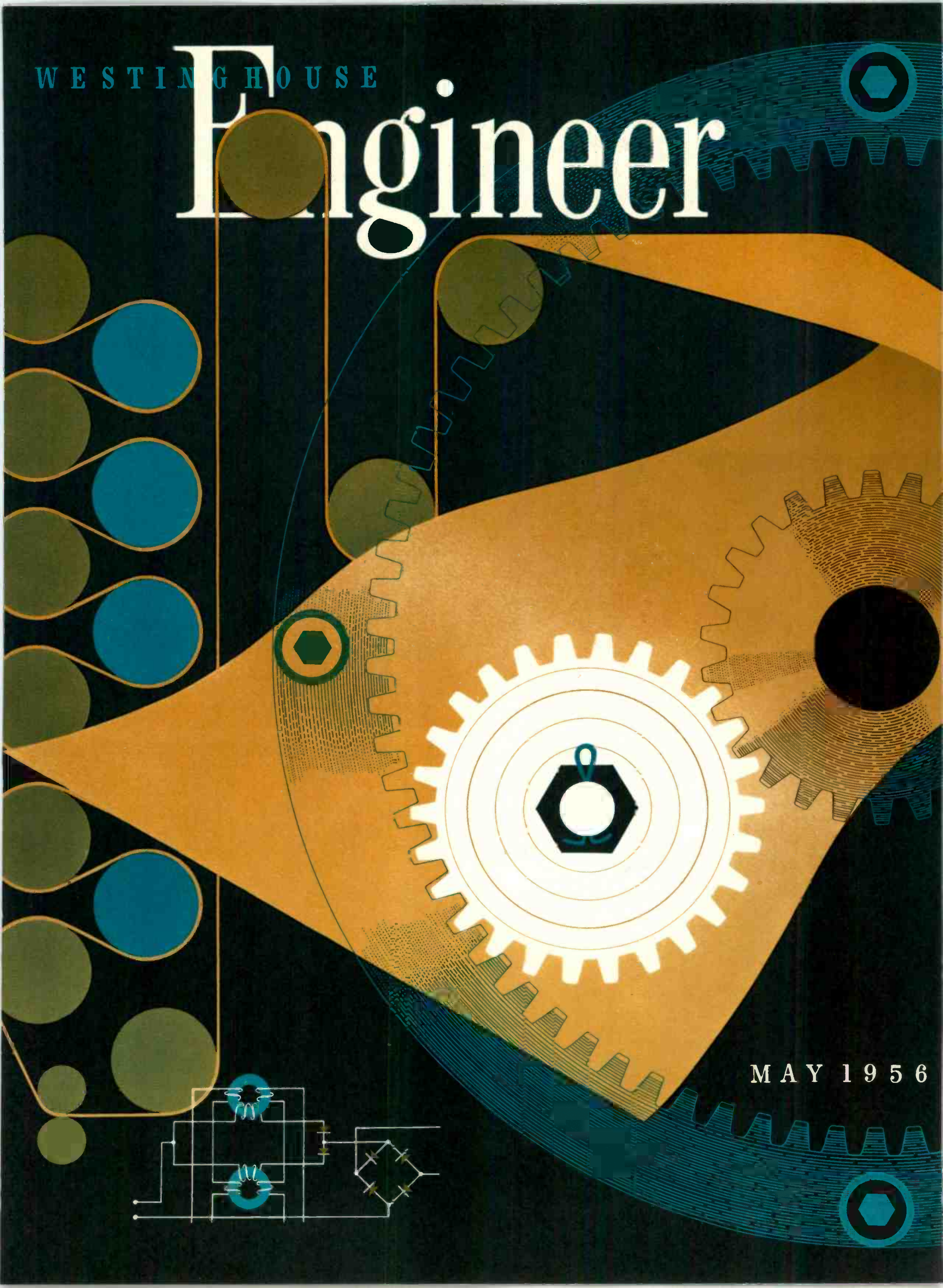
WESTINGHOUSE

Engineer



MAY 1956

Manpower for Atomic Power

The accelerating growth of the atomic-power field is almost daily increasing the demand for nuclear engineers. Huge newspaper and magazine advertisements and intensive recruitment campaigns bear witness to the urgency of the requirement for technical manpower in this new field. Perhaps some debatable questions are: Just what is "nuclear engineering"? Are the skills and background needed in this new field vastly different than those needed in more established fields? Just how is technical manpower used in the atomic-energy field? How sizable are the needs? . . .

• • • One obvious fact is that it is too early in the game to tell what the exact needs will be a decade or more hence. However, the experience in this field so far does tend to clarify present requirements. The dollar cost of research and development, for example, while it does not give a direct answer, does provide a rough idea of where the most knotty technical problems have been encountered. An informal survey of the experience of several atomic-power development laboratories shows that research and development costs for the past few years break down this way: The largest amount of money went into metallurgy and metallurgical engineering —some 37 percent. The next largest portion went to mechanical engineering, about 28 percent. Roughly 11 percent went into experimental and theoretical physics, and the same percentage into electrical and electronic engineering. A total of about 7 percent has gone into chemistry and chemical engineering, and about 6 percent into operational engineering and testing.

This distribution of funds does not necessarily identify the kinds of technical personnel involved. A better gauge for this is the approximate distribution of bachelor's degrees among scientists and engineers working in atomic power at Westinghouse. When an informal survey was made some months ago, mechanical engineers constituted some 25 percent, electrical about 22 percent. About 15 percent were physicists. Almost as many, 14 percent, held degrees in chemistry and chemical engineering, with metallurgy degrees comprising 10 percent, mathematicians 4 percent, and the rest miscellaneous. These figures do not necessarily represent the most desirable distribution, but rather actual conditions. A higher percentage of some specialties would be desirable, if such people were available. Of this group physicists account for nearly half of the doctor's degrees; and only about 10 percent of the total number of scientists and engineers have earned doctor's degrees.

This tabulation is one means of helping to size up the nuclear engineer; another is to ask the man himself. Does he feel that his principal activities are in one of the established scientific and engineering fields, or does he consider himself a part of a new category, i.e., a nuclear engineer? An informal survey at Westinghouse revealed the somewhat surprising fact that only two or three men considered themselves primarily nuclear engineers. The rest designated one of the established fields as the best "label" for their activities. Some 36 percent specified mechanical engineering; 12 percent chemistry and chemical engineering; 10 percent metallurgy; 7 percent mathematics; and the rest other technical specialties.

Clearly, then, although nuclear power is a new concept and a new field of development, most of the effort is in established technical fields. Importantly, however, within those fields there is often a sharp departure from the usual and conventional. A metallurgist for example, is faced with the brand new problem of radiation as it affects materials. Similarly an electrical engineer encounters the problem of controlling a power source unlike any other in his experience. The net result is that although he may be well trained in metallurgy or electrical engineering, an engineer needs further training in the specifics of nuclear power before he truly becomes a "nuclear engineer". This fact, plus the urgency with which trained people are needed, has resulted in intensive training programs by government and industrial organizations to produce the people necessary for the various programs in progress. Westinghouse, for example, administers a program for all new engineers and scientists; in addition, special provisions are made to enable technical people to pursue advanced study at colleges and universities.

In terms of one specific project to develop, design, and build a reactor that is novel and must be completed within a tight schedule, one estimate places the requirements for engineers and scientists like this: materials group, 70; reactor design, 30; physics, 30; power-plant group, 70, for a total of 200. This, of course is a rough estimate, and many factors could influence the figures. Significantly, these figures are only for the organization that has overall responsibility and that performs the systems work, nuclear work, and other technical work that cannot be subcontracted. It ignores the hundreds of engineers involved in supplier organizations.

Aligned against these needs are other estimates that, to date, some 500 engineers and scientists have received formal training in the atomic-energy field, and something over 4000 brought in through the process of retraining on the job. The requirements obviously far outnumber the availability. The atomic-power industry could—today—use at least three to four times as many engineers and scientists as are actually engaged in this work.

The shortage of technical manpower is, of course, not unique to the atomic-power field. Nor can the blame be laid at any one doorstep. Nevertheless, it is a further page to the long list of reasons why our engineering and scientific shortage must be filled. The fact that the prime obstacle to the advancement of atomic power is the shortage of trained people should certainly serve as convincing evidence that we cannot let the shortage continue. We cannot afford anything less than an all-out effort to correct the causes. —RWD

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VOLUME SIXTEEN • NUMBER THREE • MAY, 1956

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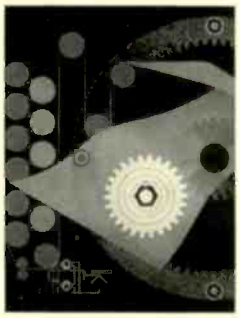
THE COVER

A mechanical differential gear and a magnetic-amplifier regulator match the speeds of the various rolls in a papermaking machine. The elements of this control system have been portrayed by artist Dick Marsh in this month's cover.



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

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

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

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

Speed Matching

Position vs *Pilot Generator Systems*

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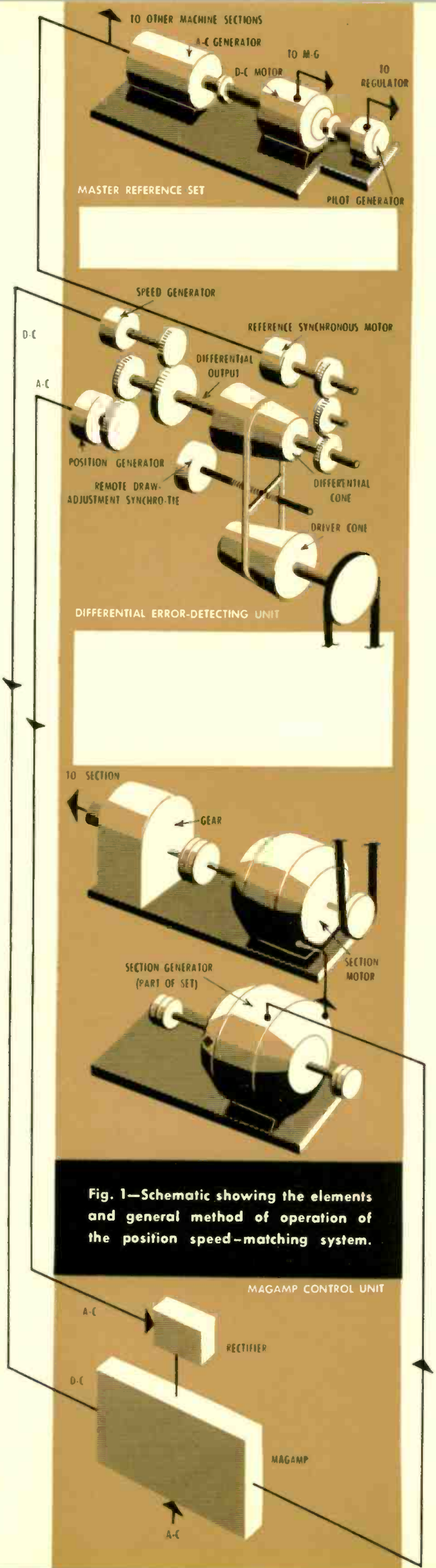


Fig. 1—Schematic showing the elements and general method of operation of the position speed-matching system.

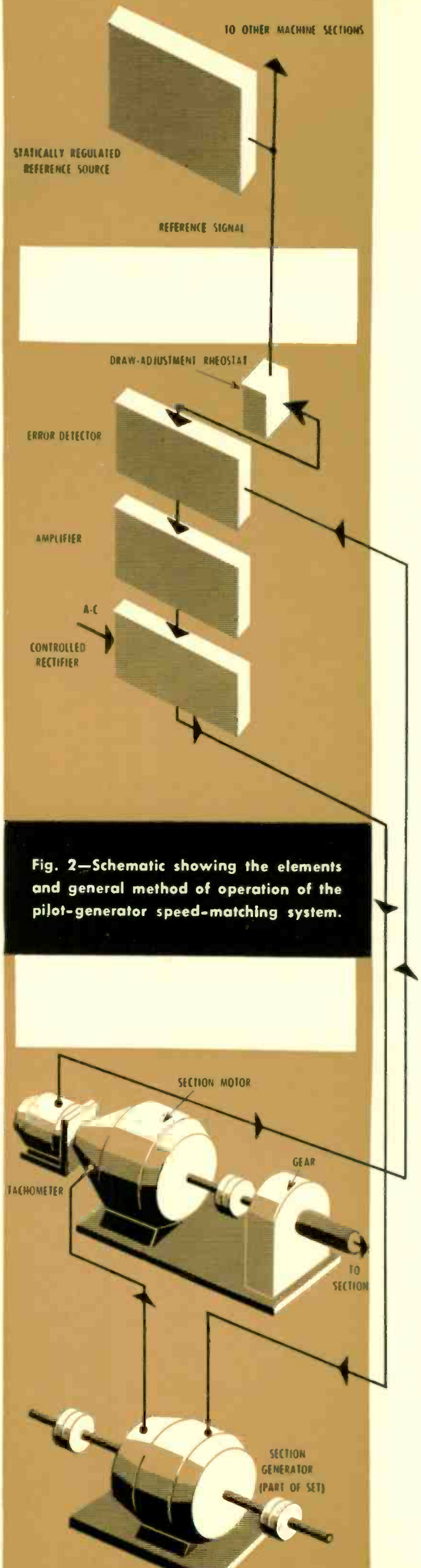


Fig. 2—Schematic showing the elements and general method of operation of the pilot-generator speed-matching system.

No sound engineering decision can be reached without a careful analysis of all the factors involved. Here is such an analysis of two well-known systems of speed matching.

SPEED REGULATION is today a well-understood problem. Not so well known, however, are the problems of speed *matching*, i.e., the precise control of speed relationships between separately driven machine sections. One reason is that these problems have been peculiar to certain industries; another is that technical advances have brought new equipment and methods for achieving speed matching.

Recently, the growth of the strand- and web-process industries—that is, those that produce such products as paper, textiles, and textile fibers, in a continuous "web" or strands—has made speed matching essential in a variety of new applications. The stretching of synthetic fibers is one example.

In these applications precise control must be maintained over the "stretch" or "draw" between sections of the machine. Stretch is a measure of the elongation of the material as it passes from one stand or section to the next. It should not be confused with tension, which is a measure of the stretching *force* applied to the materials between stands. Only when the material being processed is homogeneous and of constant cross-sectional area are the two quantities the same. In many processes, the material is relatively weak between stands, making it impossible to hold tension; therefore stretch, or draw, is the quantity to be regulated. This is done by accurately matching the speed of the stands or sections over their operating speed range, so that the rotational speeds of rolls on any stand are in the desired ratio to all other roll speeds.

At present, two basic systems are used to match the speed of electrically driven sections of a processing machine: ***position*** systems, and ***pilot-generator*** systems. In comparing these two systems it is necessary to assume that the methods of obtaining a reference quantity can have an important bearing on the performance of any regulating system.

Position Speed-Matching Systems

In a position speed-matching system the angular position of the driven roll of a particular section is compared with the angular position of a master-reference motor-generator set or with the angular position of the driven roll of another section. A mechanical-differential mechanism compares the position of the driven section with the reference; the output of this differential mechanism is converted to electrical signals, which, in turn, cue the regulator.

In their most common form, position speed-matching systems utilize the adjustable-frequency output from a small alternator as a standard of comparison. This alternator, plus a d-c motor, comprise the master-reference set. Its speed is adjustable by the operator so that it is directly proportional to the overall operating speed required for the regulated machine. The adjustable-frequency output from the master set powers small synchronous motors, each forming a part of the differential error-detector unit provided for individual regulated sections of the entire machine.

If only a few sections of a processing machine are to be speed matched, or the system must regulate from stand-still to full operating speed, small synchros can furnish the reference quantity to the position-matching devices. The synchro transmitter is driven by the lead section and a synchro receiver is then used instead of the small synchronous motor on the error-detecting unit. Yarn-stretching machines and tissue-paper winders are examples.

The error-detector unit, Fig. 1, consists of a cone pulley driven by the regulated section motor. This driven cone pulley is belted to a second cone pulley in which the ring gear of the mechanical differential mechanism of Fig. 3 is located. A ±12.5-percent draw adjustment is customarily provided in the taper of this cone; this also permits adjustments for reduction of roll size due to machining.

The sun gear of the mechanical-differential mechanism is driven by the synchronous motor, which receives its frequency from the master reference set. The planet gear, located on the differential crank, turns on its own bearing during the steady-state operating condition; it turns in space relation only when making an error correction. The differential output shaft is geared to both position and differential speed cueing devices. The position-cueing device is a small rotary transformer similar in operation to an induction regulator; it produces a signal voltage proportional to its operating position. A set of stops with a small slip clutch is mounted on the rotor shaft of the rotary transformer to limit rotor travel to about 55 electrical

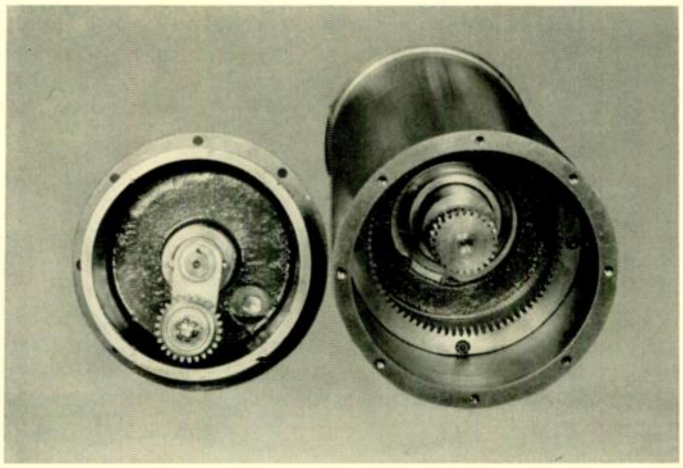


Fig. 3—The differential mechanism of the position speed matching system. The planetary and sun gear are on the right, and the idler gear which meshes with both, is on its crank arm is on the left.

degrees for the regulating range, as shown in Fig. 4. This is a regulating device and transmits no drive power. Its reliability has been proven by more than 300 000 operating hours with less than 0.001 percent down time resulting from causes attributable to the differential mechanism.

The differential speed-cueing device is a small d-c generator, which produces a signal voltage proportional to the speed of movement of the differential crank arm.

The rotary transformer and the d-c generator are in motion only during the correction period. Under steady-state conditions the only moving elements of the regulator are the cone pulleys and the synchronous motor.

Draw or stretch adjustment is accomplished by adjusting the position of the belt that connects the two cone pulleys.

Slack take-up is accomplished by means of pushbutton-operated magnet coils that allow a momentary shift of the cone-pulley belt.

The two signals produced by the error-detecting unit are fed to a control unit that contains a two-stage magnetic amplifier, a first-stage unit for amplifying the electrical signals from the error-detecting unit, and a second stage for furnishing controlled excitation to the shunt field of the regulated generator (or motor in the case of a single-generator drive). This control unit, Fig. 6, also includes control transformers, dry-plate rectifiers, calibrating resistors, and damping transformers to assure stability. The constants of the regulator are so arranged that the speed-signal amplification is high compared to the position-signal amplification. Thus, when load change occurs, considerable forcing is obtained to restore the regulated section to its original speed.

Following a load change the output shaft of the error-detecting unit assumes a new angular position and the section changes its angular position relative to the other sections. The sections are actually locked together in speed relation by the regulator. Position errors are not cumulative and once a new angular position is assumed, the rolls or other driven members maintain their relative speeds.

Changes in amplification in the position signal loop cause the regulator to operate at a modified position, but the steady-state accuracy of the regulator is not affected, as is shown in Fig. 5. Changes in amplification in the speed-sensitive loop cause a variation in the forcing effect of the magnetic-amplifier regulator circuit. Only time of response to a load change is affected. In this connection, variations as great as ±25 percent in gain do not seriously affect operation of this regulator. Since such amplification variations are not encountered in the magnetic-amplifier regulator, optimum regulator performance is assured without a special maintenance program.

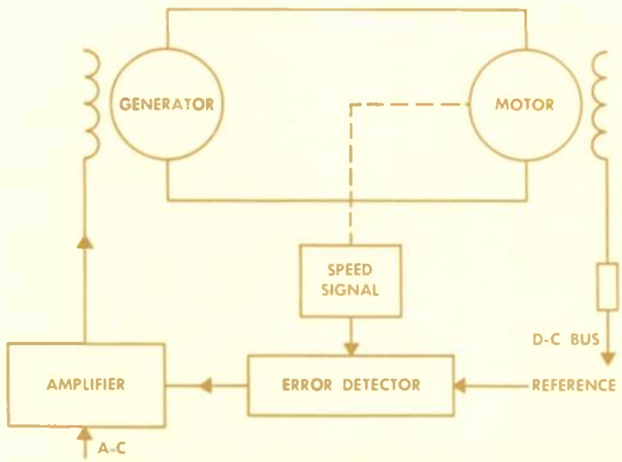


Fig. 4a—Schematic representation of a speed-regulated system. This diagram applies to either the mechanical-differential or the pilot-generator system.

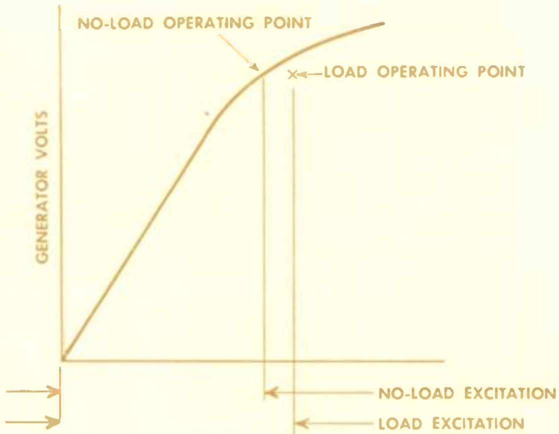
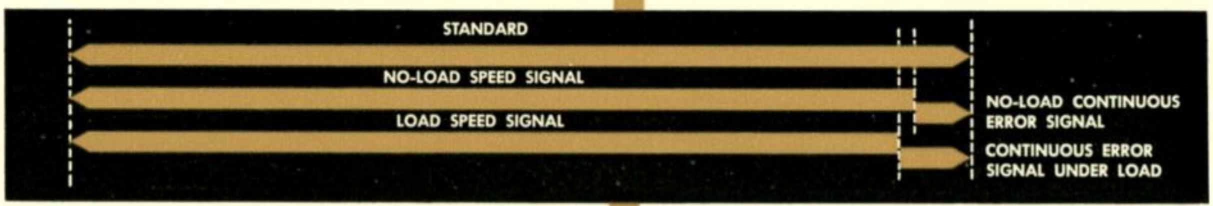


Fig. 4b—Saturation curve for a section power supply generator. Note that an increase in excitation or regulator output is required when the section is loaded.



