40 technical papers and articles on the subject.

Perhaps Harris' outstanding ability in dealing with control systems stems from his knack of reducing engineering problems to their fundamentals, and then dealing with them on that basis. As one associate stated "Harris is one of those people who not only sees the forest well, but also notices any trees out of line, and straightens them up in the process of solving the problem."

Since Harris assumed his present position as Manager of Industrial Engineering in 1953, a major portion of his time has been spent on administrative problems. However, he continues to stay close to application engineering, and is presently secretary of a company steering committee exploring areas for future advanced systems control development and application.

Harris is described by one acquaintance as ". . . a top-notch technical man, but with the personality of a salesman . . ." This is a fortunate combination since a sizable portion of his job consists of assisting sales people with application problems. With such a combination, it is only natural that Harris' services as a speaker are in high demand throughout the company. Actually, he enjoys speaking, and during a normal business trip often gives talks two or three nights a week. His favorite topic at the moment is "The Impact of Automation on the Engineer."

Many young engineers are acquainted with Harris through his graduate-level application engineering course, which he has taught in the University of Pittsburgh-Westinghouse Graduate Study Program for 16 years. Incidentally, Harris obtained his MS degree in 1941 under this program.

Earlier this year, Harris finished his term as Chairman of the Pittsburgh Section of the AIEE. He serves regularly on a number of national AIEE committees, where he divides his effort between general and technical committees. For instance, he is presently Chairman of the Prize Awards Committee, and a member of the Recognition Awards Committee, and is serving on technical groups, such as the Industry Division Committee, and the Automation and Data Processing Committee.

Anything Harris does, he makes a point of doing well. A couple of years ago, he finally decided to play golf. Previously, he had contended that golf was "an old man's game," but carefully left himself an "out" by not defining "old." He now has apparently finally decided that he has reached the eligible age. Although Harris' golf game is improving noticeably, several of his golfing companions insist it will never match his ability to negotiate handicaps on the first tee. ■

TIMING DEVICES—Essential to Automation

Since most control systems depend on "time intervals" for operation, the timing device is an essential building block in industrial controls.

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Timing devices serve as delays, sequencers, and programmers in many home electrical appliances and in all phases of automatic and complex industrial and business control systems.

When correctly applied, timing equipment helps achieve safe and consistent operating conditions, better products, and lower process or production costs.

To select the best timing device, the requirements of the application and the basic characteristics of all types of timers must be known. Often, failures occur or results are inadequate because all application factors were not established, or limitations of the timing device were not known.

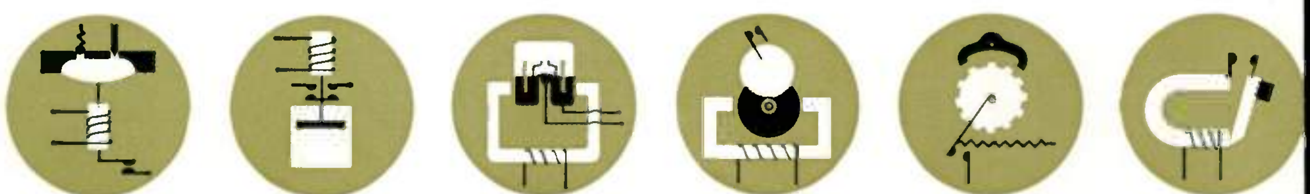
what is a timer?

A timer is a device that produces an output after receiving an input signal; the time interval between the input and output, of course, can be controlled. Three ingredients are essential to a timer: a timing method, an input to start or sustain the timing period, and an output signal (Fig. 1, page 154). A manual input signal, for example, could be the setting of a stove timer dial. An electric input signal could be used to energize or de-energize an electromagnet, motor, or circuit of a timing device. At the end of the time interval, a mechanical device moves or electric contacts make or break to produce an output.

Where are timing devices used in the field of automatic

● MATERIAL TRANSFER

TABLE I OPERATING PRINCIPLES OF TIMING DEVICES



TYPE	PNEUMATIC	DASHPOT	MERCURY	MOTOR	ESCAPEMENT	INERTIA
INPUT (initiates timing period)	Voltage—solenoid forces diaphragm to expel air from chamber	Voltage—solenoid moves piston	Voltage—pulls solenoid into mercury	Voltage—starts clock motor	Voltage—applied to solenoid. On manual device, spring is wound	Voltage—applied to relay coil
MOTIVATING FORCE (sustains time period)	Bias spring moves diaphragm and pulls air into chamber. Time is a function of spring force	Voltage—moves piston. Time is inverse function of voltage	Mercury forces gas from bell through porous ceramic or orifice	Clock motor drives gear train or cam shafts	Solenoid plunger moves. Time is inverse function of voltage and resulting pull	Voltage applied to relay coil
RESTRICTING MEDIA (controls time period)	Needle valve. Time is inverse function of orifice size	Time is inverse function of clearance and orifice size and direct function of distance piston moves	Porous ceramic or orifice. Time is inverse function of gas leakage	Speed of clock motor and gear ratio of gear train. Time is function of distance contact or cam must move	Escapement and inertia wheel moves solenoid plunger. Time is function of oscillating period	Large mass on armature delays movement
OUTPUT	Contacts—by diaphragm movement	Contacts—by piston movement	Mercury completes circuit	Contacts—by gear train movement	Contacts—by plunger movement	Contacts—by armature movement
TIME RANGE	0.2 to 200 seconds	1 to 60 seconds	0.2 second to 20 minutes	1 second to days	1 to 6 sec for magnetic—hrs for manual	0.1 second or less
ACCURACY	±10%	±20%	Average	0.1 second for synchronous motor About 5% for d-c motor	Magnetic—±15% Manual—1 second	±10%
RESET TIME	Instantaneous—with check valve	Instantaneous—with check valve	Instantaneous	Instantaneous—with release-clutch or ratchet	Instantaneous—with ratchet release	Same as time period

control or in a complete control system? The control art can be divided into three areas: pilot devices, pilot-control circuits (intelligence or information processing), and power control (Fig. 2, page 154).

Pilot devices are used to sense temperature, pressure, position of material in a machine, or a signal from an operator, to name a few.

As signals from the eyes, ears, nose, and touch organs are transmitted to the brain for decision making and final action through muscles, electrical signals in industry are initiated by pushbuttons, thermostats, and limit switches and processed in control circuits to run motors, solenoids, and other devices.

