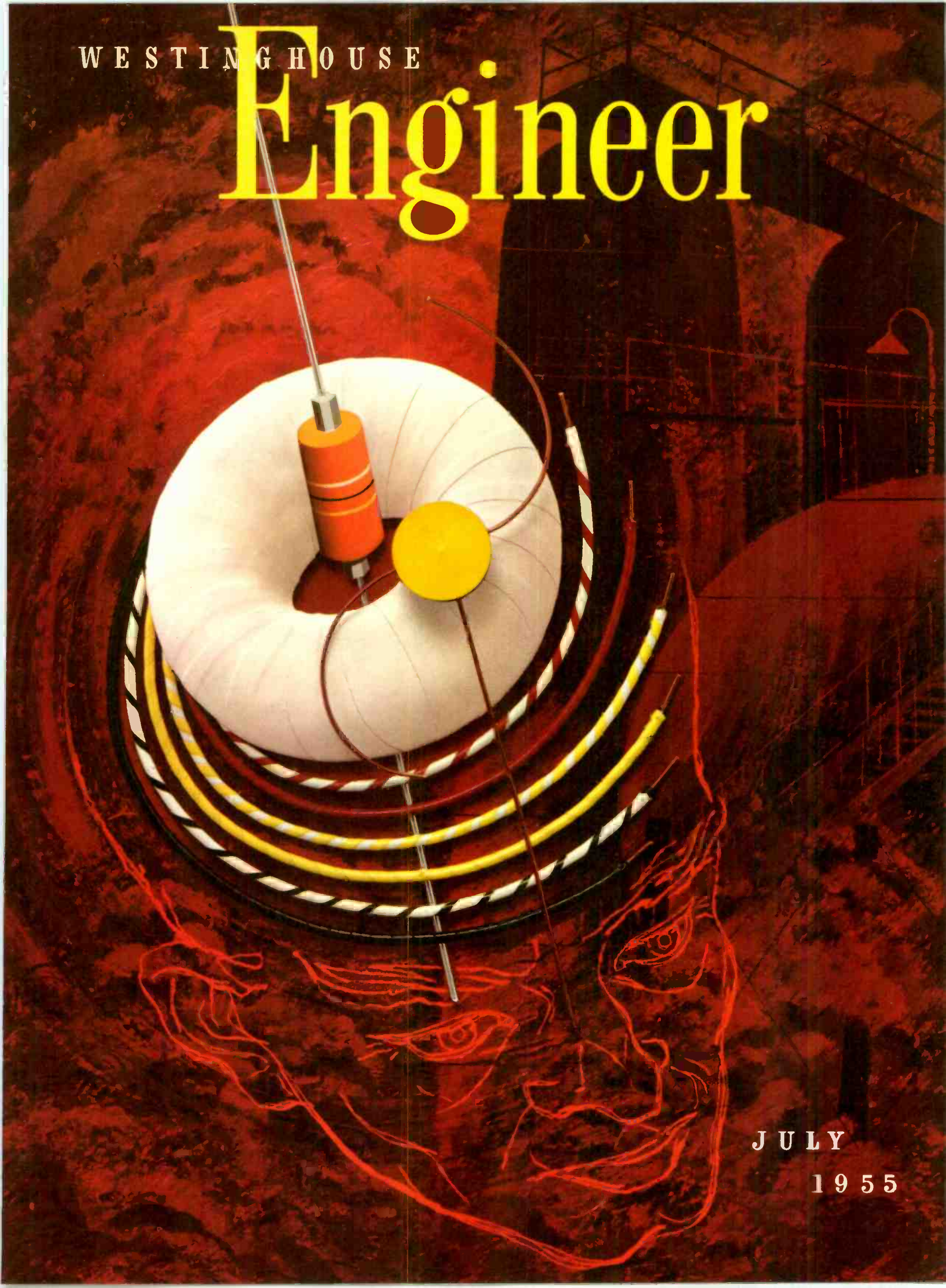
WESTINGHOUSE

Engineer



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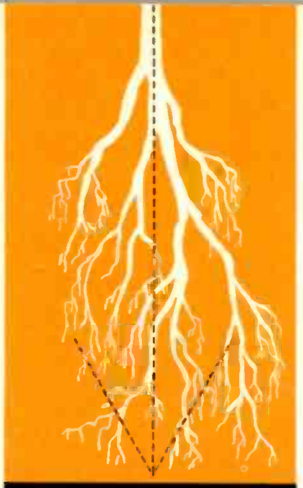

the roots of *automation*

Few words have engendered as widespread discussion as has the term "automation." Many questions have also arisen, both as to the reasons for automation and its effects. In a talk at the 19th Annual Machine Tool Electrification Forum earlier this year, D. C. Burnham, Vice President of Manufacturing, answered many of these questions. Below are a few excerpts.

AUTOMATION naturally has its roots in today's manufacturing history. It is no revolutionary concept, but rather a next logical step in a slow evolution. In our plants today are examples of the various phases or steps through which we have progressed on our way to automation. There are four of these: (1) *job shop*, the lowest volume, highest cost method of production; (2) *progressive-line* manufacturing, where machines are arranged according to the work that must be done on the product; (3) *conveyorized-line* manufacture, in which conveyors are used to carry parts from one machine to the other; and finally (4) *automation*, with its high degree of automatic handling and control. The roots of automation can be clearly traced through these four phases back to the beginning of manufacturing.

The job shop is undoubtedly the oldest method of manufacturing still in existence today. Parts are individually handled, individually machined, and assembled by hand. At the turn of the century, with few exceptions, this was the only method of manufacturing in existence for most industries.

Your automobile, for which you pay $3000 today, would cost approximately $100 000 if manufactured by job shop methods at present labor rates! Obviously, the automotive industry would be very small if such were the case.

Then someone conceived the idea of arranging equipment so that the part to be produced progressed in a straight line from machine to machine. This cut down on handling costs, raised productivity. The next step up the scale from straight-line manufacturing was as inevitable as automation is today.

The assembly line or conveyorized method was to mark America as a nation unparalleled in producing high-quality, low-cost goods. Although Henry Ford was not the originator of the conveyorized method of manufacture, he can be credited as being its greatest scholar. Ford announced in 1909 that he would "build a motor car for the great multitude" and that he proposed to do it by building 1000 cars a day! What it did for America is written in almost every minute of our present-day life. The words "United States" and "mass production" were to become complimentary. The techniques of mass production have fitted in so well with the young, ambitious, and democratic American way that it has not only made us the strongest nation in the world but has also played a major role in preserving the democracy that made mass production possible in the first place.

The step from conveyorized manufacture to what is called automation involves the use of more automatic machines and controls as well as automatic handling between machines. It is most certainly the next logical step in industrial progress—and undoubtedly not the last one.

Perhaps we will never see the advent of the completely automatic factory, but if we do, it will be because we are ready for it. It will not upset our balance. It will come simply as another step in the long evolution, as an economic necessity.

How can we go about attaining automation? Let me quote our specific case. Westinghouse has in its organization examples of each of the four types of manufacturing mentioned. Not all of any one plant is in one specific stage, but certain products demand certain types of manufacturing, either because of the nature of the product or of the process. Large, single-design steam turbines, for example, would be difficult to conveyorize.

It is not realistic to expect to automate the job shop. But we can expect to raise it to the next higher level of manufacturing. With additional investments in machinery and perhaps in floor area, any one of the manufacturing types can usually be raised one notch up the scale. This should be the goal of industry. With such an approach, economic automation may be achieved. Also, with this approach, when automation is accomplished in any operation, the change will come about naturally, slowly.

But the most important question to the confused man on the street is: What will automation do for me? It will provide a higher standard of living, but there's more to it than that.

The defense of America, now as in the past, depends on our ability to produce. In time of a major defense effort, our national production facilities are strained to the last man-hour. Automation then assumes the role of a vital defense mechanism. We can ill afford to neglect the excellent opportunities it presents.

Another facet of America makes automation a necessity. The working population and the total purchasing power of this nation are naturally closely allied. The gross national product is increasing at the rate of 3½ percent a year. However, the American working population is increasing at the rate of only 1.8 percent a year. Something, somehow has to take up the slack if we are to continue to be able to produce to the level required to improve our current standard of living. Automation is that something. We need automation just to maintain the present rate of improvement in our country's standard of living.

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In This Issue

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THE COVER

The role of Cypak system elements—magnetic cores, transistors, and diodes—in automation is suggested in the cover by Dick Marsh. If the three elements and the wires look three-dimensional, it's because they are—on the original artwork, that is.

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a new concept in industrial control

cypak

SYSTEMS

To be successful, any automatic control needs all the reliability that can be built into it. Cypak systems obtain a high degree of reliability by the use of static elements, such as transistors and magnetic cores.

PROGRESS IN INDUSTRIAL automation has been impeded by the lack of long-term reliability in certain control elements. Moving parts in the control system, particularly relays, are subject to wear and occasional malfunction and have not offered the extreme reliability required for more complete automation. Many forms of partial automation are already present in industry; however, with the development of more reliable components, the application of automatic control systems to even more complex systems—or even complete factories—may become a practical reality. A new industrial control system, called Cypak, is designed to provide this high degree of reliability, as well as many other advantages.

Cypak systems are composed of static switching circuits, consisting of magnetic amplifiers and solid-state devices, such as transistors. These "switches" are not direct replacements for relays on a one-for-one basis; rather, they are intended as replacements for complete relay *systems*.

Cypak systems represent a new concept in industrial control. Because of this, they must be considered from a slightly different point of view than relay systems. First, then, consider some of the basic principles of industrial control.

This article is based on a series of three articles on Cypak systems, written by R. A. Ramey, Manager, Magnetic Development Section; W. H. Brandt, Engineering Manager, Director Systems Department; and K. M. Patterson, Manager, Industrial Sales.

Automatic Direction Systems

The equipment comprising any automatic direction system can be subdivided into three general functional categories: (1) *sensing* units, which measure physical quantities—such as speed or position—and then translate such measurements into electrical signals meaningful to the (2) *decision-making* elements, which in turn perform the necessary operations with them, and provide another signal to control the (3) *output* elements, which actuate the process-directing members. The decision-making that is required in any industrial control system may range in degree of complexity from a reasonably simple comparison of several different signals to involved arithmetic operations, or the solution of complex equations in the variables represented by the input and output signals.

Analog or Digital Systems. To the industrial-control designer, two basic types of information are available for controlling machines and processes—a continuous signal of variable quantity called *analog* information, or a discontinuous signal in discrete amount, which is referred to as *digital* information. Industrial-control components, as well as systems, fall into one of these two categories. The tachometer generator, which generates a signal proportional to generator speed, is a good example of an analog device; a relay, or switch, is a common digital device.

The application usually determines the type of control system used. On a variable-speed planer, for example, the speed of the table during cutting is controlled by analog means, Fig. 1. At the end of the cut, however, a limit switch is used to send a signal to the control, indicating the end of the cycle and initiating high-speed return of the table. This control is digital.

Steel-mill, paper-mill, and other large drives are usually controlled by analog systems, whereas automatic-sequence machine-tool or elevator-control systems are digital. For these mill applications, large drives are continuously controlled to maintain a constant, or preselected speed, whereas the machine tool must be switched from one state of operation to another in discrete fashion. In other words, an analog system is essentially a digital system with an infinite number of steps. Cypak systems are digital in nature.

Digital Control. Many of the controls applied in automatic machines, particularly those used in high-quantity production, have been essentially digital in nature. Hence, they have contained a large number of relays or switches. What, then, are the properties of relays that make them so suitable for complex control systems?

The relay's characteristic curve is shown in Fig. 2, which graphically portrays its method of operation, showing that this device has essentially two stable conditions—on and off. Since the relay performs its operation in one step, it is known as a *step-function* device.

An important property of any step-function device is that it provides memory. When the device is put in one state or the other, it stays there until that state is changed.

Another advantage the relay provides is its comparative insensitivity to changes in other components used in direct conjunction with it. Since relays have two stable states of operation, changes in the other components do not affect the state of the relay. Therefore, comparatively inexpensive components like resistors—which show some change in resistance with temperature—can be used.

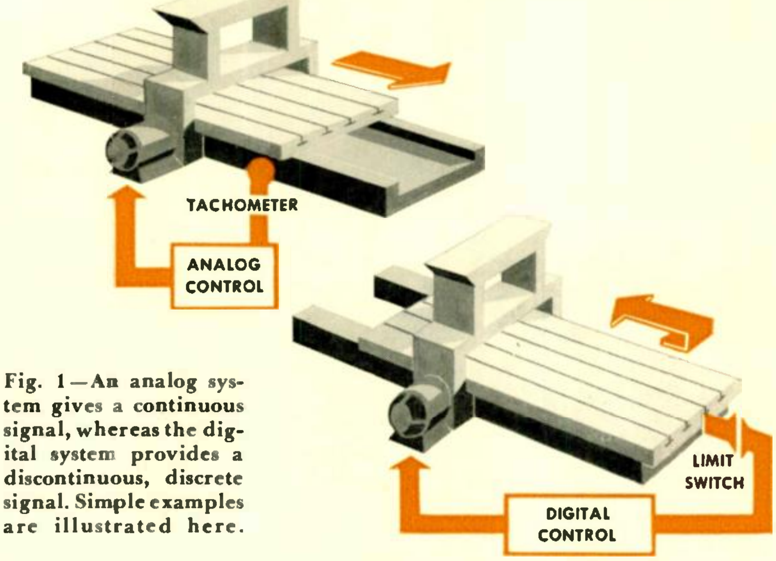


Fig. 1—An analog system gives a continuous signal, whereas the digital system provides a discontinuous, discrete signal. Simple examples are illustrated here.

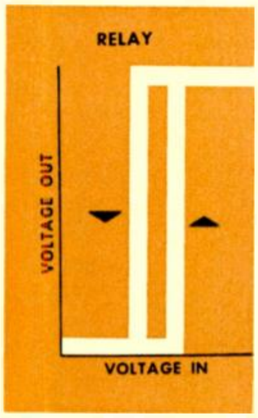


Fig. 2—The characteristic curve of a relay, i.e., a plot of input voltage versus output voltage. Note the similarity with those of Cypak system elements.

The relay has a third advantage; the output can be made several times the input. Thus a number of units can be operated from each relay. This makes it possible to construct complex networks without intermediate amplifiers between stages.

Despite these good qualities, however, industry has watched the growing complexity of relay control equipment now used in industrial control with considerable apprehension. Large relay systems are complex, hard to maintain, and expensive. Also, the possibility of having to base broad automation on a device with no higher degree of reliability than the relay is not attractive, nor can relays be considered practical as control systems continue to become more and more complex.

The relay's great weakness—lack of the required high degree of reliability—is a natural consequence of its construction. It has moving parts, which are subject to wear. It has contacts that change with time, erode, and are strongly subject to environmental conditions. Any device that is to

Fig. 3—Below left, a comparison of a Hipernik-V hysteresis loop and that of an early transformer steel. Below, at right, the output versus input curve of a magnetic amplifier with positive feedback.

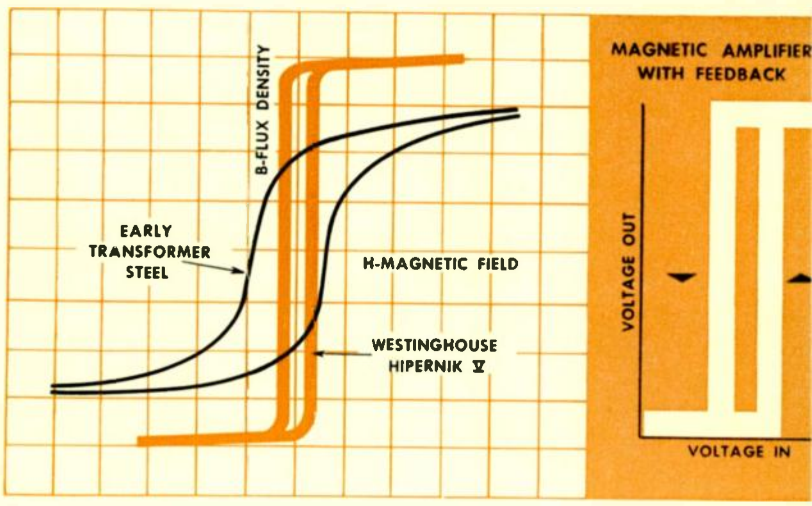
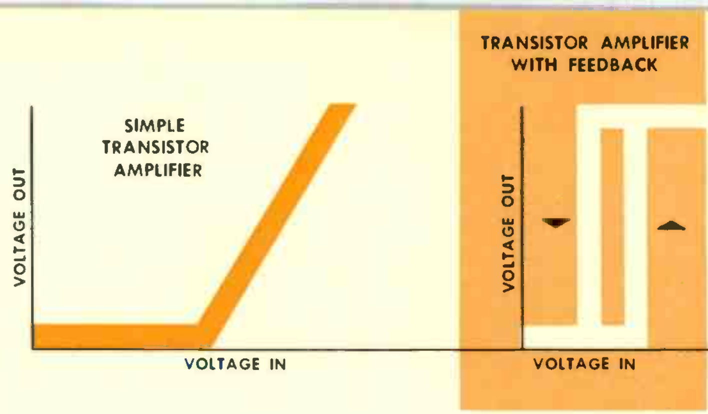


Fig. 4—At right, a transistor characteristic curve. At far right, curve of a transistor amplifier with feedback.



and function

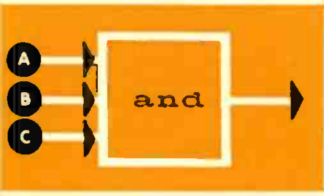


Fig. 5—The AND function is here represented schematically (left) and by an artist's sketch (above). An output occurs only when all the inputs are received.

or function

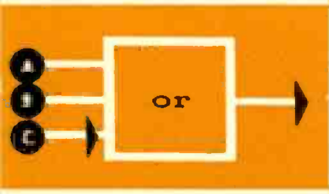


Fig. 6—The OR element delivers an output when any one of inputs A, B, or C is received. In the example, the output is caused by the existence of input C.

not function

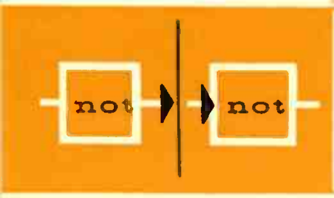


Fig. 7—The NOT element, unlike the AND and OR functions, delivers an output only when it does not receive an input, as depicted in the sketches above.

replace the relay should have no moving parts and no contacts, but yet be a step-function device whose output is higher than its input. To make the device commercially feasible, restriction of economic manufacture must also be imposed. That is, the device must be designed to be easily duplicated millions of times with nearly identical results.

Cypak Systems

Cypak systems come from the area of solid-state physics, from which have come such developments as the transistor and the magnetic amplifier. The one thing common to all solid-state devices is that they have no moving parts. Cypak systems make use of these solid-state devices. Because these new systems are, in a general sense, switching systems, they are essentially digital in nature, but can be easily combined with analog devices where the control problem warrants it. In the development of Cypak systems, principal design emphasis was placed on extreme reliability, flexibility, ultimate utility, and low cost. These design objectives have been met.

Static Switching Circuits. First, how can the characteristics of a relay be obtained from solid-state devices? The answer lies largely in the development of materials and circuitry in recent years.

A material is classified as ferromagnetic if magnetism is introduced when that material is placed in a magnetic field. If the field is changed cyclicly, the magnetism induced in the material plotted against the magnetic field gives a hysteresis-loop curve, which forms the basis for judging ferromagnetic materials. A comparison between the hysteresis loop of a turn-of-the-century transformer steel and Hipernik V, a high-grade ferromagnetic material, is shown in Fig. 3. These curves illustrate the progress that has been made in controlling the properties of ferromagnetic materials in the past 50 years.

The hysteresis curve for Hipernik V already shows a marked resemblance to the characteristic curve of the relay. Although the curve indicates that this magnetic material has two relatively stable conditions, it is definitely not a characteristic curve, that is, a plot of "volts in" versus "volts out."

What the curve does show is that Hipernik V represents progress in the development of a static step-function device. By proper use of circuitry this material can be utilized to construct an amplifier with positive feedback to obtain a curve (Fig. 3) identical to the relay characteristic curve.

Semiconductivity is the other phenomenon proposed as a basis for developing a device better than the relay. The transistor, perhaps the best known of the many semiconducting devices, has already demonstrated its ability as an amplifier. The transistor's characteristic curve, Fig. 4, has little in common with either the relay's characteristic curve or the hysteresis loop. However, circuitry can be employed to feed some of the output power of the transistor back into the input to produce a curve (Fig. 4) very similar to the relay's characteristic curve. Here again, is a step-function curve with two stable states. Also, the output can be made several times the input.

Static Switching Systems. Cypak systems are composed of a small number of basic elements, none of which has moving parts, combined to perform specific functions. The functions performed are familiar to engineers working in computer technology or with relay and switching circuits. These functions are essentially building blocks that can be combined in a variety of ways to establish a desired relationship between the information fed into the control system, and that taken out. In the broad field of cybernetics, or communications, they are referred to as logic functions.

The first is called the "AND" function, Fig. 5. Here an output is obtained only when *all* of a given number of input signals are applied. In other words, given input *a* and *b* and *c* and . . . *j*, and AND function delivers an output.

The second is the "OR" function, Fig. 6, where an output is obtained when *any one* of a number of inputs is applied. Hence, given any input *a* or *b* or *c* . . . *j*, the OR function delivers an output.

The third is the "NOT" function, Fig. 7. In this case, an output can be obtained only when *no* input signal is applied. Therefore, given an input *a*, no output is obtained; but stop input *a* and the NOT function delivers an output.

The fourth type is the "TIME" function, Fig. 8. Actually, there are two kinds of time functions—a *limited* function and an *unlimited*. Limited time means that, following an input, a specified interval passes before an output is obtained. Or in other words, given an input *a*, an output is obtained from a limited TIME function after a specified time, T_1. The unlimited TIME function, as the name connotes, delivers an output following an input until such time as a second input is fed into the system; the second input stops the output. Hence, given input *a*, the unlimited TIME function delivers an output until input *b* is applied.

These functions, of course, are not peculiar to Cypak systems. Almost any machine operation or process can be described in terms of these four functions. Even when an operator is used, his movements can usually be reduced to some combination of them. Furthermore, there are a great number of component combinations that will perform these functions—relays, electronic tubes, and many others. However, the field is narrowed by the establishment of several design objectives.

The first objective established in the design of Cypak systems, as mentioned previously, was the elimination of all moving mechanical parts, to assure longer life, higher reliability, and a high degree of freedom from environmental influence; second, was availability and reasonable ease of manufacture; third, was cost. The end product had to be produced at a cost equal to or less than existing systems. These objectives have prompted the use of semiconductor and magnetic-core devices for components of Cypak systems.

The AND and OR functions are conveniently accomplished by semiconductor diode networks. Selenium diodes, and dry-plate units have been perfected for use in magnetic-amplifier circuits. They have proved highly reliable and relatively inexpensive. If environmental conditions preclude the use of selenium diodes—silicon diodes, which are crystalline units—can be used, but at somewhat higher cost.