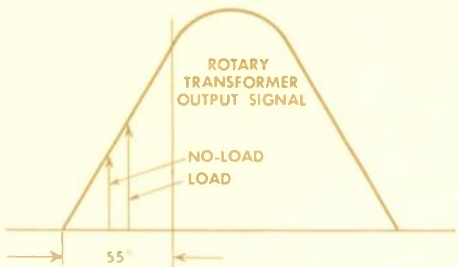


Fig. 4c—When the mechanical-differential system is used, the section speed is compared with the standard in the differential mechanism as shown in Fig. 1. The output of the differential mechanism positions a rotary transformer, which has a sine-wave output with position. When load is applied to the section, the transformer output is increased by a change in position.

Fig. 4d—When the pilot-generator system is used, the output of the section-driven pilot generator is compared with the standard in the error-detector panel of the regulator as shown in Fig. 2. The signals are algebraically added and the sum forms a continuous error signal which is amplified and used to excite the regulated machine. When the section is loaded, a change in excitation is required, as is indicated in Fig. 5. A change in error signal is necessary to obtain the change in excitation.

The operator is assured that the regulator is operating satisfactorily when the rotary transformer is in the central region of its range and the differential output shaft is not moving. If, on the other hand, the position transformer is at either end of its range, or motion is observed under steady load conditions, the regulator may be improperly adjusted. This allows the machine operator to check regulator performance without the assistance of an electrical maintenance man.

Pilot-Generator Speed-Matching Systems

Pilot-generator systems, Fig. 2, use a precision a-c or d-c generator to give a speed indication, and match speed on the basis of an error signal obtained by comparison of the output from the pilot generator with a reference signal. When load changes occur, the error signal causes a regulator output change, which results in the required speed correction. Increase in the load produces an increased error proportional to the load change, since a greater signal is required to get a greater output from the regulator. This increased error signal results in an increased continuous change in stretch or draw between sections that is proportional to the increase in the error signal. With the pilot-generator system, under steady-state conditions, accurate speed control can be maintained if components are wisely chosen and if the system amplification is sufficiently high.

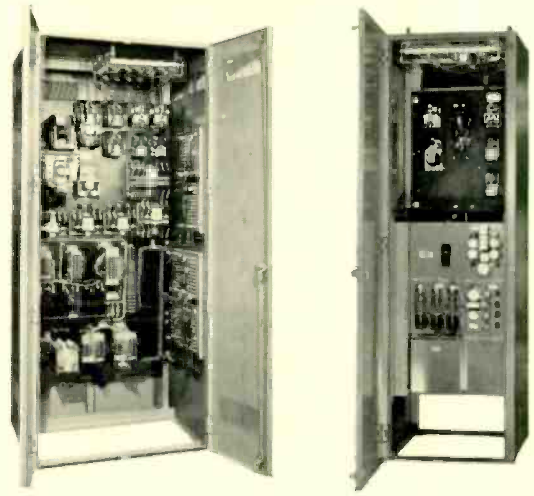


Fig. 6—*Left,* **the control cabinet for the magnetic control and the Magamp regulator used with the position speed-matching system.** *Right,* **the control cabinet that contains the magnetic control and electronic regulator for a pilot-generator speed-matching system.**

Of course, the main component in any pilot-generator system is the pilot generator itself. The accuracy of either a-c or d-c tachometers is affected by end play, out-of-round bearings, uneven air gaps, and other mechanical inaccuracies. In addition, accuracy of the d-c tachometer is affected by its use of a commutator, which introduces brush-contact variations as well as commutator ripple. In spite of all these sources of possible error, by proper design and application speed regulators using tachometer speed cue have proved extremely accurate when properly maintained.

The inaccuracies introduced in the output of tachometers increase with increasing loads, and are due principally to changes in contact drop at the brushes. In systems designed for 0.1-percent accuracy, d-c tachometers with at least one megohm resistance load are used. A-c tachometers show some improvement in accuracy, and are not so sensitive to load change. The output of the a-c tachometer must be rectified, and some errors are undoubtedly introduced. Other errors from mechanical causes affect both types of tachometers and are usually erratic and difficult to locate. In ball-bearing tachometers, for instance, rotation of the outer bearing race may introduce objectionable errors.

The accuracy of the pilot-generator system drops off as the speed of the machine or driven member decreases, since both the magnitude of the standard and the speed signals are decreased proportionately with speed. System amplification,

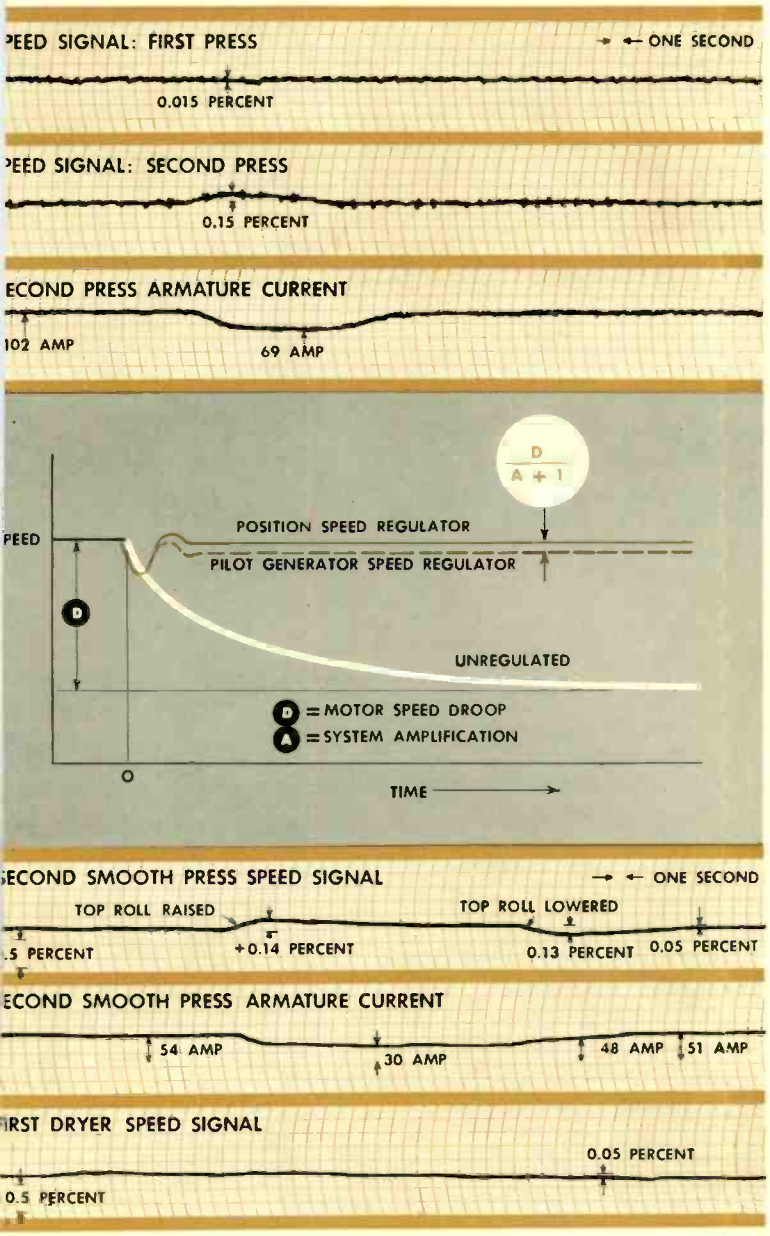
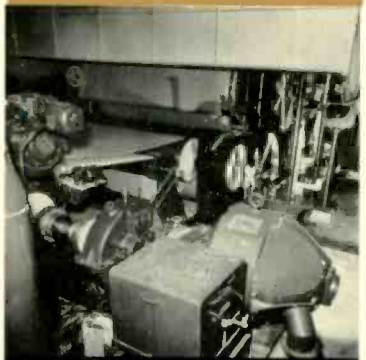


Fig. 5—*Top left,* **position-regulator test results, showing speed variation when section load is changed.** *Left,* **a comparison of the performance of the position speed regulator with the pilot-generator regulator.** *Below, left,* **test results of a pilot-generator system; this also shows speed variation when section load is changed.**

ADVANTAGES

1. Sections are locked together, and relative speed between sections accurately maintained.
2. Effects of system amplification on speed regulation are eliminated.
3. Position signal and speed signal both utilized.
4. Visible evidence that regulator is operating properly.
5. Low maintenance requirements. Maintenance limited to mechanical components.



POSITION SPEED MATCHING SYSTEMS

Drive motor on a press section of a paper machine, with differential position speed-matching equipment shown in the foreground.

DISADVANTAGES

1. Require relatively large space near machine.
2. More mechanical parts required.
3. Relatively high cost because of use of precision parts.

however, is increased at low speeds by the ratio of the change in slope of the generator saturation curve.

The net result of these two changes is a decrease in regulator accuracy at low speeds. Assuming a 5-to-1 speed range, accuracy of regulation would be about 0.25 percent at low speed in a pilot-generator system designed for 0.1-percent accuracy at top speed.

Variations in amplification, such as "drift," require continuous change in the magnitude of the error signal, which introduces another source of error in the system with resultant variations in speed. Such variations are particularly objectionable, for instance, in the dry end of a paper machine between the dryer and calender sections, or between two calender sections where variations in speed result in tension variations. A two-percent shift in relative speed here would result in change from zero to breaking tension in the paper. These variations have been overcome by the use of tensiometer devices in some cases.

Integrating amplifiers have been introduced to increase the steady-state accuracy of speed-regulating systems. These integrating amplifiers utilize the same speed reference and tachometers that the speed regulator does. Therefore, the steady-state accuracy of speed-matching systems is subject to any drift of the integrating amplifier as well as errors introduced by the reference and tachometers.

Maintenance requirements are increased by use of additional regulator components, which usually include a multivibrator and several electronic tubes.

Other Comparisons

Malfunctioning of a pilot-generator speed-matching system, unlike that of a position speed-matching system, is not easy to detect. Sensitive meters are required, and they must be used by personnel with a high degree of familiarity with the intricate electrical circuits. Erratic sources of trouble are particularly difficult to locate. Since continuous error is required with the pilot-generator speed-matching system to signal the amplifier, "tracking" or holding the speed of the various sections together is difficult, particularly when adjusting the operating speed over the adjustable speed range. This is due to the fact that the various sections may be of widely different horsepower and inertia, the section-motor characteristics may be different, and the section amplifiers are then likely to have varying output performance curves over the speed range.

One outstanding advantage of pilot-generator speed-matching systems is their relatively low cost of manufacture. A position system on the other hand, has precision mechanical parts, which force the manufacturing cost up. Roughly the same cabinet size is required for the control of a section motor with either the pilot-generator or the position-type regulator system (see Fig. 6).

Another advantage of pilot-generator speed-matching systems is the relatively small space required at the motor being regulated. The error-detecting device for pilot-generator systems is located in the control cubicle, but in the case of the position speed-matching system, the differential mechanism is the error-detecting device, and for the sake of simplicity it is mounted at the section drive motor. Mounting at this point requires more space on the machinery floor.

When considering these two systems in their entirety, position-regulating systems appear preferable for speed matching if performance is critical. If cost is the most important factor, or space near the machine is at a premium, pilot-generator systems may be an economical choice.

DISADVANTAGES

1. Inaccuracies in signal from pilot generator are possible.
2. Load changes result in a continuous error.
3. Magnitude of error varies with system amplification.
4. Mal-performance is not readily detected.
5. Tracking difficult.

A section of a press drive on a paper machine showing the compactness of the equipment required with the present pilot-generator speed-matching system.

PILOT-GENERATOR SPEED MATCHING SYSTEMS

ADVANTAGES

1. Require small space near machine.
2. Relatively low cost. Few precision parts required.

Influence of Performance Characteristics *on* Transformer Design

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The first transformer designers were satisfied if they could design a transformer that would carry the load without burning up; next, they learned how to make this transformer at a minimum cost; finally the designers found that they must compete with each other in designing for lower losses and less drop in output voltage when the transformer is loaded.

After some years of experience certain characteristics proved to be about optimum from an economic point of view. Speaking of losses, particularly, there was a certain level at which saving one kilowatt of loss would cost more in the transformer than the kilowatt would be worth. A similar level existed for the other characteristics, and the present standard ranges of characteristics have evolved on a similar basis of economics. The several characteristics are dependent on each other, so it is difficult to vary one without affecting all of the others to some degree.

The value of a given characteristic, however, varies with circumstances. If power is cheap, as at a generating station, a kilowatt of loss is not worth nearly as much as it is 100 miles away. The worth of low regulation is even harder to evaluate; sometimes it is essential to build a transformer with high internal impedance, which means higher drop in voltage at load, so that the possible short-circuit current will be limited to something the circuit breakers can handle.

It is mutually helpful if the user includes in his specification the values of load and no-load loss in dollars per kw so that the manufacturer can select the best ratio within the standard range. If the impedance specified or the ratio of load to no-load loss falls outside the standard range, the cost increases. A brief description of the design problem will help clarify this.

Impedance and Leakage Reactance

A transformer has an internal impedance that is, in large transformers, mostly reactance. This impedance, as has been said, is desirable when the short-circuit current is to be limited, but is undesirable if the maximum voltage and kva are to get through to the load.

In a similar way, designers have found that reactance is both a help and a handicap in transformer design. To attain a very low value of reactance adds to the cost, but to obtain an extremely high value of reactance adds so much to the loss that it finally increases the cost.

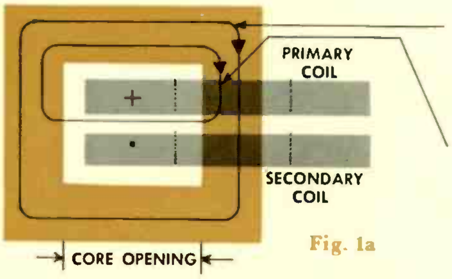
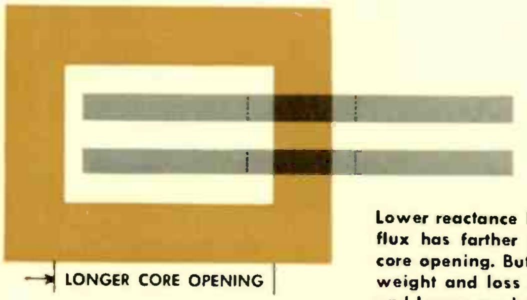


Fig. 1a



Lower reactance because the leakage flux has farther to travel across the core opening. But the iron and copper weight and loss are greater, the cost and losses are both higher.

Fig. 1b

Apparently, one range of reactance values might be best from an application point of view and another range best for the designer. Reactance is certainly not like loss, always undesirable. It would be most fortunate if the best range of values for the operator were the same as that for the designer, but experience indicates that the best range of values for operators is much greater because system conditions vary so widely. In one part of the system a low reactance may be best, but in another part a high reactance may be necessary.

To understand the relations between cost and reactance, consider a transformer that has only two pancake coils—one a primary coil, the other a secondary coil. Internal reactance exists in any transformer because some of the magnetic flux that links the primary coil does not link the secondary coil. The path of flux is shown in Fig. 1a.

Suppose that the reactance of this transformer is to be reduced, which means the leakage flux in Fig. 1a must be reduced. Thus the core opening is increased so that the leakage flux has farther to travel, as in Fig. 1b. This works fine unless the opening has to be increased so far that the weight of the core, the loss in the core, and the cost of the core increase beyond reason. The average length of a turn in the coils increases, too, raising both the loss in the copper and the weight.

So with both cost and losses increasing, only a limited decrease—or increase, either—in reactance can be accomplished by varying the proportion of the core opening.

Another way is to reduce the turns in both windings, which is very effective because the reactance decreases nearly as the square of the turns. However, the core section must be made larger, because fewer turns means that the flux in the core must be larger to induce the same voltage. This, in turn, results in higher core or no-load loss. Fewer turns would lower the loss in the windings except that the length of the turn has to increase to go around the larger core. This is illustrated by the change from Fig. 2a to Fig. 2b.

The transformer in Fig. 2b has lower reactance, but 10 percent has been added to the cost—a rather severe penalty. Suppose larger copper is used in the windings, as shown in Fig. 2c. This adds only 1 percent more to the cost and provides a real reduction in loss. In effect, a larger transformer, Fig. 2c, has been substituted for the original, Fig. 2a.

The larger transformer has more capacity than is needed, but extra capacity may come in handy at some future date. Although the no-load loss is higher, the total loss is lower, perhaps enough lower to pay for the higher cost.

The opposite situation happens when the reactance is to be increased. The iron loss goes down, the load loss goes up, and the cost goes down. A smaller transformer would have been better, except that it might not carry the required load. Fans could be added, and perhaps oil pumps, to make it carry the load. Then the efficiency of the transformer goes down, and is expensive to raise again. The sensible thing, usually, is to take the higher losses that go with the higher reactance.

Losses

Losses in a transformer are the sum of: *no-load loss*, which is the loss in the iron core that exists even though no load current flows in the windings, and *load loss*, which is the loss caused by load current flowing through the winding resistance.

Reduction of No-Load Loss—If the no-load loss must be less, the voltage on the transformer can be reduced; the loss decreases approximately as the square of the voltage. This is perhaps the easiest way to see what low no-load loss means; that is, the transformer is not redesigned, but the applied voltage simply lowered. If 90 percent as much loss is the goal, the voltage is reduced to 0.9 or about 95 percent. This seems easy—but 5 percent of the effective transformer capacity has been lost in the process.

To get the same kva out of the transformer the current must be raised 5 percent. The result is shown in the change from Fig. 3a to 3b. Total loss has increased 5 percent and the cost of radiators to dissipate this extra loss must be added.

Suppose a smaller transformer is used, as in Fig. 3c. The

TYPICAL VALUES

KVA	TURNS	PERCENT REACTANCE	COST	% LOSSES NO LOAD	LOAD	TOTAL
100%	100%	10	100	0.3	0.7	1.0
100%	85%	7.2	110	0.35	0.61	0.96
15% fewer turns, 15% larger core section.						
117%	85%	7.2*	111	0.36*	0.54*	0.9*
Put 17% more copper section back into each turn to get a larger transformer.						

*Values are based on original 100% kva.

total loss is still higher, but the transformer costs a lot less. Clearly, a smaller transformer with forced cooling is a better way to get low no-load loss.

Comparison of Fig. 3d and Fig. 3e indicates that a larger transformer operated at lower than normal current will give the desired results. The cost is higher and in most cases would be greater than the saving in loss evaluation.

Noise Limits

Transformer noise is due to core expansion and contraction as it is magnetized and demagnetized 120 times per second. This is magnetostriction.

The noise is usually the tank vibrating because it is driven by the core. The driving forces are such that no practical way has been worked out to hold the tank from moving.

Any element of the transformer, any operating handle, cabinet bracket or door, arrester support, relay arm, radiator tank panel—literally and unfortunately, *anything*—may have a natural frequency of vibration equal to one of the noise frequencies of the transformer; and if it does, the vibration of this element becomes amplified many times and may make a lot of noise.

The sheer power of the core vibration makes any real noise reduction very difficult; however many parts can become resonant, which may lead to more noise than necessary. In other words, the basic level is hard to reduce, but any number of things may make it worse.

After the resonant parts are cleared up the main method of obtaining a basic reduction in noise is to reduce the driving force.

This requires a reduction in the magnetic induction, which in our basic transformer can be obtained by a reduction in voltage. Some typical noise figures on one particular transformer that should be kept in mind are as follows:

90 percent voltage—72 decibels
100 percent voltage—75 decibels
110 percent voltage—79 decibels

This indicates how much penalty must be paid for low noise level. If the voltage is reduced to 90 percent, the effective kva of the transformer is reduced to 90 percent, and 10 percent of the transformer capacity has been sacrificed just to get 3 decibels of noise reduction.

The situation is even worse than this because, although the iron loss may be 15 to 20 percent lower at the lower voltage, the copper loss is still as high as ever, and to bring the efficiency of the transformer back to the original value means that more copper must be added—nearly 10 percent.

Thus, the noise reduction has not only derated the transformer by 10 percent, but has made it cost more, and has increased its size and weight. The reactance has not changed, but the percent reactance drop at the reduced voltage and kva has increased.

If the reactance also has to be brought down to the original value, the transformer becomes even larger and more expensive. At some value of noise level, which is something like 10 or 15 db down from the standard level, the size increase becomes so large that the very size of the transformer makes it produce more noise, and it will be impossible to reduce the noise level, at any cost, unless all the factors of efficiency are completely ignored.

Summary

These design factors are so interrelated that any change in one usually affects the others. Careful consideration of all factors, not just one, is essential to obtain the best transformer for a particular application.