In pilot-control circuits, intelligence or information processing is accomplished by logic (sequential switching), timing, and memory. Timers in the pilot-control circuit are a necessity for programmed control.

In selecting a timing device, the factors that contribute to the overall performance of a control function should be clearly understood. A knowledge of how to vary these factors to produce a given result is also essential, Table I. For example, the timing period is best adjusted by the input signal, output signal, or the restriction factor (as with a needle valve). Timer operating principles can be divided into three groups: material transfer, heat transfer, and electrical transfer.

The *material transfer* principle is merely the age-old hour-glass concept, where a metered quantity of material is transferred from one location to another in a restricted manner. Pneumatic, mercury, dashpot, and motor timers all fit in this category. For instance, the gear train of a motor timer is a metered quantity (X number of gear teeth must be moved in a certain time period).

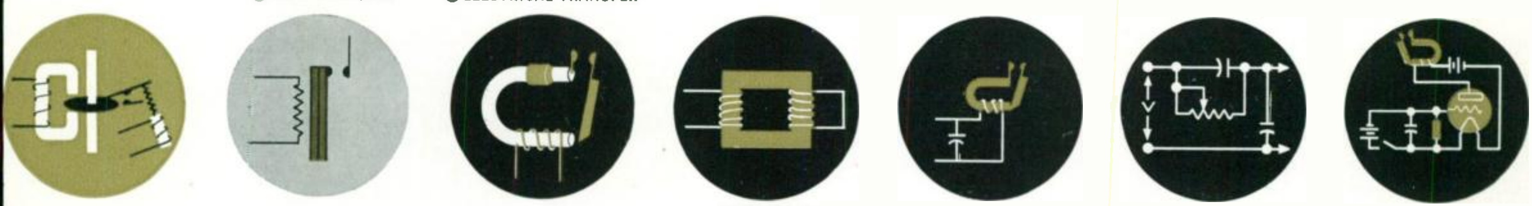
In the *heat transfer* system, heat is transferred from an electrical heater to a metallic element. As heat is absorbed, the metal stretches, bends as in a bimetal, or melts as in a solder-pot relay, closing or opening an electrical contact. Thermal timers frequently are used on automobile-turn signals as well as in motor-protective devices. Various methods are used to transfer heat to the "heat motor" or metal element. Often, the heat is generated within the metal element, as in the case of flasher timers. This minimizes the effect of ambient temperatures.

The *electrical transfer* principle (sometimes called energy storage) is an extremely flexible source of timing, and is especially suited for use in static controls. Inductive timers and capacitor-discharge or charge schemes are the more common types of electrical transfer timers.

Any phenomenon that depends on "time" may have merit as a timing device. The suction-cup timer used in roll-towel racks is an example of an inexpensive timer solution for a commercial product. Here the design engineer recognized that time is a factor in pulling loose a suction cup. Apparently, a certain time interval must pass before

HEAT TRANSFER

ELECTRICAL TRANSFER



INDUCTION DISC	THERMAL	INDUCTIVE DECAY	INDUCTIVE BUILDUP	CAPACITOR DISCHARGE	CAPACITOR CHARGE	ELECTRONIC
Voltage—applied to drag magnet	Voltage—applied to heater element. Time is inverse function of voltage	Voltage—removed from coil	Voltage—applied to winding on magnet core	Voltage—disconnected. Time is function of voltage and capacitor size	Voltage charges capacitor. Time is function of voltage and capacitor size	Same as capacitor discharge
Separate magnet armature biases spring which rotates disc. Time is inverse function of spring pull	Metal expands or moves with application of heat	Gravity or spring pulls relay armature. Time is inverse function of spring tension	Magnetic flux	Energy stored in capacitor. Time period is direct function of capacitor size	Charging voltage. Time is direct function of voltage and capacitor size	Same as capacitor discharge
Disc rotation slowed by drag magnetic field. Time is function of distance between contacts	Timing is function of heat transfer rate, thermal capacity of metal, and distance bimetal moves	Inductance delays decay of flux. Copper rings increase inductance and time delay	Inductance of magnetic circuit delays buildup or change in flux	Shunting resistor adjusts capacitor discharge. Time is direct function of resistance value	Charging rate determines time	Same as capacitor discharge
Contacts—by disc rotation	Contacts—by heated metal or bimetal	Contacts—by armature movement	Voltage—by flux buildup	Voltage. Or contacts by adding relay	Voltage—by capacitor charge	Voltage—amplified by electronic tube
1/6 second to 5 seconds	0.5 second to 5 minutes	0.5 to 3 seconds	1 second maximum	0.1 to 30 seconds	0.2 to 20 seconds	0.01 to 30 seconds
±10%	±50%	±5%	±5%	±5% depends on device sensing output voltage	±5%	±1%
0.1 second	Up to 2 minutes	Approximately 10% of time period	Same as time period	10% or less of time period, depending on charge circuitry	10% of time period	10% of time period

an elastic-plastic material returns to its original shape after being bent.

Commercial timers are normally identified by their timing principle. The operation of a pneumatic timer, for example, depends on the time for air to flow from or into a metered chamber through a calibrated orifice. A thermal timer uses the time to heat a bimetal element for its control. There are exceptions to the rule, however. The name electronic timer does not indicate that a capacitor-discharge timing principle is used.

how are timers applied?

Timing devices are best selected by outlining the conditions under which the device must operate and the functions required, Table II.

The time range is the first condition to be satisfied (Fig. 3). If delay periods less than a second are needed, as on a spot welder, an inertia or stored-energy type such as a capacitor-charge or inductive device should be considered. Since the timing range must be variable, highly repetitive, and possess good repeat accuracy, an electronic timer using a capacitor-discharge principle may be the only answer. Because the timing range of a capacitor-discharge timer can be adjusted with a rheostat, remote adjustment is possible. Pneumatic timers have been used for spot welders where the operating rate is not high. But the life or wearing qualities of the timing device should also be considered.

In optimizing control systems, such as Opcon, a timer provides the delay necessary for a process to reach equilibrium after a change has been made. Some processes require several hours to stabilize after a change has been made. Some of this can be transport time. In other words, material may have to travel over a conveyor or through a mixing system before reaching batch or end product stage where a change can be detected. In Opcon, a timer, adjustable up to a 240-minute interval with instantaneous reset, delays further corrections in the system.

The program plan of a timer is determined by the operating functions of the application. For example, the function, "start timing period when signal is applied," might describe the need for a delay between accelerating steps of a resistance-type motor starter. Pneumatic timers can be used in this application.

