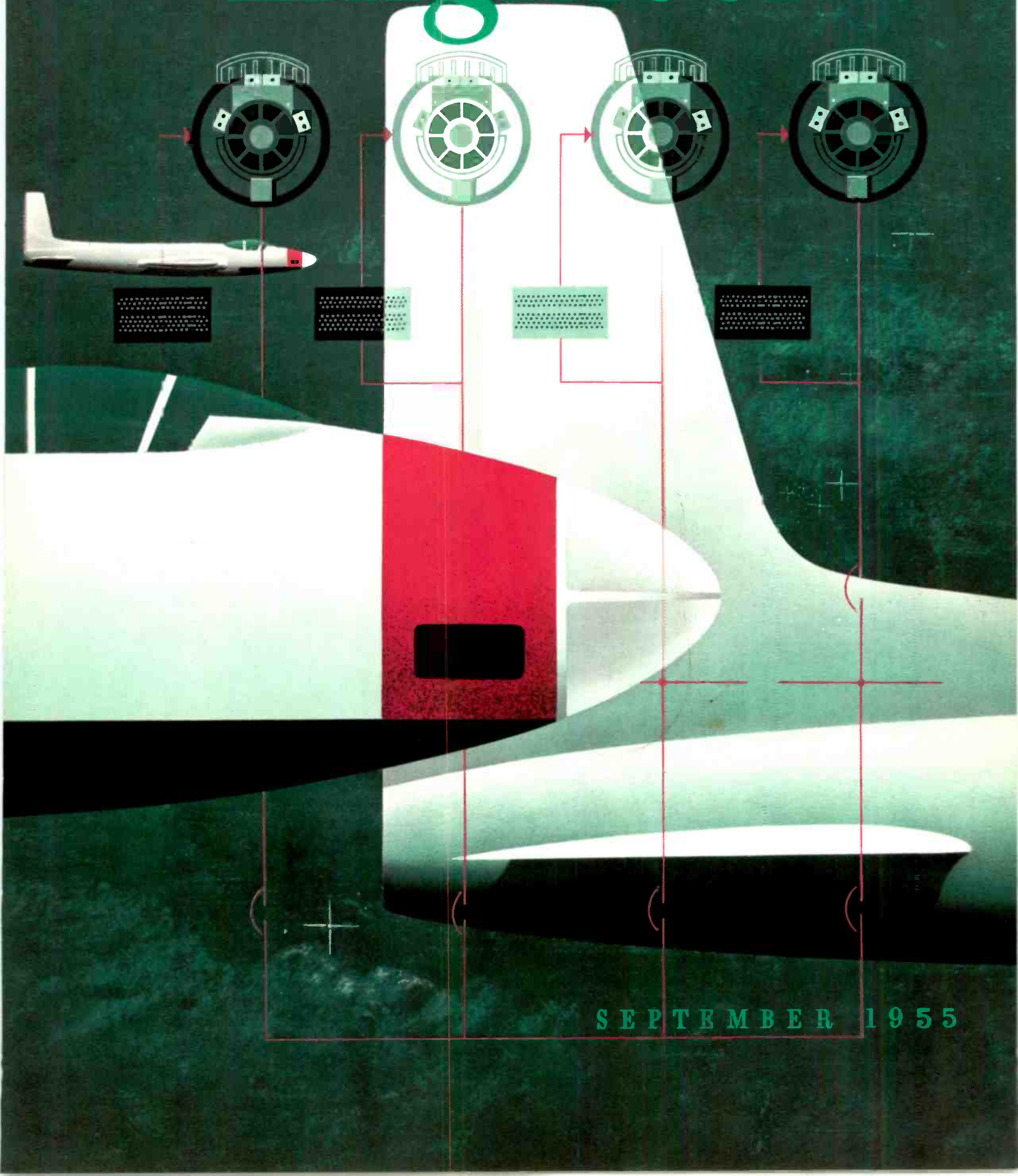
WESTINGHOUSE

Engineer



SEPTEMBER 1955

more time for Engineering...

SIZABLE CHANGES have taken place in engineering education in the past fifty years, all designed to better prepare the engineer for his profession. Concurrently, however, a rather sweeping change has also occurred in the job of the engineer—which may be at least partially responsible for the educational changes. The engineer's job has been gradually "purified," i.e., the tasks that do not require an engineering background are being delegated to others.

Consider, for example, the product-design engineer of fifty years ago. He not only conceived and executed new designs, but also did his own drafting, prepared all paper work for manufacturing, wrote all specifications, and often followed his product all the way to final installation—performing inspection in the shop, final testing of the product, and even going into the field to install and adjust the device.

Today, many of these tasks are delegated. Draftsmen make drawings; clerks prepare manufacturing information; other technicians and clerks handle production scheduling and routing, inspection, and testing; field engineers and technicians take over the installation and servicing of the product.

All this obviously leaves the engineer spending a far greater proportion of his time doing creative work. But with the current serious shortage of engineers, the need exists to use engineering time as carefully and as wisely as possible. This resulted, at Westinghouse, in a series of studies to determine what measures could be taken to further purify engineering.

The first step was to find out exactly how engineers spend their time. These studies were conducted by the engineers themselves, first in a pilot study, and then more generally throughout the company. The results have been extremely fruitful.

In the pilot study each engineer kept a careful record of the way he spent his time for a specified number of days. At the same time he indicated which of the tasks he performed could be handled by non-engineering personnel.

Engineers discovered, often to their surprise, that a relatively small, but noticeable amount of their time was being spent on tasks that they could delegate to non-engineers. Many calculations, for example, could be performed by technicians; gathering of data often could be handled by clerks. While the percentage of each engineer's time spent on such non-engineering tasks was small, in a section of, say, ten men it often added up to enough to warrant an additional technician or clerk. The engineers thus were free to spend the time gained on tasks that only they could perform.