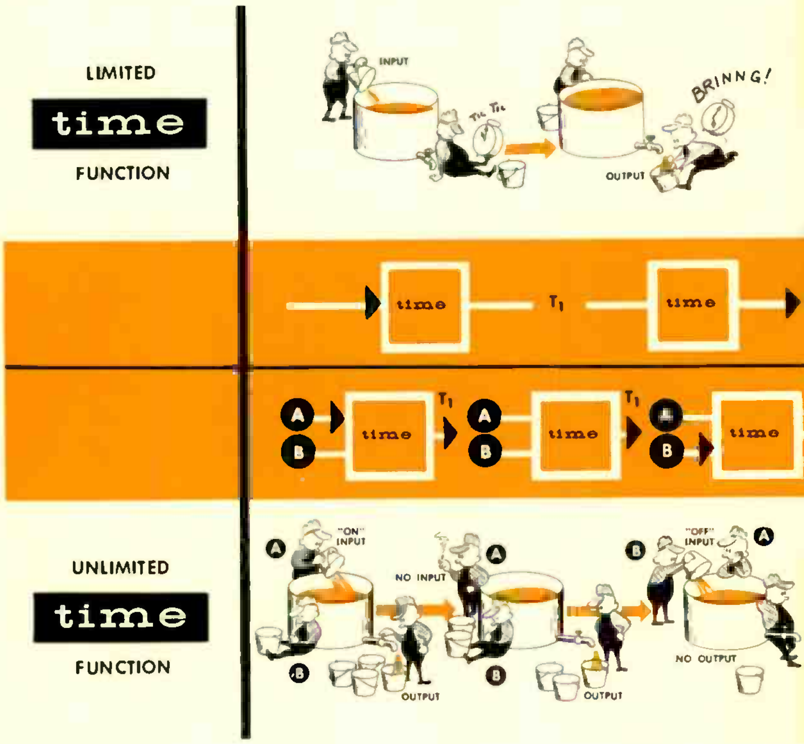
The components to accomplish NOT and TIME functions are more complex since they require information storage, plus amplification. To meet the design objectives, special magnetic amplifiers and transistors with appropriate circuit components are used. Because the signal often weakens through diode networks, it is desirable to use magnetic or transistor amplifiers to maintain the original signal strength throughout the system.

The principal method employed to maintain comparable cost is the use of very low power levels in the decision-making or logic components of the Cypak system. Current belief is that these power levels should be as low as ten milliwatts, or even less.

Another advantage of static elements over relays has barely been touched on. The transistor and magnetic elements have been designed to operate at very low power levels. In general, this saves weight, space, and complexity. All of these systems—magnetic, transistor, or relay—require input sensing devices of some sort. Many of these input devices are good, reliable units, but have the disadvantage of not having an output-power level high enough so that they can feed directly into relay systems. They hence require intermediate amplifiers. Two familiar examples are the photocell and thermocouple. Output from these units can be fed directly into Cypak systems without intermediate amplification. Present devices, such as limit switches, are often the first part of the system to wear out. With Cypak systems, input devices of much better reliability can be used.

What about outputs from Cypak systems? Since power levels are low, an output amplifier of some sort is usually required. In principle, this output amplifier can consist of either transistor or magnetic elements, or relays. However, magnetic elements are generally used only where the reliability factor is of prime importance. Transistors, on the other hand, are not yet available in power ratings sufficient for this purpose, but there is little doubt that they will be available in the near future. Until that happens, relays or breakers will likely appear as final amplifiers in the output

Fig. 8—TIME functions are of two types, unlimited and limited. The limited TIME element produces an output a definite time after receiving an input. The unlimited TIME function produces an output after an initial input until a second input occurs.



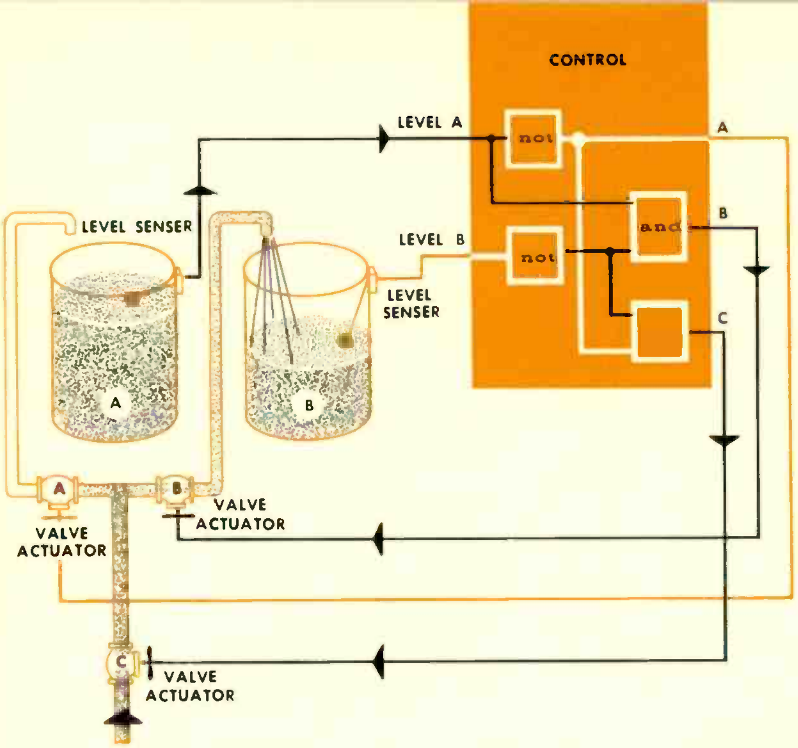


Fig. 9—A schematic representation of a two-tank, liquid-level control, showing the use of AND, OR, and NOT elements.

stage of Cypak systems. Where output amplifiers operate relatively infrequently compared to the other components of the system, the reliability penalty is not great.

Evaluation of Decision Elements. A rough comparative picture can be given of the state of the art of these three types of elements—relays, and magnetic and transistor Cypak system elements—as they are today and will be in the relatively near future.

In their cost, at present, little difference exists in the three systems. In size and weight, relays and magnetic elements are roughly equivalent, whereas transistorized units are smaller (see Fig. 10). As designs are further perfected the static elements will become smaller in size and also less expensive than relays. How far design simplification can go without sacrificing industrial reliability is as yet unknown.

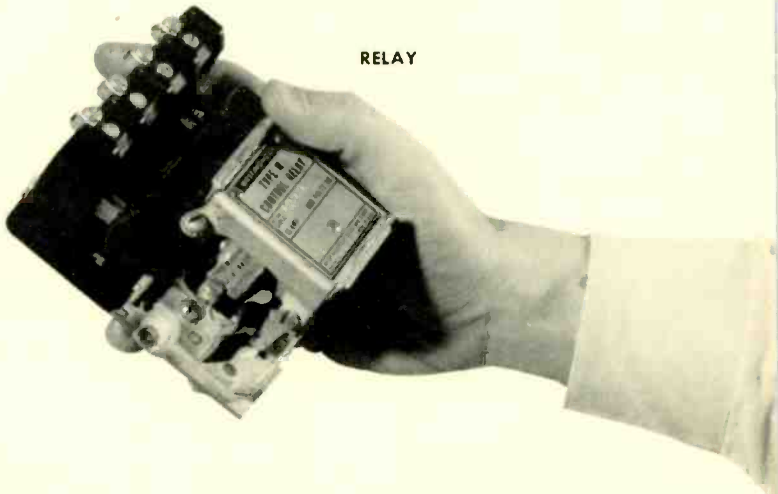
In speed of response the order of merit is quite definite. Transistors operate easily in a hundredth of a millisecond, and can be pushed to higher speeds where necessary. Relays at best require about ten milliseconds. Magnetic elements operate easily in one millisecond where necessary. However, in the case of magnetic elements the time delay is either a full or a half cycle of line frequency, so that a 16-millisecond time delay is often used where operating speed is not important. Speed of response of transistors is better than magnetic elements by a factor of about 100, and magnetic elements are better than relays by a factor of ten or more.

In rating the units in reliability—the most important characteristic of all—both of the static devices hold an advantage by orders of magnitude. Industrial-control relays, with the best circuit techniques and design, operate about 10 to 20 million cycles before major service is required. Both magnetic elements and transistors are built to reach this number of cycles in days or hours and still show no signs of deterioration whatever. At this time an upper limit cannot be assigned to the number of cycles that either of these devices will operate.

In reliability, not only are the number of cycles of operation important, but also the effect of time. Magnetic amplifiers, which are incorporated in continuous feedback control circuits, have been used in industrial control systems for many years. During this period no malfunctioning of a control system has been experienced due to instability of characteristics.

Application of Cypak Systems

Among the more important Cypak systems built and tested are (1) the control of a fully automatic six-story elevator, (2) a supervisory control system for the remote control of electrical power systems, (3) a relatively simple punch-press control and a much more complicated spiral milling machine control, (4) a system for the selective removal and delivery of ingots from a soaking pit to a rolling mill, (5) a skip-hoist director that permits the automatic charging of a blast furnace in accordance with a program selected by the operator, and (6) a relay control for an automatic bus-duct welder. Consider the latter—the relay control for the automatic bus-duct welder—in more detail.

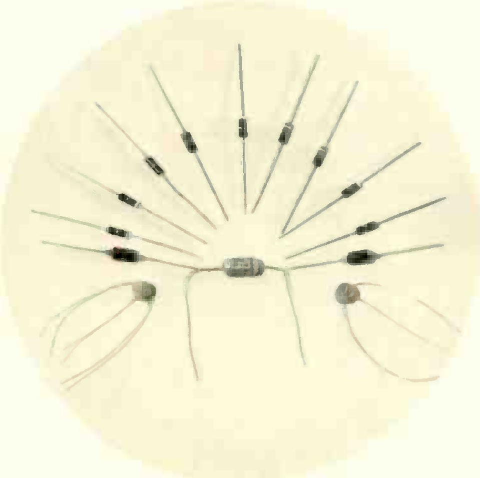


This is a simple automatic control involving facilities for the repetitive positioning and welding of a piece of work and the necessary starting, stopping, and interlocking features; it includes most of the basic functions of even the most complex controls. The original relay panel and the Cypak system that replaces it are shown in Fig. 11. The bank of switches in the center permit transfer of control from one system to the other. Since the installation of this Cypak system several months ago, over a half-million welding operations have been made under its control.

This installation should not be considered typical of the extent of industrial-control functions that can be accomplished by Cypak systems. Indeed, the entire list of applications just mentioned does not indicate the range of possible uses. The principal area where the extremely reliable characteristics of these systems will be most welcome is in the integrated direction of complex operations or processes that involve a multiplicity of equipment. Transfer machines, such as those used in the automotive industry, are basic examples of integrated systems that require coordinated control. Even they are not, however, the ultimate in control complexity that can be handled by Cypak systems.

Coupled with these new systems are modern advances in sensing or input elements to supply information to the system, and in power amplifiers, to provide muscles in response to system commands. The information-processing capabilities of this team is the stepping stone to the completely automatic factory or process. To fully appreciate all that can be accomplished, the concept of automatic control must be broadened to include its effect on work-in-progress adjustment, and in-process inspection, in addition to the straightforward control of processes and operations.

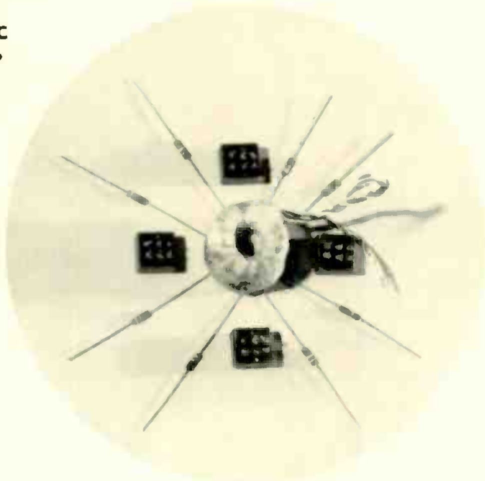
Many control systems fall into the category of automatic-sequence control; that is, controls that function to cause a number of operations to occur in correct sequence, subject to over-riding signals, interlocks, and other conditions. Many machine-tool controls, for example, are of this type. The automatic bus-duct welder control is the simplest form of such



TRANSISTOR FLIP-FLOP

Fig. 10—The components of a transistor flip-flop element, above, and a magnetic flip-flop element, below, compared to a relay, at left.

MAGNETIC FLIP-FLOP



a digital control, since a fixed program or course of action is wired into the system and the inputs and outputs are "binary variables," that is *on* or *off* signals. Relay switching networks have been used to perform the information processing as well as the power switching in such controls. Replacement of the information processing, or decision-making relays, by a static Cypak system offers the opportunity of greatly increasing reliability and at the same time reducing the size of automatic-sequence controls. Transfer machines for automatic production require extensive control installations involving relay panels, perhaps six feet high and 30 feet to 40 feet long. In such installations, the advantages of static Cypak systems are many.

An area receiving much attention at this time is numerical control. Numerical control means the storage, in terms of numbers, of the complete specification for the desired metal shape, and then the translation of those numbers, through a control system, into position information for servo-mechanisms that control the relative position of the work and tool. Various machine tools—milling machines, lathes, boring machines, cam machines, drilling machines, and punch presses—have already been, or could be, numerically controlled. Numerical control differs from automatic-sequence control in that a variety of temporary programs can be used to change the control functions to suit the part being machined. The flexibility of numerical control is superior to a system with a wired-in program.

The general principles of numerical control can also be applied in many other areas of automatic control. For example, its use in the field of process control appears attractive. Because of the large amount of information processed, both manually and automatically, in such enterprises as oil refining, pipeline operation, and chemical processing, numerical control may eventually be used widely in these areas, especially for accurate control of temperature, fluid flow, combustion, position, batch mixing, and so forth.

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

A complete tabulation of the potential applications of Cypak systems is impossible. This brief discussion, however, indicates directions in which its possible uses lie. Given sufficiently reliable Cypak systems, it is difficult to envision a limit to the use of automatic control in industrial production and manufacture.

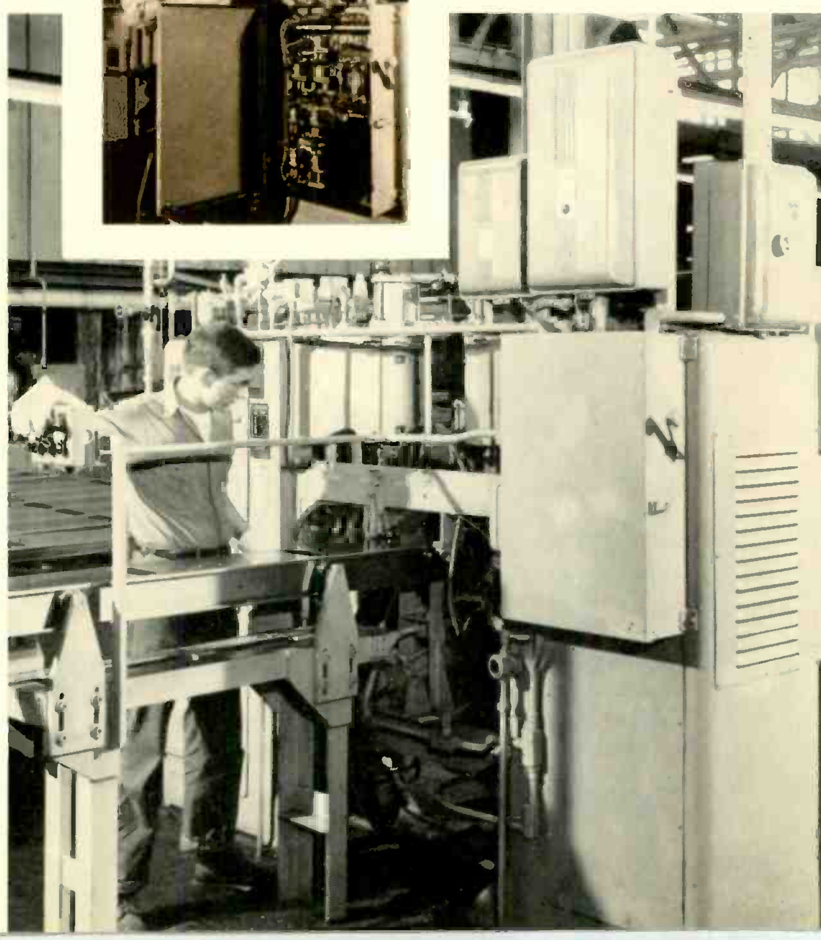
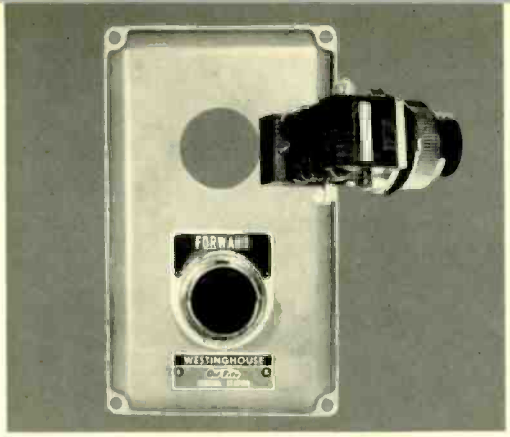
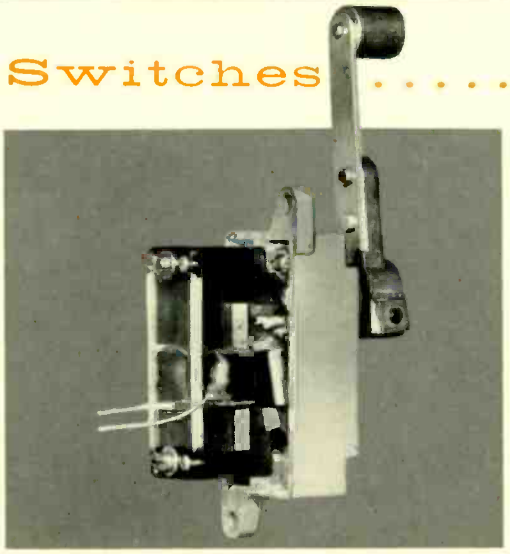


Fig. 11—The automatic bus-duct welder; Cypak cabinet is at top, relay control cabinet is below.



Switches . . . . .



Coordinated with Cypak Systems

This article is based on a paper presented at the 19th Annual Machine Tool Electrification Forum by C. B. Stadum, Motor and Control Division, Westinghouse Electric Corporation.

Paralleling the work on Cypak systems was another important development—that of producing a switch to work with them. The answer lies in new mechanical switches without contacts, designed for 18-volt systems.

Magnetic Cypak-system elements present both a problem and an opportunity in the voltage at which they must operate. Since the operating voltage is 18 volts, the question immediately arises: "Will conventional mechanical switches, like pushbutton and limit switches, work at this voltage?" Normally more than 18 volts is required to break through an oil or grime barrier on contacts, as may result in many industrial atmospheres. To the design engineer the question is somewhat different: "Is this the opportunity to design new switches with characteristics superior to present designs?" The answer appears as a new concept in design—mechanical switches without contacts.

In this solution several other benefits present themselves: (1) The perennial problem of contact erosion is eliminated; (2) elimination of sparking contacts enables operation of the device in atmospheres where explosions might result because of sparking; (3) by eliminating the jolting effect of contacts seating, life of the device can be increased; (4) in certain limit-switch applications, it may be possible to eliminate all mechanical linkages of the machine tool and the switches, thereby completely removing the question of ultimate life of the device.

Several types of transducers can be considered that operate within the desired voltage range and have the reliability of Cypak system elements themselves.

Photoelectric—A phototransistor receiving its energy from a rugged, undervoltage lamp works as an extremely accurate limit switch. With a very narrow aperture in a blind between the transmitter and receiver, almost any degree of accuracy can be achieved with no mechanical contact between parts.

Atomic—Radioactive material can be used as a transmitter of energy and a transistor can be used as a receiver to make a limit switch similar in action to the photoelectric device.

Radio-frequency—A transistorized radio-frequency transmitter has been built that is detuned when approached by a metal slug. Thus a probe in the form of a coil can detect metal sheets without being in actual contact with them.

Magnetic—Magnetic types that change their inductance with position can and have been built to work well with magnetic Cypak elements. This type appears to provide the best features of simplicity, low cost, and reliability at this stage of development of industrial Cypak systems.

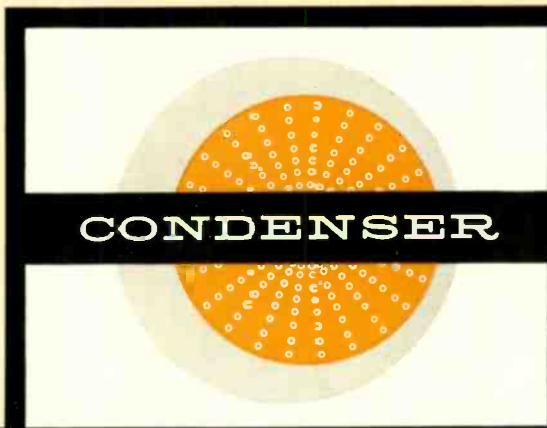
While many phases of development of pushbuttons and limit switches are proceeding, models of both types of switches have been built. A model of the magnetic pushbutton is shown at the top left of this page; immediately below is a model of the magnetic limit switch. Neither type has contacts to erode, spark over, or wear out.

These devices are *on-off* reactor-type mechanisms connected in series with a resistor. The driving power is the 18-volt source in the Cypak system. The output from the switch is placed across the resistor, which is physically located in the machine-tool control. The output voltage is varied from *on* to *off* by varying the inductance of the reactor. In the normal state, the reactor is unsaturated and most of the line voltage will appear across it. When an output is desired across the resistor, the reactor core is saturated. Consequently, it has a small impedance and a small voltage across it. The voltage, of course, appears across the resistor, which is the output from the switch.

The saturation of the core is achieved by placing a permanent magnet across the saturable reactor. The d-c flux from the permanent magnet divides so that half of it flows through each leg of the reactor. The two windings on the reactor are in series around the core. The d-c flux aids in saturating only half of the core at any given instant; the other half remains unsaturated. The winding on the unsaturated leg, however, does not present an appreciable impedance in the circuit because of the large effective air gap in the core produced by the saturated leg of the reactor. The permanent magnet itself has a permeability of about four, so it also acts like a large air gap.

The first model was tested on several circuits; one switch controlled simultaneously 17 flip-flop circuits, 22 AND-OR circuits and 4 NOT circuits of a Cypak system. The full capacity of the switch was not reached with that loading. The switches have also been used in actual circuits with success.

The Surface CONDENSER



The radial-flow surface-condenser principle is over 40 years old and has undergone numerous improvements. But engineers are a long way from running out of ideas for even further improvements.

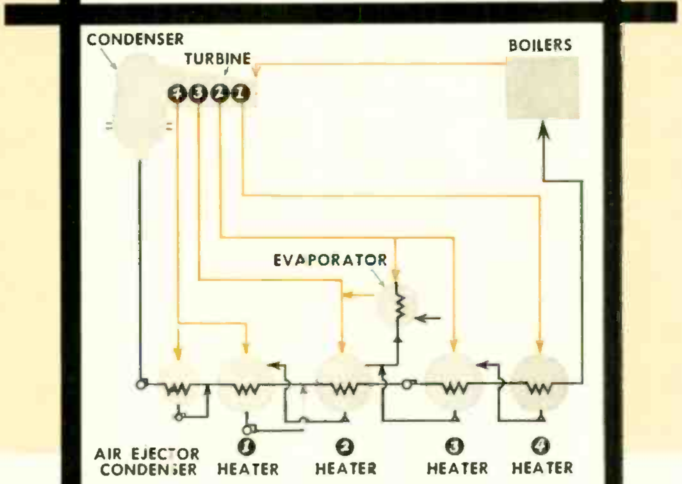


Fig. 1—A typical power-plant steam cycle.