Fig. 2

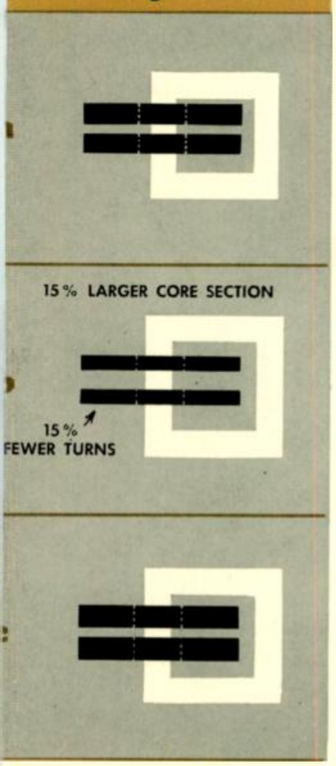


Fig. 3

	Fig. 3	KVA	NO-LOAD LOSS	LOAD LOSS	TOTAL LOSS	COST	REACTANCE	DB NOISE	EXCITING CURRENT
a	BASIC TRANSFORMER, 100% VOLTAGE, 100% CURRENT	100%	0.3%	0.7%	1.0%	100%	10%	75	1.0%
b	BASIC TRANSFORMER, 95% VOLTAGE, 105% CURRENT	100%	0.27%	0.78%	1.05%	100%+ For Cooling	11.6%	73.5	0.7%
c	86% TRANSFORMER, 100% VOLTAGE, 116% CURRENT	100%	0.27%	0.85%	1.12%+ Fan Losses	90%+ For Cooling	11.6%	74+ Fan Noise	0.9%
d	BASIC TRANSFORMER, 105% VOLTAGE, 95% CURRENT	100%	0.33%	0.64%	0.97%	100%	8.7%	77	1.5%
e	110% TRANSFORMER, 100% VOLTAGE, 91% CURRENT	100%	0.32%	0.62%	0.94%	107%	9.0%	75	1.07%

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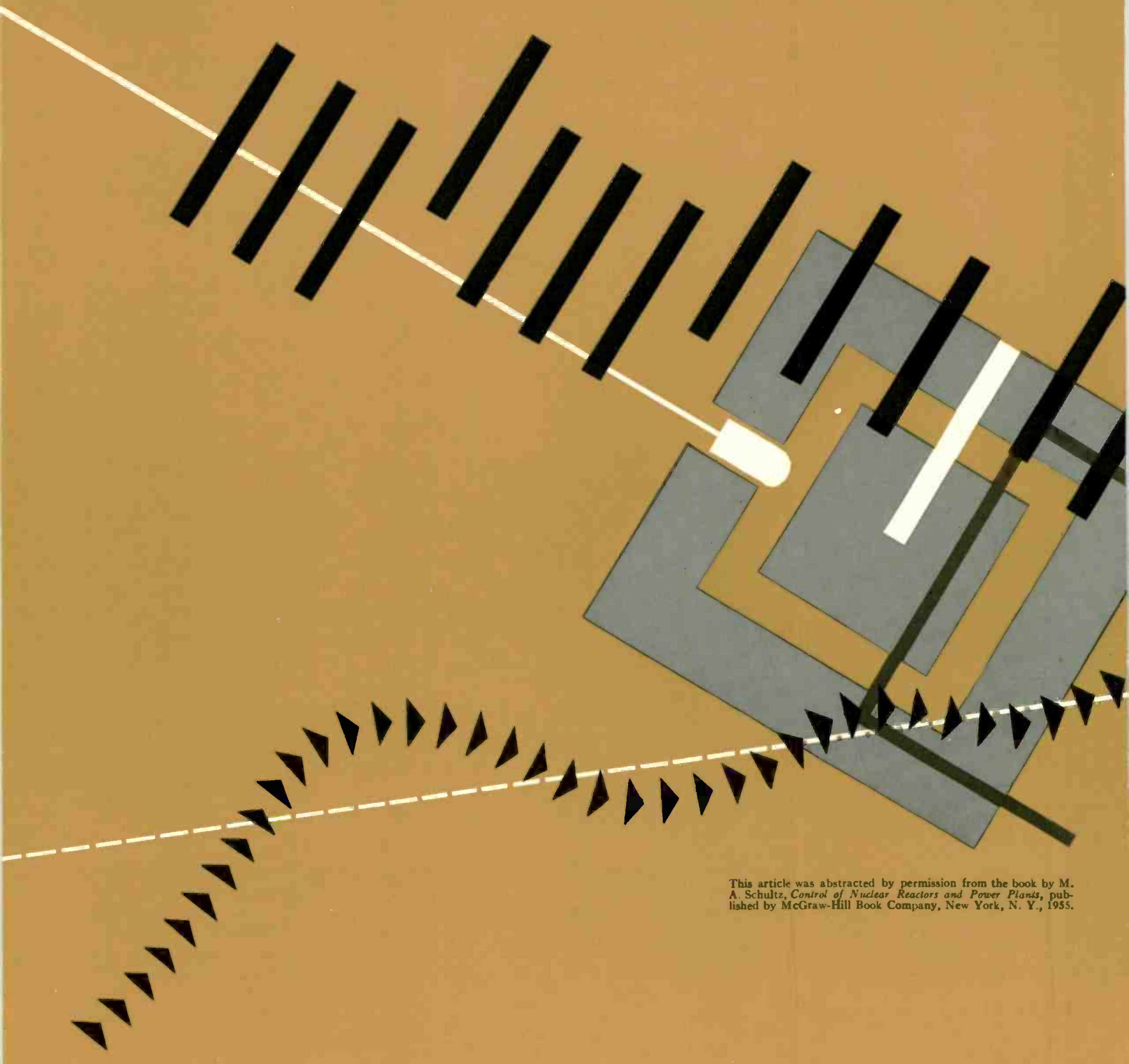
Fundamental **Aspects of Nuclear**



This article was abstracted by permission from the book by M. A. Schultz, *Control of Nuclear Reactors and Power Plants*, published by McGraw-Hill Book Company, New York, N. Y., 1955.

Control was once popularly regarded as the fundamental difference between a nuclear reactor and an atomic bomb. The refined concepts of reactor physics have since made the reactor a power-system element, which can be treated with engineering certainty. These fundamental concepts of power reactors are the basis for all present-day control systems.

–Reactor Control

THE PRESENT STATE of nuclear power plants in this country is fluid, with many technical ramifications. Several types have been built or are now on drawing boards. Each reactor plant built thus far contains a different control system. Although these control systems differ radically in mechanical design, many common theoretical problems and basic design concepts have arisen.

Elementary Physics of Reactor Control

A nuclear-power reactor consists basically of a fuel containing fissionable material, a moderator, heat-removing means, and a geometric structure in which a chain reaction can be maintained, Fig. 1. Inside the core is an initial source of neutrons for starting the nuclear-fission process. In the fission process, so called *fast* neutrons are produced which have high energies. Inside the reactor these neutrons suffer scattering collisions which decrease their energy. If most of the fissions result from the capture of neutrons slowed down to thermal energies by collisions with the moderating material, the so-called ***thermal*** neutrons, the system is referred to as a ***thermal reactor***. When most of the fission processes are caused by the absorptions of neutrons of higher energy, sometimes called ***intermediate*** neutrons, the term ***intermediate reactor*** is used. The range of neutron energies in an intermediate reactor is from thermal energies of about 0.05 electron volts up to about 1000 electron volts. If the main source of fissions is the capture of fast neutrons directly by the fuel without the neutrons having suffered any energy losses, the system is called a ***fast reactor***. Power reactors are of the thermal and intermediate types; fast reactors are usually used in weapons.

Multiplication Factor—The chain-reaction condition that each uranium nucleus capturing a neutron and undergoing fission must ultimately yield a minimum of one neutron that will cause another fission leads to a definition of the multiplication factor, k. This multiplication factor is the ratio of the number of neutrons in any one generation to the number of corresponding neutrons of the immediately preceeding generation. If k is equal to or slightly greater than unity, a chain reaction can take place. If k is less than unity the chain reaction cannot persist and will ultimately die down. For the chain reaction in the core to keep going, the production of neutrons must equal the leakage plus the absorption of the neutrons, or

$$k = \frac{\text{production}}{(\text{leakage} + \text{absorption})} \qquad \text{Eq. 1}$$

where leakage neutrons are those that escape from the core and are lost to the reaction, and absorbed neutrons are those that are picked up or captured non-usefully by materials such as the structural materials of the reactor, and therefore not available to create fission.

Reactivity, δk, refers to the amount the multiplication factor of a reactor differs from unity, or

$$\delta k = \frac{k-1}{k} \qquad \text{Eq. 2}$$

Neutron Lifetime—The average time between successive neutron generations is defined as the ***neutron lifetime***, l. The

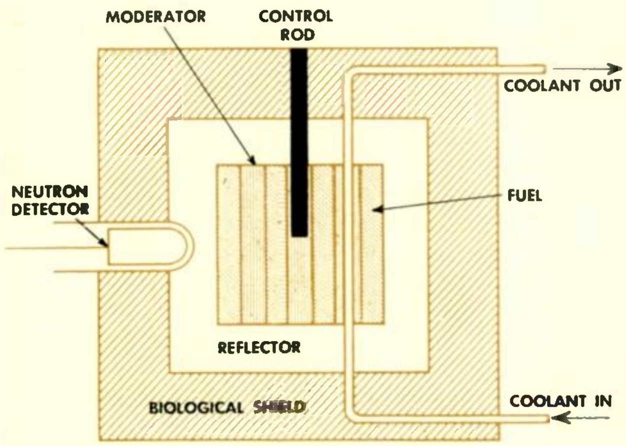


Fig. 1—Elementary components of a power reactor.

symbol l^* is used for the mean effective lifetime of a neutron in a finite reactor containing uranium 235. In other words, l^* is the mean time that elapses between the production of neutrons by fission and their return to fission or loss to the reaction. In equation (2), all neutrons created in the fission process were assumed to be given off instantly with a lifetime of l^*. Actually a small fraction of the neutrons created in fission are given off at discrete amounts of time after the actual fission process occurs. These neutrons, which are produced after fissioning, represent approximately 0.75 percent of the total neutrons produced in a uranium-235 fueled reactor and are called ***delayed neutrons***. As will be shown, the heart of reactor control depends upon these delayed neutrons.

Neutron Level—If initially n neutrons per cubic centimeter are present in the reactor core and only prompt neutrons are considered, the rate of increase for each generation is $n\delta k$. The number of neutrons present per cubic centimeter after a lapse of time t, is given by the expression

$$n = n_o e^{(\delta k / l^*) t} \qquad \text{Eq. 3}$$

where n_o is the number of neutrons per cubic centimeter initially. On this basis, the number of neutrons rises exponentially with time if the effective multiplication factor is greater than unity. The number of neutrons in the core is proportional to the number of fissions occurring (for 3 x 10^{10} fissions per second, one watt of power is produced). The power output of a reactor then is proportional to the number of neutrons in the core in any given time interval, and the symbol n designates neutron level with the implication that a power level is involved.

Period—The *period* T of a reactor may be thought of as that amount of time a reactor takes to change its level by a factor of e = 2.718. Therefore in terms of period, the above equation becomes

$$n = n_o e^{t/T} \qquad \text{Eq. 4}$$

with $T = l^*/\delta k$. The period of a reactor is thus a dynamic quantity; that is, when the reactor is in operation at a fixed power level, the period is infinite. Only when the reactor is changing level is there a finite measurable period.

Reactor State

The state of a reactor at any given instant is defined by the multiplication factor. When k equals unity, the reactor is *critical;* less than one, *subcritical;* and greater than one, *supercritical.* Hence, no power level is involved in the definition of criticality. A reactor may be critical at a level of one watt or a megawatt.

Subcritical Operation—When a source of neutrons is provided for starting the reactor, the number of neutrons that exist at the end of a sufficiently long interval of time after the source is inserted will be dependent upon k (Fig. 2). For example, with a k of 0.5 in a multiplying medium, the number of neutrons ultimately levels off at the end of several lifetimes l to a value of $n/n_o = 2$. As k approaches unity, the subcritical multiplication approaches infinity and the number of neutrons in the medium rises in a straight line with time. This situation holds only if there is a source present. Without an actual source, the neutron level in any subcritical medium must ultimately die down to zero.

Critical Operation—No mention was made of sources in the definition of criticality. Consequently, although the power level of the medium may have been inferred to be constant with $k = 1$, obviously the source neutrons continue to add in and create a rising power level. From a practical point of view this phenomena is noticeable only at extremely low operating levels. A reactor operating at a power level high enough to produce useful power represents at criticality a steady multiplication by one of billions of neutrons. The usual reactor source strength may vary from a few neutrons per second to possibly a few million neutrons per second. Therefore, the number of neutrons emitted by the source is only a minute percentage of the total involved in a power operation. Consequently, for all practical purposes at power operation, $k = 1$ represents a state of constant power level.

Supercritical operation—Equation (3) describes reactor behavior when k is greater than one assuming that all neutrons are prompt. An illustrative example of the change of level with reactivity manipulation for this condition may be given. Assume a critical multiplying medium with an l^* of 10^{-3} second; this is roughly the value of neutron lifetime for a large graphite-moderated reactor such as the Brookhaven reactor. Now if a reactivity step change of $+\delta k = 0.003$ is inserted in the reactor, the equation indicates that at the end of three seconds the power level will rise by a factor of 8000. If this were the true reactor condition, the problem of reactor control would be most difficult if not almost impossible. Fortunately, the effect of a mere 0.75 percent of delayed neutrons is such as to make the entire problem of reactor control a simple, feasible one. The relative neutron level for an actual reactor having an $l^* = 10^{-3}$ seconds as a function of time for the same step reactivity input previously stated is shown in Fig. 3. Although an explanation will not be attempted here, the effect of having delayed neutrons is at once apparent. Where for prompt neutrons the power level soared to 8000 times the original level in three seconds, when the reactor contained delayed neutrons the power increased only by 2.1 times the original level in three seconds.

Prompt Critical—When the effective multiplication factor k of a uranium 235 reactor is 1.0075, the reactor is said to be *prompt critical*, which means that the reactor is capable of sustaining a chain reaction without the use of delayed neutrons. If k is greater than 1.0075, extremely rapid exponential multiplication of reactor power level results. For this reason most control systems attempt to prevent k from ever becoming greater than 1.0075.

Elementary Reactor Operation

Production of neutrons equals leakage plus absorption for critical operation. If the production of neutrons is to be changed, either leakage or absorption can be manipulated. To change leakage, a hole or a window might be put in the reflector. Changing the multiplication by absorption is the more commonly used method, particularly for thermal reactors; and control rods containing cadmium, boron, and other high-thermal-neutron absorption cross-section ma-

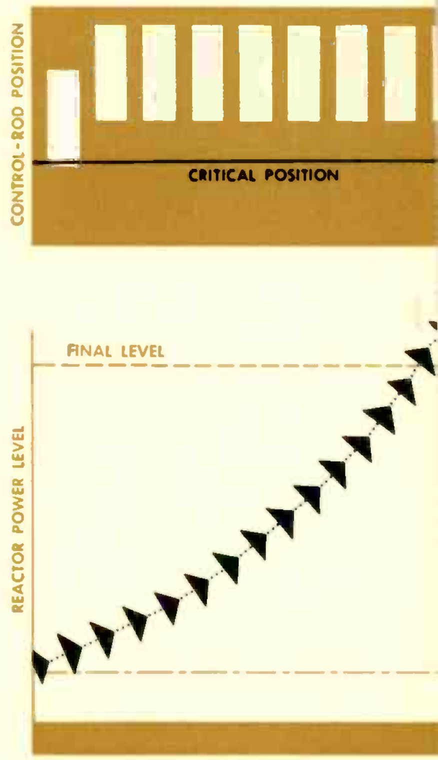


Fig. 4—Control-rod positions for a manual-level change.

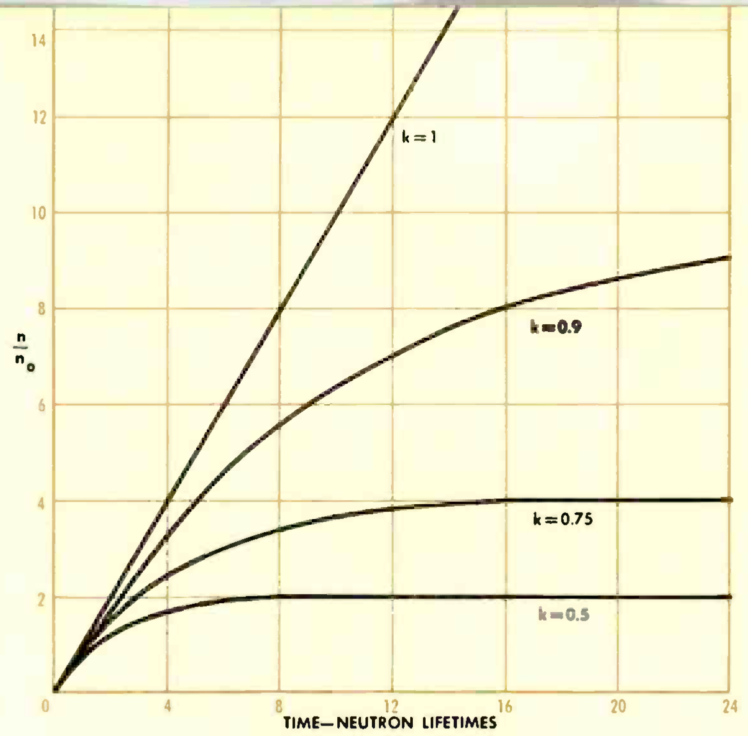


Fig. 2—Subcritical reactor multiplication.

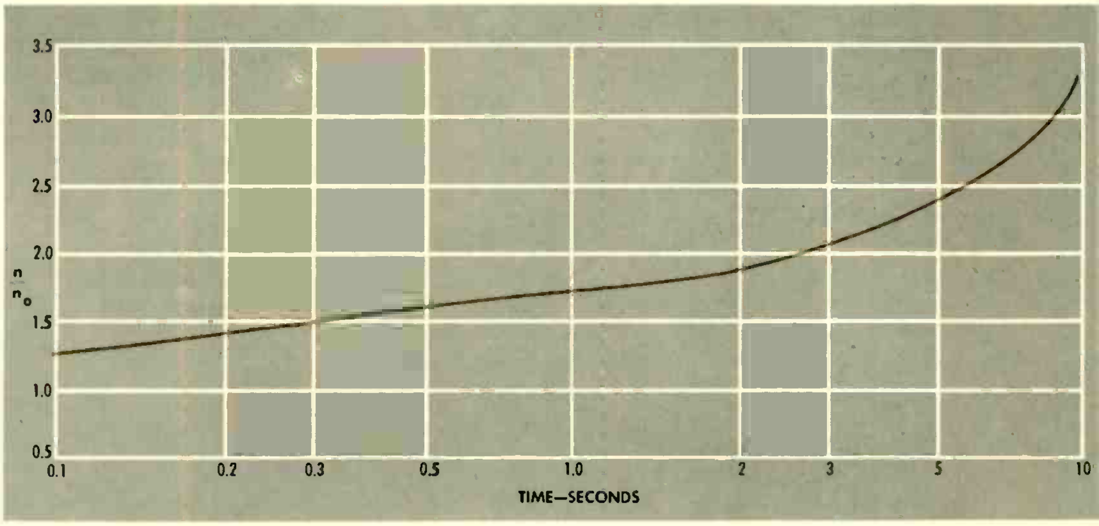
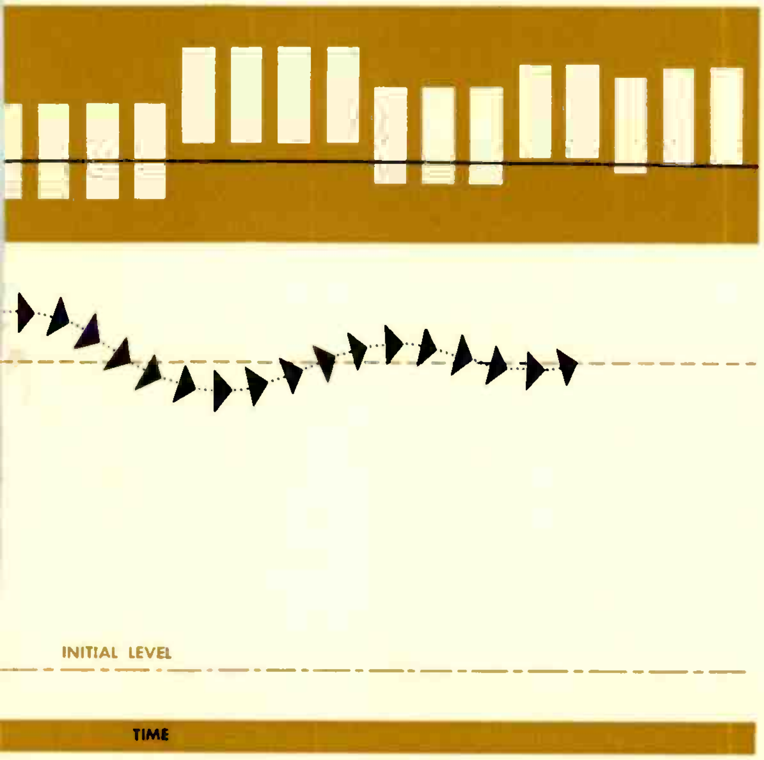


Fig. 3—Relative neutron level as a function of time for a step-reactivity change of 0.003.

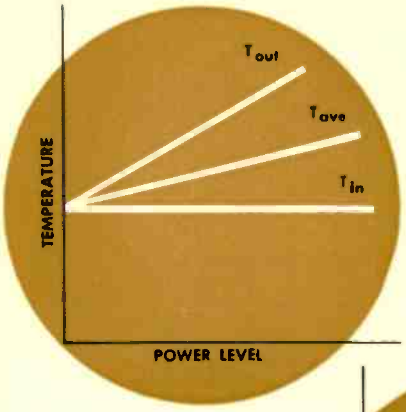


terials may be used to remove neutrons from the reaction.

Control rods can be moved in or out of the reactor singly or in banks. They are given various names according to their functions. Certain groups of rods may be designated as safety rods or shut-off rods. Other rods may be shim rods, whose function is to affect the power level in a coarse manner. A regulator rod is often used to cause fine changes in reactor power level.

To compensate for fuel depletion and other effects, a multiplication factor of k greater than one must be built inherently into the reactor and then some reactivity removed by inserting control rods partially into the reactor to obtain critical operation. The total multiplication the multiplying medium possesses when the control rods are completely extracted, minus one, is termed *excess reactivity*. One minus the total amount of multiplication in the medium when the control rods are completely inserted is the *shutdown reactivity* of the reactor.

If a reactor is initially critical at a low power level, and the level is to be increased, the first step is to extract a control rod a small amount and change the multiplication factor k from one to a value slightly greater than one. The neutron level then starts to rise, and as the power level rises and approaches the desired ultimate level, the control rod must then be inserted back to where $k = 1$. If no anticipation is provided in the system, the control rod must oscillate about the



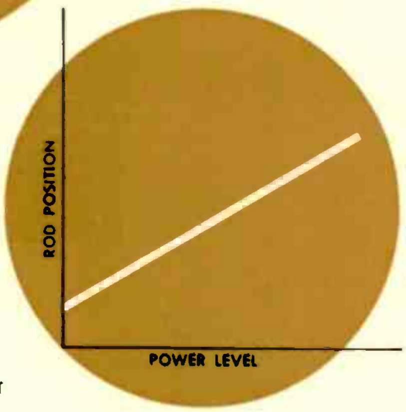
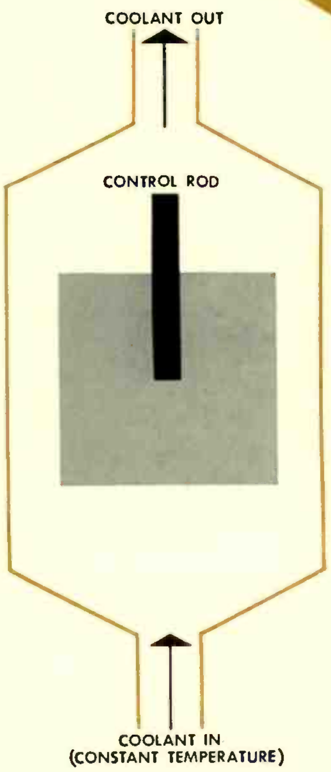


Fig. 5—Elementary operation of a reactor having negative temperature coefficient and constant coolant-inlet temperature.