Table II—FACTORS TO CONSIDER IN APPLYING TIMING DEVICES

CHARACTER OF TIME PERIOD

Time Range
- Timing intervals, time delays, dwell periods, sequencing, programming, accelerating time, pauses, repeat cycling, intermittent timer, continuous timer, elapse timer, cumulative timer, timers in hour range, timers in fractions of a cycle range, inverse time

Fixed Time

Adjustable (local—remote)
(manual—automatic)
range of adjustment 2:1—10:1

Reset Time

Accuracy—repeatability of time period

Fail Safe—operate without power

Sensitivity of Variables—ambient temperature, voltage fluctuation

Power Source—a-c, d-c

COORDINATING TIMER WITH CONTROL SYSTEM

Input Signal
- Manual
- Mechanical—operates from levers, contactors
- Electrical
  - Digital—limit switches, pushbuttons
  - Analog—motor currents, power fault currents

Output Signal
- Mechanical—pin, trip latch
- Electrical
  - Digital—electrical contacts, single-multiple
  - Analog—magamp circuits, Cypak circuits

ENVIRONMENT

Space, vibration, enclosure, dust, and corrosion

COST

LIFE, MAINTENANCE

A "start timing period when signal stops" function may be used to delay the operation of the under-voltage attachment on an oil breaker after voltage reduction. By using a capacitor-type timer, delays of several seconds are possible.

Programmed time pulses as found in a die-casting ma-

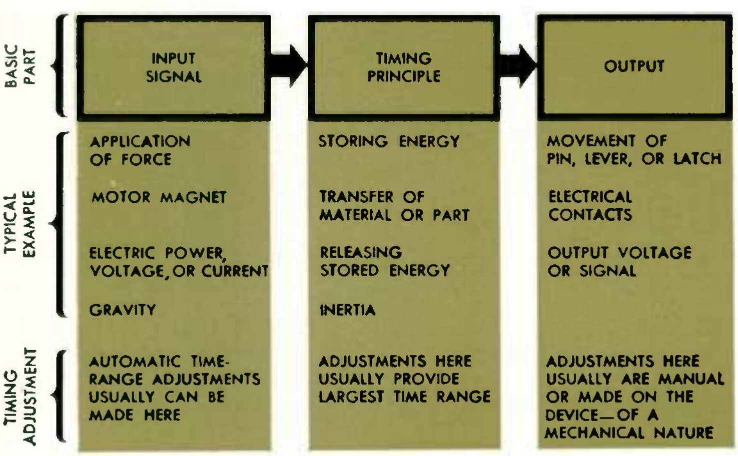


Fig. 1—Basic parts used in electrical control circuit timing devices.

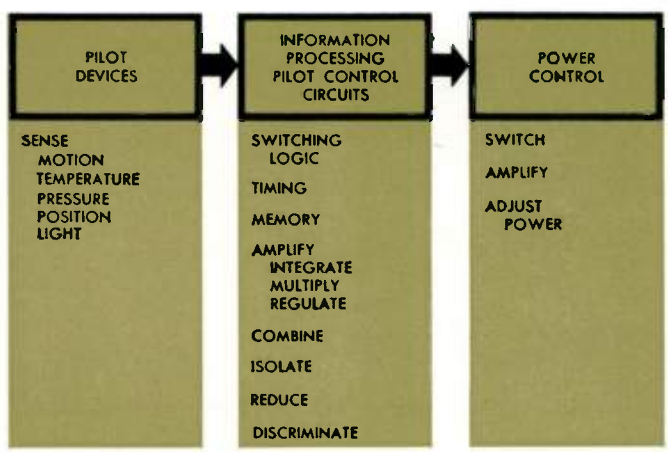


Fig. 2—Three basic functions of electrical control.

chine, with pauses for loading, heat cycle, etc., call for a multicam-operated motor timer.

Electrical input signals to a timer may be voltage pulses, as used in Cypak control, or steady-state voltage outputs from other switching devices. This does not change the time period of the timer. However, if timers operate on fixed-input signals, voltage, frequency, and ampere ratings should be considered.

The availability of reliable rectifiers makes possible operation of practically any d-c timer on a-c power. Inductive timers, for example, are operated by direct current, but by adding a selenium-rectifier bridge, they are also effective in a-c circuits. Most other timers are available with a-c or d-c operating coils. On motor-operated timers, a-c power adds a degree of accuracy because a synchronous motor can be used.

Usually the time interval of fixed-input timers can be varied by adjusting the basic mechanism of the timing principle. In the case of a pneumatic timer, the orifice size is changed with a needle valve. In an inductive timer, the rate of decay is changed by varying the number of short-circuiting rings. Less expensive and simplified versions of these timers can be obtained by omitting these adjustments. In applications where a fixed delay (for instance, tube warmup in electronic equipment) is adequate, these fixed-time-delay devices are economical.

If input voltage or current varies proportionally to changing conditions of the application, the timing period will also vary. If the time-delay range must be automatically changed to suit application conditions, this adjustable time characteristic is just what is needed.

If the time delay must be inversely proportional to signal strength, as in the case of an overload relay, a thermal timer with a timer interval inversely proportional to input current would be applicable. For instance, the time period of a motor-overload relay must be inversely proportional to the overload current. A 30-percent overload can be tolerated longer than a 200-percent overload. In this case, a signal proportional to the motor current flows through an overload heater, which operates an overload relay; as the current increases, the trip time decreases.

A dashpot timer can also be used for motor protection. Here, the current in the operating coil is proportional to the motor current. The greater the magnetic pull, the faster the piston or dashpot moves. To be used as an overload relay, the time-current characteristics of the timer must match the allowable heating curve of the motor.

The nature of the control circuit also helps with the selection of the timing device. When used in a switching circuit, the timer should have output contacts. Standard 110-volt, 10-ampere control ratings usually apply. If a timer is used with a magamp regulator, where delays on the order of seconds may have to be introduced to prevent hunting, inductive and capacitor-charge systems (using electrical-transfer principles) are best suited. A damping winding can be built in the magamp core to provide up to a one-second delay. Or a capacitor-delay circuit can be used to provide a delay of several seconds.

In general, high accuracy contributes most to the cost of a timer. In electronic timers, additional circuits can be incorporated to compensate for variables, such as power-voltage fluctuations, and also to improve the accuracy of capacitor-discharge voltage sensing. These add to cost.