J. R. Spencer, *Heat-Transfer-Apparatus Engineering, Steam Division*
Westinghouse Electric Corporation, South Philadelphia, Pennsylvania

The surface condenser plays a key role in the modern steam power plant. This shell-and-tube heat exchanger, which receives steam from the turbine exhaust and condenses it to water to be recirculated in the system, has two-fold importance in the cycle: First, by maintaining a high vacuum at the exhaust end of the turbine, the overall thermal efficiency of the cycle is improved. Although turbines with ratings above 10 000 kw are not normally designed to exhaust to atmosphere, if such were the case, the output of a 100 000-kw turbine would be reduced as much as 25 percent. Second, since the condensate is distilled water, free of solids and other contaminating elements, it can be retained in the system; use of fresh water from natural sources is impossible because impurities present would deposit in the boiler tubes and result in tube failure.

A typical line diagram showing the basic items of equipment in a power-plant system is shown in Fig. 1. Steam, having expanded through the turbine, enters the condenser, where it is reduced to water under vacuum. The condensate is pumped through feedwater heaters, where it is heated to some elevated temperature by steam extracted from various sections of the turbine, before entering the boiler to be converted to steam.

One of the most important factors involved in condenser design is the effective use of available space. This is true not only for new installations, but where larger condensers are contemplated for existing power plants. Because of friction drop through the condenser, the quantity of cooling water available and the pumping costs must be weighed against the various tube sizes and lengths. Materials of construction, especially those used for condenser tubes, must be carefully considered with respect to heat transfer, cost, and expected life. In selecting the proper condenser size, the designer must consider not only first cost but also operating cost from the standpoint of prime-mover efficiency.

The circulating water boxes of the condenser, which serve as collecting chambers for the cooling water that flows through the tubes, can be arranged for either single-pass or two-pass flow. The cooling water flows once through all of the tubes in single-flow operation; in two-pass flow water travels through half of the tubes in one direction and returns through the remaining half in the opposite direction. Single-pass condensers are generally employed where large quantities of water are available, whereas two-pass condensers are used with cooling-tower units or where the cost of water handling and treating is comparatively high. The number of water passes usually does not exceed two since the resulting pressure drop would increase pumping costs to an uneconomical value.

If the cooling water condition is such that foreign matter can enter the condenser and obstruct the flow through the tubes, it is often advisable to arrange the condenser for divided flow. By providing partitions in the waterboxes, half of the condenser can be taken out of service for cleaning while the other half remains in operation. With half of the condensing surface in use, the turbine generator can still carry a reduced load. If the necessary cleaning can be done during scheduled shutdowns, divided condensers are not normally employed.

Radial-Flow Principle

The first radial-flow surface condenser was built by Westinghouse in 1911. The same basic principles of this first radial-flow design are employed today, as shown in Fig. 2. The radial-flow condenser is designed to permit free flow of steam completely around the tube bundle; the tube spacing is such that steam flows in short paths radially toward its center. The center of the condenser, which is the lowest pressure area, acts as an air-cooler and air-removal section. The air-cooler section surrounds an open passage that is directly connected to the air offtake at the cold end of the condenser. The tubes and baffling are arranged to eliminate the entrance of live steam directly into the air-offtake zone.

The decreasing area in the radial passages between the tubes from the outer row of tubes toward the center is shown in Fig. 2a; this results in an essentially constant steam velocity. The short paths of constant velocity are coincident with radial-flow design, and result in a minimum pressure drop within the condenser. Other types of condensers are in general designed for straight-down flow, each design varying insofar as steam distribution and air removal are concerned.

In the radial-flow condenser, the sweeping action of the relatively high-velocity steam penetrating the bundle from the entire periphery continually frees each tube of condensate. The direct contact between steam and condensate in the lower portion of the condenser reheats the condensate to the saturation temperature corresponding to the condenser vacuum. Without means for reheating, the condensate would be sub-cooled after having come in contact with the colder tubes in the lower half of the condenser. The heat lost to the cooling water would have to be added elsewhere in the feedwater cycle before the condensate enters the boiler at some predetermined higher temperature.

In addition to maintaining high vacuum with no subcooling, a surface condenser must produce high-purity condensate, containing a minimum of dissolved oxygen and other non-condensables. The radial-flow condenser functions well in this respect, particularly in the lower half of the condenser, where, like a deaerator, steam flowing upward through the falling condensate atomizes the droplets, thus driving out or liberating any noncondensables and allowing them to be extracted at the central low-pressure section.

The importance of high-purity, oxygen-free condensate becomes more critical with each increase in boiler pressure and temperature. The presence of dissolved oxygen in feed water entering the modern high-pressure, high-temperature boiler is known to have caused boiler-tube failure; therefore the oxygen content is kept as low as possible—0.03 cubic centimeters per liter or less. The radial-flow condenser has no difficulty producing condensate with a maximum oxygen content of 0.01 cc per liter if all drains, vents, and possible sources of contamination are properly introduced into the condenser shell. While past practice has been to employ deaerating heaters and chemicals to remove oxygen from the system, the condenser is now being called upon to produce condensate of such quality that no additional treatment is required.

Condenser Performance

Since condenser performance (as far as vacuum is concerned) is dependent on the heat-transfer rate for a given water

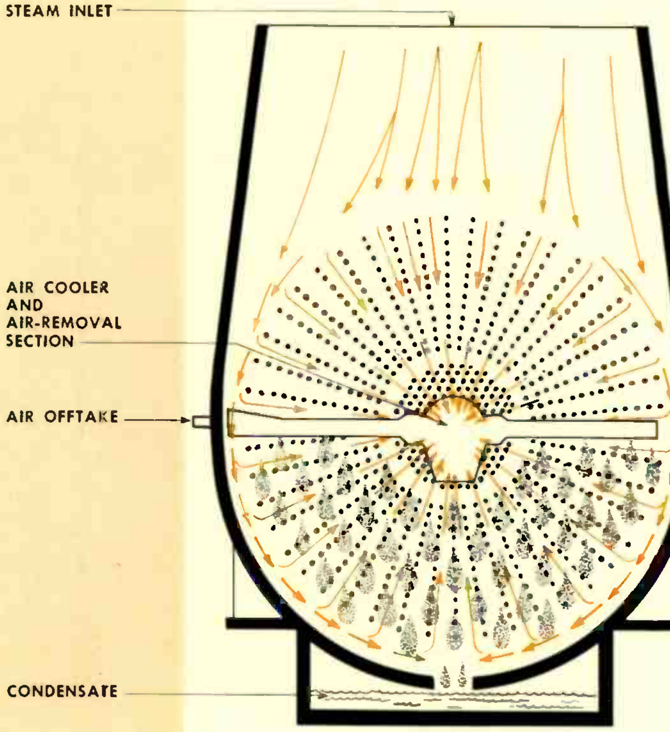


Fig. 2a

temperature and velocity, great emphasis is placed on maintaining a high thermal effectiveness—the rate that a given tube condenses steam on its outer surface while cooling-water is flowing through. Aside from conductivity of the metal, tube cleanliness is the most important factor. The degree of cleanliness is dependent on the source of cooling water and the amount of chemical treatment, along with the method and frequency of cleaning. Unless experience dictates a more realistic figure, condensers are designed on the basis that the average heat-transfer rate of the tubes, between cleanings, will be comparable to, or greater than, 85 percent of the basic design rate.

Where the water supply and arrangement of the circulating-water system is such that a large quantity of debris is brought into the water chambers of the condenser, some means must be provided to prevent tube plugging. One method is to reverse the water flow in order to flush the tubes and tube sheets. This can be accomplished by either using flow-reversing valves or reverse-flow pumps. Although reverse flow complicates the piping system at the condenser, it insures a more effective tube surface. The added installation is more than offset by improved performance and less-frequent manual cleaning.

The use of reverse-flow pumps for maintaining tube cleanliness is a comparatively recent development. A typical head-capacity curve for a pump designed for flow-reverse service is shown in Fig. 3. It will be noted that capacity in reverse direction is considerably less than in the forward direction. Since the pump is designed for forward rotation over the major portion of its life, normal operation is favored. Actually, the lower capacity during reverse operation aids the cleaning operation; with smaller quantities of water flowing through the condenser, the temperature rise is higher. This elevated circulating-water temperature is desirable when tube

Fig. 2—Fundamentals of radial-flow design are shown by these cross-section views (left) of a single-pass condenser.

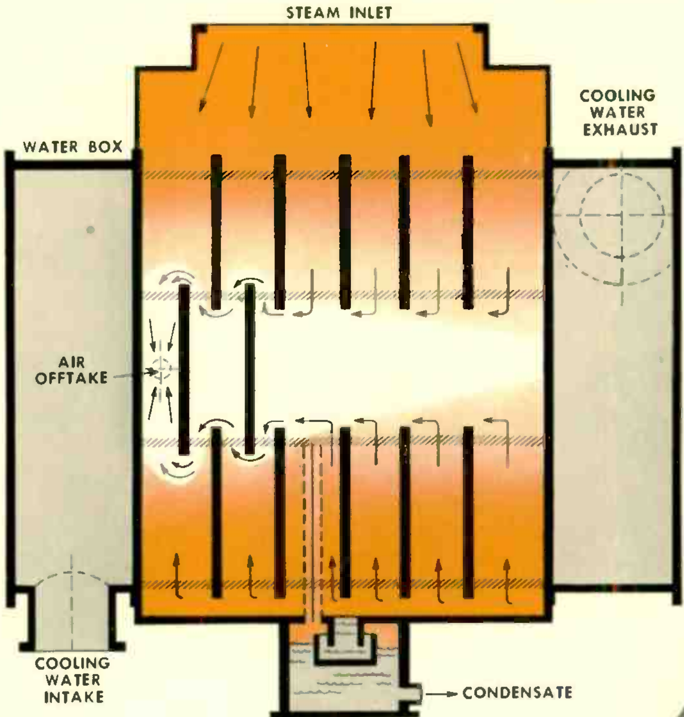


Fig. 2b

Circular single-pass divided condenser.

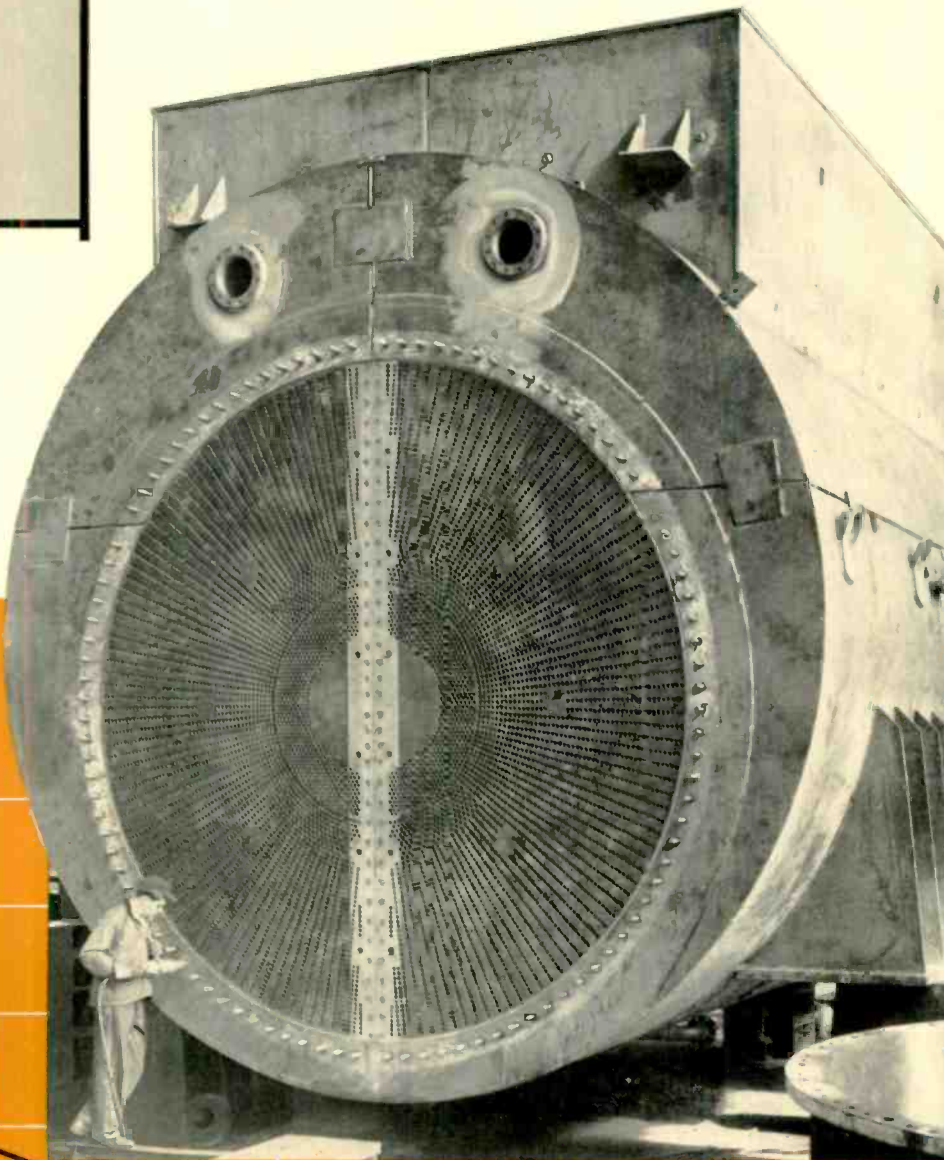
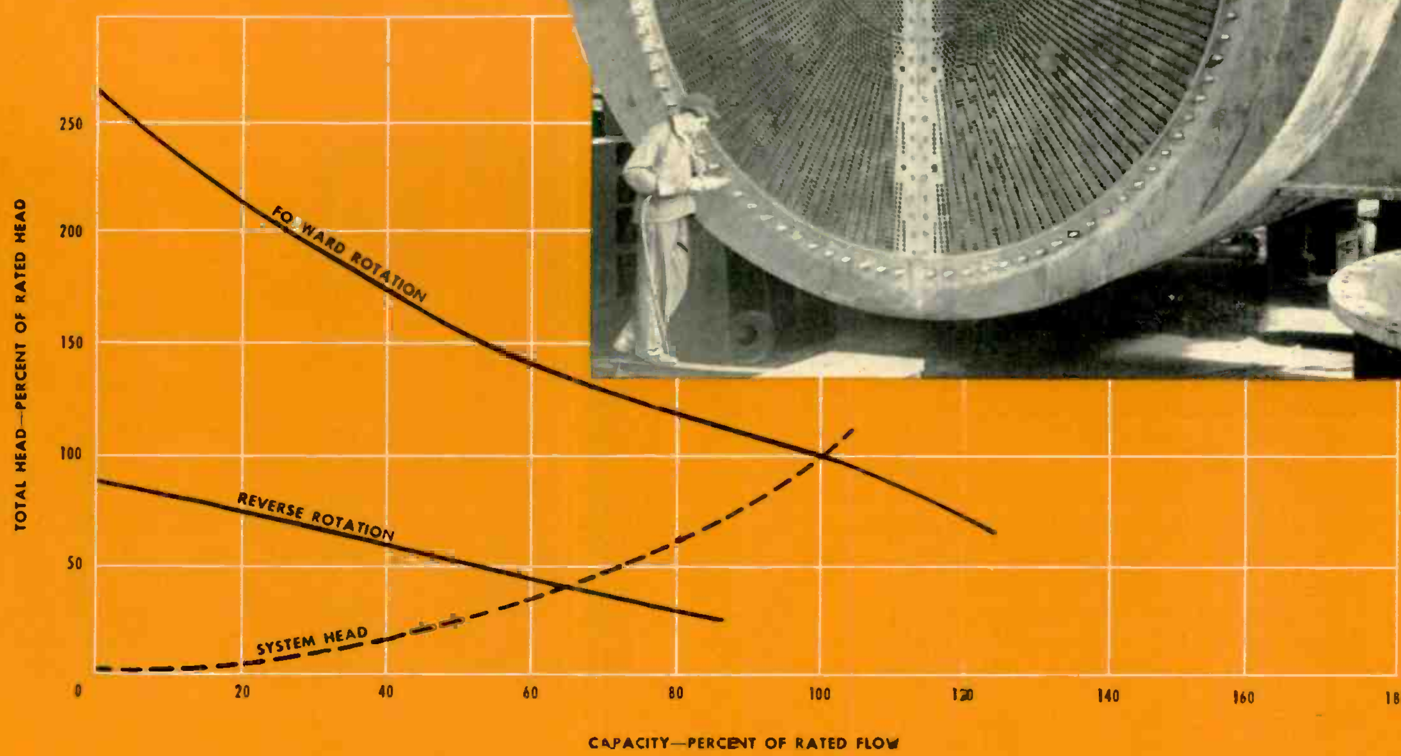


Fig. 3
TYPICAL HEAD CAPACITY CURVE OF REVERSE FLOW PUMP



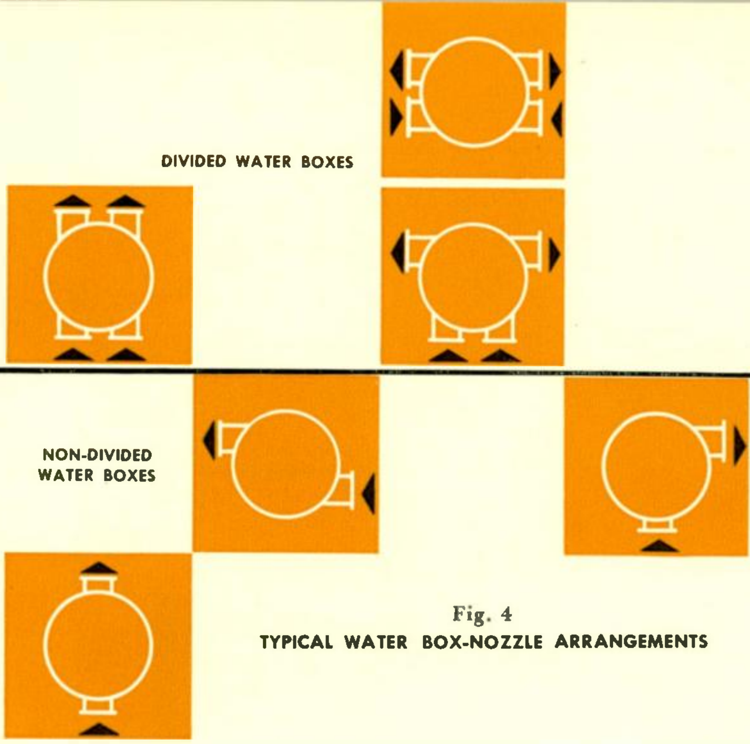


Fig. 4
TYPICAL WATER BOX-NOZZLE ARRANGEMENTS

fouling is due to growth of marine life, since it can be killed by sudden increases in temperature.

Moments Imposed On Turbine By Condenser

One of the problems that confronts the condenser designer during the initial design stages is that of turning moments. When the condenser is connected rigidly to the turbine exhaust, the turbine load and moment limitations are of concern. Such limits have been established for the turbine to prevent any harmful distortion of the turbine casing. The loads and forces are not only those imposed by the static weight of the condenser, but also those introduced by water forces at the free joints to and from the condenser. Whether the condenser is single- or two-pass, divided or non-divided, there is generally an ideal arrangement for the location of all circulating-water expansion joints. By proper location, the effects of the water forces can be minimized or counter-balanced by springs. Several water-box nozzle arrangements are shown in Fig. 4. Although some arrangements are applicable to a wide range of operating conditions, others must be considered carefully from the standpoint of water forces that could result in excessive thrust on the turbine casing. Where limited space prevents the ideal piping arrangement, it is advisable to install an expansion joint between turbine and condenser, thus eliminating any external forces. If the expansion joint cannot be justified, it may be necessary to resort to tie-rods to rigidly fasten the condenser to the foundation structure, thereby eliminating any possibility of movement.

Heaters In Condenser Steam Inlet

In recent years, as many as three or four low-pressure, feed-water heaters have been located in the steam inlet section of large condensers (usually over 40 000 square feet of condensing surface). The pressure drop between bleed point and heater is kept to a minimum by reducing the length of piping, which also makes valuable floor space available for other equipment. The heaters are located so that excessive turbulence and pressure drop does not occur within the condenser. It should be noted, however, that heaters installed in the steam inlet of the condenser have no provision for isolation from the rest of the system. The economics of all factors—available space, piping arrangements, and various pressure drops—must be considered in order to evaluate the desirability of condenser inlet heaters.

Differential Expansion

Provision must be made for differential expansion between the copper-alloy tubes and the steel shell of the condenser. This difference can amount to as much as a half inch in a 30-foot-long condenser. In early methods of construction, tubes were rolled into the tube sheet at one end and packed at the other so that the tubes could slide. Modern practice, however, is to roll the tubes solidly into both tube sheets; steel diaphragms take care of the differential expansion. These disk-type diaphragms, located at each end of the condenser, are designed to flex with axial movement of the tube bundle, yet are sufficiently strong to support the vertical load of the tube sheets and water boxes. This eliminates the need for external support for the water boxes.

Transportation

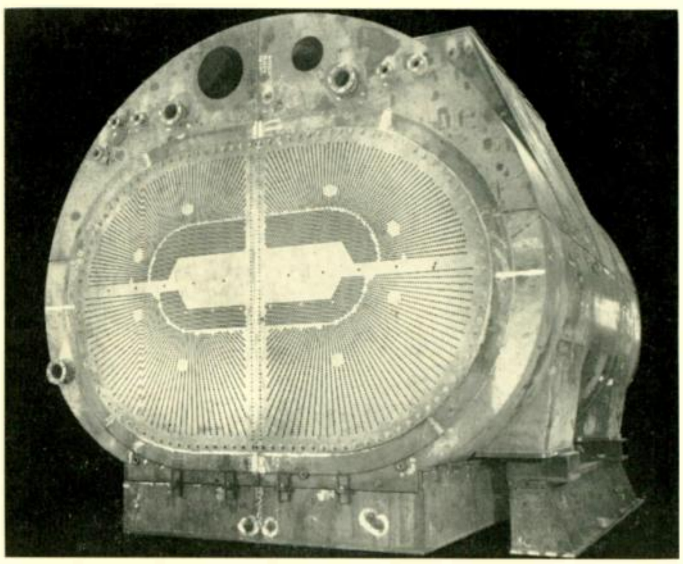
The shipment of completely assembled condensers of cylindrical construction is limited to approximately 15 000 to 20 000 square feet of surface, whereas under special conditions rectangular condensers containing up to 30 000 square feet of surface can be shipped as a unit. Each of the large condensers is unique, however, inasmuch as the method of transportation dictates, to a certain extent, the method of construction. Each condenser is prefabricated so that a minimum number of large sections can be shipped as individual sub-assemblies. This insures that all joints and tube holes are properly aligned for ease of assembly in the field.