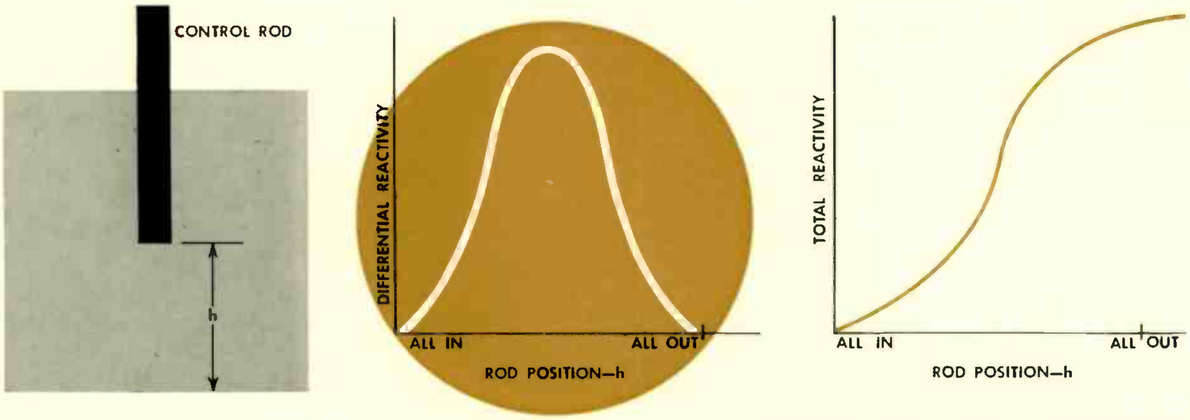
$k = 1$ position as shown in Fig. 4 but ultimately will settle down at its original position. Power level is independent of rod position, and in order to change power level the control rod is moved temporarily in or out of the medium and then returned to its original position. This reactor concept is the classic one of reactor control. As fuel in the reactor is used up, the number of fissions occurring will decrease; consequently k will be reduced and control rods will have to be moved out to compensate for the reduction in k.

Negative Temperature Coefficient—Other causes exist for moving control rods, one of them being the temperature of the reactor. Most reactors have what is termed a ***negative temperature coefficient;*** as the reactor heats up, its reactivity is reduced. Reactors that have water or gas as moderators usually have large negative temperature coefficients. This temperature coefficient is actually a most important control-system parameter.

For example, assume that a reactor is critical at a low power level and consequently is effectively at room temperature. The control rods are in a given fixed position. Now, through some external means such as that of heating the reactor coolant the average temperature of the reactor is raised to where it might actually run as a power reactor. This process of heating reduces the reactivity of the reactor. Conse-

Fig. 6—Relative peak xenon poisoning reactivity as a function of time after shutdown for a thermal reactor.

Fig. 7—Control-rod effectiveness as a function of rod position in a reactor.



quently, the reactor is no longer critical but probably greatly subcritical. Control rods must then be extracted to make up for this loss of reactivity. Actually it does not matter whether the heat is applied from an external source or whether the reactor power level is changed. *Cold critical* then refers to the position of the control rods when the reactor is critical at room temperature, and *hot critical* refers to the position of the control rods when the reactor is critical at its normal operating temperature.

An interesting type of control-rod operation results when the inlet temperature to this type of reactor remains constant. For a simple example assume that the coolant into the reactor is supplied from a faucet or equivalent at constant temperature and the coolant out of the reactor is used in heating radiators and then dumped, Fig. 5.

If the flow from the faucet is constant, as the power output of the reactor rises, the average temperature rises, and to compensate for this rise in average temperature, control rods must be extracted to keep the multiplication factor unity. Assuming then that the control rods are equally effective at all positions in the reactor, it can be seen that under this condition the position of the control rods is directly proportional to the power output of the reactor. In a practical situation many other types of programming can exist. The position of the control rods will rarely be either of the two simple functions of power level just described.

Fission-Product Poisoning—Another quantity that plays a vital role in the operation of large thermal power-producing reactors is *fission-product poisoning*. As the reactor continues to operate, fission products are created from uranium. Many direct-fission products exist, and in addition, a host of daughter nuclides are created by decaying emissions from these fission products. Some of these direct and indirect nuclides may have large cross sections for the absorption of neutrons, and therefore they can act as poisons. If produced in appreciable amounts, these poisons can affect the over-all multiplication of the reactor. Because some poisons continue to be formed by radioactive decay even after the reactor is shut down, the concentration of the poison can increase to a maximum after reactor shutdown. Obviously, additional excess reactivity must be designed into a thermal reactor to offset this effect.

Because of its large thermal-neutron-absorption cross section one nuclide is of particular interest, xenon 135. Xenon 135 is formed as a result of the decay of the direct-fission product, tellurium 135. Tellurium 135 actually consists of over five percent of the direct-fission products, and decays rapidly by beta emission in the following manner:

$$Te^{135} \xrightarrow{1\ \text{min.}} I^{135} \xrightarrow{6.7\ \text{hr.}} Xe^{135} \xrightarrow{9.2\ \text{hr.}} Cs^{135} \xrightarrow{2.1 \times 10^6\ \text{yr.}} Ba^{135}$$

Barium, the final end product, is stable. Xenon 135 has an extremely high probability of absorbing thermal neutrons, and later decays to cesium with a half life of approximately 9.2 hours. The steady amount of poison built up from this source during a power-level operation is called *equilibrium* xenon poisoning.

When a thermal reactor is shut down from a high-power-level operating condition, the thermal-neutron level is effectively reduced to zero, and the xenon 135 concentration goes up to a maximum from the iodine 135 which has been previously formed. Ultimately the radioactive decay of xenon to cesium takes over and the total xenon concentration drops off. The time involved in this process is shown in Fig. 6, with a peak in xenon concentration appearing approximately 11 hours after shutdown. The magnitude of this peak again depends upon the initial steady-state power level of the reactor and its specific design. However, the peak xenon poisoning may be many times the value of the equilibrium xenon-135 poisoning when the reactor is in operation.

TABLE I

Long-Time Operating Flux	Equilibrium Poison Percent	Maximum Poison After Shutdown Percent
10^{12}	0.54	0.55
10^{13}	2.8	3.0
10^{14}	4.5	20.0
2×10^{14}	4.6	38.0

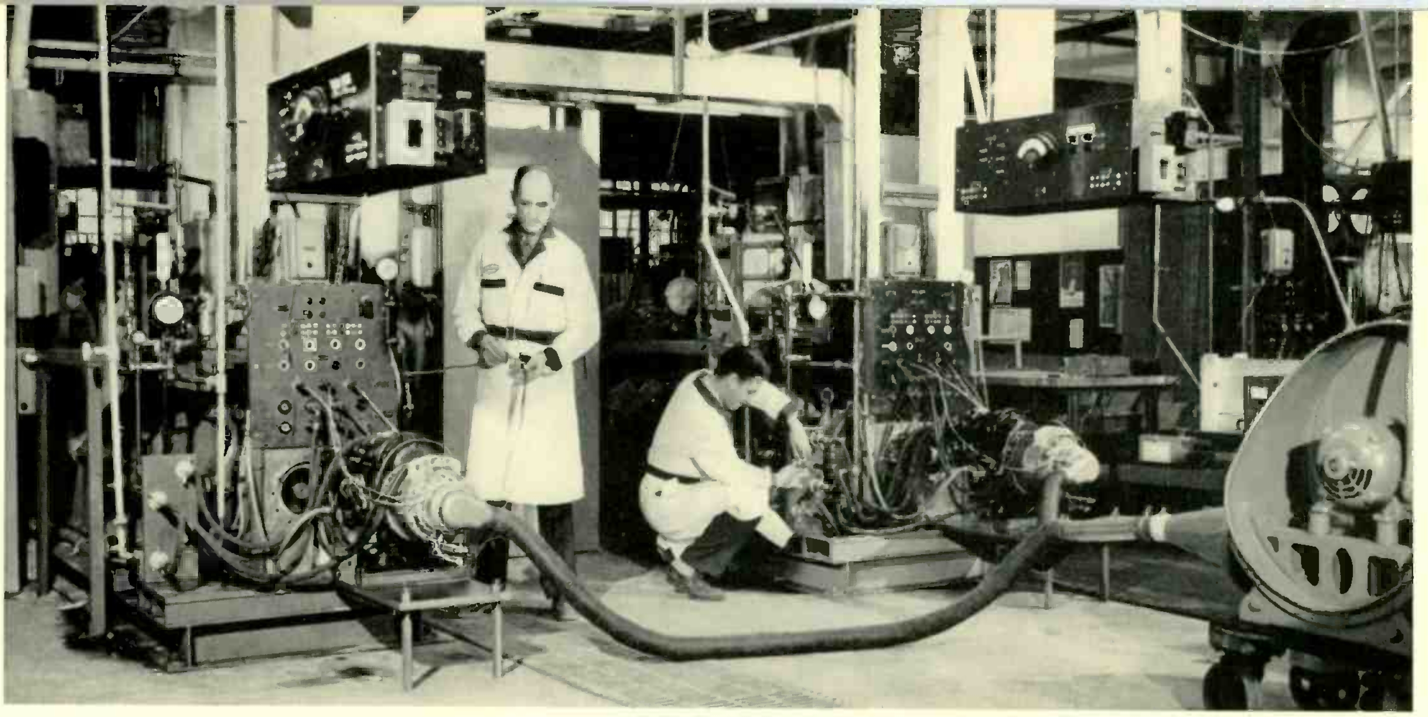
Other variables of operation can enter. After a reactor has been shut down and the xenon-poisoning concentration partially built up, the reactor may be turned on again and subsequently *burn out* the xenon back to the equilibrium condition. This operation calls for a fast rate of change of reactivity from the control rods to keep the reactor critical and is a determining factor in the speed of reactor control rods.

A very appreciable amount of reactivity can be involved in both equilibrium and peak xenon poisoning. (See Table I) Conceivably, the peak poisoning may be so much that the reactor does not contain sufficient uranium to completely "override" this peak even when the control rods are pulled all the way out. Under these conditions, where only a fixed amount of reactivity is available, unless the reactor is started up quickly after shutdown a large period of time exists in which it will be impossible to start the reactor until the xenon poisoning decays. As an example in Fig. 6, assume that sufficient reactivity exists in a reactor so that it can still be made critical up to one-half hour after shutdown from a given power level. The curve indicates that unless a startup is made within this one-half hour, the reactor cannot be started up again for 40 hours.

Control-Rod Effectiveness—The control rods have been shown to be the heart of a nuclear-control system. They must maintain the power level of the reactor at the desired level, and compensate for fuel depletion, temperature, and poisoning. Previous discussions have assumed that the effects of control-rod position in reactivity are linear with rod position in the reactor. Actually, it is not this simple. Moving a control rod or a bank of control rods in a simple geometric reactor, such as a cylinder, normally produces a change in reactivity that varies approximately as the sine squared of the rod position, as shown in Fig. 7. To make the matter more complex, the position of each individual rod usually affects the reactivity worth of the nearby rods.

The rate of reactivity change produced by the rods during startup is especially important. Likewise, the position of minimum rod effectiveness is also an important consideration when following transient xenon poisoning by means of control rods, since the xenon transient when decaying at its maximum rate will be rapidly inserting reactivity into the reactor.

These give some indication of the factors that must be considered in the design of a control system for a nuclear-reactor plant. All thermal-reactor control systems are based on these fundamental principles of reactor operation.



Testing **Aircraft Electrical Systems**

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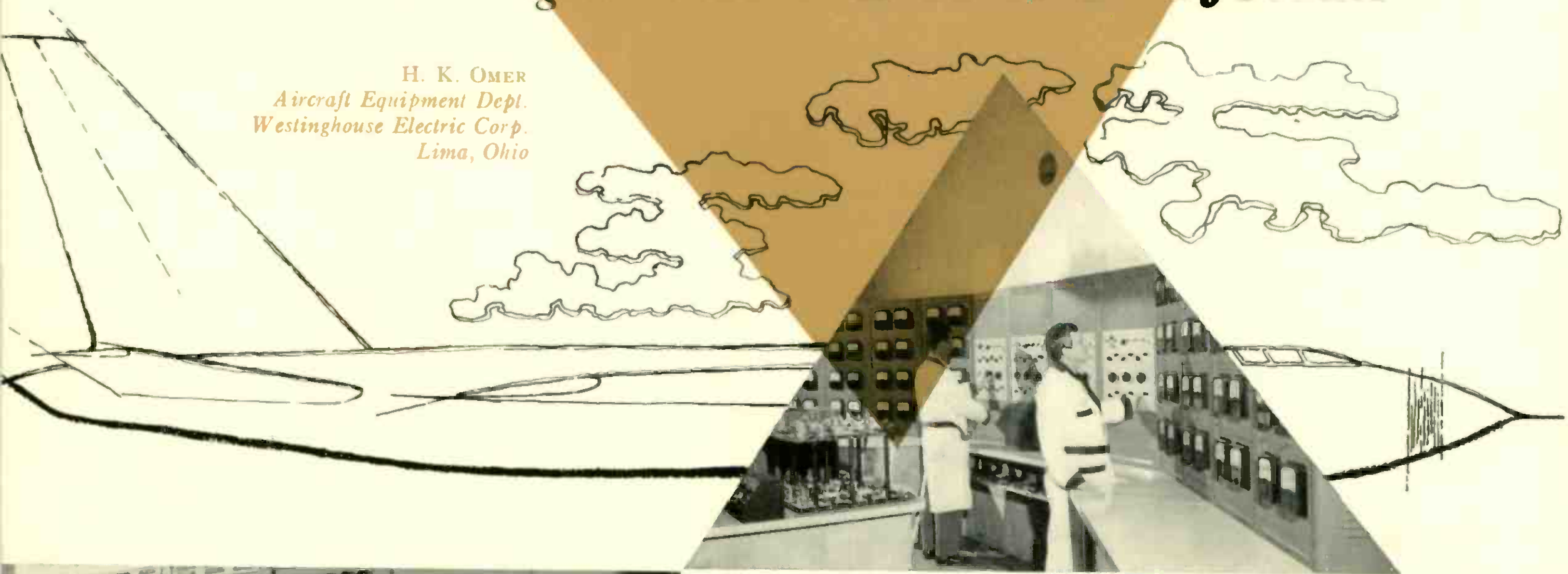


Fig. 1—The control center. Here generator output and excitation can be measured. Elements in development stages can be installed on table at left, and their operation observed.

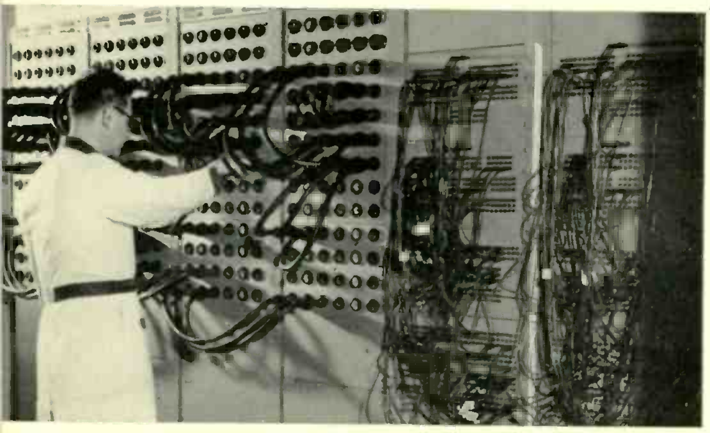


Fig. 2—The power center (left) and patch panel (right). Different bus configurations are obtained by changing jumper connectors on the power center. Control and protective components are interconnected on the patch panel according to the system design under consideration.

Coordination of the many interrelated components of any electrical system is at best a complex job. Aircraft electrical systems are no exception; in fact, the nature of their task often imposes unique requirements.

In an a-c aircraft system, the most important factors are performance and reliability. Achievement of satisfactory results, of course, requires careful system analysis, and the development of good components to meet the necessary system requirements. In the development of a-c electrical systems, however, another step is needed in most cases to prove system performance and reliability. This is an actual test to evaluate the system.

Fig. 3—
These 200-hp variable-speed d-c motors are two of the four prime movers for the four-generator mock-up. They are used to vary the input speed, thus simulating engine speed changes. The a-c generators are on the near end of the shaft.

Many problems in a-c systems cannot be solved easily by calculation; this is particularly true where two or more generators are operated in parallel. An actual system mock-up thus provides the best means for overall evaluation. Such a mock-up—designed to simulate actual aircraft conditions—is shown in the photographs on these pages.

This test facility is designed so that from two to four generators, with ratings up to 60 kva, can be operated in parallel. Two of the drive motors are 200-hp variable speed d-c; the speed of these motors can be varied to simulate engine speed changes. The other two drive motors are 200-hp a-c induction motors. The ratings of these motors, which simulate the aircraft engines, is large enough that overloads and faults on the aircraft electrical system do not affect appreciably their speed.

These motors are connected to the aircraft generators through Sundstrand constant-speed drives, which are identical to the drives used in aircraft. The a-c generators are in turn connected by plug-in type leads to the permanent wiring in the test facility.

The power center and the patch panel used to interconnect the various system components are shown in Fig. 2. The power center is arranged such that by plugging in power jumpers any bus configuration can be obtained. Also, such faults as line-to-line, line-to-ground, and open phases can be applied to the bus system, to the generator feeders, or to the load feeders. Oscillographic recording equipment can be installed by means of plug-in jumpers, thus making it possible to obtain permanent records of fault conditions.

The various control and protective components can be interconnected on the patch panel. Permanent wiring is installed from the system current transformers, the various system circuit breakers, the regulators, the control and protective panels, the flight engineer's control panel, and from the generator. Any system design can be quickly and accurately connected by jumpers.

The control center, shown in Fig. 1, contains the controls for the system and the measuring and metering devices. In addition to the built-in metering devices, others can be added to the system to enable special readings. Also, if observation of the operation of control or protective relays is necessary, these units can be readily connected into the system on the table shown in front of the panel.

System analysis and the development of reliable components are fundamental, but not sufficient to achieve the best system performance and reliability. Test and evaluation by laboratory, ground, and flight programs are required to prove the electrical designs just as they are to prove the aircraft aerodynamic and structural design. Flexible test facilities such as this system mock-up provide a means to prove and demonstrate system performance, and in addition provide data for future component and system development.

Fig. 4—
A close-up of a 40-kva a-c generator driven by a 200-hp induction motor on the mock-up.

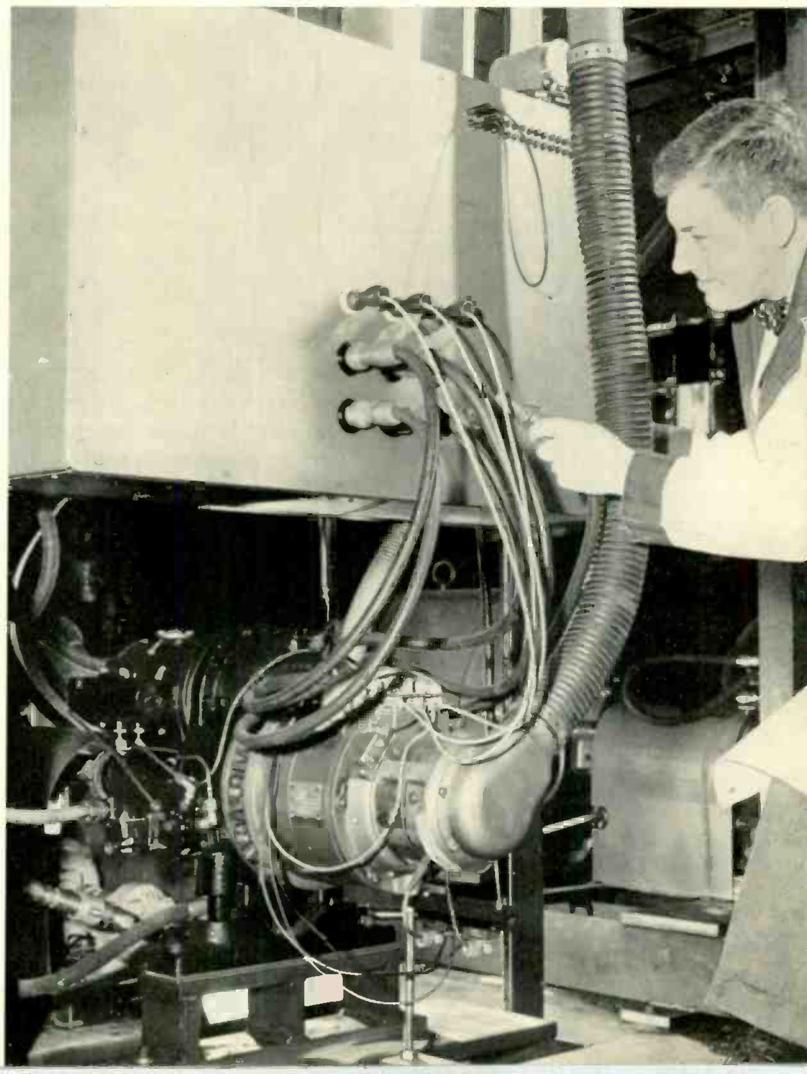
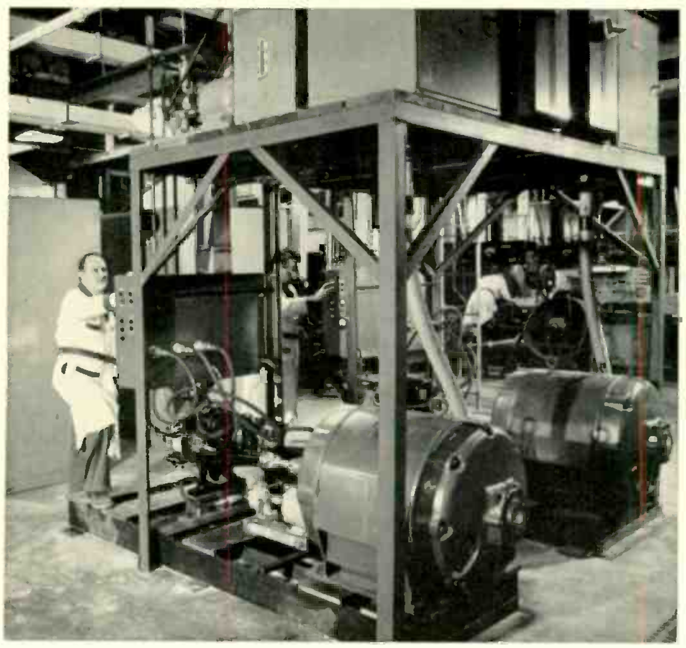


Fig. 5—The other two prime movers are these 200-hp a-c induction motors.