However, reliability does not necessarily increase cost. Solid-state devices such as rectifiers and transistors are making possible reliable timers. The increased use of static components indicates why the capacitor timing principle is so well qualified.

Analog computers make use of the capacitor-charge principle. In the feedback element of a d-c amplifier (Fig. 4a), the parallel combination of a capacitor and resistor produces a time delay. If the input is a step function, the output will be an exponential rise of voltage. The time interval depends on the resistance and capacitance values. This is a direct analog of input-output characteristics of a generator, as shown in Fig. 4b. The gain of the amplifier and the time delay of the circuit can be adjusted to correspond to the characteristics of the generator circuit, allowing reproduction of the dynamic and steady-state conditions of the generator.

As application and resulting control requirements become more exacting and complex, the basic needs of a problem should be evaluated, and the fundamental characteristics, including limitations should be understood. The commonplace should not be ignored—a suction-cup is as much a timer as an overload relay. ■

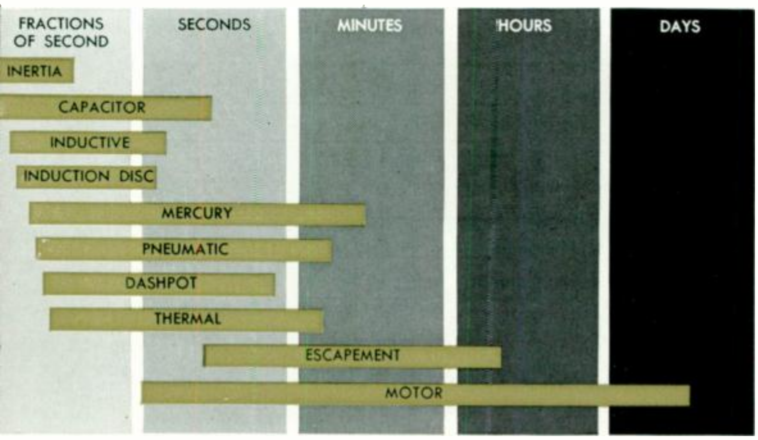


Fig. 3—Practical time ranges for various timing principles.

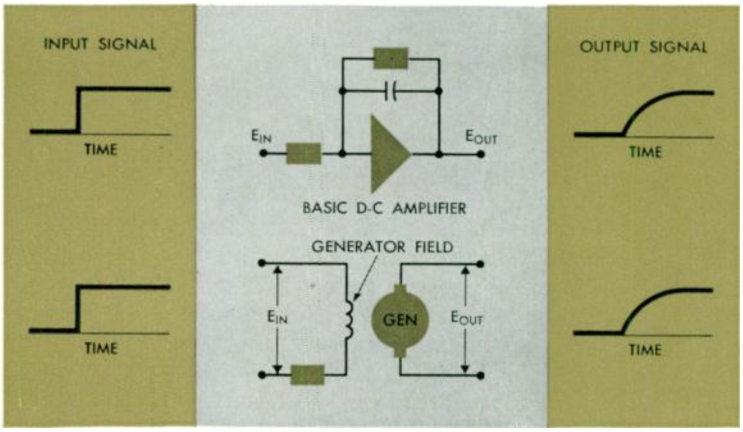


Fig. 4a (Top)—Time-delay circuit; **4b (Bottom)**—D-c generator circuit.

Application of Reactor Control to A-C Motors

With the following reactor control schemes, completely static control can be applied to large wound-rotor and squirrel-cage motors, and many different starting and running requirements also can be satisfied.

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Though fixed and saturable reactors have been used primarily in low-power controls in the past, with proper application they can control squirrel-cage and wound-rotor motors up to 1000 hp. Numerous reactor-control schemes have been designed to meet many different starting and running requirements. For instance, applications have been made on general cranes, conveyors, continuous handling cranes, transportation equipment, missile handling equipment, and many other material handling drives.

Reactor control is most effective where one or a combination of the following requirements exist: (a) repetitive operations, (b) frequent reversals, (c) speed control, (d) torque control, (e) cushion starting, and (f) high reliability.

Because static components are used, reactor control, in general, reduces downtime and increases reliability. Although one fixed reactor costs the same as two to three contactors, and one saturable reactor costs a little more than five contactors, the advantages of static components can outweigh the higher initial cost. And in specific cases, reactor control offers advantages not obtainable with other control schemes, such as cushion starting.

operation of fixed and saturable reactors

A *fixed reactor* is a continuous coil of wire and, as its name implies, its impedance cannot be varied, whereas the impedance of a *saturable reactor* can be controlled. A saturable reactor has one a-c primary winding, and a second d-c control winding, which controls the impedance of the a-c winding; an increase in the d-c control current decreases the a-c winding impedance. While single-phase saturable reactors are most common, two- and three-phase units are sometimes used.

If the primary winding of a saturable reactor is connected in series with a load, and the control winding is not energized, a small amount of alternating current flows through the load and the primary winding, Fig. 1. With this small excitation current, most of the voltage drop is across the reactor, with little across the load. If the direct current is increased to 50 percent of the reactor rating, the voltage across the a-c winding is reduced, permitting more a-c current to flow through the load. If the load impedance limits the current to 50 percent of the full-load alternating current, the voltage drop across the reactor is low. If load impedance is less, the alternating current increases and voltage across the reactor increases, limiting the load current. If more load current is desired, more d-c current is required to reduce the voltage.

Conversely, as direct current in the control winding decreases, more voltage is absorbed across the saturable reactor, reducing the load current.

The time constant of the saturable reactor can be varied with different a-c winding arrangements. The smallest time constant is obtained by connecting the a-c power windings in series. A longer time constant is obtained by arranging the power windings in a parallel or a series-parallel combination.

single-phase primary saturable reactor control

Cushion starting or some speed and torque control can be obtained most easily by connecting a single-phase saturable reactor to one phase of an induction motor, Fig. 2. For maximum cushioning, the d-c voltage should be low to eliminate the need for a resistor. For less cushioning, the d-c voltage should be increased, and a resistor used to maintain the same current as before. For variable-torque or variable-speed control, the resistor is replaced with a rheostat. After the drive is started, or after reaching full speed, the reactor can be shorted out.