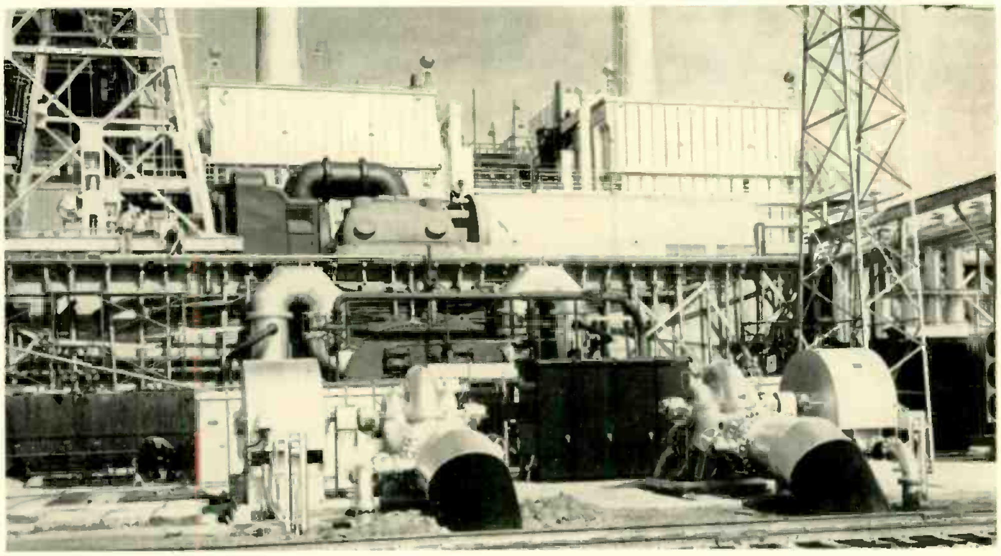
Trends

Increasing construction costs have focused attention on the desirability of reducing the distance between turbine-room floor and basement, with the ultimate possibility of locating the turbine and condenser on one level.

While over the years a great many condensers have been cylindrical in appearance, the present trend is toward rectangular construction. Where low headroom has dictated that condensers be of rectangular shape rather than cylindri-

Tube arrangement for oval shaped, two-pass divided condenser.





This shows the general arrangement of an outdoor installation, where the condenser is mounted directly below the generator.

cal, no particular problem exists. The radial-flow principle can be employed whether the condenser is circular, oval, or rectangular in construction.

Development of the vertical, pit-type pump has also reduced headroom requirements on the average of $2\frac{1}{2}$ feet per installation. This pump, with its shaft, impellers, and guide vanes submerged in a casing that extends below the floor, may also have its suction nozzle completely below the floor line. The comparative submergence requirements of the pit-type versus the horizontal centrifugal-type pump are shown in Fig 5, as well as the headroom requirements.

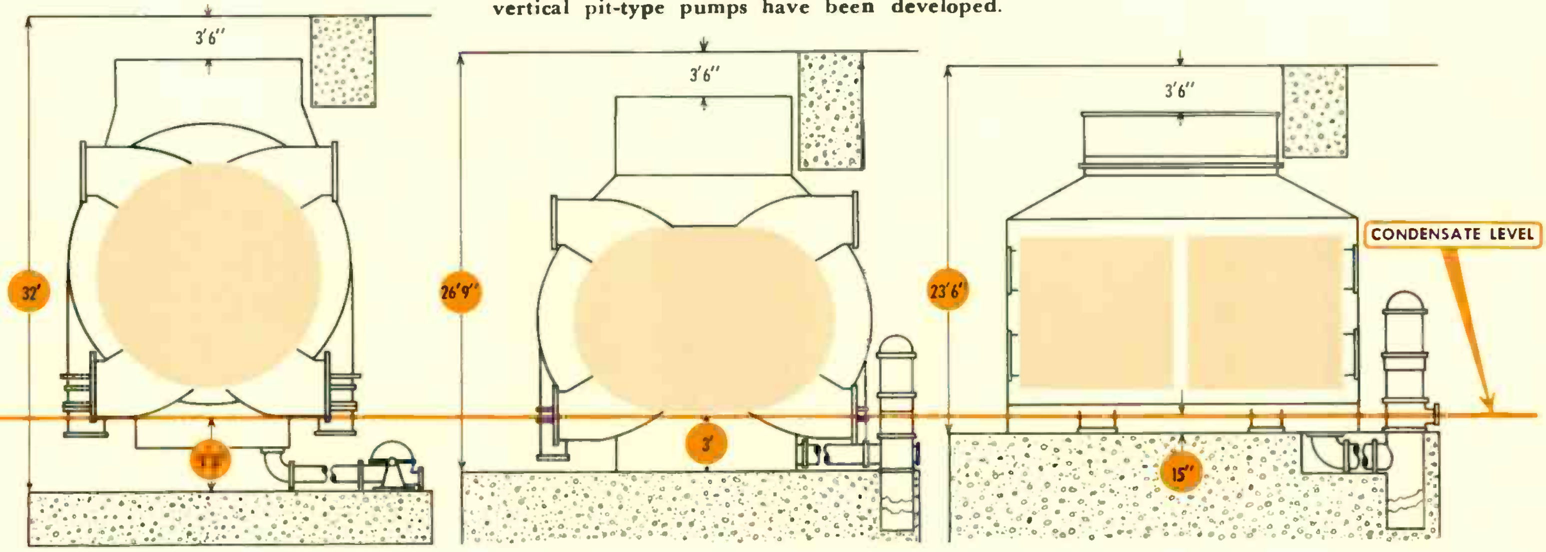
Where low available headroom excludes the use of a single condenser below the turbine and between supporting columns, it has been found advantageous to install twin condensers—one on each side of the bottom- or side-exhaust turbine. With this type of arrangement, the top of the condenser, which is usually above the base of the turbine, offers a convenient location for the air-removal equipment. Twin, as well as single, side-mounted condensers have been installed in a number of southern outdoor installations.

Conclusions

On the basis of today's standards the surface condenser as presently manufactured is acceptable to the industry. This does not mean, however that the ultimate in condenser design has been achieved. Work is continually being done to increase the thermal effectiveness of condenser tubes. Studies are being made to improve the physical arrangement of tubes and baffling within the condenser shell. New tube materials are being investigated for their thermal properties. Further studies are being made on dropwise condensation, which would improve heat transfer rates by making the condensing surface non-wettable, so that steam condenses as droplets rather than as a film. Since heat-transfer rates increase with increased water velocity, ways of prolonging the life of condenser tubes subjected to velocities higher than the present practical limit of seven to eight feet per second are being investigated. Great strides have been made over the years in the design of condensers and associated equipment for steam power plants. Present studies are expected to result in condensers of even greater efficiency in the future.

Figure 5

To save valuable overhead space, condensers are being designed in oval and square shapes, and vertical pit-type pumps have been developed.



an Engineering Personality

LEO J. BERBERICH

Challenging engineering problems are an every-day occurrence to Leo J. Berberich. His job: to help engineers of the various Company divisions find answers to their toughest questions. Berberich is manager of the Liaison Engineering Department, whose function is, as he puts it, "to render engineering assistance wherever and whenever it is needed."

The liaison engineer's job, primarily, is to recognize the engineering problem and know where to find the answer, drawing upon knowledge and experience with similar or related problems. In a sense, he acts as a consulting engineer. Here, one of Berberich's talents shows to advantage. As one of his acquaintances says, admiringly, "Leo's mind must work something like an electronic card-sorting machine. It almost seems like all the technical information he has encountered is filed away in his mind for future reference, and when a specific problem arises, he sorts through it quickly and comes up with a parallel or identical situation that at least gives a lead to the answer. As far as he's concerned, there are very few unique engineering problems—there's an analogous one somewhere in the 'file'."

Berberich's specialty is electrical insulation, in which he has an extensive and noteworthy background. In fact, most of Berberich's career up until he assumed his present position was research in the field of insulating materials.

Berberich was raised on a farm near Petersburg, Virginia. He was, as he laughingly puts it, "the top man in my high school class—as a matter of fact I was the only man." In 1924 he entered Johns Hopkins University, where he first became engrossed in the mysteries of electrical insulation. The Dean of Engineering at that time was Dr. J. B. Whitehead, a world-wide authority on insulation, and he played a large part in arousing Berberich's interest in this field. When Berberich received his bachelor's degree in electrical engineering in 1928, Dr. Whitehead was instrumental in encouraging him to remain at school and work toward his doctorate, which he earned in 1931.

After a few years as a research engineer and group leader for the Socony-Vacuum Oil Company Inc., Berberich came to Westinghouse in 1937 as a research engineer at the Research Laboratories; here he was to delve into all aspects of electrical insulating materials. In 1941 he was made a group leader, and in 1943 Berberich became manager of the Physical Section of the Insulation Department. During his period at the Research Laboratories, Berberich made several important contributions to the insulation art, as evidenced by over a dozen issued patents and over twice as many papers and articles.

In 1940, one of Berberich's assignments was to develop a coil insulation for high-voltage generators that could replace the conventional asphalt-type insulation when generators outgrew its characteristics. The basic problem was to find a material that had the ability to expand and contract with large copper coils, and in addition had improved electrical characteristics. When Berberich stopped at an adjoining laboratory one day, an associate was working on a resin insulation for high-frequency transformers. Berberich arrived just as some of the new resin was being removed from the oven. He picked up a hot piece of the resin and pulled on it with both hands. It stretched—and regained its shape. This started Berberich and several associates on the long hard road of developing some combination of a resin and mica that would serve large generators. This culminated with the development of Thermalastic insulation, for which he is a co-inventor. For this development Berberich and two of his associates received a special Company award for outstanding invention.

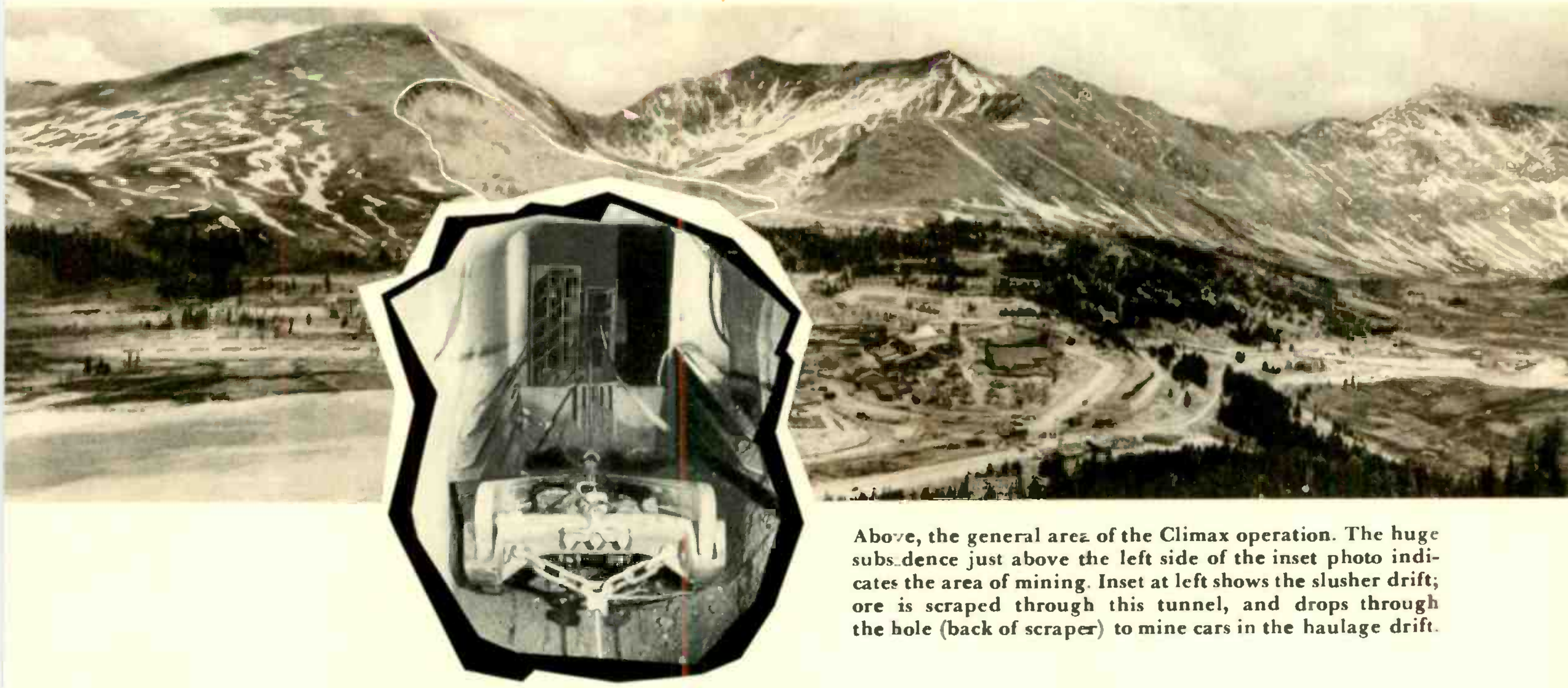
Among other developments in which Berberich has played a part is that of Coronox, a semiconducting coating for the end windings of large generators, to prevent corona; a conducting coating for the slot portions of large generator coils, to prevent slot discharges; and several improvements in materials for impregnated-paper capacitors.

In 1949, Berberich left the Research Laboratories and took over his present assignment as manager of the Liaison Engineering Department. Despite the much broader technical aspect of his job, he has retained his interest in insulation, and is the chairman of the Company-wide committee for coordination of insulation information.

He is also an active member of several engineering societies, including the AIEE, in which he has served as chairman of numerous committees and was recently elected chairman of the Pittsburgh section; the American Chemical Society; the American Physical Society; the American Society of Testing Materials; and the Westinghouse Engineers Society, of which he is a past president. He also served as United States delegate on a committee on insulating materials for meetings of the International Electrotechnical Commission held in Yugoslavia in 1953, and in Philadelphia in 1954.

A man of tremendous energy, Berberich finds ample opportunity to exercise his broad and varied talents. As an associate describes it, "Berberich instinctively uses all facilities at his disposal to the fullest extent of their capabilities. Not only does he pour his own ability into every problem, but also he succeeds in making maximum use of both the men and materials available." His record of accomplishment in research, development, and liaison engineering bears ample proof of this characteristic.

Molybdenum...



Above, the general area of the Climax operation. The huge subsidence just above the left side of the inset photo indicates the area of mining. Inset at left shows the slusher drift; ore is scraped through this tunnel, and drops through the hole (back of scraper) to mine cars in the haulage drift.

Cave Mining and Concentration

Molybdenum is a metal found in large concentrations in a very few spots in the world. Near Climax, Colorado is one such area; here moly is mined and processed.

ONE SLOPE OF Bartlett Mountain, high up in the Colorado Rockies, appears to be sinking slowly into some subterranean opening. This, in fact, is exactly what is happening, although the occurrence is man-made and not an accident of nature; in a general sense the mountain is being systematically caved in from the inside. The object: the mining of molybdenum ore—for Bartlett Mountain is one of the richest sources of moly in the world. The mountain is mined by the Climax Molybdenum Company, who also process the ore to produce molybdenum disulfide in mills near the mine.

The process used at Climax to recover the ore is known as cave mining. Simply stated, it consists of tunneling in the side of the mountain, under the body of ore to be produced, and by means of a system of undercutting and caving, the mountain above is converted into a great mass of broken rock, to be drawn from beneath much as gravel is drawn from a hopper. Of necessity the work must be performed in accordance with precise engineering procedures.

At Climax, the ore body can be roughly compared to half of a cantaloupe turned upside down. The meat of the cantaloupe represents the molybdenite ore; the seed portion, the non-commercial, highly siliceous core. This mineralized cantaloupe is perhaps 2000 feet across and the meat portion (commercial-ore zone) is 200 to 300 feet thick.

The access tunnel, which is driven from the mountain's side, meets the ore body tangent to its outer or skin side, and encircles the mineralized area. A similar tunnel encircles the inner, non-commercial zone—thus providing two concentric circular tunnels, which are linked by parallel haulage tunnels at 200-foot intervals. This entire network of tunnels is served by the mine train system, and is known as the haulage level of the mine.

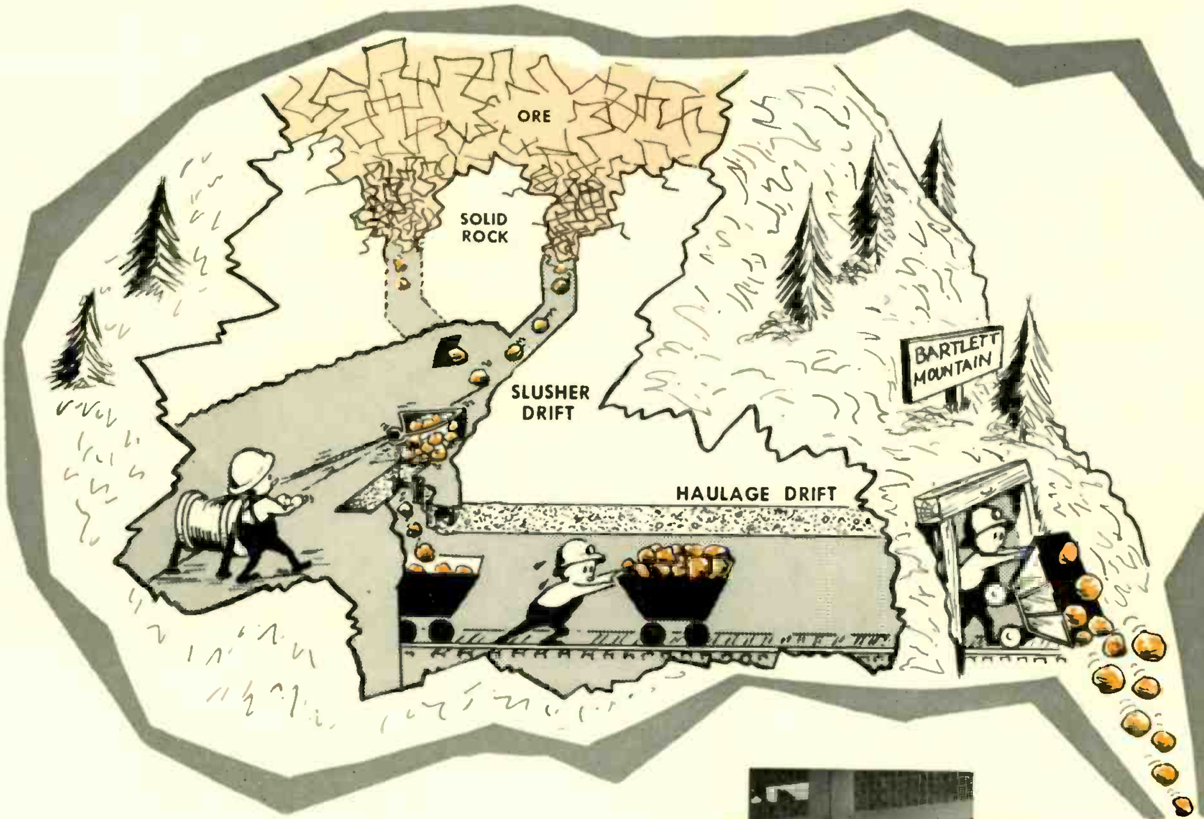
Immediately above and perpendicular to the haulage tunnels are located, at regular intervals, galleries or slusher drifts 112 feet in length. A hard-rock roof 40 feet thick provides protection for the haulage level and slusher drifts from the mass of broken rock that lies above. Through this roof angular tunnels or "fingers" project into the broken-ore zone and permit the ore to feed into the slusher drifts by gravity. From the drifts, the ore is scraped to draw holes where it falls into ore cars located immediately beneath in the haulage tunnels (see photograph above).

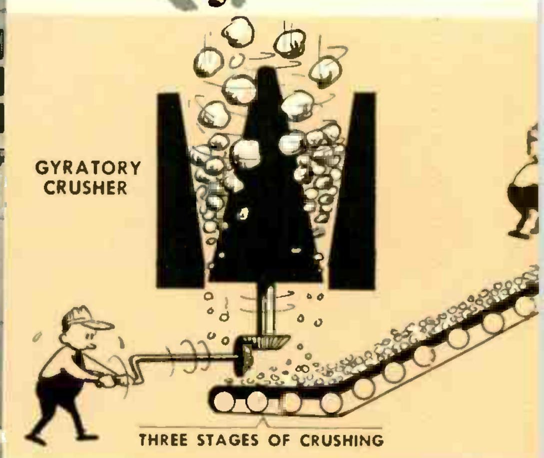
The molybdenum-bearing ore, in chunks as big as six feet across, is then hauled out of the mine to start the milling process. An average of over 27 000 tons of ore is produced in each 24-hour day.

The ore must be crushed and ground in a series of processes to reduce the rock to particles no larger than one-thirtieth inch. In this dimension, ore particles containing molybdenum disulfide are sufficiently small to be separated from the large amount of waste material by flotation. Crushing is performed by three stages of gyratory crushers. Here the rock is crumbled much in the manner of a druggist's mortar and pestle.

Next the material, about the size of pea gravel, is fed to large ball mills where it is mixed with water and pulverized. A spiral classifier working with each ball mill separates the coarse particles for further grinding; the fine material is pumped as a watery slurry to the flotation section.

Molybdenum disulfide has an affinity for certain oils. When oil and air are fed into the mixture, the moly disulfide attaches itself to the oil, and tiny bubbles of air carry the oil-coated mineral to the surface, forming a froth at the top of





the cell. This froth is drawn off to produce the so-called rougher concentrate, an intermediate in the milling process. In the regrind plant, this material is subjected to further grinding to produce material of 0.005-inch average particle size. Further flotation, followed by thickening, filtering, and drying, produces a concentrate of 90 percent MoS_2.

This powder is then packed in hopper freight cars, for shipment to the Climax conversion plant at Langeloth, Pennsylvania for production of molybdic oxide, ferro-molybdenum, and other forms useful to the metal and chemical industries.

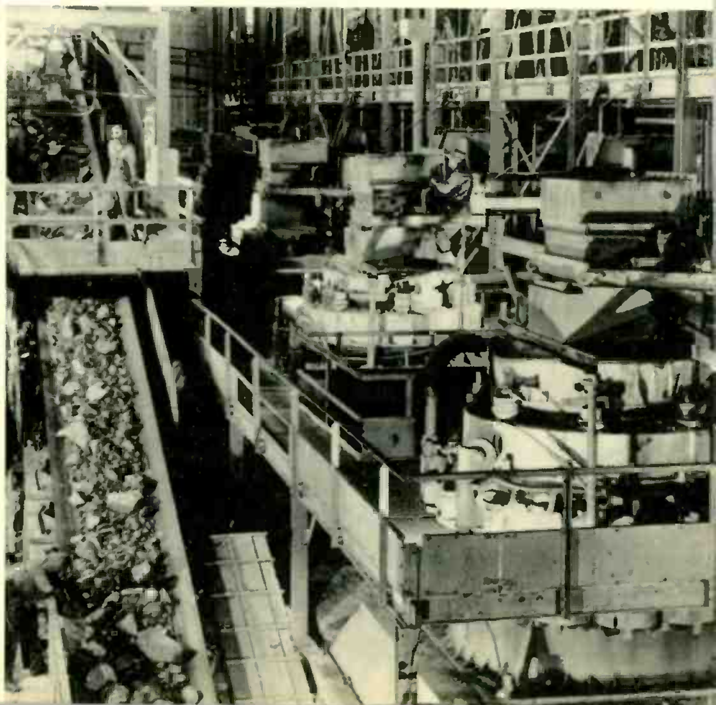
The tailing remaining after removal of moly is carefully reprocessed to remove such by-products as tungsten, tin, and iron pyrite. The ore also contains monozite and topaz, but no economic use for these minerals from this source has yet been found, so they are not removed.