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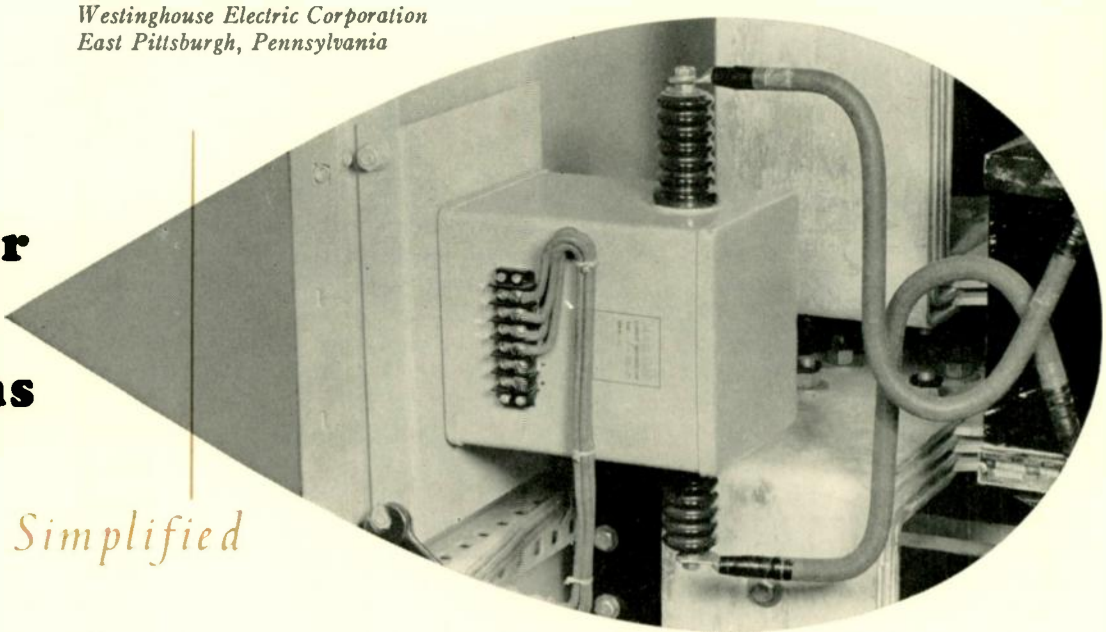
Transductor Applications

Simplified



A new magnetic-amplifier circuit is the engineer's latest answer to the need for a "d-c transformer" for measuring large direct currents and voltages.

Small voltage and current Magamp transductors have been employed for direct-current and potential isolation in industrial, railway, and mining applications for several years. Functioning as d-c instrument transformers, they are connected to shunts or in parallel with a section of a bus for d-c current indication, and directly across a d-c potential for voltage indication, thereby providing isolation of instrument and control circuits from d-c potentials of 300 volts and above.

A Magamp transductor is a magnetic amplifier of the saturable-reactor type. The small transductors that have been employed for potential isolation consist basically of a pair of two-winding transformers and a full-wave rectifier as shown in Fig. 2a.

The application of small transductors to metering and control circuits was made practical with the introduction of "square loop" core material. However, even the best available core materials do not provide an exactly linear relationship between the input and output currents from zero to full input. The first small transductors were commercially applied with the basic circuitry shown in Fig. 2a. The output current at zero input (Fig. 2b) is reactor magnetizing current. Since an appreciable output exists for zero input, a transductor with these characteristics has limitations in instrumentation and control applications. For example, totalizing of a number of circuits is a difficult application to make practical. Furthermore, the indicating instruments used with this transductor were hand marked to agree with the transfer curve.

Push-Pull Operation

The first answer to the problem of non-linearity was the use of two of these basic units, as shown in Fig. 4a. The dotted lines of Fig. 4b show the transfer curves of this combination, with the output of the two units of opposite polarity. The addition of bias windings to the two basic units shift the transfer curves as indicated by the solid-line curves. If the output circuits of the two basic transductor units are then connected to separate and equal windings of an instrument, the effective resultant ampere turns will be a straight-line function of the input current.

This use of two basic units is now known as a ***push-pull*** transductor. The arrangement shown has the disadvantage that the end device must have two entirely separate windings, which limits the field of application. The addition of dropping resistors makes possible the use of an end device with a single winding. Since any current drawn by the end device to measure the potential difference results in non-linearity, the arrangement can only be used with instruments that require no current (such as null-type instruments) if no error is to result. Hence, the field of application for push-pull transductors is also limited.

A push-pull transductor is polarity sensitive. However, only a limited number of applications require polarity sensitivity. In addition to the application disadvantage discussed above, a push-pull transductor requires a relatively large number of components. And close matching of the basic characteristics of the core elements and special calibration is usually required.

New Transductor Design

A transductor circuit has recently been designed which eliminates the undesirable characteristics previously discussed. This has simplified its application and made new applications feasible. The circuitry is basically the same as that previously employed except for the addition of a transformer between the series-connected reactors and the output rectifiers, as shown in Fig. 3a.

The addition of the transformer, T, makes possible a trans-

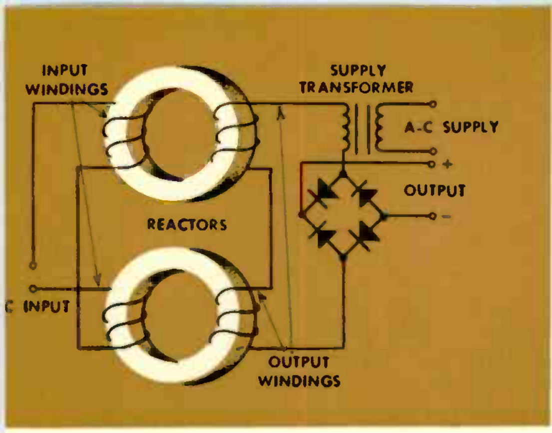


Fig. 2a
Basic transductor circuitry.

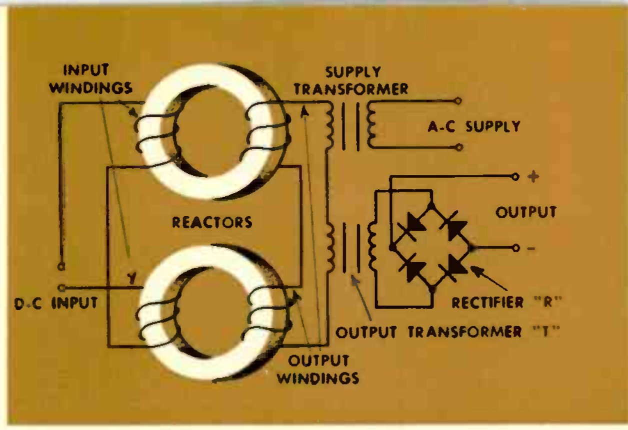


Fig. 3a
Transductor with transformer connected between reactor output and rectifier input to eliminate output at zero input.

Fig. 1 (left)
Typical installation of current transductor of Fig. 3a design. Transductor is connected to 100-millivolt shunt.

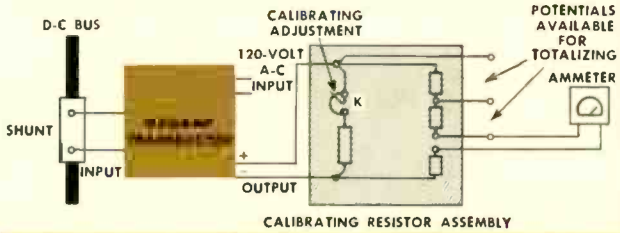


Fig. 3b
Diagram showing how standard resistor assembly is employed to simplify transductor application.

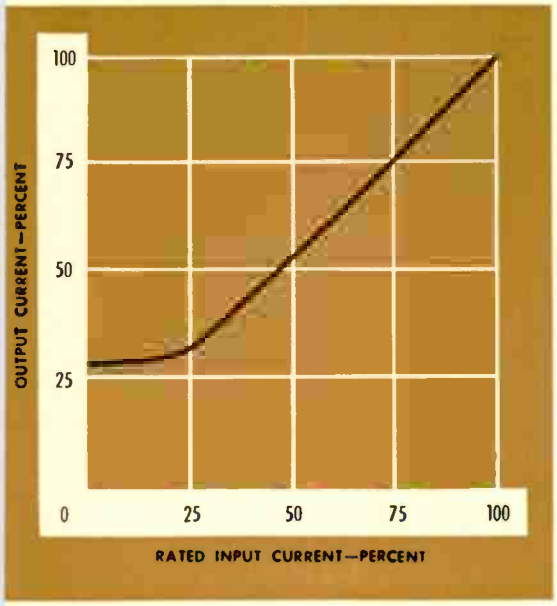


Fig. 2b
Actual transfer curve of transductor employing circuitry of Fig. 2a.

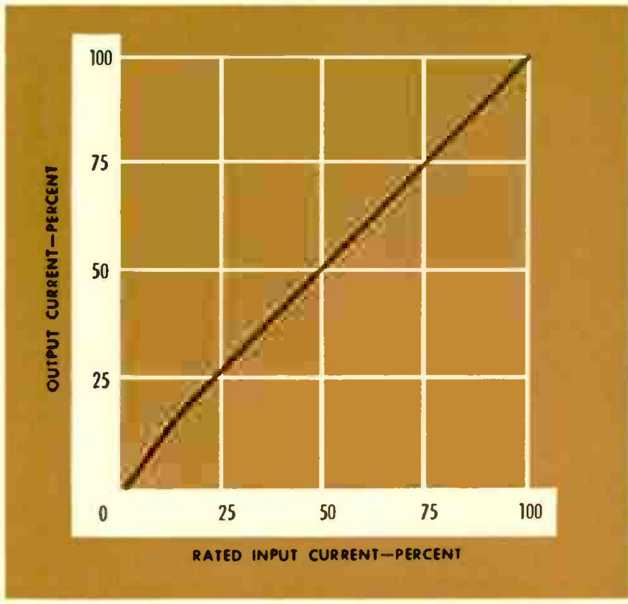


Fig. 3c
Transfer curve of transductor employing circuitry of Fig. 3a.

ductor that has essentially linear characteristics, and zero d-c output with zero input. The circuitry obtains these results primarily because of the non-linear characteristics of transformer T at low values of current. As previously mentioned, the transductor reactors provide a magnetizing current output at zero input. The transformer can be designed with characteristics such that the magnetizing current of the transductor reactors with zero input is just sufficient to excite the transformer.

Actually, the exciting mmf due to the exciting current does produce a flux change in the transformer core, and consequently a low voltage is induced in the secondary winding of the transformer. Theoretically if the rectifier, R, was perfect, an appreciable output would result. However, rectifiers do not have linear characteristics at low voltage, and therefore do not have appreciable outputs.

It is apparent from the foregoing that the combination of a properly designed matching transformer together with the inherent characteristics of the rectifier can result in a zero output current with zero d-c input. Fig. 3c shows a typical transfer curve for the new transductor circuit. The transfer curve provides zero output with zero input and is essentially linear over its working range. A typical installation of this design current transductor rated 100-mv input with 3300 volts d-c insulation level is shown in Fig. 1.

A measure of the suitability of a transductor for a wide range of applications is its stability under various operating conditions. The three most important stability considerations for application of transductors are (1) supply voltage variations, (2) temperature variations, and (3) output resistance variations. Experimental results obtained with a potential transductor of the type shown in Fig. 1 for these three basic stability considerations are shown in Fig. 5. It will be noted that the error for a relatively large range of supply voltage, temperature, and output resistance is small, and hence need be given little consideration in applying the unit.

A single current-transductor design and a single potential-transductor design of this type can be used for all instrumentation and control applications where unidirectional current flow is to be measured. The single basic design of this type of transductor provides approximately a three milliampere d-c output for full scale, since low values of current are adequate for instrumentation and control applications. To simplify manufacture and testing procedures, no attempt is made to have the transductor provide an exact current output for a particular input value. Instead a calibrating resistor assembly is provided with each transductor to provide for accurate adjustment regardless of the particular instrumentation or control application (Fig. 3b). Resistor K is the only adjustment required to provide the desired output

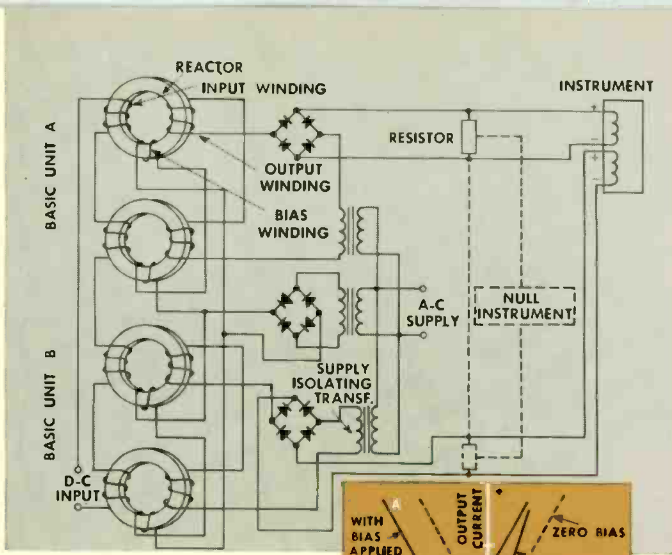


Fig. 4a—Two basic transductor units connected in push-pull.

current. Terminals are provided on the resistor assembly so that a milliammeter can be connected to indicate the magnitude of current in the individual circuit to which the transductor is connected. Other terminals are made available to provide millivolt drops proportional to the input current so that totalizing of any number of circuits can be readily accomplished by adding the millivolt drops of all transductor output circuits.

Telemetering

The fact that the new transductor can be operated into an output resistance of 10 000 ohms or more makes possible the use of this transductor for telemetering over metallic circuits. Only a single pair of line wires is required to connect the transductor to the remote milliammeter. Since 10 000 ohms is in series with the line wires, the error that results from a change of line-wire resistance will be negligible for line-wire resistances up to 2000 ohms, more resistance than is encountered for most telemetering applications using complete metallic circuits.

Of course, the transductor provides a d-c millivolt output that can be connected to a telemetering transmitter for applications where telemetering cannot be accomplished by circulation of direct current over a pair of wires.

Single Design for all Applications

This single basic transductor design can be universally employed in all instrumentation and control applications for a single direction of current flow. Where both directions of current flow are desired, a bias winding can be added to this same basic transductor and two transductors can be connected to provide push-pull operation to give output reversal. Application problems with this type transductor are simplified because for all practical purposes linearity has been achieved and zero output results for zero input. Also, standard simple calibrating means take care of small differences in individual transductors. Thus, the application of transductors has approached the relative simplicity of a-c current and potential transformers.

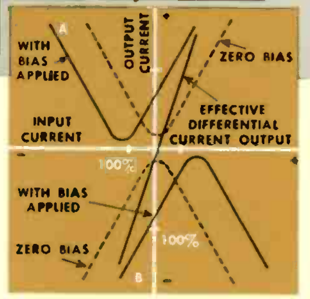
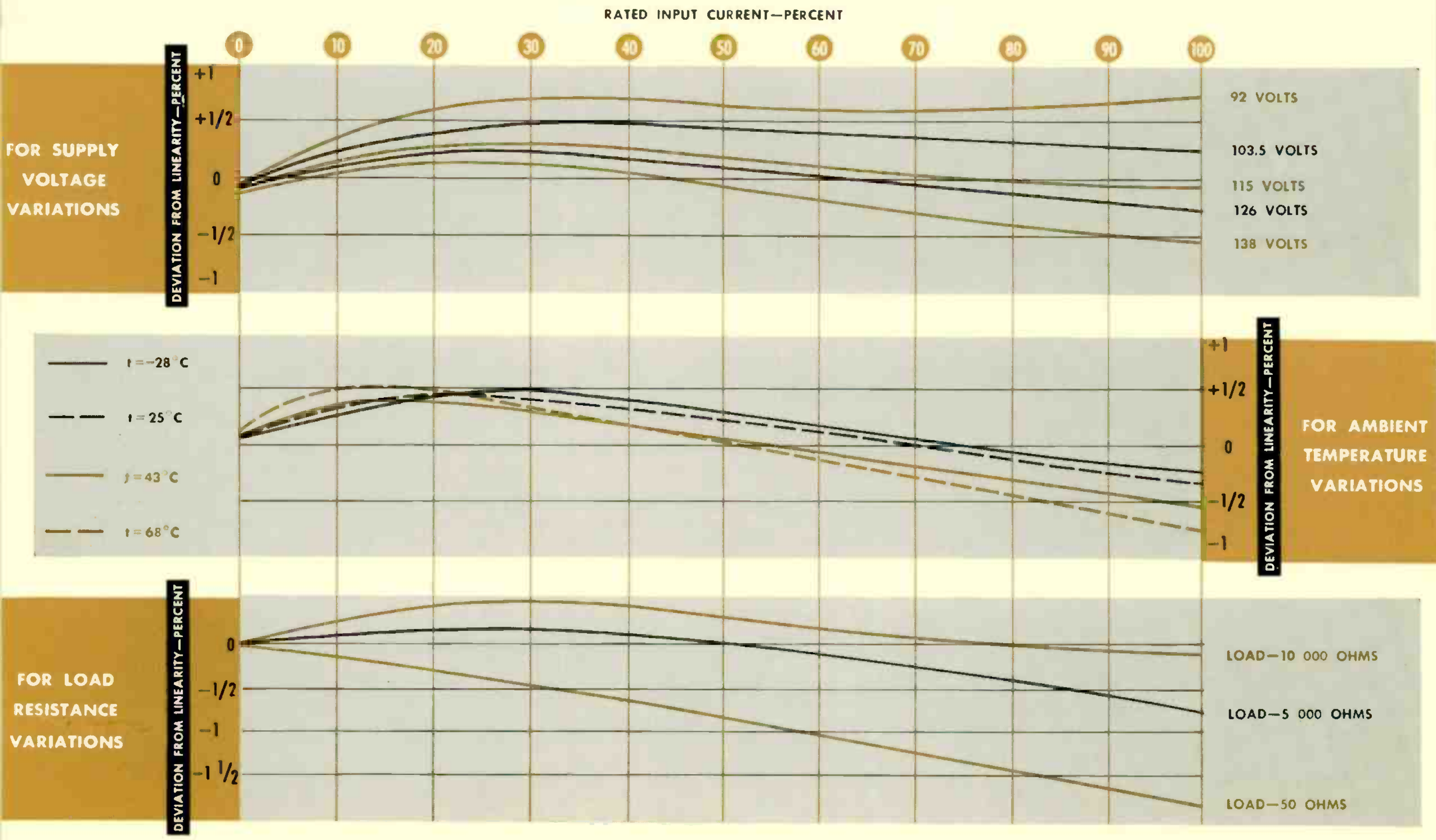


Fig. 4b (right)—Transfer curves showing effective differential current resulting from push-pull operation of two basic transductor units.

Fig. 5—Deviation from Linearity for new transductor circuit . . . . .



An Engineering *Personality* / SAMUEL B. GRISCOM

"SAM may not have the greatest number of patents in Westinghouse, but they're certainly the most diversified."

This compliment recently paid Samuel B. Griscom by one of his associates is an apt one. For although Griscom has spent most of his 34-year Westinghouse career as an electric-utility engineer, his diversity of interests and abilities keeps him ever in search of new or better ways of doing things. He has an uncanny sense of proportion for grasping a problem, from which comes a practical feel for what the answer should be. These attributes would seem most desirable for a consulting engineer, and indeed, Sam Griscom has used them well.

The skill and resourcefulness with which Sam Griscom attacks a problem are reflected by the patents that have resulted from his studies. When the theory of power-system stability was in its infancy, Griscom participated in staged tests to prove the newly developed theories. He came up with a fundamental idea for high-speed reclosing, and invented a basic mechanical analogy for power transmission, which has since been used universally to demonstrate the concept of system stability. The model (see photograph) that was originally developed to illustrate his mechanical analogy is still in use. He has been a co-inventor of several regulator systems, and has come up with patents for such devices as initiating elements for automatic oscillographs, a generator grounding system, a transmission-line protective system, and a starting means for synchronous motors, to name a few.

Griscom's ability to apply himself wholeheartedly to the task at hand started in college. He entered Cornell University in the fall of 1917 and graduated with a degree in electrical engineering, completing a five-year course in four years. This was accomplished by passing special examinations in some subjects for which he studied in his spare time. He came immediately to Westinghouse on the Graduate Student Course. In one of his student assignments, he worked in the engineering labs performing developmental tests on lightning arresters. His work was appreciated, and he agreed to leave the graduate course to continue the testing. However, after a year and a half in the lab, Griscom began to yearn for a wider variety of problems. In 1924 he transferred to the central-station section of the General Engineering Department. His first project in the department is not easily forgotten. He assisted in an exceedingly detailed analysis of the Virginian Railroad. He smiles when he recalls that five men worked better than six months with hand calculators, analyzing the complete electrical network by conventional vector methods—the same problem can be done on a calculating board today in about one week's time.

His attention was next devoted to subjects of power-system stability. He worked with such people as C. L. Fortescue, R. D. Evans, and C. F. Wagner, assisting them in their development of the theoretical aspects of long, high-voltage, electrical power transmission. During this time he picked up additional experience in the utility field as an exchange engineer, working for the Southern California Edison Company in Los Angeles. Shortly after returning to Westinghouse in 1927, he developed the theory of high-speed reclosing of power circuit breakers for prevention of service interruption. The principles of this invention have since been widely accepted, with numerous installations in this country and abroad.

In 1929 he was made a sponsor engineer, to assist utilities in the application of Westinghouse equipment. His first assignment was with utilities near Detroit, which included the state of Michigan and parts of Ohio. Shortly after this he picked up the remainder of Ohio, as well as western Pennsylvania. Later he added several projects in the southeastern states.

In 1941, his beat was shifted to the company's eastern district, which includes New York City and small portions of the states of New York and New Jersey. Although the physical territory is small, New York City is a central location for many utility syndicates and consulting engineering firms, as well as the headquarters for the company's international business. Thus the scope of his activity was broadened considerably—nothing could have been more to Sam's liking.

Now an Advisory Engineer in electric-utility engineering, he works with utility companies world wide. In India, he assisted in the twelve-million dollar Nangal project; in Brazil, it was the Paulo Afonso hydroelectric-power development; during the war he spent a lot of time on the special facilities for power generation and distribution for the Manhattan project; add to this the countless number of other projects in which Griscom is involved, all over the world, and you have some idea why, as far as he is concerned, "It's the best job in Westinghouse."

Griscom's personal interests show even more diversity. He had a radio amateur's license before World War I. After college he developed a liking for golf and played, as he describes it, "fanatically" for a period of years. This was followed by duplicate bridge, often two and three sessions a week. In 1936 astronomy caught his eye, and he went into this one with even more enthusiasm. He even built his own telescope, right down to grinding the lenses.

Two sons growing up again switched his interests, this time to mechanical toys. An excellent mechanic, he built a miniature powered bulldozer and a shovel, both remotely controlled, which could perform all of the conventional motions of the prototype devices.

When television came into its own, Griscom's interests returned to the electronics field. He had one of the first tv sets, constructed from the first kits available, which circuitry he promptly proceeded to improve. This renewed his interest in radio, and he put his amateur station back on the air. Completely homemade, it is the best available—a single side-band outfit with an all-wave receiver.