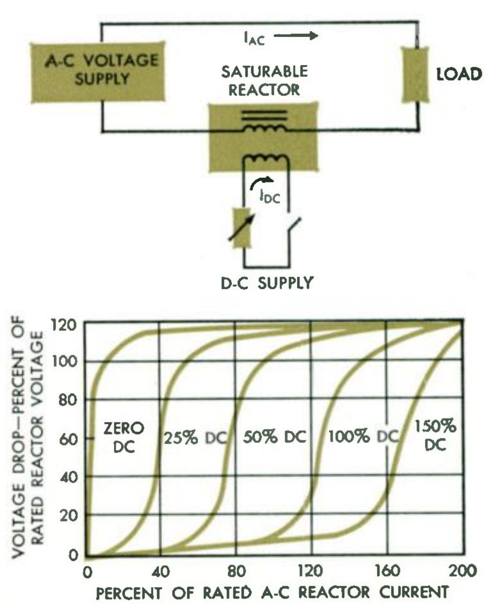

Fig. 1—(Top) Simplified saturable reactor circuit. **Bottom**—Typical saturable reactor characteristic curves.

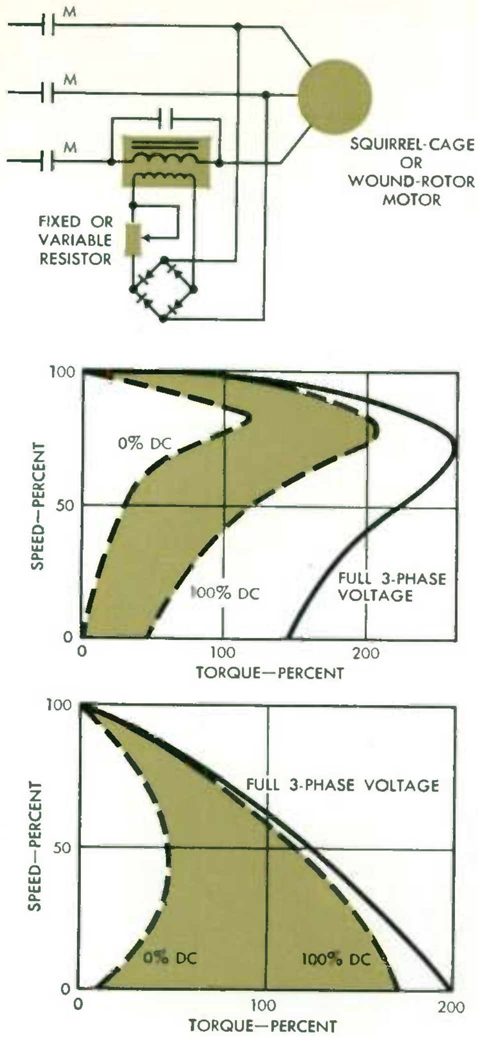

Fig. 2—(Top) Simplified schematic of a single-phase primary saturable reactor control. **Center**—Performance curves of a single-phase saturable reactor control with a NEMA-B squirrel-cage motor. **Bottom**—Performance curves of a single-phase saturable reactor control with a wound-rotor motor—external resistance in rotor.

This nonreversing circuit is limited to infrequent cushion starting of small conveyor drives and small traversing drives. It has been used on a few NEMA-B squirrel-cage motors, but the low-starting torque is a disadvantage. If a NEMA-D squirrel-cage motor with 8- to 13-percent slip at full load is used with a saturable reactor rated for full-load motor current, starting torque of 100-percent full-load torque or greater can be obtained.

The best combination with a single-phase saturable reactor is a wound-rotor motor with secondary reactors, because the majority of slip loss due to both positive- and negative-sequence voltages is outside the motor and can be dissipated easily. By varying secondary resistance of the motor with contactors or other means, saturable reactor size can be reduced, and the drive can then be used either on intermittent or light-duty cycles. However, the system is not suited for continuous operation at low speeds.

The operator can vary torque to maintain speed, or a d-c tachometer can be connected to the drive motor and its voltage used to oppose the control voltage to automatically reduce torque when motor speed rises.

reversing an induction motor with two saturable reactors

Both motor speed and direction can be controlled by varying excitation of two saturable reactors, Fig. 3. Forward rotation is produced when the forward reactor is saturated and the reverse reactor unsaturated, so that a positive-sequence voltage is applied to the motor. Reverse rotation is produced by applying a negative-sequence voltage to the motor; this is accomplished by unsaturating the forward reactor, and saturating the reverse reactor. Sub-synchronous speeds are obtained by using combinations of forward or reverse reactor impedance. This provides an adjustable, unbalanced voltage, and causes the rotating magnetic field of the motor to become, in effect, elliptical, which results in a net decrease in torque.

This system yields inherently smooth acceleration and deceleration. Since both reactors are in series with one motor terminal, they are at some degree of unsaturation and oppose current or torque changes. Test data indicate that time for torque changes is from 0.2 to 0.4 second. This contrasts sharply with normal a-c wound-rotor motor controllers that permit peak motor torques of approximately twice full load within 0.008 second, when the load changes from zero to full load.

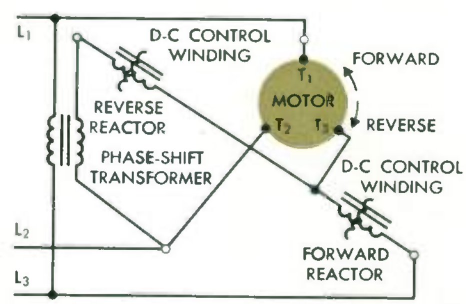

Fig. 3—Simplified schematic of a two-phase saturable reactor control.

If a d-c tachometer is connected to the motor shaft and its output voltage applied to the reactors, an infinite number of speed-torque points can be established with a given saturable reactor bias-voltage setting. Other curves can be obtained by changing the relative strength of forward- and reverse-reactor control fields with the bias voltage. To produce greater torque in the forward or reverse direction, the external secondary resistance of the motor is changed with contactors.