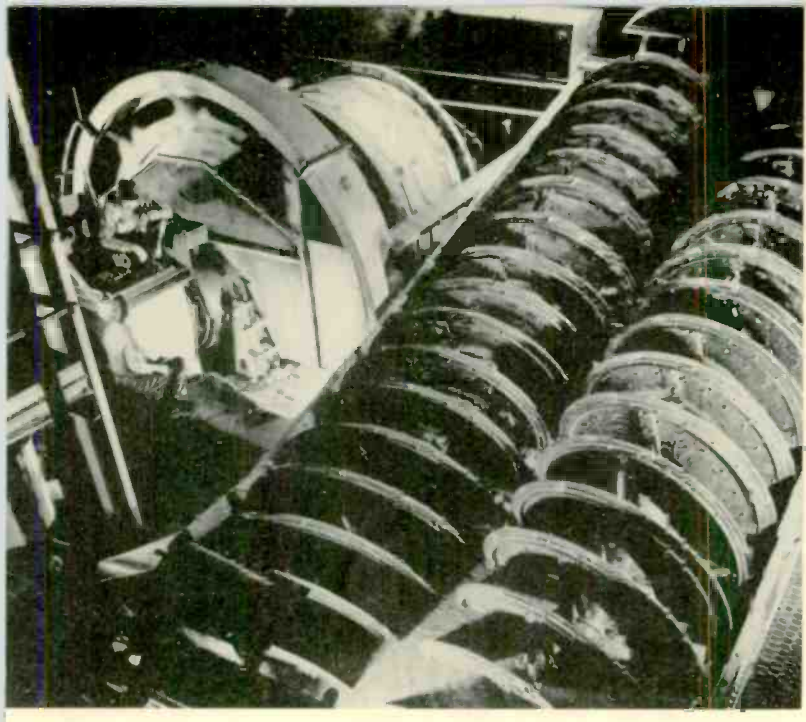
The whole Climax operation is geared to produce moly as a primary product, with tungsten, tin, and other materials as by-products. Curiously, this makes the operation unique, in that most of the moly otherwise mined in the world is a by-product of some other metal mining, usually copper.

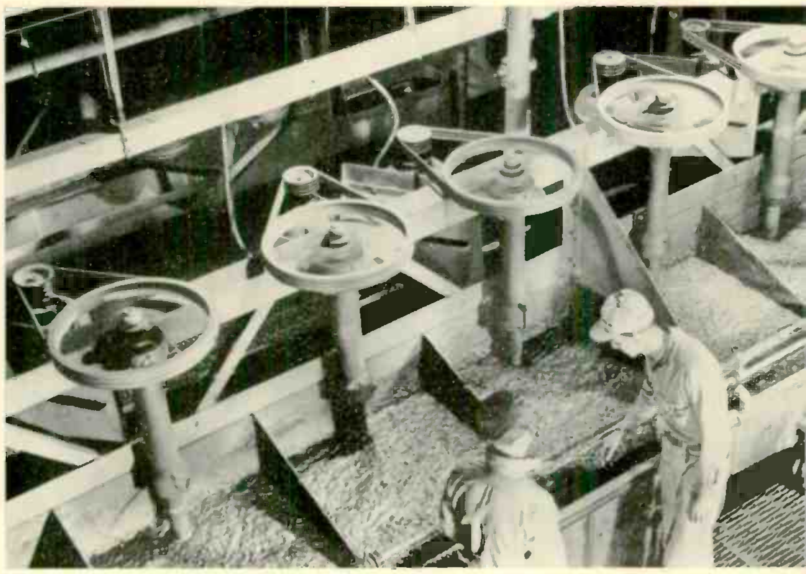
Molybdenum is in plentiful supply in the world, but most of the known deposits of any size are concentrated in specific areas. Colorado and Utah contain most of the moly presently being mined. The Climax Molybdenum Company operation alone produced about 42 million pounds of molybdenum in 1954, or approximately 73 percent of the country's production. Proven ore reserves in this mountain are sufficient to supply the free world's need, for many years.

Molybdenum goes into a wide variety of different end uses. The primary application, of course, is as an alloying element for steel, to which it lends high-temperature qualities, strength and hardness. Molybdenum chemicals and compounds are also finding increasing use; molybdenum sulfide, for example, has proved to be an excellent lubricant. Another important use for moly compounds is in pigments, and in catalysts. Moly as a pure metal is also widely used, especially in electronic tubes, lamps, and similar applications.

CRUSHERS. Ore undergoes three stages of crushing. Conveyor is carrying ore to second crusher; third crushers are at right.

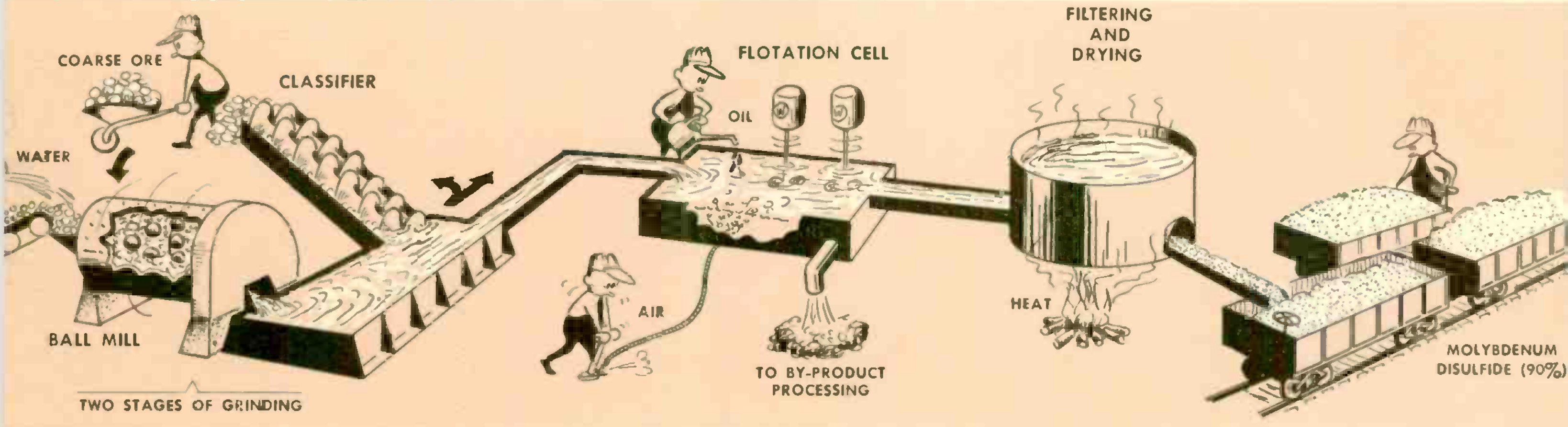






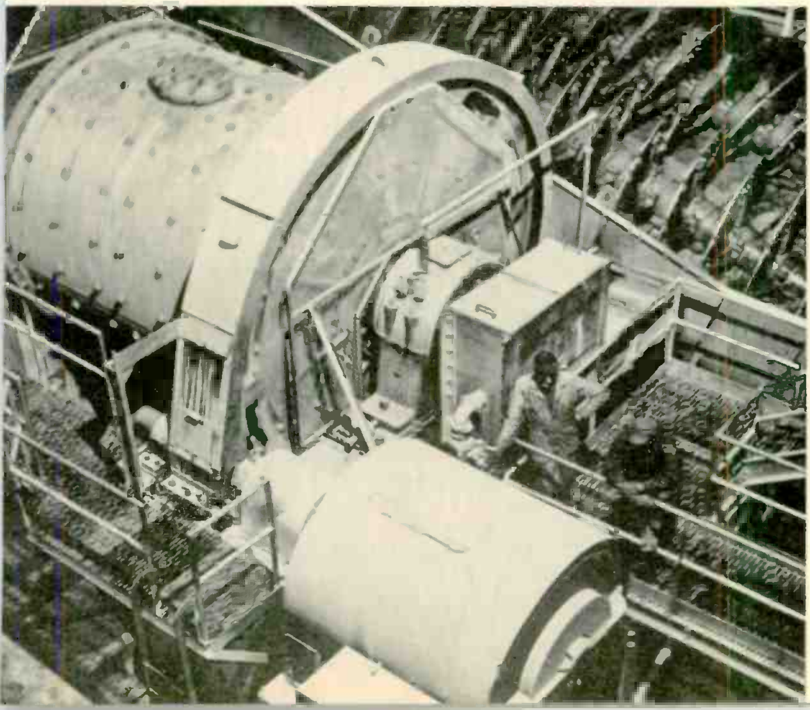
CLASSIFIERS. The mixture of water and ground ore from the ball mills is fed into a spiral classifier. Coarse particles are carried to the top and reprocessed. The remaining watery slurry goes on to the flotation cells.

FLOTATION CELLS. Oil and air are fed into the water-and-ore mixture. Molybdenum attaches itself to the oil and the bubbles of air carry it to the surface, where it forms as a froth, as shown in this cell.

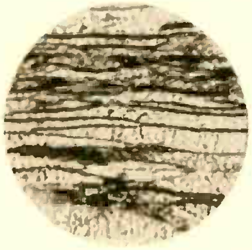


GRINDERS. Crushed ore is ground in ball mills powered by a motor and gear drive. Ore must be ground to less than one-thirtieth inch in size for the flotation cells. From the ball mills ore goes to the spiral classifier.

BY-PRODUCT. Iron pyrite is separated by flotation from the mineral mixture taken from a spiral classifier. The remaining material is treated on these vibrating tables for separation of tungsten and tin.

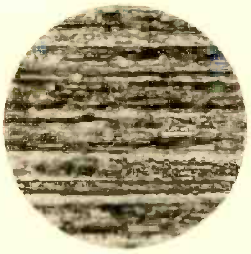


Raw material is first reduced in a hydrogen atmosphere to molybdenum dioxide. Photos below are enlargements of partially worked (top), and fully worked molybdenum.



MOLYBDENUM

a High-Temperature Structural Metal



WILLIAM M. FRASER
and
ROBERT R. FREEMAN, *Lamp Division, Westinghouse Electric Corp., Bloomfield, N. J.*

THE SEARCH for tough, high-temperature structural materials has turned the spotlight on many metals once used only for special purposes and in small quantities. One of these is molybdenum, long known as an alloying agent in the manufacture of high-grade steels, but only recently in the pure form for structural purposes. Part of the reason for its slow acceptance as a pure metal lies in certain deficiencies, such as low ductility at room temperature and lack of resistance to oxidation in air at elevated temperatures. However, the highly desirable physical and electrical properties of the metal have engendered considerable research and development, with the result that molybdenum is fast overcoming its handicap and increasing its field of applications.

Molybdenum is of the heavy metal family, which includes tungsten, and has a high melting point of 4750 degrees F and a specific gravity of 10.3. The supply of the metal is plentiful, and, in fact, the largest part of the world's supply is produced in the United States. Pure molybdenum, formerly used almost entirely as wire for the lamp industry, now is being applied in an increasing number of applications requiring high strength at elevated temperatures, and exceptional stress-rupture and creep properties, such as in gas turbines or rockets. Great strides have been made in the manufacture and fabrication of molybdenum, which have enabled it to be produced in new shapes and sizes, and broadened its possibilities considerably.

Properties of Molybdenum

Although molybdenum has many outstanding properties, most applications take advantage of its high melting point, high strength at elevated temperature, and good thermal and electrical characteristics.

Molybdenum's melting point is higher than any of the common metals except tantalum and tungsten, both of which are much more costly. This permits its use at temperatures far above the melting point of steel and the usual "high temperature" iron-, nickel-, or cobalt-based alloys.

The strength of molybdenum at temperatures over 1650 degrees F exceeds that of any other commercial metal except tungsten, which occasions its major interest today in the fields of rockets, aircraft engines, and gas turbines.

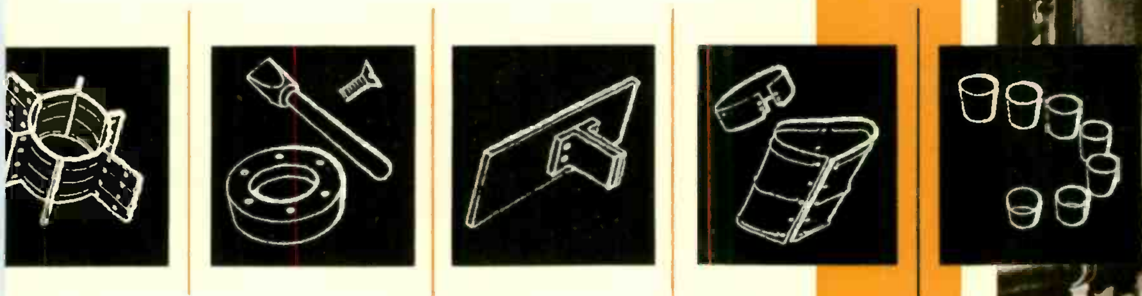
The thermal and electrical conductivities of molybdenum are several times higher than those of the usual steels and high-temperature alloys. Molybdenum also has a low coefficient of thermal expansion, which insures dimensional stability at high temperatures.

Chemically, molybdenum is resistant to many acids and molten glass, but is rapidly attacked by molten oxidizing salts. When polished to a high luster, it does not tarnish in air at room temperatures. The metal oxidizes slowly when heated in air to a temperature of about 750 degrees F, and the oxide starts to come off as a dense, white smoke at about 1100 degrees F. The molybdenum trioxide formed melts at about 1450 degrees F and affords no protection to the base metal. This factor makes it necessary to protect molybdenum at elevated temperatures by means of a vacuum, a neutral or reducing atmosphere, or by protective coatings applied to the surface. Typical coatings are clad platinum and nickel, plated chromium and nickel, sprayed or dipped aluminum, and ceramic coatings.

Molybdenum subjected to temperatures of 1800 degrees F or greater for several hours becomes recrystallized and is brittle when cooled to room temperature. The original ductility cannot be restored by heat treatment alone.

Machining Molybdenum

As recently as 15 years ago, molybdenum was generally considered difficult to machine. Losses on machining were usually quite high, but little was done to improve this situation due to the relatively low demand for machined molybdenum parts.



These sketches show some shapes now made of molybdenum.

Electric sintering bottles for moly ingots.

With the development of radar tubes during World War II, it was found necessary to make many elements from molybdenum because of the high operating temperatures involved. The molybdenum parts for these tubes required close tolerances, smooth surfaces, and freedom from defects, which necessitated the development of new techniques for both manufacturing and machining.

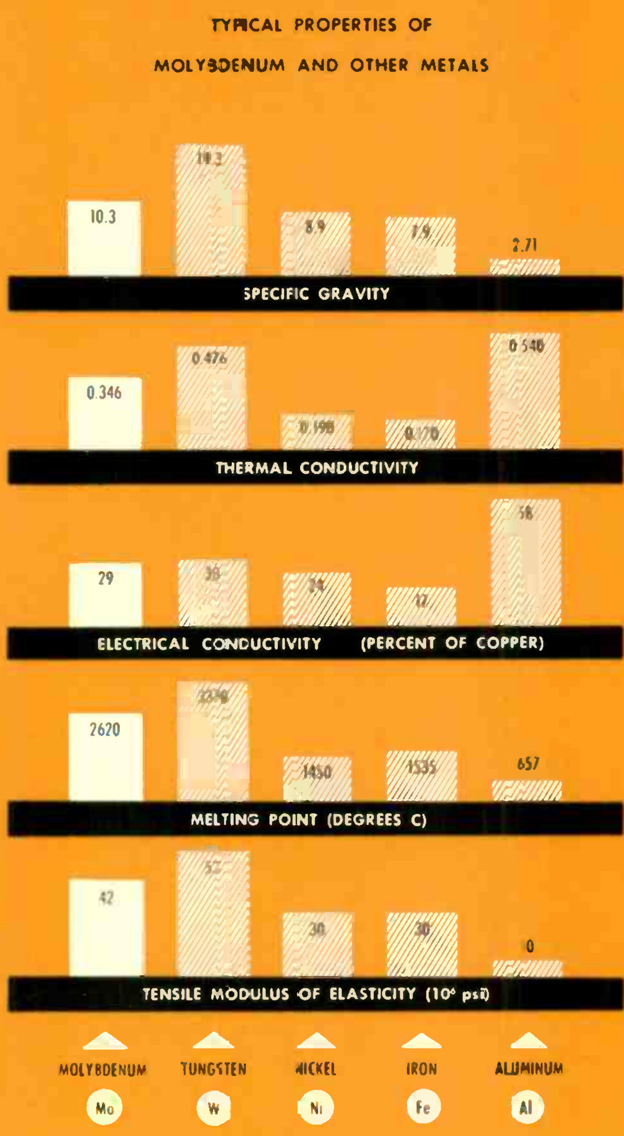
Swaged molybdenum rod normally is made up of elongated grains, which tend to pull out of the surface when machined, thus causing a rough surface. On the other hand, a completely recrystallized structure is hard and brittle and does not machine easily. A grain structure intermediate between these extremes provides best machining qualities.

Improved manufacturing methods have made possible a supply of rod that is more nearly split-free than that available in the past. At the same time, new and improved methods of machining this metal have been developed, so that little difficulty is experienced today in the manufacture of machined molybdenum parts.

While tungsten carbide tools are sometimes preferred, the majority of tools used on molybdenum are of high-speed steel. Molybdenum is not a hard metal (about 90 Rockwell B) but the chips produced are very abrasive and rapidly dull the cutting tool. For this reason, the tool must be kept clean by removing the chips as rapidly as possible from the cutting area. The tool must be kept sharp by frequent dressing to obtain a satisfactory job.

In drilling molybdenum the drill must be kept cool because of the much higher expansion of the steel. This can easily lead to seizing of the drill and cracking of the molybdenum. A variety of cutting lubricants are used on molybdenum, including water-soluble oils, carbon tetrachloride, trichlorethylene, and molybdenum disulfide.

Molybdenum can be readily cut using a hack saw, band saw, or cut-off wheels of the rubber-bonded carborundum type. Milling cutters of high-speed steel have a very short life when machining molybdenum and it is desirable to use a shaper whenever possible. Milling cutters with carbide tips give excellent results but are quite expensive.



Spinning, Drawing, Forming, and Bending

As in the case of machining, very little mechanical working of molybdenum had been done before World War II. At that time the demands for shaped parts became so great that it became necessary to concentrate on methods to improve its working properties. The electronic industry, which expanded rapidly, was one of the largest groups to require unusual shaped parts. Engineers met this challenge by producing molybdenum sheet that could be readily formed by any of the common methods. Many complicated parts are now made from molybdenum, which feat seemed virtually impossible a few years ago.

Thin molybdenum sheet up to 0.010 inch can be deep drawn and spun successfully at room temperatures. However, when using heavier sheet some heat must be applied. The temperature may vary somewhat with the thickness, but 200 to 400 degrees F is generally sufficient to give enough ductility to the metal for good working conditions.

Special sheet for deep drawing and spinning is also produced. In processing, the physical properties peculiar to this type of working, such as grain size, ductility, and directional distribution of grains, are all controlled. This sheet has been spun from sizes as heavy as 0.090 inch and has been drawn in thicknesses up to 0.062 inch. Although this is rather heavy for molybdenum, it does not necessarily represent the upper limitation for these forming operations.

The glass industry and others have required parts, such as heavy angles, bent from plates up to three-fourths inch thick. These are readily formed into 90-degree angles by the use of heat and a bending press.

Through better fabricating techniques and improved material, the mechanical working of molybdenum is no longer considered difficult.

Joining Molybdenum

Molybdenum can be joined by a number of different methods, depending upon the thickness of metal, strength desired, degree of tightness required, etc. The following methods include those that are most widely used at present.

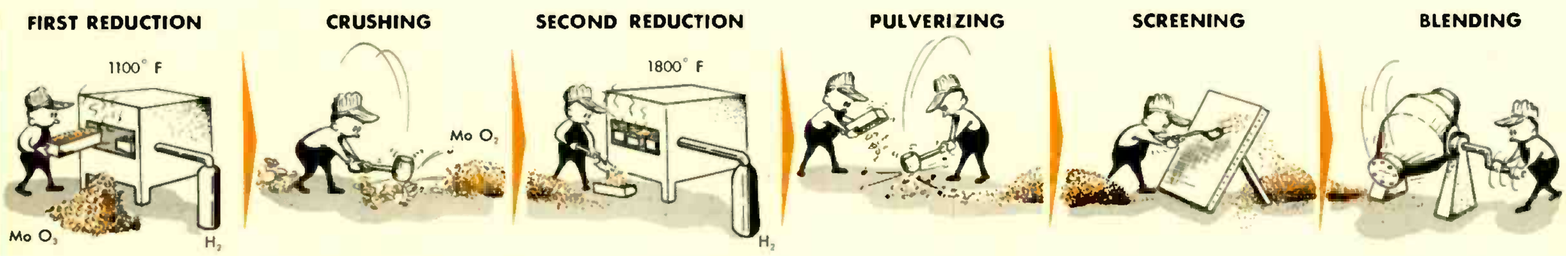
Riveting—This method is used for joining both thin sections and very heavy sections where good strength is essential but the joint is not required to be gas-tight or water-tight. Cold-headed molybdenum rivets, about one-sixteenth inch in diameter, are used in the electronics industry to fabricate tube parts from sheet approximately 0.005 to 0.03 inch thick. Plates as heavy as three-fourths inch are joined by large diameter rivets made on a lathe from molybdenum rod three-eighths to one inch in diameter. The small-diameter rivets can be peened cold but large rivets must be heated during the riveting operation.

Bolting—For joining heavy sections, large bolts are sometimes desirable; these are made by threading molybdenum rods. The head can be left round or machined to provide flat surfaces for a wrench.

For some applications large diameter (one to six inch) molybdenum rods must be joined end to end. This is done by the use of external and internal threads on the rods themselves, or by a threaded coupling connecting the two threaded ends of the rods.

Brazing—Although copper and silver wet molybdenum they do not alloy with it, and a copper or silver alloy containing either nickel or phosphorous is necessary to insure good bonding. The parts to be joined should be thoroughly degreased and all surface oxide removed before brazing in a hydrogen furnace or other reducing atmosphere. For brazed joints subject to temperatures above the melting point of copper or silver solders, it is possible to use eutectic compositions of molybdenum and iron, cobalt, or nickel, which melt in the vicinity of 2450 to 2700 degrees F.

Resistance Welding—Resistance welding is widely used in the electronic industry for joining thin molybdenum sheets. Short welding times—one-half cycle or less—must be used to prevent brittle welds. Due to the high conductivity and high melting point of this metal, the kilovolt-ampere requirements for welding heavy sheet become very large, and welds in thicknesses over one-sixteenth inch are not practical.