His study of any project he enters is thorough. In tv, he developed a patent for a color television tube; another patent has resulted from his all-wave radio-receiver circuitry; even a passing interest sometimes results in patentable ideas for Griscom—his latest is a new escapement mechanism for automobile electric clocks. Once, when he was confined in a hospital, he even devised a new gadget for removing kidney stones.

No subject is too remote to escape analysis from Griscom. Even at lunchtime, an everyday "bull-session" may suggest a new field for investigation. You'll have to admit, Sam Griscom is a most diversified engineering personality.

New Look *in Kitchens*

If you are proud of your new automobile with all its built-in accessories and conveniences, take a look at what's on tap for the distaff side. The latest word in kitchens, accelerating the trend toward more built-in equipment and incorporating many revolutionary color and design ideas, is being introduced this year. Flexibility of installation has been the keyword in every instance: a built-in refrigerator-and-freezer combination can be mounted either vertically or horizontally; washer and dryer units can be mounted side by side or one above the other; surface-cooking units are made in both two-and four-element sizes for a combination of installation arrangements; and all come in a variety of colors—aqua, yellow, pink, gray, and white—some also in copper, chrome, or stainless steel. A guided tour through the kitchens on these pages will illustrate our point.

This 17-inch wide True-Temp oven is a new addition to the Westinghouse line of built-in ovens. It is equipped with an automatic timer, clock, single-dial oven control, and all controls are located below the door out of the heat zone. Styling of the oven carries out the family resemblance to the new built-in refrigerator-freezer combination.

For surface-cooking capacity in conjunction with the built-in oven are two new 2-element surface-cooking units. The unit shown features a new 6-inch Super Corox element that "gets red hot in 20 seconds" and another 6-inch Corox element. Another model offers a 6-inch standard element and an 8-inch Corox element. Both models have remote controls that can be located at any convenient place near the unit—possibly on a counter backsplasher out of reach of children, or right on the counter top beside the units. The separation of the usual four-surface units into two groups gives flexibility for locating the units anywhere in the kitchen, wherever specific cooking jobs are to be done.

A two-door combination refrigerator and freezer can be installed horizontally (below) with the refrigerator and freezer compartments side-by-side, or vertically (right) with the freezer compartment located beneath the refrigerator compartment. Both the vertical and horizontal model have total storage volumes of 12 cubic feet—with a refrigerator capacity of over 8½ cubic feet and a freezer capacity of over 3 cubic feet, providing storage for over 105 pounds of frozen foods and ice cubes.

This is one of the four dream kitchens shown by Westinghouse at this year's Furniture Market. It features a built-in horizontal installation of the new Westinghouse refrigerator-freezer combination, a 24-inch built-in oven, a 4-unit surface cooking platform, and under-the-counter installation of a dishwasher and a food-waste disposer.

A new innovation in home laundry equipment—completely automatic washing and drying in a floor space just 25 inches wide—is possible with this new 25-inch dryer and its matching twin, the Laundromat 25. These two appliances have been designed to permit dryer installation above the Laundromat, making the two into a single unit. This not only saves space, but it also permits the homemaker to dry one load of clothes while another is washing.

The front-opening feature, combined with the front-mounted control dial on each model, makes the vertical installation possible as either free-standing or built-in units. The appliances can also be installed side by side. Features of the new dryer include a modified direct-air-flow system for quicker drying, and a door that can be hinged to open right or left, whichever best suits the installation requirements.

what's NEW!

Cold Tests for Turrets

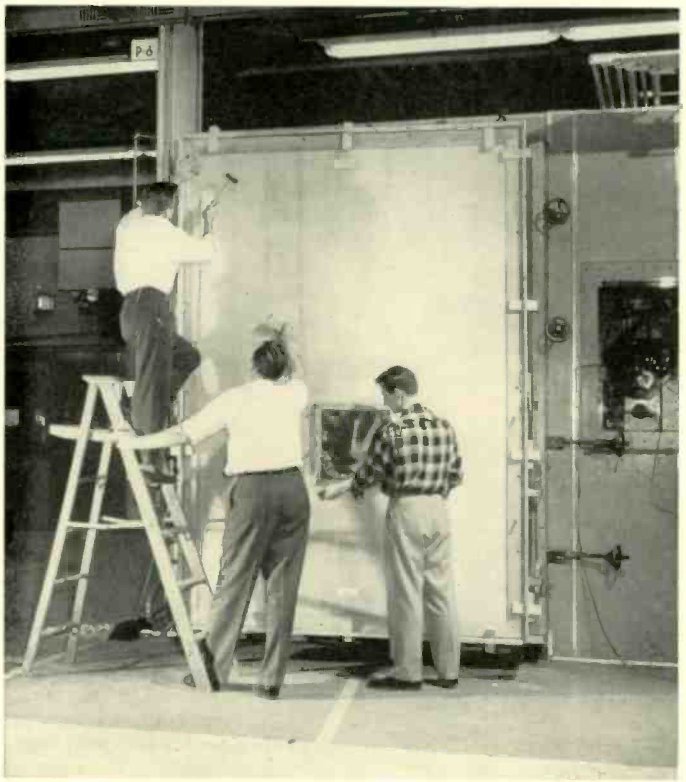
THE DYNAMIC accuracy of radar-controlled turret systems has been tested by engineers of the Air Arm Division for several years. Now they have added a new wrinkle—same tests, but at —54 degrees C, conditions that closely simulate high-altitude operation. Several problems had to be tackled and solved before the tests could be successfully completed.

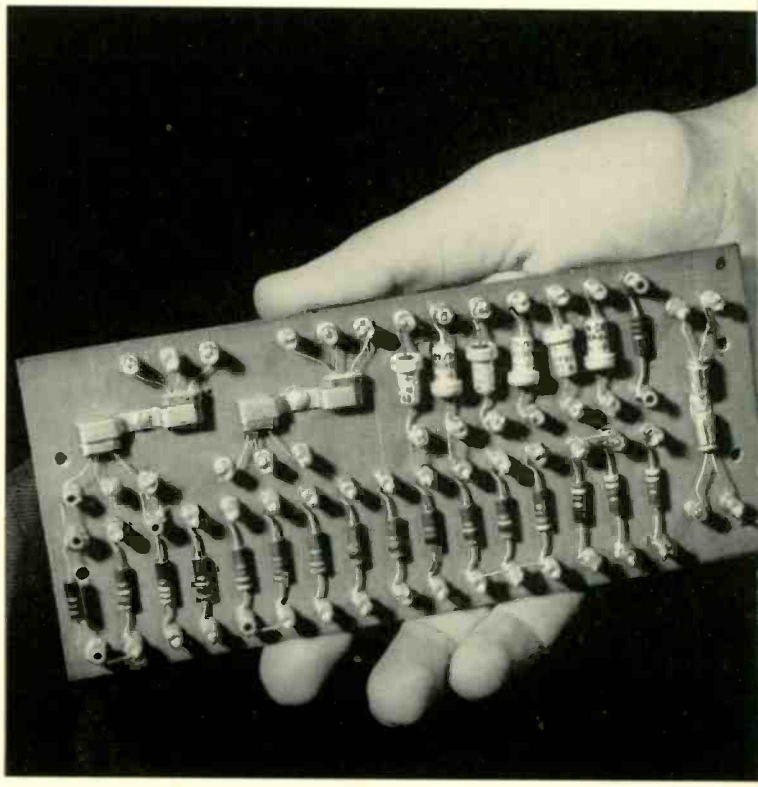
First problem was radar beam distortion, caused by the proximity of reflective surfaces in the plant area where the low-temperature chamber is located. To eliminate reflections, a free-space simulator, consisting of a chamber 12 by 12 by 30 feet long, lined with radio-frequency absorptive material, was developed. A target-simulating device is located in the chamber. When the turret radar system seeks a target, it will locate a transponder horn, which is rotating in a vertical plane. The horn receives the radar beam, relays it to a target simulator, which "reflects" the beam back to the turret radar via the transponder horn after a suitable delay, representing the time necessary for a radar beam to travel and return a predetermined distance in space. Also on the rotating arm with the transponder horn is an optical device that is set with proper "lead" to optically check the position of the turret guns.

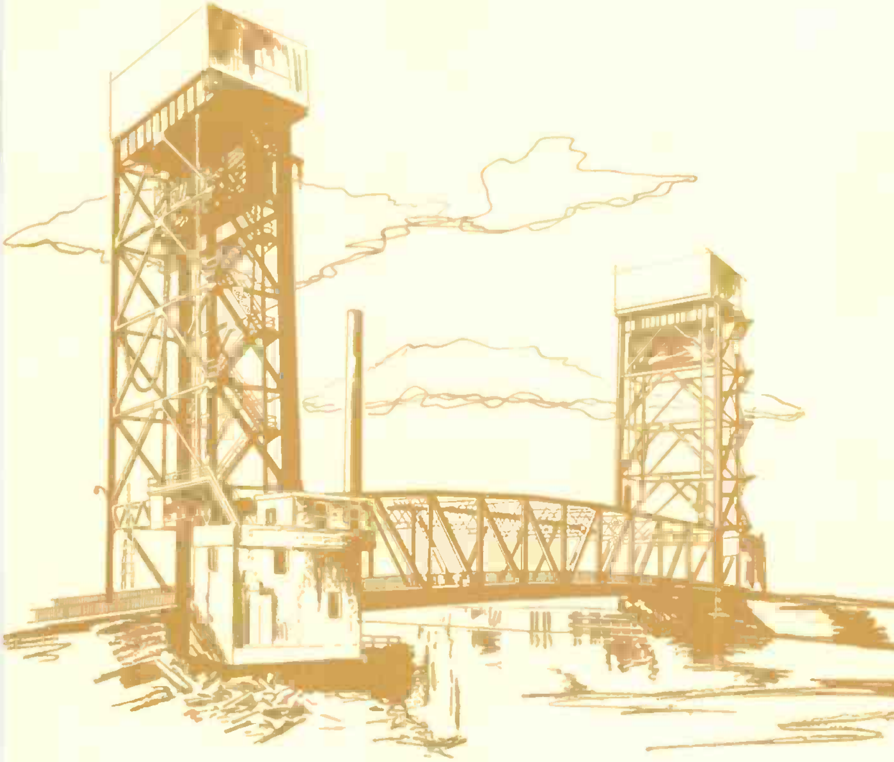
Another problem was the selection of a suitable "radio-frequency door" for the cold-test chamber. The complete aircraft tail-turret system consisting of the tail "bubble" which holds the radar scanner, the electronic computing equipment, and the gun-turret assembly is mounted in the cold-test chamber adjoining the space-simulator chamber. A door to the cold-test chamber was required that would introduce no more than one mil boresight shift in the radar beam. This door has a thermal conductivity low enough that when the inside of the chamber is at a —54 degrees C, the outside of the door will be above the dew point (or about +28 degrees C) to prevent condensation.

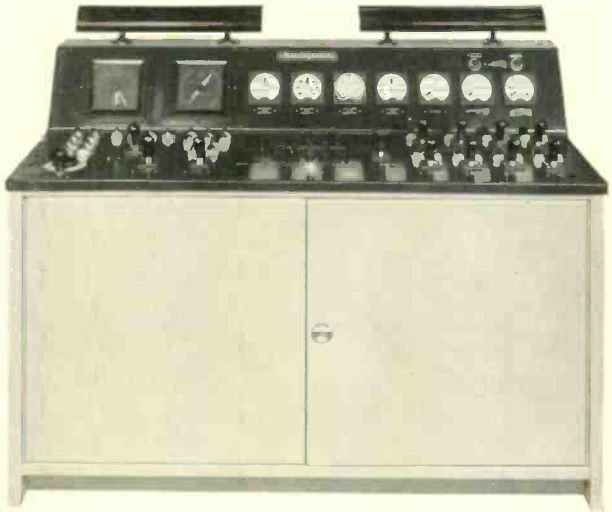
A third major problem was the elimination of boresight shift due to proximity of the metal cold chamber. This was solved by a truncated cone of r-f absorptive material surrounding the antenna, and a wooden extension to the cold chamber, which allowed the antenna and turret to be moved away from the metal chamber.

In operation, only the gun barrels of the tail turret project from the cold chamber into the free space tunnel. This is because the turret operation must be checked optically by sighting from the gun barrels to the optical device on the rotating target. In operation, the radar fire-control system tracks the rotating transponder horn and computes the lead angle required, causing the turret guns to follow the target. The optical system checks to see that the freezing cold of the test chamber has not affected the system's ability to "think and act" accurately.





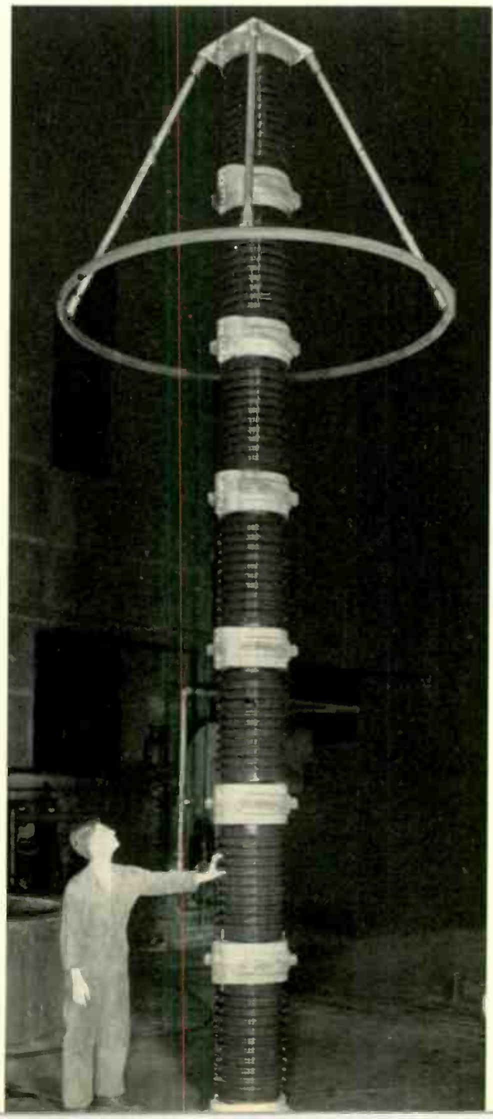




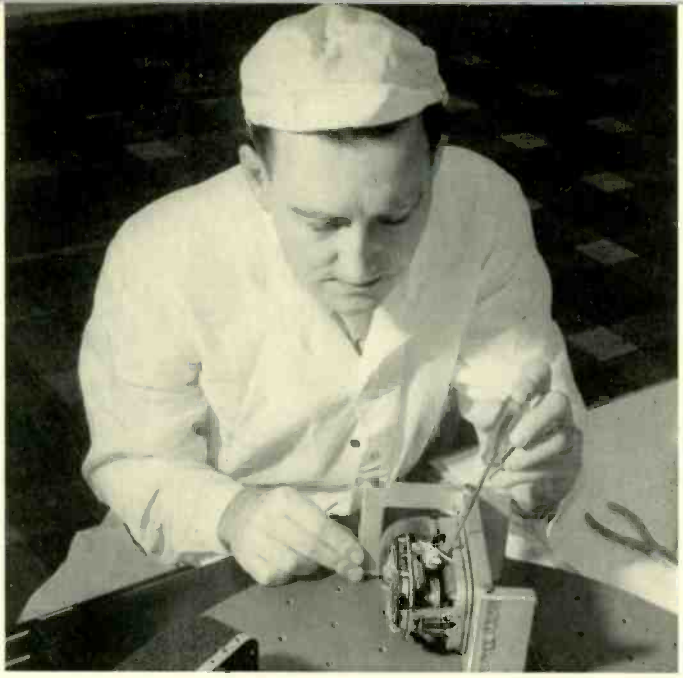
In tower-type bridges, such as this one in Buffalo, New York, two separate drives, one in each tower, raise the span. This means that the two sets must be closely synchronized to maintain the bridge in a level position as it moves up and down. The d-c adjustable-voltage drive that powers this bridge is controlled by a combination magnetic amplifier and Rototrol regulator that maintains the span level within one inch over the complete travel from down position to the top. The use of adjustable-voltage instead of an a-c drive reduces the likelihood of the bridge drive seriously affecting voltage regulation of electric-utility systems. A similar drive, without the circuits that maintain the span level, is used on a bridge in Seattle. This is a bascule double-leaf bridge, where there is no need to keep leaves in perfect synchronism; this is the first use of adjustable-voltage drive on a bascule leaf bridge.

A transistorized amplifier for controlling an electro-hydraulic control valve in a high-performance servomechanism is the first step in the development of an all-transistor automatic pilot for aircraft. Transistor circuitry offers advantages in size, weight, and efficiency over previous conventional circuits employing vacuum tubes and magnetic amplifiers. The silicon-junction transistors used will operate satisfactorily throughout a temperature range of -55 degrees C to $+100$ degrees C.

The transistorized amplifier compares the sum or difference of several command and feedback signals, amplifies the resulting quantity, and provides the necessary electrical power to operate an electro-hydraulic control valve.



High-voltage lightning arresters grow smaller and better. Another mechanical construction has been added to the four already in use, providing still greater flexibility of design to suit station needs. The new type-SVS arrester consists of self-contained units about half as high as those hitherto standard. The reduction in height is accomplished by arranging three stacks of elements in a single porcelain housing. The stacks are physically in parallel and electrically in series. The elements are full-size Autovalve station-type blocks and series gaps. Improvements have been incorporated in both, thereby lowering the protective characteristics and increasing the surge-current withstand ability. The SVS arrester requires no mechanical bracing even up to the highest voltage ratings. Thus, installation is simplified and space requirements reduced. The heights of the units are the minimum considered practical, the limitation being creepage distance and wet flashover over the outside of the housings.



Electric Couplings Gain Their Independence

Where previous electric couplings have been overhung from the diesel engine and driven gear respectively, a new electric coupling for the Navy's LST vessels will be supported by its own bearings.

Electric couplings are devices for transmitting torque by means of electromagnetic forces, in which there is no contact between the driving and driven member. The outer member carries poles which are excited by direct current through slip rings. The inner member has a double-bar, squirrel-cage winding. Rotating either member will, by induction, cause torque to be exerted on the other member and the speed of the two will only vary by a small slip required to produce the necessary torque.

Electric couplings are used to connect more than one diesel engine to pinions driving a common bull gear connected to a ship's propeller. The electric coupling eliminates shocks and

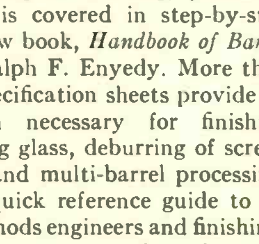
Permanent-Magnet Rate Gyro

A hermetically sealed, permanent-magnet rate gyro has been designed for use in armament control systems where extremely accurate angular-rate measurements are necessary. The spinning gyroscope wheel is mounted in a magnesium gimbal suspended on ball bearings. A current coil is rigidly attached to the gimbal, and free to rotate between two powerful permanent magnets. When the assembly is turned (when the aircraft makes a turn) the gyroscope resists turning with a force proportional to the rate of turn. The interaction of the permanent magnet and coil when a current flows in the coil creates a force in opposition to the gyroscopic force. Therefore, the current necessary to balance the gyroscopic force is an accurate measure of angular rate.

A new d-c magnetic brake (Type SA) eliminates all need for adjustment throughout its service life. Designed primarily for steel-mill and crane service, the brake can be used on all applications requiring rapid stopping of a motor, such as hoists, conveyors, turn tables and lift bridges. Brakes are usually floor mounted with the brake wheel mounted on the shaft extension of the motor, but can be mounted directly on the motor frame by means of a special brake adapter. Once brakes are set for proper torque, no further adjustment is required during the life of the brake lining. The brake automatically adjusts itself to compensate for brake-lining wear and expansion of the brake wheel. By not permitting shoe tips to drag, the self-aligning feature provides for even lining wear, and in some applications increases lining life about 50 percent. Wheel wear and scoring are also minimized. The brake is available in sizes to fit all d-c motors. Applications to a-c motors are possible with the addition of rectifiers.

what's NEW! in literature...

Barrel Finishing



Every phase of barrel finishing from cleaning and deslugging to coloring, polishing, and burnishing is covered in step-by-step sequence in a new book, *Handbook of Barrel Finishing*, by Ralph F. Enyedy. More than 150 complete specification sheets provide all the information necessary for finishing metals for sealing glass, deburring of screw-machine parts, and multi-barrel processing. The book is a quick reference guide to industrial and methods engineers and finishing-department supervisors, and makes apparent the cost-saving advantages of barrel finishing over tedious, expensive hand-finishing operations.

Prior to joining Westinghouse in 1952, Mr. Enyedy was methods and industrial engineer with Remington Rand, Inc., where he became extremely interested in the possibilities of barrel finishing. He devoted much time to experimenting on advanced methods of tumbling. At Westinghouse, he has continued his research, and has instituted several new tumbling developments and set up complete standardization of methods for barrel finishing at the Electronic Tube Division.

The book is published by the Reinhold Publishing Corporation of New York, and priced at $7.50.

Principles of Electric Utility Engineering

Although today's utility industry is too complex for anyone to know in its entirety, a knowledge of the essentials of the industry are a must for any young engineer starting out in this field. A new 251-page book, *Principles of Electric Utility Engineering*, by Charles A. Powel, reviews the everyday problems facing the electric utility engineer in all branches of the industry. Typical chapters discuss: corporate organization, objectives, and finance; sources of energy; steam generating stations and their auxiliaries; transmission systems and equipment, power distribution; power-system fault control, lightning phenomena and insulation coordination.

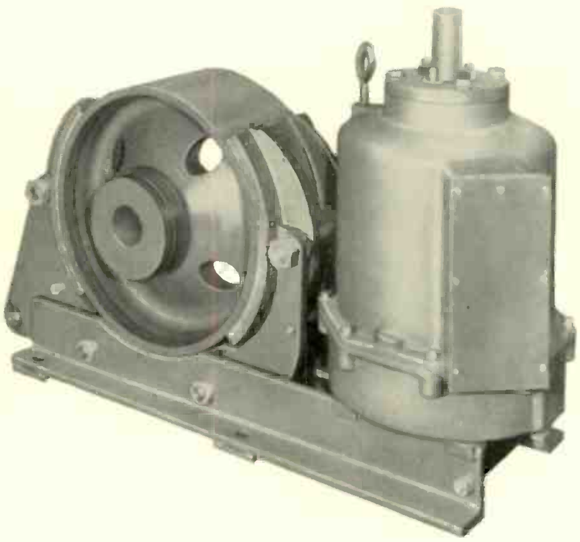
Mr. Powel has had 43 years experience in power engineering. A graduate of the Institute of Technology, Bern, Switzerland in 1905, he served 10 years with Brown Boveri and Company, including four years as resident engineer in Japan. In 1919, Powel joined Westinghouse, where he remained until his retirement in 1949 as assistant to the vice-president of engineering. He then joined the staff of the Massachusetts Institute of Technology, where he lectured on everyday problems of the utility industry until 1954. He is a past president of the AIEE.