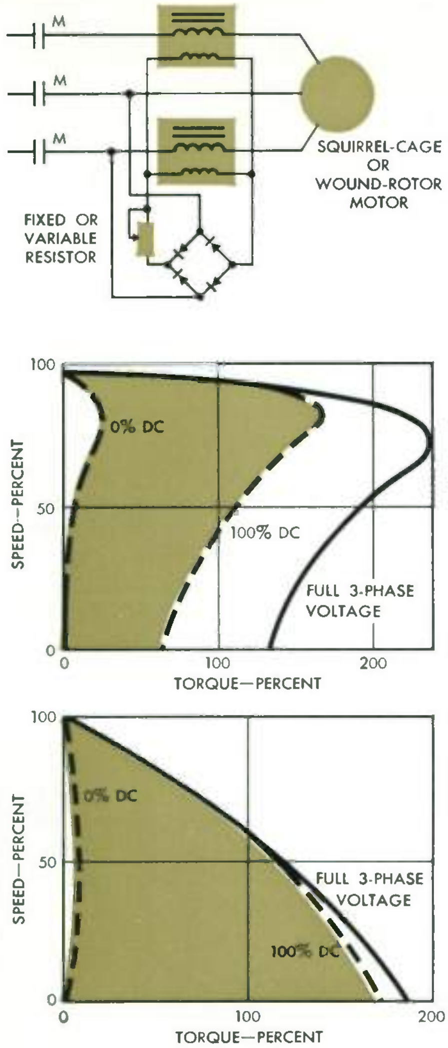

Fig. 4—(Top) A two-phase primary saturable reactor control. By adding a saturable reactor in the third phase, a three-phase primary saturable reactor control can be obtained, with similar performance curves. **Center**—Performance curves of a two-phase primary saturable reactor control with a NEMA-B squirrel-cage motor. **Bottom**—Performance of a two-phase primary saturable reactor control with a wound-rotor motor—external resistance in rotor.

The system is best adapted to drives that run at full speed or accelerate infrequently. On these drives, the control and wound-rotor motor can be operated continuously, 24 hours a day. However, the system is not suited for continuous operation at low speed.

The numerical value of secondary resistance of a saturable reactor drive is very important. For least heating, resistors should allow the motor to operate as close to full voltage as possible. Also, for a given secondary resistance, the operating range should be kept between zero and 80 percent of slip at breakdown for that resistor, if full, three-phase voltage is applied to the motor.

This type of control has the advantages of: minimum number of reactors; minimum direct current required for control; accurate speed control; 20- to 30-percent inherent speed regulation; 4- to 8-percent speed regulation with a speed regulator; torque control; controlled plugging on stopping; and a reduction in the number of contactors.

However, because torque and speed control can only be obtained by unbalancing motor voltage, motor currents in two phases never decrease with load. Also, application with squirrel-cage motors is limited.

two-phase primary saturable reactor control

The two-phase system for nonreversing (or reversing with contactors) and reversing drives uses two or four saturable reactors respectively (Fig. 4). These reactors carry rated motor current and sustained line voltage when unsaturated. They are smaller in kva rating and physical size than those used in a reversing single-phase system, and are the same size as the nonreversing single-phase drives.

If motor power factor is exceptionally poor, or higher than normal torque is required, the reactor kva must be increased.

With the main contactor closed and no control current, the reactors are unsaturated (high impedance) and permit only a small amount of current to flow through the motor. Normally, saturable reactors are selected to keep this current to less than 5-percent full-load current in the two reactor lines; the third sees the sum of these, or less than 10-percent full-load current. This produces less than 0.5 percent of motor losses developed at full load and full speed. As d-c control current increases, motor voltage rises and torque is developed.

The two-phase system has a wider speed range, better torque control and less motor heating than the single-phase system. These features permit application of a two-phase system to intermittent-duty squirrel-cage motors. In some cases, squirrel-cage motors have operated below synchronous speed by using blowers to dissipate heat.

On most material-handling drives, at least 10 percent of motor torque is used to overcome friction. Therefore, a two-phase nonreversing control, shown in Fig. 4, can provide stepless control with any load, whereas the single-phase nonreversing system requires a higher minimum load. Also, most cranes requiring good speed or torque control are operated frequently enough to require wound-rotor motors.

This two-phase circuit is useful for nonreversing drives that require speed or torque control. By adding reversing contactors in front of the two reactors, a reversing plugging drive also can be achieved.

When a drive is required to handle motoring loads, overhauling loads, frequent reversals, or loads requiring a wide speed range (up to 200 to 1), a reversing two-phase primary saturable reactor control can be used (Fig. 5); this control also can be operated easily. This system uses the principle that an induction motor can be reversed by reversing just two motor leads. The pairs of reactors can be considered as two-pole reversing contactors.

When the main contactor closes, no power is delivered to the motor because both forward and reverse contactors are open. For forward rotation, the two-pole, forward contactor must be closed and the reverse open. With this connection, the motor runs at full speed, and if necessary can develop full torque. To reverse the motor, the two-pole forward contactor is opened and the two-pole reverse contactor is closed.

Though the use of forward and reverse contactors does not simplify the system over the conventional contactor systems, the motor does not require any contactors to start, stop, or reverse. If direct current is supplied to the forward reactors but not to the reverse reactors, the motor develops speed and torque in the forward direction.

This scheme provides a maintenance-free, static, reversing control, and also has other important advantages. If less than rated d-c control current is applied, the reactors do not saturate completely. This means that a voltage drop appears across the reactors, and therefore, less than full-line voltage appears at the motor. By reducing the primary voltage, motor torque is reduced.

By adding a reference voltage with a polarity to turn on the forward d-c supply, the motor can produce about 170-percent torque at zero speed. As the speed increases, the tachometer voltage bucks the reference voltage and reduces the forward torque of the motor by reducing the motor's primary voltage. With a light load, the motor accelerates until the tachometer voltage equals the reference voltage. At this point, both pairs of saturable reactors become unsaturated because the motor requires essentially no power at no-load and low speed. If load is applied, the motor slows down until the difference in reference and

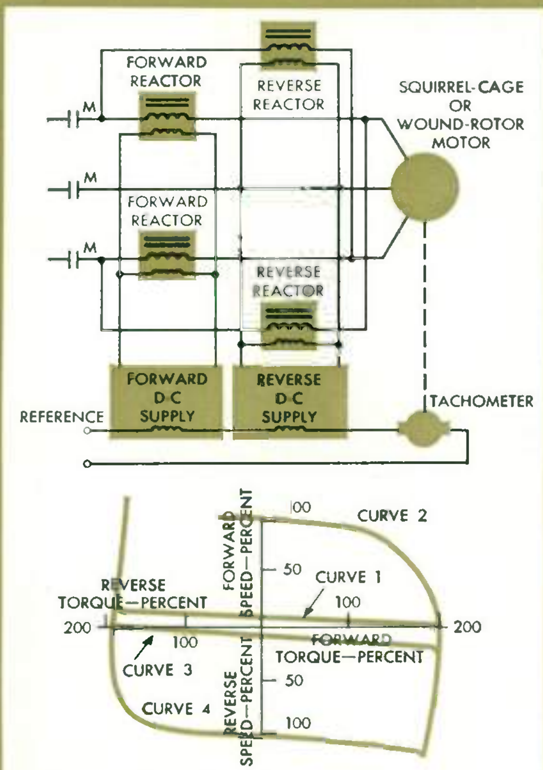

Fig. 5—(Top) Simplified schematic of a reversing two-phase saturable reactor control. **Bottom**—Performance curves of a reversing two-phase saturable reactor control.

tachometer voltage produces enough forward control current to maintain the load at the desired speed. If the drive speed is reduced further, the reference voltage exceeds the tachometer voltage by a greater amount and produces torque to accelerate the drive to the desired speed. The converse of this is true if the speed rises.