MANUFACTURE OF POWDER METALLURGY MOLYBDENUM

The raw materials used for molybdenum metal are of two types: (1) molybdenum trioxide, a fine, slightly off-white powder; and (2) ammonium molybdate, a pea-size, colorless crystal. Although there is a slight variation in processing these two materials to metal powder, the basic method is the same; thus they can be classified as a single material. Being of the same family as tungsten, their manufacture is generally parallel.

The initial step is known as first reduction, in which the raw material is reduced in hydrogen to molybdenum dioxide (MoO_2). This is carried out in a gas-fired tube-type furnace, heated to a temperature of about 1100 degrees F. Then the dioxide is removed from the furnace, crushed, and given a second reduction in the same type of furnace at a temperature of 1800 to 2000 degrees F. This reduces the dioxide to a gray metal powder, which is then pulverized, screened, and blended. The furnace tubes are made of special heat- and corrosion-resistant alloys, while the boats in which the molybdenum is reduced are of nickel or molybdenum.

The metal powder is then packed into a steel mold and hydraulically pressed at 30 000 to 40 000 pounds per square inch into an ingot, the size of which is dependent on its ultimate use. The pressed ingot is then sintered in either a high-temperature furnace or by passing an electric current through it. In either case the sintering is done in a hydrogen atmosphere. The ingot, now in the form of a solid, silver-gray metal, may have a specific gravity of 9.8-10.0, and is ready for fabrication.

Close quality controls on the powder are maintained, and such physical data as particle size and distribution, bulk value, and apparent density, are closely watched. In the ingot form, quality checks for density and grain count are made.

Molybdenum wire is produced by swaging

Thin sections for electronic tubes are often joined by spot welding using nickel or platinum foil between the sheets as a brazing agent. The surfaces to be joined are usually prepared by grit blasting or chemical etching.

Arc Welding—Both the atomic-hydrogen and inert-gas metal arc welding processes are used for welding molybdenum. Applications for this type of joining are limited due to the brittle nature of such welds at room temperature. Considerable development work is being carried out on this problem at the present time so that the advantages of this type of joining can be realized in the fabrication of a broader variety of molybdenum structures.

Applications of Pure Molybdenum

One of the original uses for pure molybdenum was in the form of wire in the manufacture of electric lamps. This application is still an important one and large quantities of wire are used each year for the small "hooks" that support the tungsten filament in the bulb. The tungsten filaments for coiled-coil lamps are wound on a molybdenum wire mandrel, which is later dissolved, leaving the tungsten coil. Small-diameter molybdenum wire is also used by the electronic-tube industry for winding grids.

Large-diameter wire and rods are used as heating elements in furnaces that operate in the range of 2500–3000 degrees F. Large rods, one to six inches in diameter, also serve as heating elements and stirring devices in electric furnaces used to produce high-quality glass.

Large quantities of sheet and rod are used by the electronic-tube industry for such things as plates, anodes, grid frames, side rods, and caps. The development of new tubes for radar equipment caused a great increase in the requirements for molybdenum rod; the high temperatures involved prevented the use of the more common materials.

Molybdenum sheet is used in high-temperature thermostats for fire-detection purposes and as a heat shield in furnaces that operate at temperatures of 3000 degrees F or more.

The discovery that sprayed molybdenum can act as a bond between the base metal and a sprayed metal coating has led to the use of molybdenum wire for this application. Steel shafts that have become undersize due to wear are first sprayed with a thin layer of molybdenum and then with a layer of steel, followed by turning or grinding to size. It has recently been found that sprayed molybdenum alone has excellent resistance to wear and such bearing surfaces have greatly increased life as compared to non-metallized surfaces.

Molybdenum powder is often mixed with other metals, such as silver, in the production of electrical compacts. The finished compact combines the high-temperature strength of molybdenum with the excellent conductivity of the silver.

Large molybdenum rods and heavy plates are used in the manufacture of rocket and guided-missile parts because of their high-temperature properties.

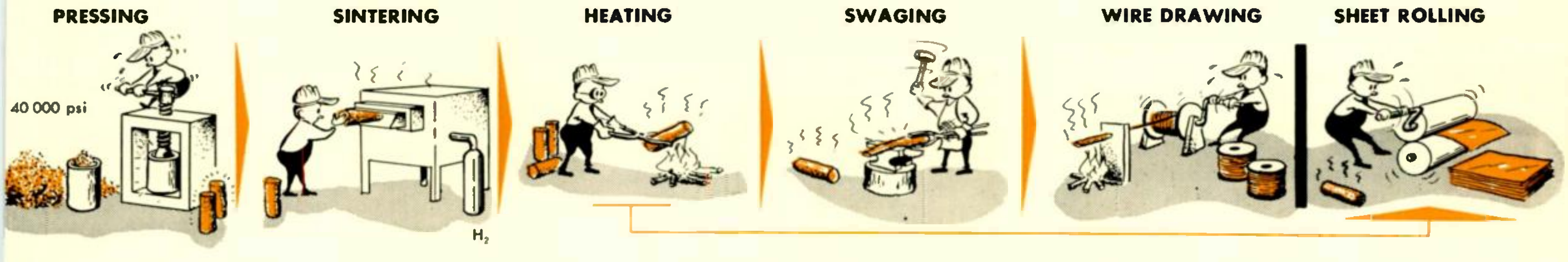
Molybdenum sheet can be clad with metals such as Kovar, Nichrome, Inconel, and nickel, either on one or both sides.

Future of Molybdenum

The greatest future demand for molybdenum may well be in the field of jet engines. Present engines operate near the upper temperature limits for the usual alloys and their output can be increased considerably if the operating temperature can be raised. Molybdenum and molybdenum alloys will permit higher operating temperatures when the oxidation problem is solved.

The development of a satisfactory arc-welding process for molybdenum will lead to its use in the chemical field for piping, tank linings, and reaction vessels, where its resistance to most chemicals will prove valuable. The use of molybdenum in the glass industry should continue to grow in this country and Europe as its advantages become more widely recognized and understood.

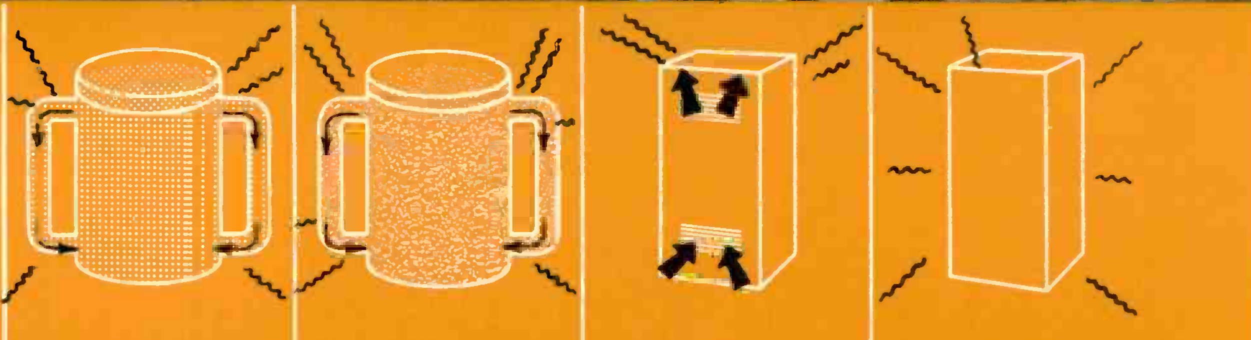
Molybdenum, once considered one of the rare metals, has become quite commonly known. It may well become a widely used metal in the future because of its unusual and desirable properties, which fit into the solution of many problems facing a rapidly advancing technology.



the sintered ingot through a number of dies until it reaches a diameter where it can be drawn. The first few swaging passes are made by heating the ingot in a furnace with a hydrogen atmosphere to 2550-2700 degrees F. The following swaging passes are made after heating in gas-fired furnaces with the temperatures reduced in relationship to the reduction in diameter of the rod. Starting at 0.18 inch diameter, the wire is drawn through dies on a draw bench until it reaches 0.08 inch, from which diameter it is further drawn to finish sizes on specially designed wire-drawing machines. Finish sizes vary, depending on the wire use, but the wire is not generally reduced below 0.002 inch in diameter. Heat is applied in all drawing operations and a heat-resisting graphite lubricant used at all times. At various stages in the swaging and drawing operations, the molybdenum is either recrystallized or stress-relief annealed. The anneal positions are governed by the end use, as they control tensile strength, ductility, and elongation. Carbide dies are used for drawing the larger sizes and diamond dies for the smaller sizes.

The rolling of molybdenum is a process that varies considerably according to the end product desired, such as heavy plate, sheet for spinning, stamping or deep drawing, or round rolled rods. The ingots are passed through a breakdown mill at temperatures of 2200-2500 degrees F after which they go to various size rolling mills for further reduction. As the sheet becomes thinner, the temperature is reduced until the sheet is about 0.03 to 0.04 inch thick, after which the sheet can be rolled to finish size without heat. During the rolling operation the metal also receives recrystallization and stress-relief annealing according to its end-product use. Sheet as thin as 0.001 inch is rolled on four-high mills. Surface oxides are removed by cleaning in molten caustic baths or by heating in hydrogen-atmosphere furnaces. Quality control checks are made for tensile strength, ductility, surface defects, bend strength, and other characteristics.

Industrial



SUMMARY OF TRANSFORMER APPLICATION CHARACTERISTICS	OIL	ASKAREL	VENTILATED DRY TYPE	SEALED DRY TYPE
APPLICATION	Outdoor or Vault	Indoor or Outdoor	Indoor	Indoor or Outdoor
RELATIVE INITIAL COST	100	120	120	144
FIRE HAZARD	Potential	None	Low	None
EXPLOSION HAZARD	Primary and Secondary	Primary Only. Toxic Gas May Result	None	None
USUAL MAINTENANCE	Normal	Above Normal	Below Normal	Almost None
RELATIVE WEIGHT	100	125	75	135

Ventilated dry-type transformer balcony installation in a steel-fabricating building.

Transformers...

THEIR SELECTION AND APPLICATION

V. H. Vogel, *Network and Power Engineering, Transformer Division, Westinghouse Electric Corporation, Sharon, Pennsylvania*

The choice of a transformer for a given industrial application is a matter of weighing many factors against each other and deciding upon the best balance of qualities. Engineering advantages, ambient conditions, maintenance, and first cost are all important factors in this decision.

In general, transformers located as near as possible to the load center offer the most economical means of supplying industrial plants. Preference is also for unitized equipment, consisting of transformers combined with high- and low-voltage switching and protective equipment in a common assembly, because of its lower installation cost and compactness. Therefore, the considerations outlined here apply primarily to transformers for use with unitized equipment and generally to other installations involving ratings of 112½ to 2000 kva or more.

Based on insulating materials and methods of cooling, there are now four basic types of transformers, each more or less suitable for nearly all industrial-plant applications. These are the mineral-oil immersed, the askarel-filled, the ventilated dry-type, and the sealed, nitrogen-filled dry-type. The industrial engineer must determine the type best suited to his particular plant application.

General Application Characteristics

Oil-immersed transformers have been the most widely used since the a-c distribution system was developed. They have the advantages of lowest cost, highest impulse strength, and inherently weatherproof construction. They must be maintained pressure tight to prevent deterioration of the oil and insulation, and a regular program of pressure testing and oil sampling is desirable to obtain the most dependable service. They should not be used indoors unless installed in fire-resistant vaults in line with the existing requirements of the National Electric Code. While a fire or explosion is a remote possibility with modern transformers adequately protected and maintained, nevertheless it is a factor that must be considered for the protection of personnel and adjacent property.

Askarel-filled transformers may be suitable where the National Electric Code does not permit the installation of oil-filled transformers. Their higher first cost is offset by reduced installation costs because fireproof vaults are not necessary. Pressure-relief devices are required on askarel-filled transformers of 25 kva and larger. Indoor installations, except in certain well-ventilated locations, are required to have these devices vented to the outside of the building or to be equipped with suitable gas-absorbing equipment.

Askarel is more sensitive to contamination by atmospheric moisture and other impurities than mineral transformer oil. Equipment normally used for transformer oil reconditioning is not practical for askarel; additional special equipment is usually necessary. Special care and training in handling the liquid and coil structures are required.

An electric arc in askarel produces gases that are toxic but not explosive, so secondary explosions cannot occur. However, these gases can build up pressure in the sealed tank if the arc is continued and cause a primary explosion.

The weight of askarel transformers is greater than the oil-immersed and ventilated dry-type. A given quantity of askarel weighs 73 percent more than an equal quantity of mineral transformer oil.

Ventilated dry-type transformers were developed to fulfill a need for those indoor installations where the use of liquid-immersed transformers creates installation problems. They can be installed without vaults. Dry-type transformers do not have the liquid maintenance and other problems of liquid-immersed transformers. They do require a certain amount of cleaning at intervals depending on the installation. The cost of ventilated dry-type transformers is the same as for askarel transformers. The total weight of this transformer is less than any of the others; this can be an important factor in total installation cost.

The amount of organic material in ventilated dry-type transformers classified as group 2 is not great, so the fire hazard is very low. The explosion risk in any normal installation is completely eliminated. However, under extreme conditions of dust or moisture-laden atmospheres, or a combination of these, the ventilated dry-type transformer may not be applicable.

Ventilated dry-type transformers larger than 500 kva are available with forced-air-cooling equipment to increase the capacity to 133 percent of the self-cooled rating. For liquid-immersed transformers within the kva range under consideration, forced-air-cooling equipment increases the capacity to 115 percent of the self-cooled rating.

Sealed dry-type transformers are completely noninflammable and explosionproof. They can be completely submersible and are not affected by extremes of dust and moisture. Gaskets are eliminated by the use of welded-on handhole covers and bushings with metal-to-metal seals. First cost of sealed dry-type transformers is greater than for the others; however, this is offset by reduced installation costs and practically no maintenance expense.

Location

The selection of a transformer may be determined by the choice of location. If an outdoor location is available near the center of load, this can be most economical in cost of space. The lowest-cost oil-immersed transformers can be used provided there are no applicable code restrictions for fire hazards. Askarel transformers are normally used for outdoor installations where a fire hazard exists.

Frequently no suitable outdoor location exists sufficiently near the center of load; then the choice is narrowed to the askarel or dry types. Indoor overhead installations on platforms between building columns, on balconies, or even in the roof-truss structure have the dual advantages of being most nearly at the center of load and of taking the least valuable space. Movement of materials in production aisles is least hindered by this arrangement.

Dry-type transformers are best suited to these overhead installations. The weight of the ventilated dry-type is much less than the askarel type and this results in more economical supporting structures; also, it is more easily removed.

Maintenance operations become more difficult when transformers are mounted overhead; therefore, the reduced maintenance requirements of the dry types are a definite advantage. Filtering and handling askarel is a greater problem when the transformers are relatively inaccessible.

Sealed dry-type transformers should be considered for overhead installations and frequently are most economical where dirt conditions would require cleaning the ventilated dry-type at shorter than normal intervals.

Installations at floor level are usually more accessible for maintenance operations. Reduced installation and maintenance costs partially offset the additional cost of space occupied as compared to more inaccessible locations.

Dry-type transformers have lower impulse strength than the liquid-immersed variety. They are adapted to the economical installation of low-ratio lightning arresters and, when necessary, these can be installed inside the transformer case.

The worst exposure condition is encountered when transformers are connected to exposed overhead lines by underground cables. Under this condition line-type arresters are normally installed at the line end of the cable. In addition, arresters are frequently necessary at the transformer, regardless of transformer type, for the purpose of restricting the reflected surge to a value below the impulse strength of the particular transformer.

Ventilated dry-type transformers depend on air passing through ducts in their windings for cooling, so consideration must be given to the quality of this air from the standpoint of dirt, possible corrosive fumes, and moisture. Dirt may restrict air circulation, and reduce insulation strength by depositing on insulation creepage surfaces. In general, this need not be considered except when the deposit is of a conducting and sticky nature, when it is combined with moisture, or possibly when the amount is excessive. Moisture due to high humidity is not a problem except during shutdown periods when the transformers are not energized. In highly humid climates where periodic shutdowns are a part of normal operation, heaters in the transformer are advantageous.

Economic Factors

Industrial-transformer selection is largely a matter of economic considerations. Any one of the four types of transformers can generally be used for any specific application. The particular installation requirements of each type will immediately eliminate one or more of them, when all costs are considered. For example, oil-filled transformers cannot usually be considered if fireproof vaults must be built to enclose them. Again, the ventilated dry-type usually is not economical if a special weatherproof structure must be provided for it.

All economic factors must be considered and correctly evaluated. These include first cost and costs of installation, maintenance, losses, depreciation, etc. The amount of space required and the value of that space must also be considered.

Oil-immersed transformers have the lowest first cost; askarel-filled and ventilated dry-type transformers are somewhat more expensive; and sealed nitrogen-filled dry-type transformers presently have the highest first cost.

Transformer installations located at the load center provide least expenditure of copper for low-voltage feeders. This saving of copper may be partially offset by increased cost of floor space and vaults, or premium-priced transformers since these are usually indoor installations. Indoor installations are frequently made on or immediately adjacent to working areas. Under these conditions dry-type transformers are ideal.

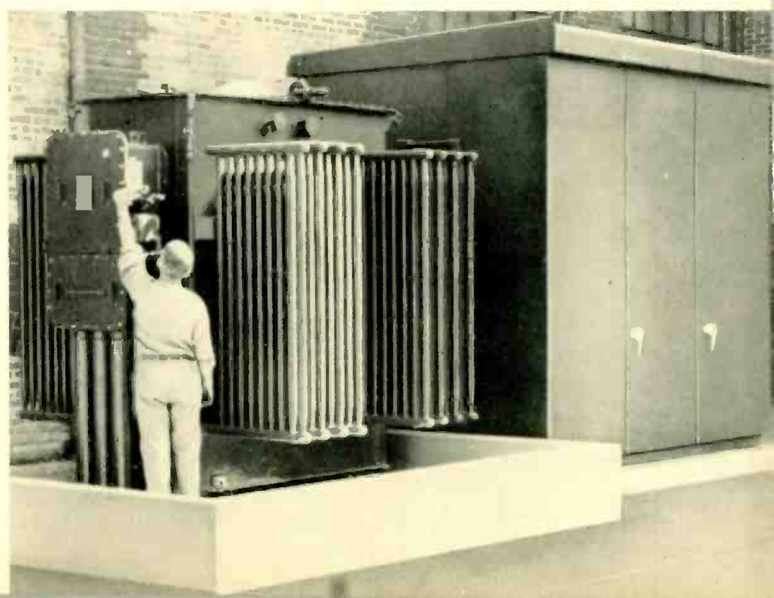
Economy of floor space can frequently be obtained by overhead platform locations along the side of manufacturing aisles or between roof trusses. For these installations the weight of the unit may be of more importance than actual floor space required.

Maintenance costs are lowest for the sealed dry-type transformers, followed by the ventilated dry-type and the liquid-immersed transformers.

Loss and impedance characteristics are essentially the same for all four types of transformers. The basic design of each type is such that the standard impedance and the range of impedances obtainable for special application requirements are also about the same.

Depreciation normally is not a factor affecting the selection if transformers are given normal maintenance as required

An outdoor power center with oil-filled, 2000-kva transformer serving a large southern industry.



by the type of transformer applied and the particular requirements of the installation.

Typical Applications

Each industrial application has its own peculiar combination of problems; however, these can be grouped according to general types of industry. Consider a few categories.

Heavy manufacturing includes steelmaking and steel fabricating industries, which are characterized by concentrated power requirements. Transformers are often subject to extremely dusty conditions, sometimes in higher than standard ambient temperatures. The atmosphere may also be somewhat corrosive.

Ventilated dry-type transformers can be used for most of these applications. Particular attention in regard to the maintenance cleaning schedule is required. If conditions require cleaning too frequently, the usual saving in maintenance cost over the liquid-immersed transformers may not be fully realized in many cases.

Ventilated dry-type transformers are well suited to special ventilation arrangements. In one case where ambient temperature within the building was expected to be high, a forced-air duct system was arranged to bring cooler outside air directly into the bottom of the transformer case. In other cases where the additional heat due to dissipation of transformer losses was objectionable, duct systems connected to the top of the case have removed practically all this heat directly from the transformer.

Light manufacturing includes household appliances, radio and television, photographic supplies and equipment, instruments and meters, some aircraft parts and many other items. Buildings may not be designed for concentrated floor loads. While the unit kva may be rather low, the weight saving of the dry-type transformer can be an advantage in building design. There is no dust problem as far as transformer maintenance is concerned. The dry-type transformer contributes to the cleanliness of the surroundings, since there are no liquid handling problems.

Textile industries are characterized by the problem of lint, which is a potential source of trouble in production areas, especially when combined with moisture. Ventilated dry-type transformers may require more than normal maintenance. Consideration should be given to installation in separate rooms, which is also desirable for air circuit-breaker switchgear with which the transformer is associated. Lint absorbs moisture under humid atmospheric conditions; space heaters may be required in ventilated dry-type transformer cases during periods of shutdown if the units are de-energized. Sealed dry-type transformers should be considered for production areas if lint is excessive. Their premium cost can be justified by reduced maintenance and reduced hazard.

Mining applications frequently require portable units. Recent developments in mining equipment have brought about increased requirements for electrical power in mines. Portable transformer substations are required so that the low-voltage feeder cable lengths can be kept to a minimum as the working face advances. The lighter weight of dry-type transformers is an important advantage in these portable units. If the application requires an explosionproof design, as do most coal-mining operations, the sealed-dry-type transformer serves very well. Ventilated dry-type transformers are well suited to dry non-hazardous applications such as potash mines.

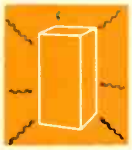
Complete mine power centers combining dry-type transformers with primary and secondary switching and protective equipment are available in low-height designs that meet the space restrictions common to mining operations.

Other applications as widely diverse as chemical plants, paper mills, petroleum refineries, food and drug processing and many others have problems that are similar to, or a combination of those described.

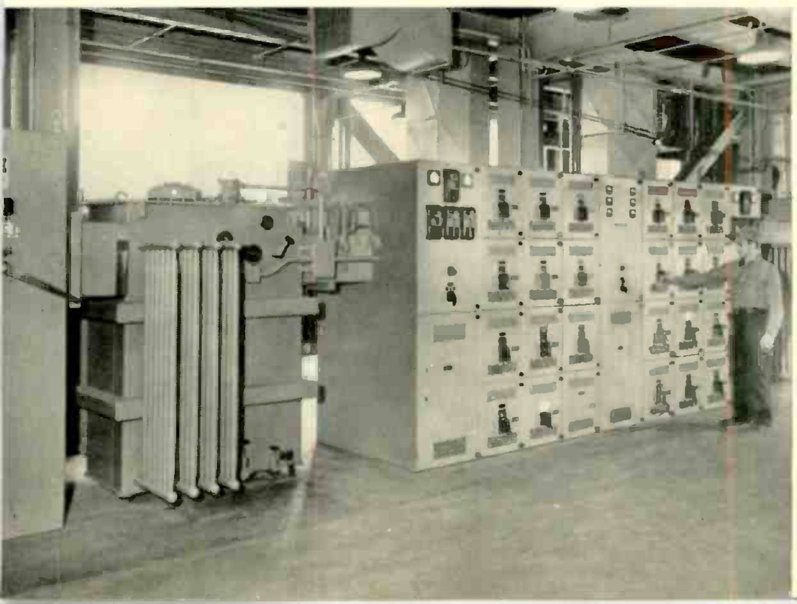
Summary

The transformer-selection problem is essentially safety and economics. First, the most economical location should be selected as near the load center as possible. Then the correct type of transformer should be applied, giving consideration to any peculiar problems.