The book is published jointly by the Technology Press of the Massachusetts Institute of Technology and John Wiley & Sons, Inc., and is priced at $6.00.

limits the transmission of torsional vibrations, acts as a quick disconnect clutch, limits the maximum torque to a safe value, and permits a small amount of engine-gear misalignment.

In past applications, the inner element has usually been overhung from the engine shaft and the outer element from the gear-pinion shaft, although there are cases where this has been reversed. Because of high shock requirements, the LST couplings have been supplied as a complete unit with bearings and bedplate.

Another feature of the LST coupling is the provision for straight-through drive in case of electrical failure. This drive is the equivalent of supplying a flexible coupling of fuel-engine horsepower capacity that will take misalignment, no easy problem in itself. Clever design has provided that when not used for emergency drive, the direct-drive parts become ventilating fans, and can also be used for shipping supports.

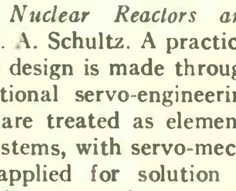


Electric Stairways

THOSE LONG desperate treks across the college campus are being mechanized—students are changing classes on electric stairways! This innovation has already taken place in the University of Illinois' new $5 500 000 East Dentistry-Medical-Pharmacy Building in Chicago, where classroom and laboratory space is provided for students of pharmacy and other professional colleges.

Ten Westinghouse electric stairways travelling at 120 feet per minute are capable of transporting more than 10 000 students to their classes in a ten-minute period. Considerably faster than usual stairways, which travel 90 feet per minute, these express models can carry a student from the basement to his class on the fifth floor in 78 seconds, with no puffing.

Nuclear-Reactor Control



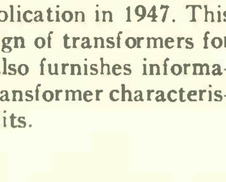
The article on fundamental aspects of nuclear reactor control appearing on page 74 of this issue was abstracted from a new book, *Control of Nuclear Reactors and Power Plants* by M. A. Schultz. A practical approach to control design is made through the use of conventional servo-engineering methods. Reactors are treated as elements of larger control systems, with servo-mechanism techniques applied for solution of control problems. The relationship between physics, servo engineering, and thermo-dynamic requirements of nuclear controls is thoroughly explained.

The book treats modern design technology for solid-fuel heterogenous thermal reactors in such a manner that more complicated types of control systems may be designed by extending these basic methods.

M. A. Schultz joined the then newly-formed Westinghouse Atomic Power Division in 1949 as Manager, Instrumentation and Control Subdivision. In this capacity, he was responsible for the instrumentation and control development of the submarine thermal reactor plants and for much of the control philosophy of present-day pressurized-water reactors.

The book is published by McGraw-Hill Book Company, and priced at $7.50.

Electronics



The second edition of *Electronic Transformers and Circuits* by Reuben Lee incorporates the advances in this field since the book's original publication in 1947. This basic work on the design of transformers for electronic apparatus also furnishes information on the effects of transformer characteristics on electronic circuits.

New chapters include one on magnetic amplifiers, where the more common components and circuits are described; another on pulse circuits contains material on line-type radar pulsers, false echoes after main pulse, charging reactors, and related details.

Other chapters cover: transformer construction, materials, and ratings; rectifier transformers and reactors; rectifier performance; amplifier transformers; amplifier circuits; higher-frequency transformers; electronic control transformers; and pulse and video transformers. Mr. Lee has prepared entirely new sections on reactor surges, toroid curves, r-f power supplies, wide-band transformers, and charging chokes. He has also reworked his earlier discussions of transformer theory, core material, reactor theory and design, Class-B transformers, audio-filter inductors, and rectifier regulation.

Mr. Lee has been affiliated with Westinghouse for over 30 years, and is now advisory engineer at the Electronics Division. He holds 24 patents on transformers and similar devices.

Published by John Wiley and Sons, Inc., the book is priced at $7.50.

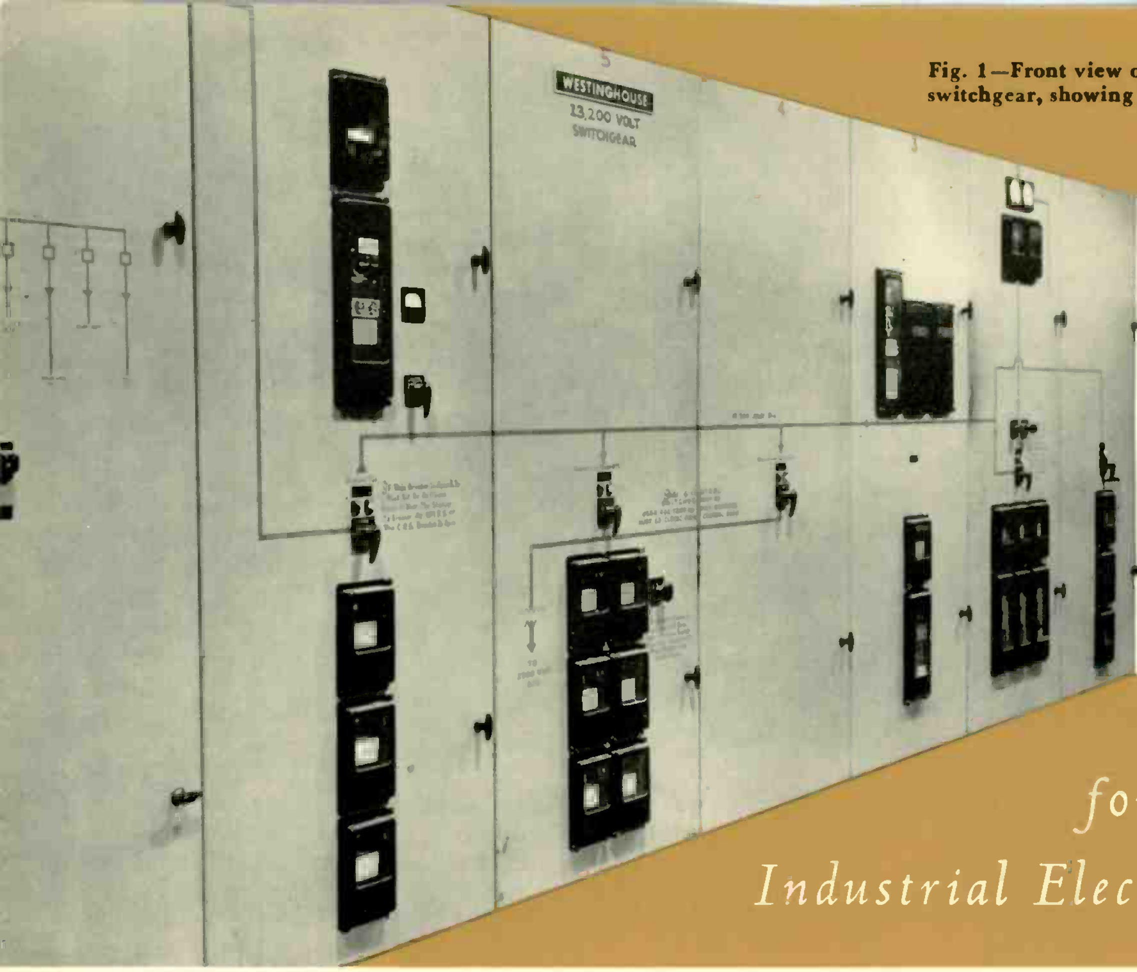


Fig. 1—Front view of 13.8-kv indoor switchgear, showing relaying panels.

Protective Relaying... *for* Industrial Electrical Systems

W. C. Woods, *C & A Engineer*
Engineering and Service Department
Westinghouse Electric Corporation, Houston, Texas

Protective relays have been called the brains of the electrical power system. As these systems grow and become more complex, relaying practices must be modernized to keep pace.

In the early electrical systems for industrial plants, little emphasis was placed on protective-relaying. Since these early systems were often relatively small and simple, and maximum service continuity was not always considered necessary, this lack of planning was not a serious handicap. In recent years, however, systems have become more complex, short-circuit currents have increased, and manufacturing processes have come to demand more reliable service. Because of these and other factors, plant electrical engineers have found it necessary to give much more consideration to relaying problems to provide more reliable service to major processing and manufacturing units, as well as prevent or limit damage to equipment in case of improper operation or electrical failure.

Requirements of a Relaying System

Before discussing specific relaying problems, consider some of the requirements of a good relaying system.

Dependability—Above all, a relaying system should be dependable, particularly when a lack of dependability would cause a shutdown of a major process unit.

Selectivity—The system should be selective to the point that a fault in any part of the system will not cause an unnecessary outage to any unaffected load, particularly if this load is a vital process unit.

Speed—As systems increase in size and fault currents become greater, decreased relaying time is desirable to limit damage to electrical and associated equipment. In some locations, it is even more vital that any fault be cleared as soon as possible to reduce the probability of a nonelectrical fire or explosion. Fast clearing of faults can mean less system disturbance, thus reducing outage time to the affected circuit. It may also prevent instability between generators or other synchronous machines.

Simplicity—The relaying system should be kept as simple as possible, consistent with other requirements. For example, the proper use of instantaneous trip attachments on induction overcurrent relays may sometimes be used in preference to more complex relaying with similar results.

Economy—The question of economics cannot be overlooked during selection of any type of equipment. However with protective relays, proper evaluation of first cost plus maintenance of protective equipment compared to the probability of extended or unnecessary outage time and additional equipment damage under fault conditions is difficult. However, one unnecessary outage of a major process unit can result in losses of production many times the value of a few protective relays that could have prevented the outage.

Information Required for Relay Selection

Selection of the proper relays for any piece or group of electrical equipment without looking at the electrical system as a whole is impractical. Before relays are selected, a system one-line diagram or equivalent should be analyzed, and normal system operation should be understood. Both maximum and minimum system fault currents should be known for all

Assistance in the preparation of this article was provided by R. B. Squires, Manager, Technical and Computer Section, Switchgear Division, and R. F. Lawrence, Manager, Distribution Engineering, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania.

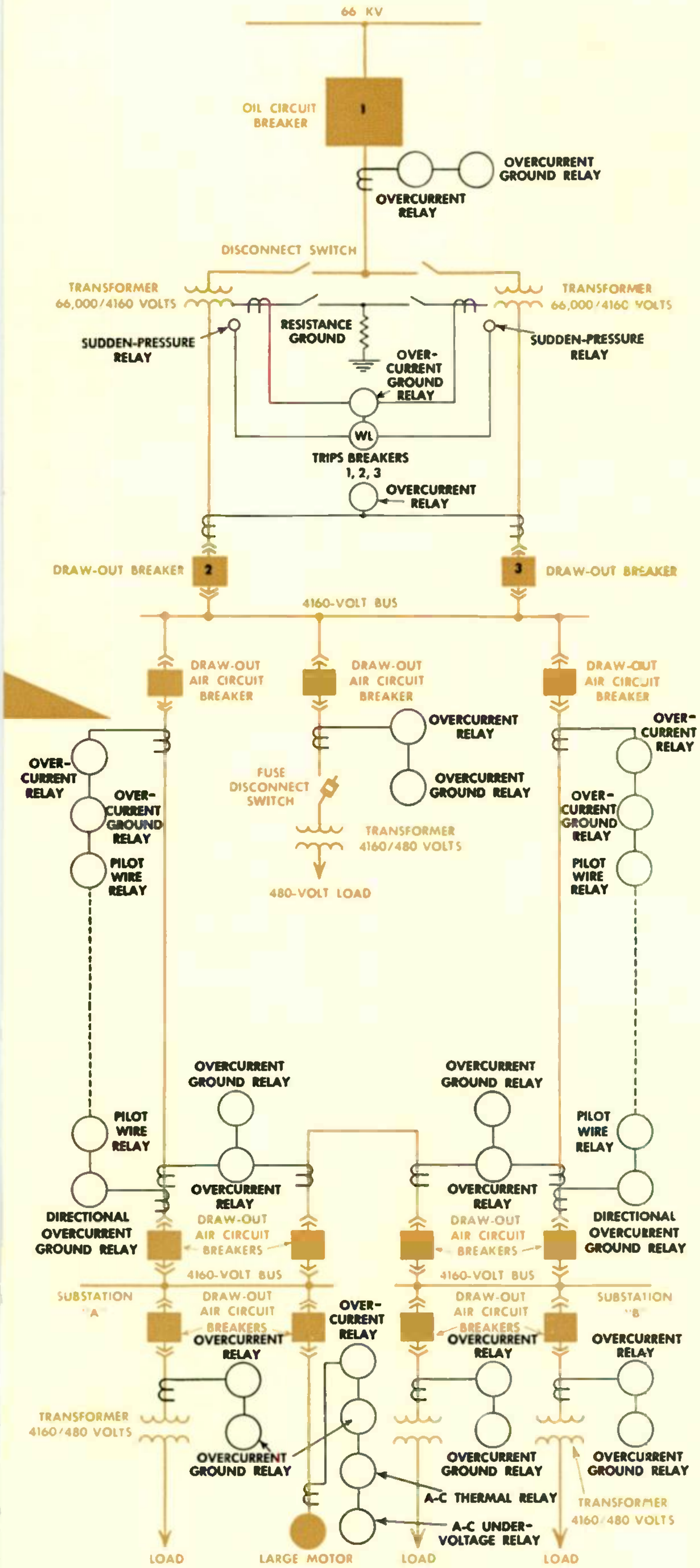


Fig. 2—Typical diagram of a relatively small industrial power system. As the system becomes more complex, additional relaying equipment is necessary to assure service continuity.

types of faults. Normal full-load and peak-load currents should be known. Where transient stability may be a problem, the approximate time for the system to become unstable should be known for various abnormal conditions. Characteristics of instrument transformers must be evaluated.

When new equipment is added to an existing system, the characteristics of other protective equipment on the system must be known. For example, selection of time-overcurrent relays requires a knowledge of the time-current characteristics of other protective equipment (such as fuses, series overcurrent trip devices on breakers, other relays, etc.) with which the new equipment must coordinate.

Basically, relaying of one component part of an electrical system usually affects the relaying of other parts of the system. Protective equipment improperly selected can make difficult and sometimes impossible proper coordination of the protective system.

Protection of System Components

Generally speaking, an electrical system can be divided into protective zones so that a minimum system disturbance results when a fault is isolated by the proper relays and associated circuit breakers. It is desirable that each protective zone include only one major system component such as a generator, transformer, bus, transmission circuit, or feeder circuit. While this is an ideal setup, economic considerations often dictate that more than one system component be included in a particular zone of protection. A description in detail of the many relaying schemes used for the protection of each zone would be impractical. However, a brief description of some of the relaying schemes used in modern systems for each protective zone will be of interest.

Generators—Although the majority of industrial plants purchase power, many industrial systems generate some or all of their electrical energy. Until recent years, a large number of these generators had no protective relays whatever to

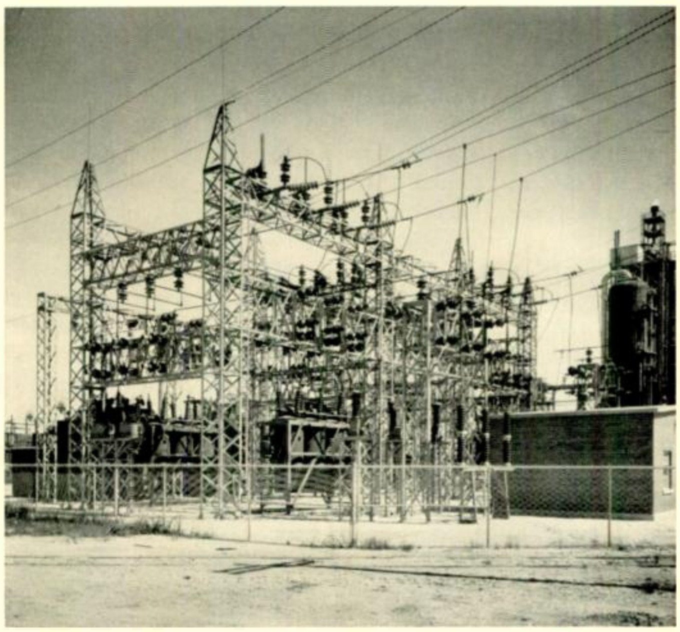


Fig. 3—High-voltage substation feeding a refinery in Texas. Two 66-kv incoming lines provide a dependable power supply. Relaying panels are located in battery and control house at right.

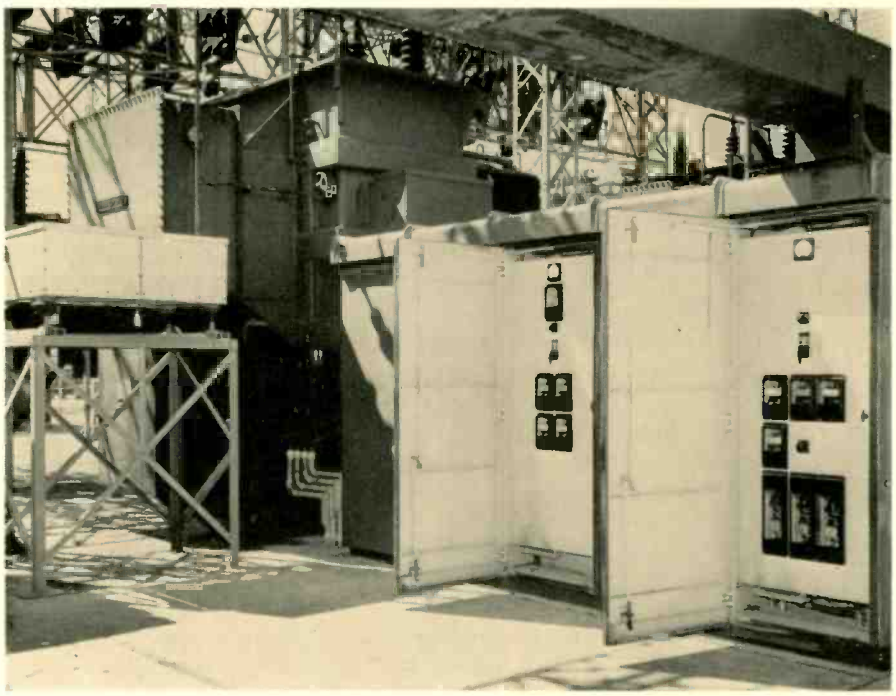


Fig. 4—Transformer with 15-kv metal-clad switchgear. The panel on the left shows feeder relaying. Mounted on the right-hand panel are differential and overcurrent relays for a tie bus.

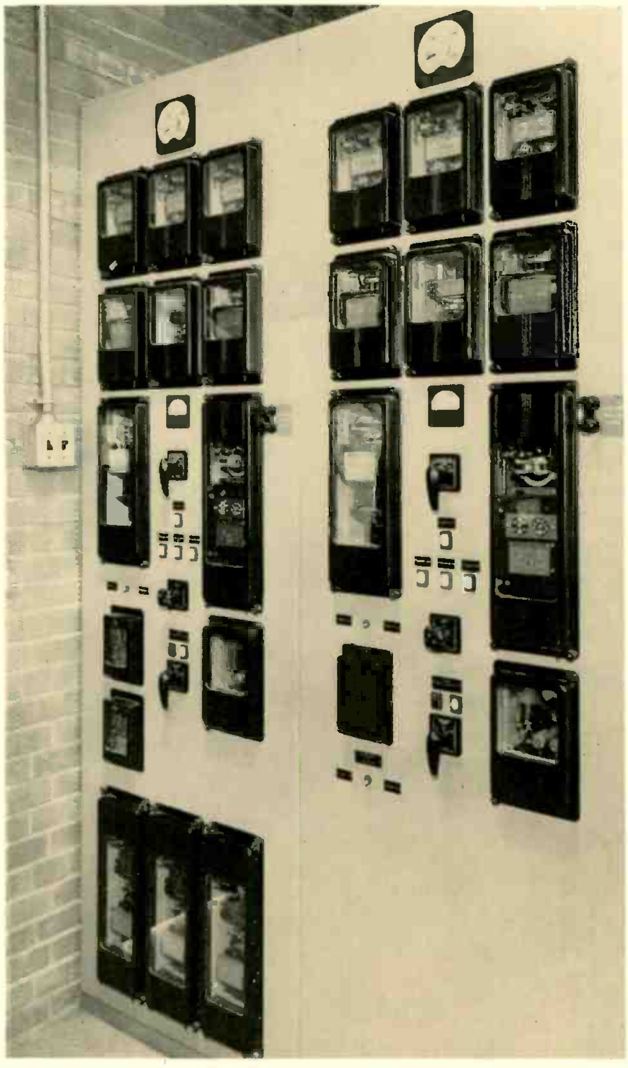
Fig. 5—Relaying panels in outdoor metal-clad switchgear. The panel on the left shows transformer overcurrent, differential and ground relays. The panel on the right protects a feeder circuit with phase and ground overcurrent relays.

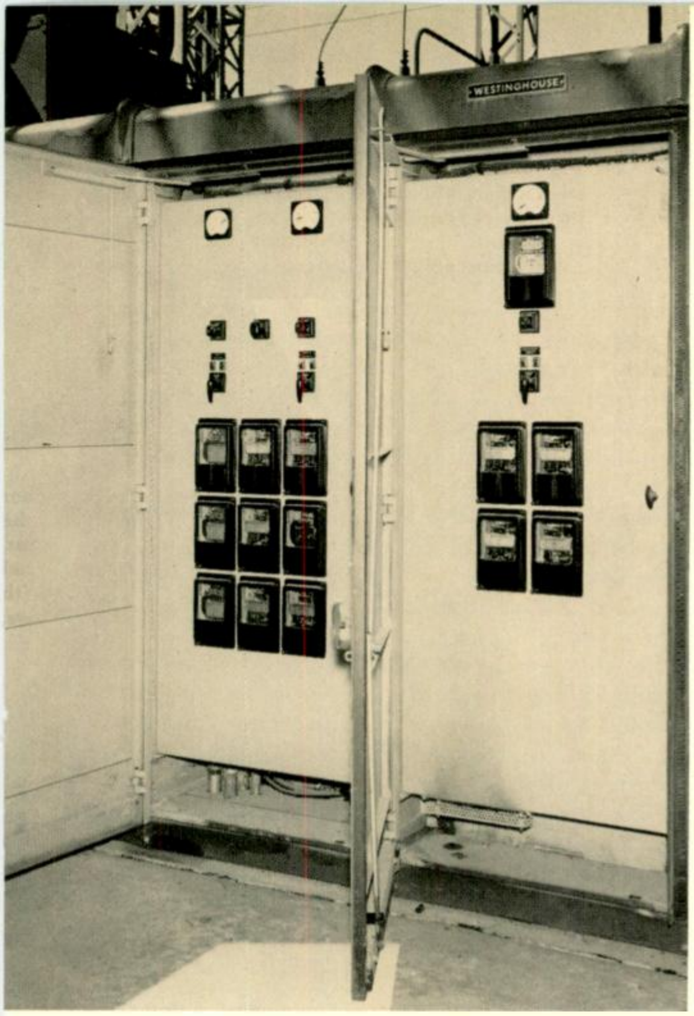
remove them from the system in case of internal or external trouble. The general feeling seems to have been that there was little justification in risking the loss of a main unit because of an erroneous relay action, particularly since generator faults occur so infrequently. Some efforts were made to use overcurrent relays on generators, but this practice proved difficult if not impossible. The usual argument was that an operator was on duty at all times and could trip the unit from the line in case of absolute necessity.