If the load overhauls the motor, the tachometer voltage exceeds the reference voltage and circulates control current in the reverse direction, turns off forward torque, and turns on reverse torque to provide controlled plugging. This is inherent in the reactor reversing system and is used on hoists for lowering a load below synchronous speed. It is also used on traverse motions where the moving load overloads the motor on deceleration.

To obtain other subsynchronous speed-torque curves, only the reference voltage need be changed. Any number of speed points can be furnished, or a stepless control can be obtained.

A squirrel-cage, NEMA-D, motor can be used with this speed-regulated drive, but only for intermittent duty. With a wound-rotor motor, the secondary resistance should be varied to provide the best torque-per-ampere relationship. The secondary resistance can be changed by contactors under control of accelerating relays, or by a fixed reactor.

However accomplished, the two-phase primary saturable reactor drive is the most economical for obtaining repetitive operations, high reliability, frequent reversals, and speed and torque control. Also, this scheme can be applied more widely than the single-phase and the three-phase circuits. It is limited on large motors, where the small unbalance in voltage will cause other small motors to overheat. This is only true if the motor makes up the majority of a load that is operated from one power supply, and where the motor operates at full load most of the time.

The two-reactor system is suitable for the limited number of continuous-duty material-handling drives where force-ventilated motors are used and where a few changes in secondary resistance can be made over the speed range. The two-phase system, however can be applied to most any duty cycle or intermittent drive, provided the motor runs at full speed or is stopped most of the time.

three-phase primary saturable reactor control

With a three-phase primary reactor control, all currents and voltages can be maintained at load balance, as shown in Fig. 4. A three-phase primary saturable reactor control essentially replaces a three-pole contactor with three single-phase reactors or one three-phase reactor, to obtain speed and torque control. For material-handling drives and many other applications, three single-phase saturable reactors should be used instead of one three-phase saturable reactor.

Three-phase control is used only where drives require balanced voltages and currents, or where reduced motor losses permit the use of a reduced motor size. It can be used readily as a torque drive or be made into a regulated drive.

fixed secondary reactor control

Fixed reactors in the secondary of a wound-rotor motor can provide constant torque for accelerating a conveyor; or they can be used with a primary saturable reactor control, to vary the secondary resistance (Fig. 6).

This circuit is based on the principle that high rotor resistance produces high starting torque, and low rotor resistance produces maximum speed at full load. By using secondary contactors, rotor resistance can be varied in any number of steps and motor torque is always proportional to secondary current. With secondary reactors, secondary current is not always proportional to torque. But this is a small penalty for eliminating the contactors.

Rotor frequency of a wound-rotor motor varies with slip. At a slip of 1.0 (zero speed), rotor frequency equals stator frequency (60 cycles on most applications). As slip decreases (speed increases), rotor frequency decreases in direct proportion. For this reason, fixed reactors actually function as variable reactors in the secondary of a wound-rotor motor.

When a motor with a static secondary circuit is plugged at full speed, the rotor frequency is twice the supply frequency, or 120 cycles per second on most power systems. This raises the fixed-reactor current during plugging.

secondary saturable reactor control

A saturable reactor can be substituted for a fixed reactor to obtain a variety of speed-torque curves with full voltage applied to the stator (Fig. 6). Saturable reactor impedance is varied by the variable frequency of the rotor and the d-c control current. Minimum motor torque is governed by the maximum secondary resistance. The saturable reactor can thus control the torque the motor produces in excess of its minimum value. Torque control at low speeds is good, but the reactor becomes less effective as speed increases, because the inherent reactor impedance is reduced with frequency. This circuit can use a three-phase or three single-phase saturable reactors. One three-phase reactor in a secondary circuit is better than one three-phase reactor in a primary-reactor circuit because the chance of one phase opening in the secondary of the motor is less than that of one phase opening in the primary of the motor.

This circuit is most suitable for nonreversing drives or where reversing is infrequent. These drives should be used where the motor is always loaded to one-third full-load torque or above. The voltage rating of each phase is equal to the secondary-phase voltage for nonreversing drives, and twice this value when used with reversing contactors for plugging and accelerating duty.

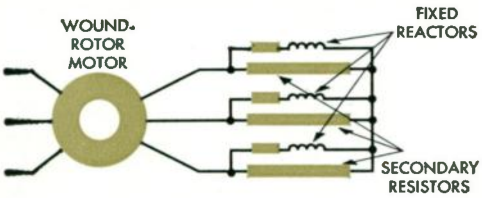

Fig. 6—A fixed-secondary reactor control. By using saturable reactors, a saturable reactor control can be obtained.

This scheme has been used on crane drives for all motions, but generally must be augmented by an artificial load to keep the drive from running near full speed on light loads or over-hauling loads. The control can be used for starting large conveyors if variable torque is required for different starting conditions. It can also be used in combination with primary saturable reactors, but generally the same performance can be obtained with primary saturable reactor control at less cost.