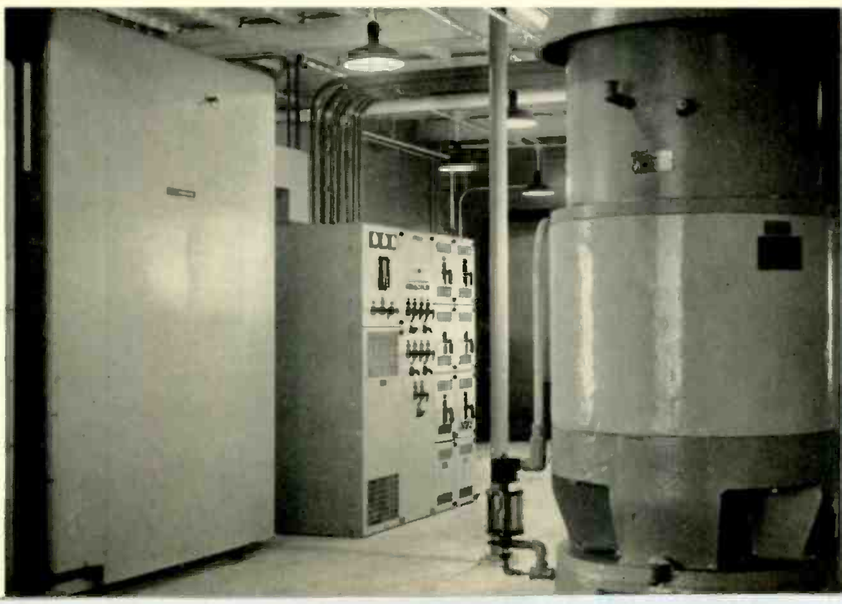
Choice for outdoor installations is usually the oil-immersed transformer, but if a fire hazard exists, the askarel-filled becomes more attractive. For indoor installations the dry types are selected for less maintenance, and are ventilated for the usual installation, or sealed for greatest safety, least maintenance, most extreme conditions of dirt and moisture. Indoor askarel installations can be made where some risk of primary explosion can be tolerated, where there is adequate ventilation, where dirt conditions are extreme, or where probability of partial submersion exists. Askarel provides somewhat lower first cost than sealed dry-type but greater maintenance cost.

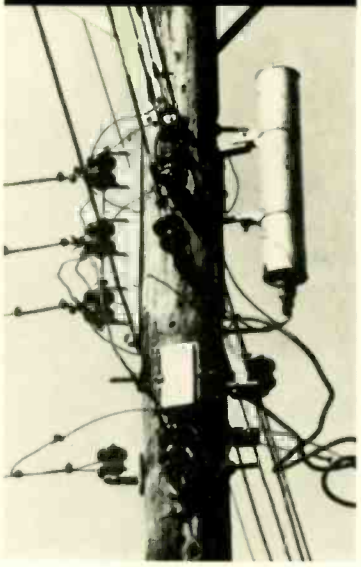


An indoor power center with two askarel transformers. Fireproof vaults are not required for such transformers.

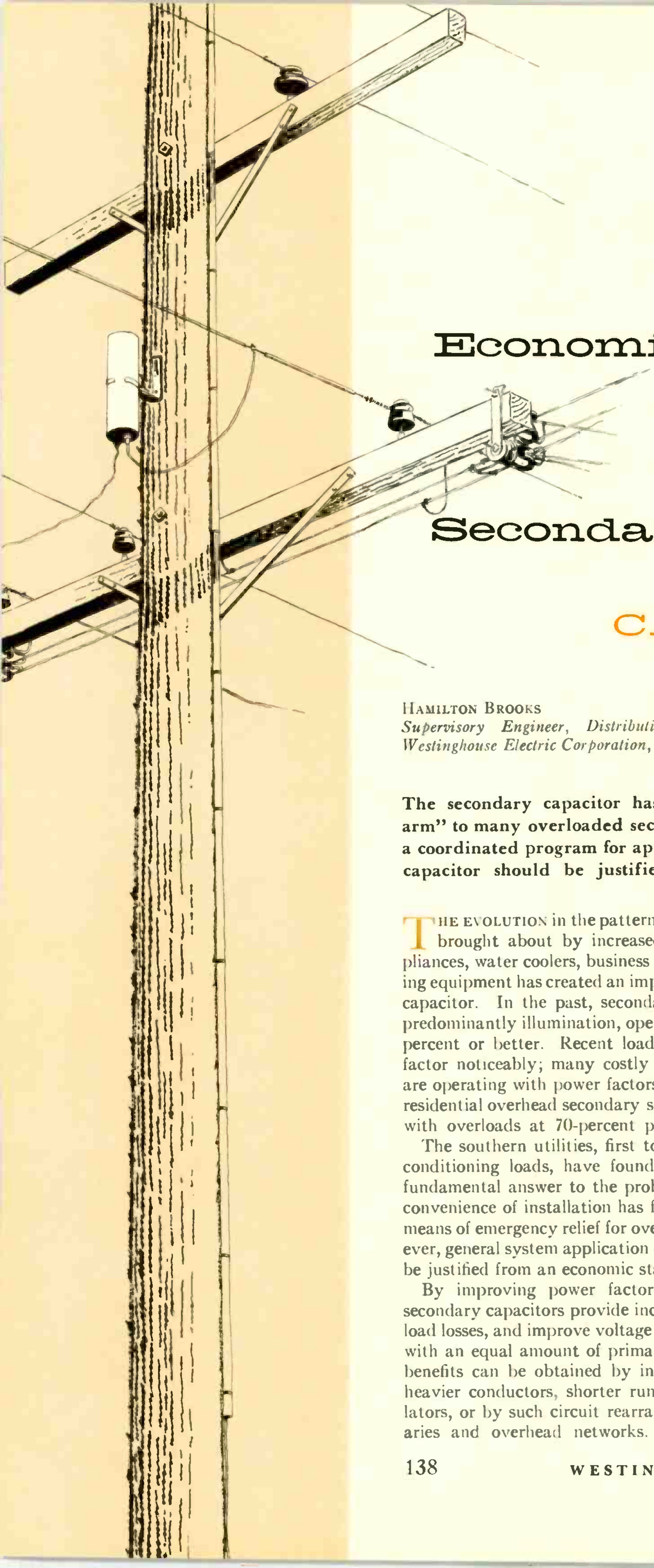


Sealed dry-type transformer installation in a chemical-plant pump-house. Such units are explosionproof.





Typical pole-mounted secondary-capacitor installation.



Economics of Secondary CAPACITORS

Hamilton Brooks
Supervisory Engineer, Distribution Apparatus Engineering, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania

The secondary capacitor has proved a "shot in the arm" to many overloaded secondary systems; however, a coordinated program for application of the secondary capacitor should be justified on economic grounds.

The evolution in the pattern of electric-utility load cycles brought about by increased use of small-motored appliances, water coolers, business machines, and air conditioning equipment has created an important role for the secondary capacitor. In the past, secondary-system loads have been predominantly illumination, operating at power factors of 90 percent or better. Recent load growth has lowered power factor noticeably; many costly secondary network systems are operating with power factors as low as 80 percent, while residential overhead secondary systems must sometimes cope with overloads at 70-percent power factor.

The southern utilities, first to feel the effect of large air-conditioning loads, have found the secondary capacitor a fundamental answer to the problem. Its moderate cost and convenience of installation has frequently led to its use as a means of emergency relief for overloaded transformers. However, general system application of secondary capacitors must be justified from an economic standpoint.

By improving power factor in the secondary circuit, secondary capacitors provide increased load capacity, reduce load losses, and improve voltage level to a degree not possible with an equal amount of primary capacitance. These same benefits can be obtained by installing larger transformers, heavier conductors, shorter runs, voltage boosters or regulators, or by such circuit rearrangements as banked secondaries and overhead networks. Therefore, to be justified

Fig. 1a—Load curves for a residential distribution feeder circuit in 1948.

Fig. 1b—Recent load curves for a residential distribution having a large air-conditioning load.

Fig. 2—The region for fixed capacitors and switched capacitors is based on the annual minimum and maximum reactive kva.

economically, secondary capacitors must provide the benefits at lower cost than other methods. Experience has shown this to be the case if the improvement necessary is within the range obtainable by power-factor correction.

Capacitors have been used on secondary circuits for many years, but in limited quantity, and usually because of some special situation. Generally, these capacitors were adaptations of industrial equipments or were especially designed for a particular installation. While they served their purpose well, the increased demand for secondary-network capacitors and overhead distribution units has resulted in equipment developed specifically for secondary-circuit application. The availability and the installation economies resulting from these new capacitor-unit designs have contributed greatly to their widespread use.

Application of Fixed Capacitors

The load-cycle curves shown in Fig. 1a are typical for circuits feeding residential districts prior to 1948, and show the predominance of lighting load on the annual load factor as well as on the daily load cycle. The peaks occurred in winter, and during that period of the day when the need for lights was greatest. Now this pattern is undergoing a radical change in many sections of the country; the peak-load season has been reversed, so that the mid-winter peak created by lighting demands of early winter evenings has been replaced by a mid-summer peak as a consequence of air conditioning. The load factor has been improved from a standpoint of daily and seasonal demand, but at the expense of power factor.

Overload relief may be obtained by offsetting the decreased power factor with secondary capacitors. However, secondary capacitors are fixed capacitors, there being no economical method yet available for switching them with load changes. Therefore, it is required that they be applied to handle the minimum reactive kilovolt-amperes that flow at light rather than peak load. Actually, this is not a handicap if the installation of fixed-secondary capacitors is coordinated with existing primary capacitors. The primary capacitors can be switched automatically at no great expense and thereby used to take care of the peak-load demands; secondary capacitors are permanently connected and supply kilovars based on the minimum load periods. Fig. 2 shows the minimum and maximum kilovar demands for a typical load, and the proportion of fixed capacitors that can be safely applied.

In order to evaluate the benefits of secondary capacitors, it is necessary to consider the results obtained and their relative importance. The useful results are threefold: (1) Release of thermal capacity for peak loads; (2) reduction of load losses; (3) improvement of the customers voltage.

The relative value of these benefits will vary with the individual power system. For example, released thermal capacity is of no consequence where system capacity is already adequate, but is of primary importance when overloads have matured or are anticipated. While reduction of load losses always has some value, it is never a predominating factor. Voltage improvement may sometimes be of great importance; at other times may be altogether discounted because of the difficulty of attaching a value to it.

Economic Analysis of Secondary Capacitors

The economic worth of secondary capacitors as compared to their cost may vary widely with individual system condi-

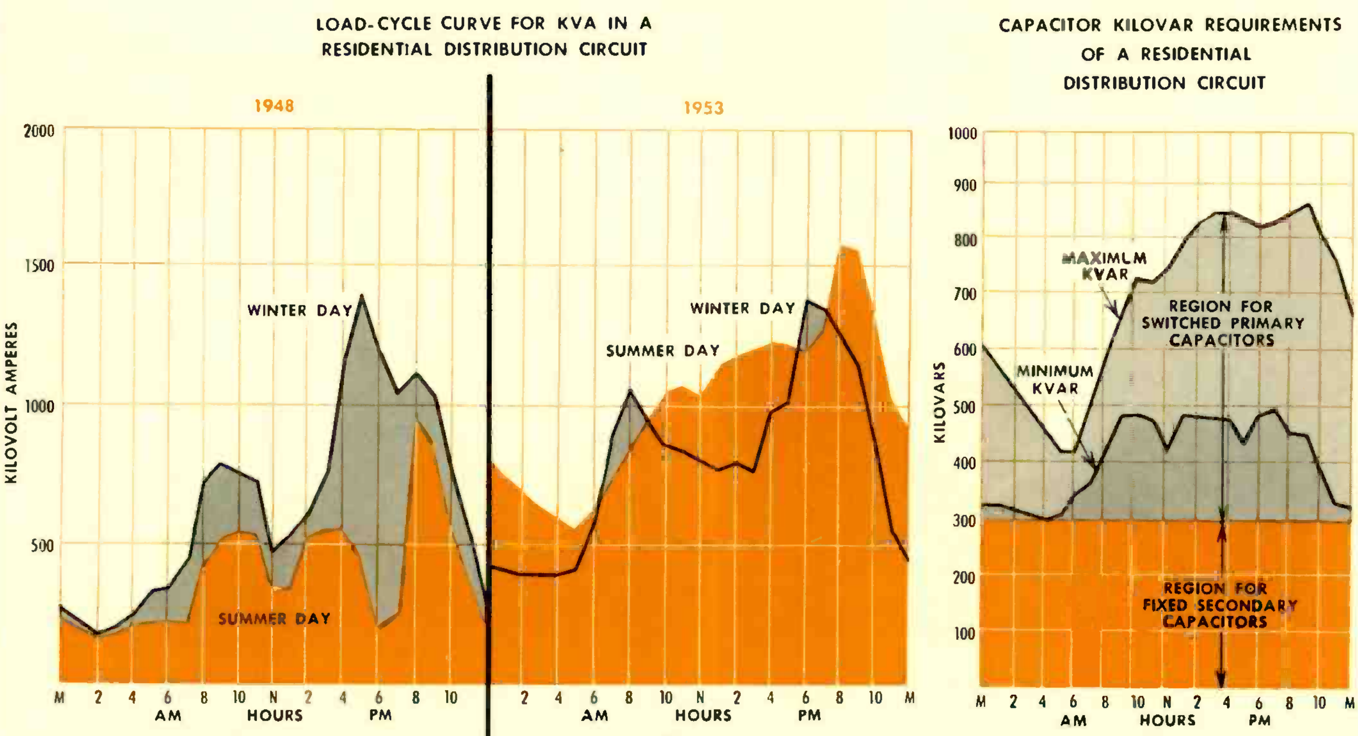


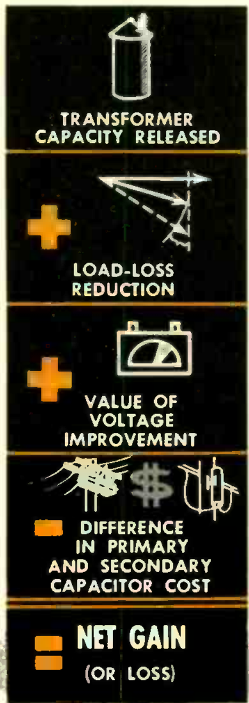
Fig. 1a

Fig. 1b

Fig. 2

tions. This applies particularly to capacitors on overhead secondary circuits, where the economic value of capacitors is admittedly more marginal than for underground networks. Although the overhead secondary-capacitor cost is much lower than that of equipment suitable for underground vaults, the potential savings are smaller because the overhead system represents a smaller investment. Therefore, in an economic analysis of overhead secondary capacitors, it is necessary to give due consideration to each of the potential benefits. The customary plan of analysis may be simply outlined algebraically, taking into account the difference between secondary and primary capacitor cost, value of transformer capacity released, value of load-loss reduction, and value of voltage improvement. The solution giving the net gain (or loss) from the application of secondary capacitors to the system is shown by the equation on the right.

It will be noted that the result is based on the difference between the cost of secondary and primary capacitors rather than the cost of secondary capacitors alone. This stems from the fact that primary capacitors must be economically justifiable in order to warrant the consideration of secondary installations. The secondary capacitor produces the same benefits for the system as an equal amount of fixed primary capacitor kvar, and in addition relieves the secondary circuit and distribution transformer of reactive power due to low power factor. However, since secondary capacitor kvar is about twice as costly as primary kvar, the additional cost of the secondary capacitor need only be balanced against the additional benefits they provide. The many studies that have led to the present broad use of primary capacitors in modern practice permits this short cut.



Released Transformer Capacity—The value of the released transformer capacity is easily calculated, using appropriate installation costs and overhead charges. This should be on a capitalized basis to permit the addition of the other benefits that may be less tangible. The load increase made possible at various load power factors as a result of capacitor installation is shown in Fig. 3. When peak loads are being considered, which is almost always the case, the value used for transformer rating should be the permissible overload rating that has been adopted. Thus, with an allowed overload of 25 percent, a 15-kva transformer would have a peak-load rating of 18.75 kva. Six kvar of secondary capacity, commonly used with a 15-kva transformer, would yield a 16-percent gain in allowed load for an 80-percent power factor.

Load-Loss Reduction—Load-loss calculations are simple, although a rigorous calculation of line losses is tedious because of the distribution of the line current along the secondary as taps are taken off. It is sufficient to determine the loss reduction for the transformer and then add about ⅔ as much for the line. It is often questioned whether credit can be taken for loss reduction and increased capacity at the same time. Consider, however, that for equal loads, the combination of transformer and capacitor is more efficient than a sufficiently larger transformer alone, simply because the capacitor reduces the amount of current that has to flow through the transformer and the affected line. On an efficiency basis, it can be seen that the loss saving is real.

Voltage Improvement—While an economic evaluation of voltage improvement presents difficulties, there is much to substantiate the possibility of a tangible return. For example, a 180-kvar capacitor was connected near the end

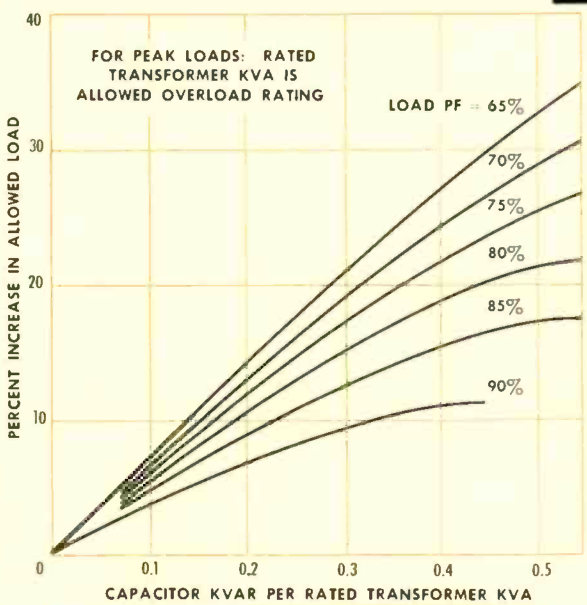


Fig. 3—These curves show the increased load capacity obtained by adding capacitors to transformer secondary.

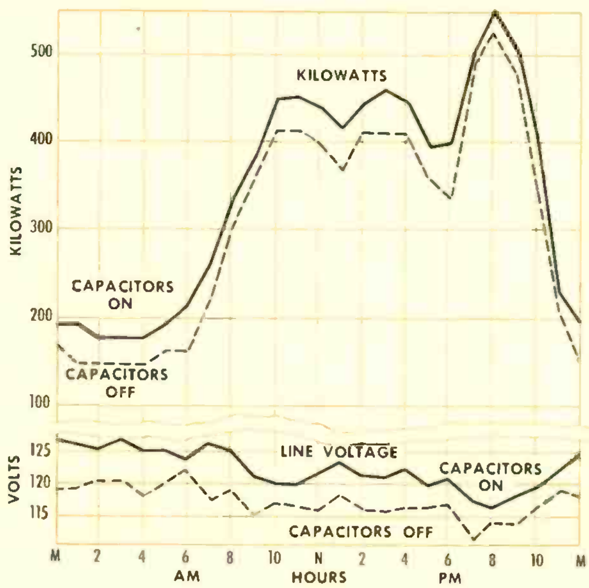


Fig. 4—Load curves show the increased use of power as a result of voltage improvement with secondary capacitors.

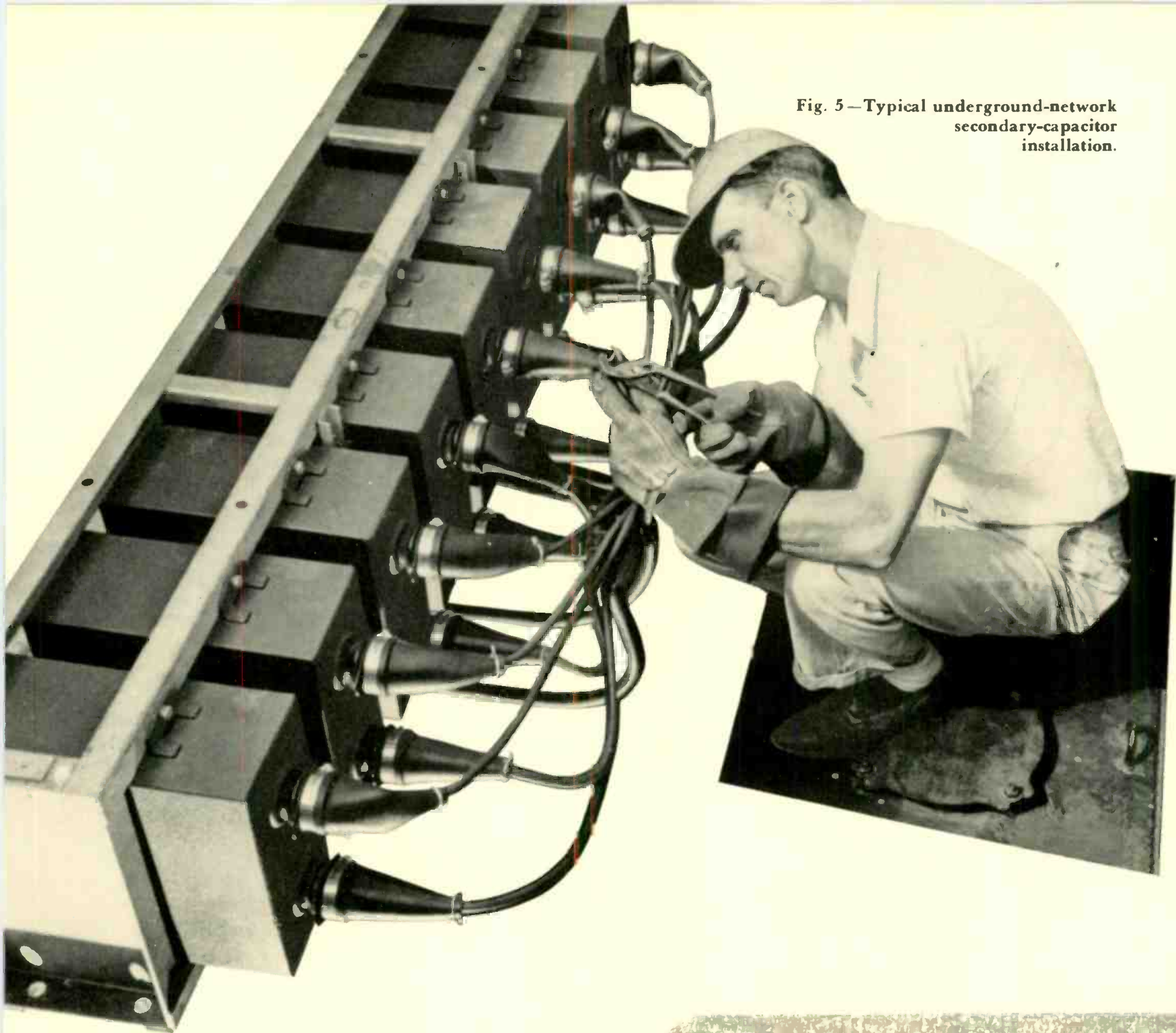


Fig. 5—Typical underground-network secondary-capacitor installation.

of a heavily loaded feeder and the capacitor switched on and off at half-hour intervals over a 24-hour period. The wattmeter readings clearly show the increased return secured by holding voltage to a more satisfactory level, Fig. 4. Although the result is somewhat exaggerated over a more typical condition because of the abnormally poor voltage at peak load, it serves to emphasize the potential benefits when voltage drop is a factor. There are various methods for estimating the increased revenue obtained by better voltage. A simple one is to estimate the proportion of load accounted for by heating and lighting; this part will increase about as the square of the voltage improvement. Taken over a year's duration, the annual increase in revenue may be substantial.