As the size of generators increased to provide power for increased loads, fault currents also increased and system operation became more complex. Since excellent generator differential relays were available, their use could easily be justified, particularly on all important units. Thus modern practice is strongly in favor of differential protection for all major generating units. To supplement the generator differential relays and to provide backup protection for other system relays, the voltage-controlled overcurrent relay should be used. It will remove the generator from the line when external faults near generator terminals are not properly cleared. As previously mentioned, application and adjustment of overcurrent relays to generators to obtain proper coordination on external faults with proper tripping is difficult. These voltage-controlled relays can be satisfactorily applied on small systems where bus-differential relaying cannot be economically justified, or as backup protection for bus or close-in feeder faults. It should be pointed out that if the overcurrent element of the relay is set below full-load current of the generator and a potential-transformer fuse opens, the unit may be tripped incorrectly from the line. One compromise is to set the overcurrent element slightly above full-load current so that the unit will not trip incorrectly unless there is an abnormal current at the same time that voltage is lost to the relay. Hence, if the generator is equipped with an automatic voltage regulator, there generally will be adequate current to trip the relay for this setting under fault conditions.

As machines have increased in size, experience on utility systems has shown that loss of field on a major generating unit can cause severe system disturbances. However, this is

Fig. 6—Relaying panels for control of two incoming 66-kv lines, showing pilot wire and associated relays.





a relatively rare fault, so that the size of generator units in industrial systems does not usually warrant loss-of-field protection. But when large generators with critical requirements on service continuity are involved, such protection should be considered. Upon complete loss of field, the flux decays slowly and the machine, instead of feeding reactive kva into the system, takes its excitation from the system and approaches the characteristics of an induction generator. Even though the generator continues to feed power into the system, the voltage at the machine terminals may be reduced to the point where system instability can result. If the voltage at the machine terminals does not go too low, excitation can be restored to the unit without removing it from the line. If after a given period of time the field is not properly restored, or if the terminal voltage drops too low, the unit should be taken off the system. Stable operation is possible with loss of field but continued operation can result in damage to the generator. Relays are now available to perform these functions.

External phase-to-phase faults, a potential cause of generator damage, have gained considerable attention in recent years. This type of fault can cause severe local heating in the rotor circuit of the unit. The heating is much more severe for unbalanced than for balanced faults. Thus in recent years, negative-sequence relays, which are responsive to the negative-sequence component of current, have been designed and applied. These relays have time-current characteristics to protect a generator from these unbalanced-fault conditions.

Many other special-purpose relays are available for application to generators, such as thermal relays of various types, and relays that will detect grounds in the field windings, etc. Such special-purpose units can be properly applied at the discretion of the system designer.

Basically, differential relays should be used on all important generating units; loss-of-field relays should be given serious consideration on all major units; and negative-sequence or voltage-controlled overcurrent relays may be properly applied under many conditions involving all types of units.

Buses—As with generators, major electrical buses are not particularly susceptible to faults. However when such faults are not cleared quickly, they can cause major equipment damage and extensive service outage.

The most common methods for bus protection use some form of differential relaying. Originally overcurrent relays were used in a differential connection for bus protection. Due to the saturation of current transformers on high fault currents, high-current and longer time settings were necessary to prevent tripping on external faults. These settings made the protective scheme insensitive to internal faults. Ratio differential-current relays, which are quite sensitive to internal faults but are relatively insensitive to heavy external faults that cause current-transformer saturation, have been used for many years and have given excellent service.

Several methods have been devised to avoid the saturation effects of current transformers used in differential schemes when heavy external faults occur. One eliminates the problem completely by using linear couplers instead of current transformers. Since there is no iron to saturate, the voltage output of the coupler is directly proportional to the primary current. The secondaries of the couplers are then connected in series and the resultant secondary-winding voltage fed to an instantaneous voltage relay. If the sum of the currents into the bus equals zero, then the linear coupler voltages add to zero and there is no voltage applied to the relay. For an internal fault, the differential current causes a voltage proportional to this current to appear across the relay, and results in fast clearing of the fault.

Another arrangement that is gaining popularity for bus protection in the load area is the bus-overload scheme. This is particularly applicable for substation buses with dual feed, such as a loop system. Basically, the current transformers in the two incoming circuits are paralleled, as is shown in Fig. 2, allowing the bus-overload relays to see the sum of the currents fed into the bus. This simplifies coordination with feeder relays fed from the protected bus, and also provides backup protection for feeder circuits. Although less expensive, this scheme has the disadvantage of being slower and less sensitive than bus differential relays. Generally, this scheme should be considered only for buses fed from two or three sources where differential relaying cannot be economically justified.

Transformers—Smaller power transformers are usually protected by overcurrent relays actuated by current transformers located on the primary side of the transformer. Fuses are sometimes used where circuit breakers with relays cannot be economically applied. The protection of larger transformers is more complex and requires further consideration.

The most common type of first-line protection for large transformers is provided by differential relays. Because most transformers have taps that change the ratio of primary-to-secondary turns, and because current transformers are often difficult to match from a ratio as well as a saturation standpoint, transformer differential relays cannot be as sensitive as those for generator and bus protection.

One of the major problems associated with transformer protection is the magnetizing inrush current when the unit is first energized or when a nearby fault is cleared. Various methods are employed to prevent tripping on this inrush current. One is to temporarily desensitize the relay when the transformer is first energized; fast tripping on any major internal fault is still allowed.

In recent years, a sudden-pressure relay has been developed for mounting in the gas space of a liquid-filled transformer. This relay operates on a sudden increase in gas pressure inside the transformer tank. An arc under oil results in the evolution of gases, causing a pressure wave to be sent out in all directions. The relay is sensitive to rate-of-pressure rise, so that any significant arc under oil causes the relay to operate. Thus fast, sensitive protection for any fault under the transformer oil is provided.

Protection of power transformers should consist of overcurrent relays, often used in conjunction with differential or sudden-pressure relays. A major transformer may justify the use of both of these latter types of relays.

Tie Circuits—Where an electrical system has grown to more than one power plant, or where the plant electrical system operates in parallel with an electric-utility company, the major tie circuits between these power sources can well be termed transmission lines. Protection of these circuits usually demands reliable high-speed relaying.

At one time, overcurrent or directional overcurrent relays were most commonly used for the protection of these as well as feeder circuits. In recent years, provision of high-speed relaying on these tie circuits often has been found necessary, not only to limit fault damage and outage time, but also to coordinate with other system relays and to prevent system instability. There are several methods available to provide this high-speed protection. One works on the principle that currents are normally equal on similar parallel circuits. A fault on either of the protected circuits will cause proper clearing of that circuit due to the unequal currents. However, where the circuits involved are relatively short, pilot-wire relaying is gaining in popularity. This scheme uses the mechanics of symmetrical components to compare the currents at the two ends of a given circuit. If the current leaving the circuit is not approximately equal to, and in phase with that entering the circuit, the breakers at both ends of the line are tripped simultaneously.

This method of protective relaying provides fast, selective clearing of internal faults, and should be considered on all major tie circuits.

Feeder Circuits—If the majority of feeder circuits are radial type, induction-overcurrent relays are used as the main protection. Where more reliable service is required than can be provided by radial circuits, loop circuits often are used to furnish dual feed to a substation. On these circuits, special conditions sometimes require the use of the pilot-wire relays previously discussed. Usually, induction-overcurrent and directional-overcurrent relays can provide relaying that will coordinate satisfactorily and still be fast enough that system stability will not be lost.

Large Motors—Many types of protection are used for large motors. Protection in the form of overcurrent relays or series overcurrent devices mounted directly on circuit breakers are almost always used; in addition, differential relays often can be justified on larger units. Thermal relays of many types are available and are used quite extensively. Undervoltage relays may be desirable where a sustained reduction in voltage can occur.

If power fuses are not used extensively in the distribution system, phase-balance or negative-sequence relays may not be required. However, a relatively small voltage unbalance can cause a severe unbalance in current and excessive motor heating, which may not be detected by overcurrent or thermal relays. Therefore, where voltage unbalance or single phasing is a problem, negative-sequence or phase-balance relays should be given serious consideration.

Load Shedding by Underfrequency Relays

Many emergency situations can arise to cause a shortage of power generation, and result in underfrequency. For example, loss of one or more generators on an isolated plant system can cause such a shortage of power that the remaining units cannot maintain frequency. Or if an interconnection is normally maintained with a utility, this tie can be lost with a resultant shortage of power.

Regardless of the cause of power shortage, corrective steps must often be taken quickly to avoid complete system shutdown. The allowable time to make these corrective steps depends on system characteristics, types of load, and relative magnitude of power shortage.

Often an operator can act fast enough to prevent shutdown. However, time is required for an operator or dispatcher to obtain and analyze system information under these emergency conditions; and decisions made under such conditions may well be in error.

One of the most satisfactory solutions to an emergency shortage of power is the use of underfrequency relays to drop nonessential load. This can be done by as many underfrequency relays as required, these relays being set at proper frequency intervals. The operation of each relay will drop one or more feeders, and load will continue to be dropped until system frequency is stabilized. Thus no excessive amount of load will be dropped, and the system can still carry the more essential or critical loads.

When generators operate in parallel with a utility system, tripping the interconnecting tie for power-shortage conditions may be desirable. For example, if a power shortage develops within the plant, the interconnection should be maintained to provide service to as much load as possible. On the other hand, disturbances on the utility should not be allowed to drag down plant-system frequency. Therefore, to get the desired tripping of the interconnecting breakers, an underfrequency relay in conjunction with a reversed-power relay can be used; an underfrequency condition will cause opening of the interconnection if power is flowing from the plant to the utility, but will not cause tripping if the power flow is into the plant system.

The use of underfrequency relays for load shedding should be considered if a serious power shortage is likely to occur. Judicious use of these units may prevent an unnecessary system outage.

Backup Protection

The above discussions have dealt primarily with the first line of protection. However, many things can prevent this first-line protection from functioning properly. Instrument transformers, protective or auxiliary relays, circuit breakers, tripping supply for circuit breakers, or other equipment may fail to function correctly. Such failures may be caused by equipment trouble or human error. Regardless of the cause of failure, adequate backup relaying that will ultimately clear a fault is highly desirable. Although operation of backup relays can cause disruption of service to units not directly involved in the fault, excessive equipment damage or complete system shutdown can be prevented. Every system must be studied separately, but careful consideration should be given to backup protection so that a fault cannot remain on the system indefinitely, even when the first line of protection fails to operate.

personality profiles

M. A. Schultz • *W. C. Woods* • *M. H. Fisher* • *E. C. Wentz* • *W. A. Derr and E. J. Cham*

• *M. A. Schultz* came to Westinghouse from the Massachusetts Institute of Technology, with a BS in EE in 1939. His first assignment was with the Industrial Electronics Division where he was engaged in early Westinghouse television-receiver work. Later as war clouds gathered over Europe, he was responsible for design and construction of long-range radar equipment.

In 1945, Schultz left Westinghouse, but returned about a year later to the Research Laboratories, to take charge of development of FM radar and sonar detecting equipment for use in gun computers and torpedoes.

With the formation of the company's Atomic Power Division in 1949, Schultz was appointed manager of the instrumentation and control subdivision, where he was responsible for the development of instrumentation and control for the first submarine thermal reactor plant.

Following an assignment as assistant manager of physics at APD, and a subcontract assignment at Princeton University, Mr. Schultz joined the new Commercial Atomic Power Activity as project manager for the engineering of the Westinghouse Test Reactor, which is now in the drawing-board developmental stage.

Mr. Schultz holds several patents in electronic circuitry and nuclear-control systems. He is the author of the first definitive engineering book in the nuclear field, "Control of Nuclear Reactors and Power Plants," from which his article appearing in this issue was abstracted.

As manager of the instrumentation and control subdivision for the submarine thermal reactor plant, Schultz was responsible for much of the control philosophy of present-day pressurized-water reactors. He has written numerous technical articles and reports on the subject.

Schultz in his spare time is an enthusiastic woodworker. His most ambitious basement project to date has been the complete rebuilding of a 1905 piano to which he fell heir. As a result, the Schultz's now have a modern piano in their living room.

• The nicest compliment you can pay *W. C. Woods* is to say something good about the State of Texas. Woods proudly proclaims to be a native Texan, in fact, never resided outside the state until he came with Westinghouse upon his graduation from the University of Texas (where else?) in 1943. After a short period on the Graduate Student Program, he stayed in the Transformer Division in the instrument and regulator section as a design engineer. In this capacity, he worked on the design of step-type regulators, load tap-changing power transformers, type CSP power transformers, and mobile substations.

But the call of Texas was too strong—and in 1947 he returned to the Houston office as a consulting and application engineer in the electric-utility field. In this position he has had the opportunity of working with both electric utilities and large industrial plant distribution systems. This activity has lead to extensive work in the relaying field, of which he writes in this issue.

Woods' loyalties are evident by his two favorite sources of information—the technical data in his Westinghouse diary, and the Texas Almanac.

• Analyzing the drive and control needs of industrial processes is an old story to *M. H. Fisher*. Although young in years, his experience in this field has been varied. After graduation from Alabama Polytechnic Institute in 1941 he came to Westinghouse. He had hardly started graduate student training when the war came along and he was transferred to the Motor Division to help with the flood of orders from the Navy. Six years in this assignment served, among other things, to make him an expert on Rototrol rotating regulators. In 1947 he joined the industry engineering group, which is concerned with electrification of basic industries. Here he worked principally on paper and textile applications until 1952, when he was made manager of his section.

Fisher is no stranger to these pages, having appeared as an author several times during the past few years. Regular readers will probably remember him best for previous articles on paper and textile problems.

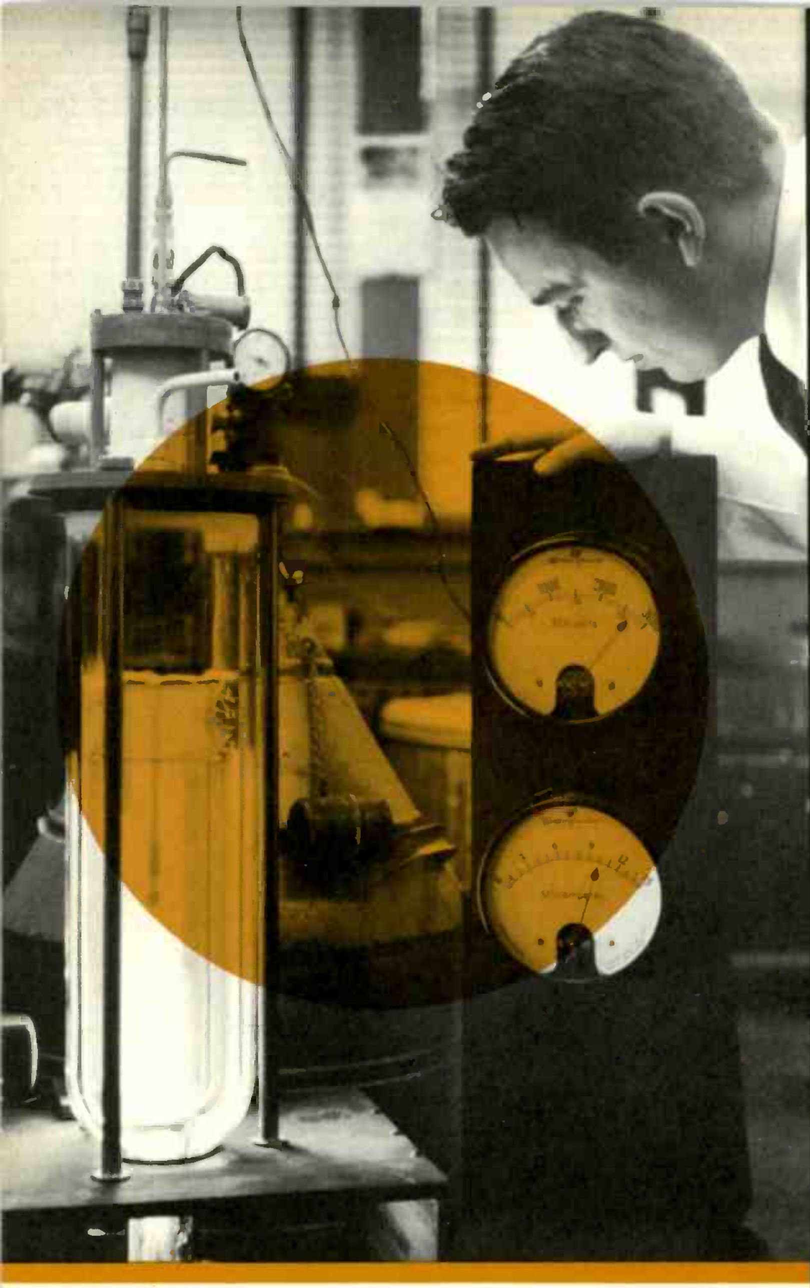
• As a writer, *E. C. Wentz* has the not-too-common facility for reducing complex subjects to simpler terms, as his article on transformer design indicates. This same aptitude carries over into his talks, where his dry sense of humor also comes into full play. However, Wentz can as readily whip off a highly technical mathematical treatise on the same subject. Such diversity comes, in part, from a thorough knowledge of his subject.

Wentz is a University of Minnesota graduate, class of 1926. Since he completed the Graduate Student Course he has been a transformer engineer. His first assignment was in the instrument-transformer section; in 1942 he became manager of the instrument-transformer design section, where, among other things, he developed linear couplers for bus-differential protection, and did much theoretical and design work on saturable reactors. About two years ago Wentz switched from the small to the large variety of transformers; he is now manager of the section that concentrates on finding new and better designs of large power transformers.

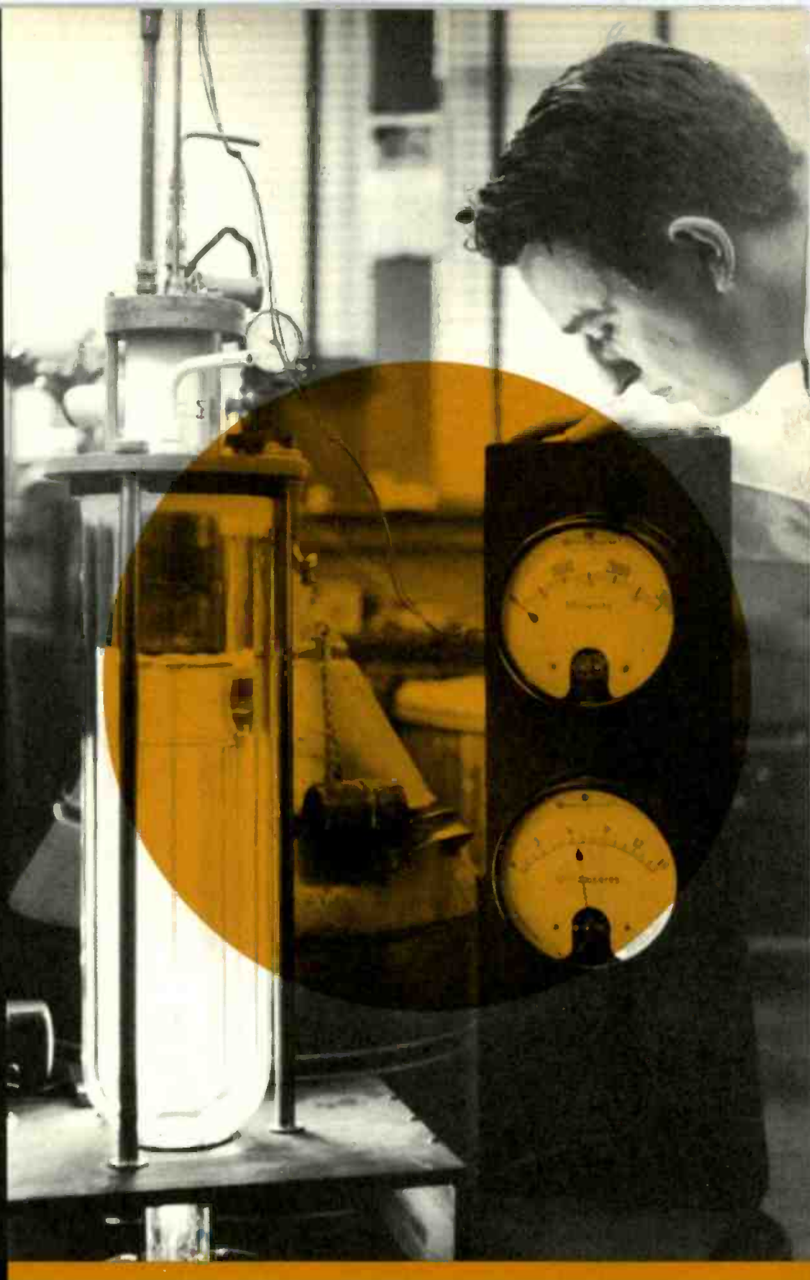
• *W. A. Derr* and *E. J. Cham* again team up to say more about one of their favorite subjects, the transductor. Both have advanced in their respective fields since their joint appearance in the Engineer two years ago.

Derr has been appointed assistant manager of the Switchboard Engineering Department. Now reporting to him is his original supervisory control section, along with the switchgear technical and computer section, and the newly formed power systems control section. Hence, Derr's activity in the general field of systems communication and control has expanded considerably.

Cham has moved from the automatic switching section of the Switchgear Division to the power conversion section of the Industry Engineering Department. Where before he was concerned primarily with switchgear for rectifiers, he now works with the complete rectifier installation, which includes the rectifiers, transformers, and associated switchgear apparatus. As Cham so aptly put it, ". . . guess our thinking has had to increase three-to-one."



Coil in flask has electrical resistance.



Now the coil has lost its resistance.

Superconductivity

In the photo at left above, the coil in the flask is above the temperature at which it loses its resistance. Meters indicate current fed into the coil and voltage across the coil. When the temperature is lowered . . . . . .

. . . . . the photo at right shows the result. Voltage across the coil drops to zero, indicating absence of resistance. The flask is filled with liquid helium to lower the temperature enough to make the coil superconducting.