Though reactor control can now be applied to a wide variety of material-handling applications, this static control can be used in other jobs, not strictly classified as material handling, where the reliability of static components is essential, such as in control of nuclear control rods, and in other areas where the advantages of a particular control scheme are needed. ■

Table I—APPLICATION LIST FOR REACTOR-CONTROL SYSTEMS

I. Nonreversing single-phase control (or with reversing contactors)
  a. Small conveyor starters (cushion starting)
  b. Intermittent-duty crane-hoist drives

II. Reversing single-phase control
  a. Intermittent-duty crane-hoist drives
  b. Intermittent-duty trolley and bridge drives
  c. Continuous-duty bucket-hoist drives
  d. Missile-shelter automatic drives
  e. Precision manipulator drives
  f. Precision crane-hoist drives
  g. Movable traffic bridges
  h. Semi-synchrotie traverse and hoist drives

III. Nonreversing two-phase control (or with reversing contactors)
  a. Variable-speed conveyor drive
  b. Intermittent hoist, trolley, and bridge drives with squirrel-cage motors
  c. Intermittent hoist, trolley, and bridge drives with wound-rotor motors
  d. Stirring control for large dollies
  e. Most types of reversing plugging drives

IV. Reversing two-phase control
  a. Incline railway drives
  b. Most types of single-hoist drives
  c. Continuous-duty crane drives
  d. Position-regulated roof drive with squirrel-cage motors
  e. Unloading tower travel drives
  f. Mine-hoist drives

V. Nonreversing three-phase control (or with reversing contactors)
  a. Most applications above, but cost is high

VI. Reversing three-phase control
  a. Most applications above, but cost is high

VII. Fixed-secondary reactor
  a. Conveyor starters
  b. Two- or three-phase primary saturable reactor drives

VIII. Saturable secondary reactor
  a. Intermittent hoist drives
  b. Intermittent trolley and bridge drives
  c. Adjustable-speed conveyor drives

Personality Profiles

After a three-year stint in the Army during World War II, **GORDON E. COSSABOOM** enrolled at Northeastern University in Boston, Massachusetts. His undergraduate years included work as a cooperative student, and through association with an architectural firm, he realized the increasing importance of welding. After graduating in 1952 with a BS degree in civil engineering, he decided to specialize in welding. He enrolled at Ohio State University, and graduated with an MS degree in welding engineering in 1954.

Cossaboom joined the Welding Department in Buffalo in October 1957, and in December was promoted to Supervisor of Product Planning, his present position. As his title implies, Cossaboom develops new product ideas, and guides engineering development programs from the idea stage through introduction of the product.

Although not engaged in design work, Cossaboom's interest in welding has resulted in a joint patent application for an overload protection method for welding power sources.

The unusual behavior of phosphors under different kinds of excitation is a familiar phenomenon to both **W. A. THORNTON** and **HENRY F. IVEY.** Both have worked with phosphors in one way or another for most of their careers.

Thornton is a graduate of the University of Buffalo, where he earned his degree in physics in 1948—after a four-year interruption for war service. He first became interested in phosphors while earning his MS and PhD in Physics at Yale University between 1948 and 1951. Here his primary interest was particle accelerators and scintillation counters. In 1951 he joined the staff of the Brookhaven National Laboratory as a physicist, and after a short stay there joined an industrial research laboratory where he worked on cathode-ray tubes, phosphors, and electroluminescence. In 1956, he joined the Research Department of the Westinghouse Lamp Division, and has concentrated largely on electroluminescence since that time.

Ivey, the author of a previous article for the ENGINEER about electroluminescence (May 1957), earned his AB and master's degrees in physics from the University of Georgia, then went to Massachusetts Institute of Technology as a teaching fellow. Here he earned his PhD, while working in the Radiation Laboratory on cathode-ray tube screens for radar.

In 1946 he joined the Research Department of the Lamp Division, and has been engaged in electronic and phosphor problems since that time. Ivey is presently manager of the phosphor section.

MARIO F. PIERPOLINE graduated from Cornell University in 1945 with a B. of M.E. He earned his way through college almost completely by competitive examination, winning four different scholarships, two from New York State, and two through the Board of Trustees of Cornell.

He came directly on the Graduate Student Course, and was permanently assigned to the Steam Division. Here, he has worked in the mechanical design section, the thermodynamic section, the condenser section, and was recently assigned as a Senior Engineer to the small turbine engineering department, where he works on boiler feed pump turbines, natural gas turbines, and other small turbine designs.

VINCENT P. BUSCEMI, who joins Pierpoline in describing boiler feed pump turbine application, came with Westinghouse on the Graduate Student Course after graduation from Pratt Institute, where he obtained his BSME in 1951. At the Steam Division, Buscemi has worked in the thermo section, the development section, and is now a Senior Engineer in the large turbine apparatus section.

HERMAN B. WORTMAN is just as much an expert at his leisure time activities as he is at his engineering duties. His particular hobby is fishing, and Wortman really goes at it with a vengeance. As soon as the ice goes out in Ontario and Quebec, he heads for the Canadian lakes in search of trout. Later in the year he goes to the ocean, where he trolls off the Jersey coast for Blues and Bonito.

Wortman is presently working on an assignment in the Switchgear Division, where he is studying the application of computer mechanization to customer order development. Wortman's background is all with the Switchgear Division. After graduation from Drexel Institute with a BSEE in 1936, he joined the company on the test floor. Later he was transferred to metal-clad switchgear engineering, and became a design engineer in the indoor switchgear section. From 1948 to 1952 he was a supervisory engineer in the outdoor metal-clad section. He then became section manager for outdoor metal-clad and station type cubicles, from which job he came to his present position in 1958.

As evidenced by his previous article on motor braking schemes and his present contribution on timing devices, **JOHN C. PONSTINGL** is adept at wrapping up a complex subject into comprehensible form. No doubt, this turn of mind is also an asset in his position of Engineering Supervisor of the Cleveland Engineering and Service Department.

An equally notable characteristic is his interest in education. Ponstingl developed and conducted evening courses for engineers at the Engineering Society in Cleveland entitled, "Orientation to Machine Drives and Controls." He also helped the Cleveland Technical Society council present a Saturday advanced-science class for about 250 promising high-school students. Ponstingl also has made several appearances on television, discussing the field of engineering.

In his last appearance, **H. A. ZOLLINGER** described the Load-O-Matic crane control, one of the saturable-reactor control schemes. In this issue, he broadens the subject to include the gamut of reactor control schemes, which can be used in a wide variety of material-handling applications.

After graduation from the Michigan College of Mining and Technology in 1951, Zollinger joined Westinghouse; and after a year on the Graduate Student Training Course, he went to the Material Handling Section of the Industrial Engineering Department, his present position.

In June 1958, he obtained his MS degree from the University of Pittsburgh—his thesis, appropriately, dealt with motor heating with Load-O-Matic control.

This 25-ton waterwheel generator half "spider" at the Westinghouse East Pittsburgh works is being positioned for welding by a special work-handling machine, called a manipulator. The manipulator can ease handling and positioning of heavy fabrications, such as this spider, weighing up to 30 tons, and can tilt the workpiece 90 degrees in two minutes through a range of 135 degrees from the vertical position. Driven by a 15-hp motor, the speed of rotation can be varied from 0.03 to 0.3 rpm.