Secondary-Capacitor Application

As experience has been gained in the application of secondary capacitors, certain rules have been established for simplifying the engineering required. Capacitors on overhead secondaries in particular must be applied according to some workable rule, since individual consideration cannot be given to each small installation. Once the economic justification has been proven, or the necessity established because of unexpected load growth, capacitors can be applied according to plan. For overhead distribution, a rule that has been widely used calls for capacitor kilovars operating to approximately

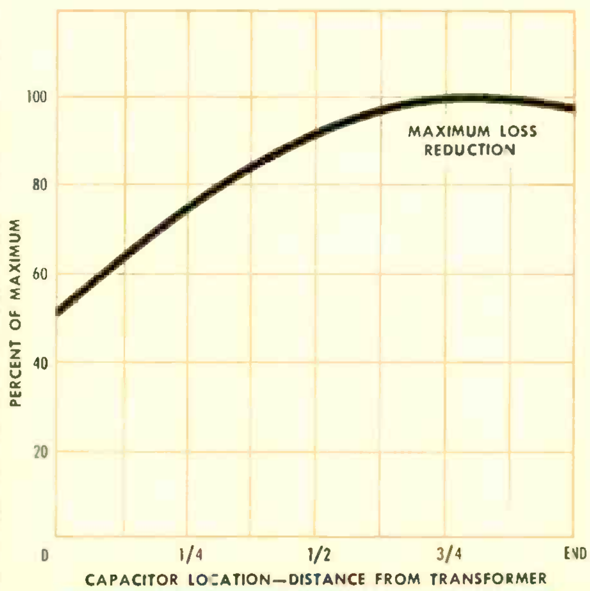


Fig. 6—Benefit in reduced losses is obtained when secondary capacitors are located out on the secondary line.

40 percent of the nominal transformer rating. Capacity up to this amount has not proved troublesome at light-load periods even though power factor may be somewhat leading.

As to location, the best results are obtained when the capacitors are out on the line away from the transformer. For this reason the installation is preferably made in pairs, with a capacitor located in each direction from the transformer. The most effective point for secondary line-loss reduction will be from $\frac{2}{3}$ to $\frac{3}{4}$ the distance to the end of the line. Fig. 6 shows how the loss reduction varies, and it can be seen that anywhere from half the distance to the end gives good results. This assumes, of course, a reasonably uniform load distribution among customers. Much the same thing can be said for the effect on voltage improvement, although the end of the line produces the maximum benefit in this respect.

Network capacitor applications demand more consideration of the possible consequences of overcorrection at light loads than do the small installations on overhead systems. Here again, the extra benefits that might be derived by a higher degree of power-factor correction have not usually warranted the extra cost and complications of automatic switching. Therefore, network capacitors are permanently connected to the system. It has been found that capacitor kilovars sufficient to correct the peak-load power factor to 90 percent cause no trouble at light load. With network loads of 80-percent power factor, correction to 90 percent releases usable equipment capacity amounting to 12 or 13 percent.

If the network capacitor is considered a part of the network unit, capacitor size can be related to the network transformer rating as shown in table below. The gain in usable capacity with 80-percent power-factor loads, together with the moderate size and cost of the necessary capacitor equipment, make network capacitors attractive.

Secondary-Capacitor Equipment

New capacitor equipment for secondary systems has been designed for the service conditions encountered in these applications. The pole-mounting units for overhead circuits are especially suited to outdoor, pole-mounted installation. Extruded-aluminum tubular cases not only conserve space on the pole but are also light in weight and easy to install. Convenience of installation is especially important, since the economy of secondary capacitors can be completely offset by excessive installation costs.

Space in underground vaults is always at a premium. One of the most important requirements of underground network capacitors is small size and mounting flexibility. The new underground network capacitors have been designed with this in mind. Equipments of 40, 80, and 120 kvar use the space-saving $13\frac{1}{3}$-kvar, 216-volt capacitor unit, shown in Fig. 5. These equipments are floor- or wall-mounting to take advantage of available space. However, in case the required space for these equipments cannot be found in a vault, the units may be individually located in such odd corners as do exist, and at no premium except for a small amount of extra work in installation. Submersibility is attained by neoprene terminal sleeves and neoprene-jacketed cable connections, with a hermetically sealed capacitor unit. Capacitor cases are given corrosion resistance by a heavy coat of sprayed-on zinc, and further protected by painting.

Reliability and fault protection are secured by current-limiting fuses, mounted on the capacitor terminals and enclosed by the neoprene insulating sleeve. The current-limiting fuse provides fault protection almost independent of the available fault current.

Conclusions

The usefulness of low-voltage capacitors on secondary distribution systems is a relatively recent development brought on by the changing wants of the domestic power consumer. Application engineering can be reduced to simple considerations based on tested rules. The economic value of secondary capacitors is being established by thorough study on the part of many electric-utility companies, and the increasing need for this type of equipment on present-day systems is now recognized. The high value of the secondary capacitor as purely an emergency device to relieve overloaded circuits is of no small importance. However, the fundamental benefits revealed by careful economic analysis have made the secondary capacitor a very profitable investment for many utilities. Moreover, when the application has been dictated by emergency demands, the benefits from improved efficiency and equipment utilization remain even after system expansion removes the emergency.

INCREASED LOAD CAPACITY OBTAINED WITH CAPACITORS (65% USABLE TRANSFORMER KVA)

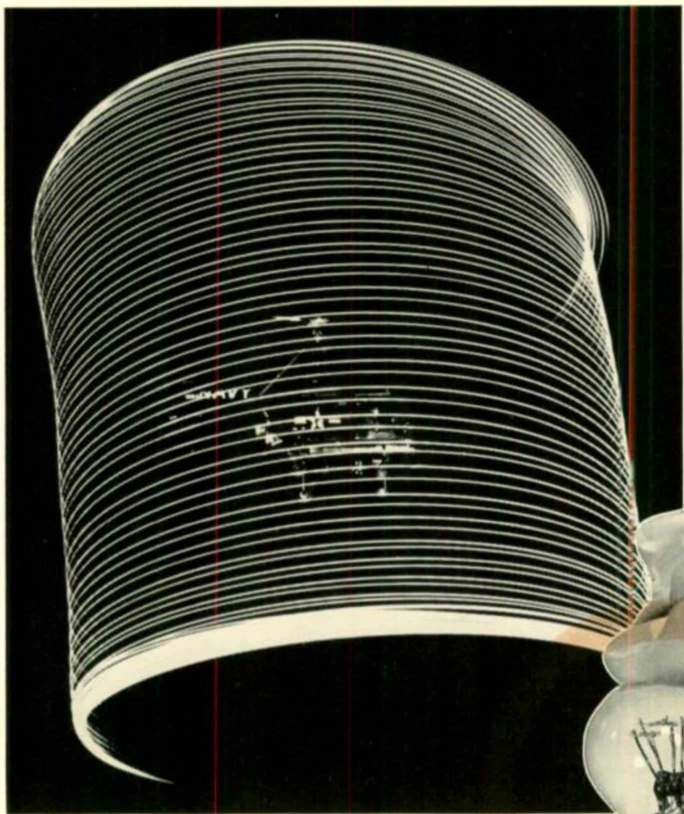
TRANSFORMER RATING KVA	CAPACITOR RATING KVAR	KILOWATTS OF USABLE CAPACITY			
		WITHOUT CAPACITOR		WITH CAPACITOR	
		90% PF	80% PF	80% PF	% GAIN
300	40	176	156	173	10.9
500	80	293	260	293	12.8
750	120	439	390	440	12.8
1000	160	585	520	587	12.8

what's NEW!

Helicopter Lamp Withstands 1000 G's

A NEW AIRCRAFT LAMP that can withstand centrifugal forces up to 1000 times the force of gravity has been developed primarily for installation in helicopter blade tips.

Helicopters have unusual maneuvering characteristics and therefore require special identifying lights to distinguish them from other types of aircraft. Biggest problem in the development was in making a lamp with a reasonable life-span at the high centrifugal forces existing at the blade tip. These forces can exceed 700 "g" on present helicopters, and reach 1000 "g" under certain speed conditions. The lamp developed will withstand 1000 "g," each part of the lamp being subjected to a force 1000 times its normal weight.



A gay-bladed helicopter, its rotor tips lit up, traces an unusual pattern of arcs in this time exposure. Photographer "froze" helicopter with flash midway in its climb.

Designed primarily for installation in helicopter blade tips, this ruggedly-constructed lamp can withstand centrifugal forces 1000 times the force of gravity. In helicopter application, the lamp axis coincides with the longitudinal axis of the blade.

Exhaustive tests were made on a series of gradually improved designs, until the final result was a lamp with closely spaced, rigidly supported filament wires. Actually, in order to provide the light intensity required, the lamp has two tightly coiled filaments in series. The lamp itself produces about 35 candlepower, and reflectors in the blade tips increase the effective light output approximately nine times.

A clear plastic housing in the blade tip encloses the lamp. and is designed to follow the blade contour as closely as possible so as not to affect the aerodynamic blade design. The lamp operates at 12 volts, and is supplied power from the helicopter's 28-volt electrical system through resistance cable inside the blade. A system of silver slip rings and brushes at the blade hub transfers electrical power from the fuselage to the blades.

Experimental work has been done in automatically switching on and off green and red lights in the blade tips so they create a green half-circle on the right side of the helicopter and a red arc on the left side. This color system makes any change in the plane's flight path readily discernible to pilots of other helicopters in formation, or to other approaching aircraft. Since a helicopter can back up or fly sideways, it is vital to air safety that its movements be correctly interpreted.

Helicopters equipped with blade-tip lights are easily identified as far away as five miles, even against a background of city lights. Helicopters that use lights on the blades will continue to have green and red lights on the fuselage to identify the right and left sides of the plane.

The new lamp is a joint development of The Kaman Aircraft Corporation and Westinghouse. The Kaman Aircraft Corporation, helicopter manufacturer of Bloomfield, Conn., has been working with the U.S. Navy Bureau of Aeronautics in developing a distinctive lighting system that will not only enable other aircraft to recognize helicopters in night flight, but will also make possible helicopter night-formation flying.

Mount Palomar's 'Horseshoe'

PLASTIC MODELS of huge movable parts of powerful generators and bearings are the subject of concentrated study at the Westinghouse Research Laboratories. Among the demonstration models is a replica (p144) of one of the principal bearings that support the mammoth 200-inch telescope atop Mt. Palomar, near Pasadena, Calif. A research engineer is moving the 'horseshoe' with ease as oil is forced into the pads—or receptacles—from the reservoir beneath them. Without the oil, friction between the two surfaces, both on the model and on the telescope, would cause the bearing to stick firmly. Engineers designed the flotation method so that with a film of oil three-thousandths of an inch thick the

huge 500-ton telescope could be moved with a ½-horsepower motor. This oil-flotation process is the same as is sometimes used in construction of waterwheel generators.

Computers Cut Transformer Design Time

COMPLETE DESIGNS for power transformers can now be produced by computers in a matter of minutes, producing a speed advantage of more than 100-to-1 over previous design methods. Using IBM-701 computers, engineers have successfully programmed the design of power transformers in ratings from 500 to 10 000 kva. The series of designs made by the machine were verified against existing designs, and the machine always produced a better-balanced design.

The desired characteristics of the design are loaded into the machine, and in five minutes or less the complete electrical design and much of the mechanical design are printed out in detail, ready to be transmitted to the shop for manufacture of the core and coils. Input data includes such specific values as impedance, limiting values of iron loss, total loss, exciting current, sound level, and temperature rise. The computer then designs the transformer, making necessary adjustments of physical quantities and proportions of iron, copper, and insulation to converge the design within acceptable limits of the guarantees. During the design of the core and coils, the computer calculates surge strength and designs to withstand standard impulses.

After the proportions of the core and coils are established, the computer calculates tank dimensions and the tank cooling required to meet the temperature-rise guarantee. In addition, it calculates the amount of cooling required on each panel of the tank and the number of cooling fans required on each panel, if the unit has a forced-air rating.

This development is significant to users of power transformers in many ways. Consistency of designs will result, and design quality is assured since more refined control of design limits within the program is maintained, and human errors are minimized. Better transformer designs will evolve because it will be possible to study the effect on many different transformer designs by varying one or more design parameters at a time.

New Microwave Loop System

A NEW UNIQUE MICROWAVE SYSTEM developed by electronics engineers will provide a high degree of reliability in a microwave-radio system without using conventional standby-radio equipment. The new system will provide protective relaying and supervisory control for the City of Austin, Texas.

The 2000-mc microwave system (Type FR-FJ) will provide twenty channels among ten stations. The stations are arranged in a circular pattern; one of the stations normally acts as two terminals so that the system from this point looks like a complete loop. If a break in continuity should occur anywhere around the circle, the stations on either side of the break will automatically switch to terminal operation, and the original terminal station switches to repeater operation. As a result, the system still represents a continuous loop, separated at the point of system breakdown. Consequently, each station can be served in two directions, giving automatic path diversity to the system.

Elevators That Talk

TO BRING THE POWER OF SPEECH to the electronic brains in charge of operatorless elevators, engineers have developed a "voice" to communicate recorded messages to elevator passengers. This voice is intended to bring information and assurance to passengers who are not familiar with the elevator system or the building that it serves.

A demonstration of the new equipment in New York recently showed how messages stored on a magnetic tape in a remote location are reproduced by loudspeakers concealed within the walls of the elevator car.

As passengers enter, the recorded voice announces "This car up" or "This car down." Later, if the first passenger to enter has neglected to select his floor by pressing a floor button, the voice admonishes him to "Press your floor button, please." Should a passenger attempt to delay the car by restraining the doors, the recorded voice again intervenes to speed service by courteously requesting, "Release the door, please." The voice is so completely in touch with traffic conditions that it may request, "Step to the back of the car, please," if passengers are crowding near the doors.

When used with operatorless elevator systems in department stores, a special adaptation of the communication system will announce the floor number of the next stop and then summarize the merchandise to be found on that floor.

The system demonstrated includes magnetic-tape reproduction equipment installed in the elevator machine room, loudspeakers in each car, and interconnecting cables. The system is fully automatic and, without supervision, is capable of reproducing whatever message is called for by traffic conditions.

personality profiles

• *H. Brooks* • *J. R. Spencer* • *V. H. Youel* • *William M. Fraser and R. R. Freeman* •

• Present-day arguments for a more rounded education for engineers would probably receive a nod of approval from *H. Brooks.* Brooks graduated from Marshall College in 1925 with a liberal arts degree, and followed this up with an electrical engineering degree from the University of Pittsburgh two years later. When questioned about this apparently devious route into the engineering profession, Brooks laughed and replied, "Marshall College was in my home town (Huntington, West Virginia) and in those days, $18 a semester took care of just about everything including the registration fee and an athletic ticket." As it turned out, he obtained an excellent base for an engineering degree, including mathematics, chemistry, and physics, along with the other beneficial liberal arts subjects that many engineers must often forego.

Although writing of capacitors in the ENGINEER is a new experience for Brooks, the subject matter is one with which he is well acquainted. Of his 28 years with Westinghouse, 26 have been spent in capacitor engineering. Brooks came with the Company on the Graduate Student Training Course in 1927, and went into d-c motor design. From there, he went to capacitor design and has been there since. His success in this phase of engineering was highlighted a couple of years ago when he won the Switchgear Division's Most Valuable Patent Award, certainly an "Oscar" for a design engineer.

Brook's special interest is statistical methods, which is now almost as much a hobby as a job. He frequently spends his spare time at home studying statistics, which he then applies in the design of capacitors.

He belongs to the AIEE, the Institute of Mathematical Statistics, Pennsylvania Society of Professional Engineers, and is a registered professional engineer in Pennsylvania.

• *J. R. Spencer*, who writes on condenser design in this issue, came with Westinghouse on the Graduate Student Course from the University of Alabama in 1947. A mechanical engineer, he was interested in the mechanical aspects of power generation, and went to work with the condenser and heat exchanger section of the Steam Division in South Philadelphia.

Spencer often accompanies equipment that he has designed to the field to check its operating performance, in conjunction with turbine performance tests. Notable among these were the large condensers for the 100 000-kw turbogenerator for Niagara Mohawk, and the 200 000-kw installation for TVA.

A woodworking enthusiast, Spencer spends a good deal of time in his home shop. This ability recently came in handy when he built a couple of condenser models to study some of the structural problems. These models helped him evaluate design and manufacturing problems brought about by space limitations and arrangement requirements.

His spare-time activities extend into the sports field. He is a member of softball, bowling, and golf teams.

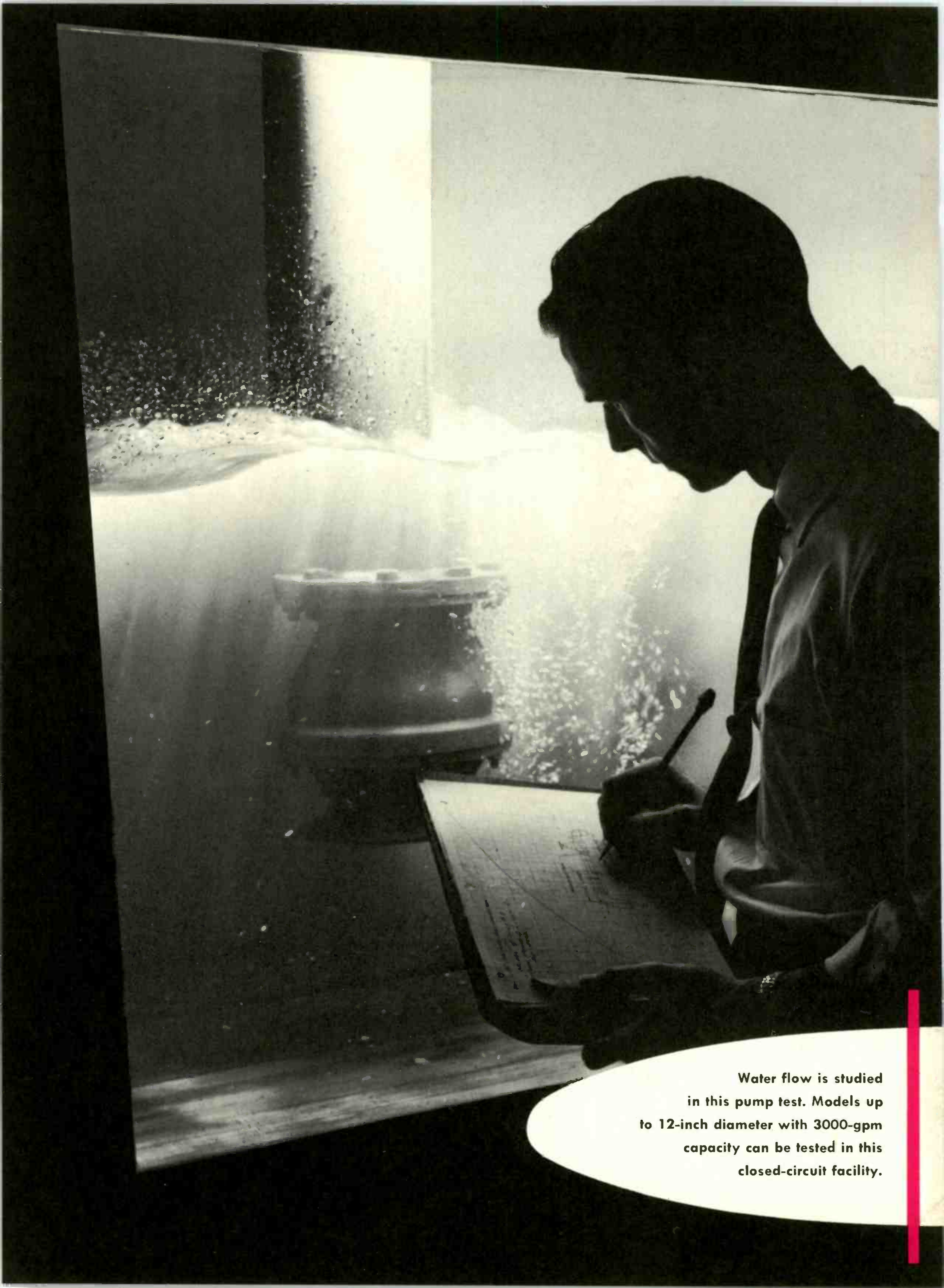
• *V. H. Youel* has a long-standing acquaintance with the subject of his article in this issue, industrial transformers. He struck up the acquaintance in 1929, when he joined the Westinghouse transformer test department shortly after graduation from South Dakota School of Mines and Technology with a B.S. degree in electrical engineering. As a member of the network and power division of the transformer engineering department, he has devoted his time largely to the design and application of unit substations and power centers. This includes those with liquid-immersed and dry-type transformers and unit substations with load tap-changing equipment. He has also been active in the engineering coordination of multi-circuit unit substations and the development of mine power centers.

• Molybdenum and tungsten are tough to produce in pure metal form. But both of our coauthors on moly in this issue, *William M. Fraser* and *R. R. Freeman*, mastered the two metals and learned their peculiarities in their metallurgical work at the Lamp Division.

Freeman has worked with both metals almost since the time he joined Westinghouse in 1939. A graduate of Kansas State College in 1938 with a B.S. in Chemical Engineering, he went on to obtain his M.S. degree at Carnegie Institute of Technology in 1939. Shortly afterward he entered the Westinghouse Graduate Student Course and on completion joined the Lamp Division at Bloomfield, N. J. His first job threw him in close contact with both tungsten and moly. As a quality engineer in the wire-products group, he was responsible for the quality of ingots produced from ore. In 1943 he transferred to the chemical and metallurgical engineering department, where he did development work on new molybdenum products and alloys. Since 1946 he has been largely concerned with the development of new products of moly and tungsten, and finding new uses for the two metals.

Fraser studied chemical engineering at Columbia University and metallurgy at Stevens Institute of Technology. After several years in the chemical and metal pigment industries, he joined Westinghouse in 1941, to do development work on chemical products. He soon found himself supervising the construction of the metals pilot plant, of which he served as supervisor until 1946. Since that time he has been a metallurgist in the chemical and metallurgical section, doing development work on rare metals as well as tungsten and molybdenum.

Freeman and Fraser frequently cooperate on application and development problems and quite naturally teamed up to write the molybdenum article in this issue.



Water flow is studied in this pump test. Models up to 12-inch diameter with 3000-gpm capacity can be tested in this closed-circuit facility.