Other measures have also helped to "purify" engineering jobs. When engineers were in plentiful supply, they were often used in "fringe-area" positions, where their background and training were useful, but not always mandatory. Such areas include some sales positions, purchasing, production planning and scheduling, industrial relations, and similar jobs. During the period of shortage, however, experience has shown that business administration and liberal arts graduates, with supplemental training in engineering fundamentals and industry methods, can perform these functions as well as engineers, and have equal potential for advancement into management positions.

These fringe-area jobs require a high order of intelligence, but are semitechnical in nature, largely in the business and management area. Thus, while the engineer was ideally suited to such work, his training was not being used fully. Nontechnical graduates were first hired for such positions in 1952, and have since performed even better than anticipated.

Other efforts have, of course, been made toward enabling better use of engineers' time. Numerous educational opportunities are made available to the individual engineer to enable him to become more proficient. Devices such as the analog and digital computer are saving many man-hours of design calculations and similar tasks.

Steps such as these are occasionally mistakenly considered as substituting a machine or a less-skilled technician for an engineer. There is no substitute for a professional engineer who can create, design, and develop. And there is more engineering to do than there are engineers to do it. The engineer can use all the assistance he can get, whether it be human or mechanical.

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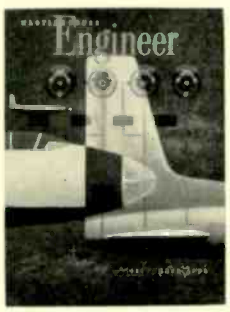
In This Issue

THE COVER



Underneath the sleek skin of modern airplanes lie the electrical nerves and muscles that control its operation. On this month's cover, artist Dick Marsh suggests this function, using a circuit of an electrical control system plus parts of a modern plane.

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To say that size and weight of any equipment installed on aircraft are "important" would be the understatement of the year. They're critical. But performance and reliability are just as critical. The designer of aircraft electrical-control systems must work in both directions. He's made a lot of progress on both counts.

a-c control for Aircraft Electrical Systems

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Many airplanes flying today have electrical systems of sufficient capacity to satisfy the demands of the majority of homes in a small city. However, conditions are far different in supplying electric power for ranges and washing machines than for aircraft, since the lives of the people in the community do not depend completely upon the electrical-power system, as is often the case on aircraft. This places a premium on the safe and effective operation of aircraft electrical-system control and protective devices; but concurrently all aircraft equipment must be small and lightweight.

Although electric utilities long ago standardized on a-c power systems, only recently have airplanes used a-c power to any great extent. The first important use resulted from the large electric-power requirements needed for big military aircraft. This power could not be economically provided with the commonly used 28-volt, d-c system, because of the excessive weight of cabling and the large number of generators required to supply the power. Many aircraft designers were reluctant to use a-c because of its relatively complicated control and protective devices as compared with the tried and proven d-c devices. However, recently the tremendous advancements in centralized a-c control and protective panels, accurate voltage regulators and lightweight constant-speed drives, have increased the application of a-c electrical systems by leaps and bounds.

Early Electrical Systems

The use of a-c power on aircraft dates back to World War I when Westinghouse wind-driven, a-c generators powered the first spark transmitters on Air Corps airplanes. Probably the first important application of a-c systems was on the Douglas XB-19, which first flew in 1941. This system provided a total of 25-kva from two a-c generators operated in parallel at 400 cps and driven by auxiliary gas engines.

The first large-scale use of an a-c system was on the Convair B-36 airplane. The power generated by the four 40-kva generators, operated in parallel, far exceeded that of any previous airplane. The a-c generators were driven from the main airplane engine through hydraulic constant-speed drives. This arrangement has been quite successful on hundreds of airplane installations. However, the control devices were held to a minimum and consequently the system required a maximum of attention from the flight personnel.

The increased dependence upon electrical navigational and landing aids, as well as the use of electrical actuators for control surfaces, has made the electrical system as essential as the fuel that powers the engines. As the importance of the electrical power system increased, the need for more adequate fault protection and the greater use of automatic functions became readily apparent. As more components were added, the problems of installation and maintenance soon made the use of separately mounted components impractical. To overcome these problems the centralized control and protective panel was introduced. The advantages are:

1. Ease of airplane installation. A minimum number of interconnecting leads are provided at a central point delegated for control and protective cables.

New control systems are evaluated in this four-generator mock-up.

2. Ease of aircraft maintenance. The complete protective system can be replaced in a matter of minutes.

3. Ease of component maintenance. The panel can be removed from the airplane and quickly checked on a test stand. Cost and repair time are reduced to a minimum.

4. Smaller size and weight. It requires a minimum of hardware and lends itself to miniaturization of components.

Designing the Electrical System

Designers of early a-c electrical systems for aircraft felt that the protection of the generator and its feeders was of first importance. Although this philosophy generally prevented fires in the wing and engine areas, it often resulted in good generators being removed from the system because of faults in other generators or in other parts of the system. Today emphasis is placed on the maintenance of uninterrupted power to the load buses. This does not indicate lack of concern with the danger of generator and feeder faults. Protection is fully as good and at the same time nuisance tripping of good generators, which might cause interruption of power to essential loads, is avoided. The line diagram in Fig. 1 shows a typical system that provides a maximum flexibility for maintaining uninterrupted load power. With this arrangement any combination of generators can be operated in parallel to supply the load buses or any one generator and its load bus can be operated isolated. In case of faults in load-division functions or on the paralleling bus, generators can operate isolated, each supplying its own bus.

Comparison of Various A-C Control Panels

EARLY A-C PANEL

A typical control panel used on the first a-c systems includes only the generator control relay, generator and feeder fault protection, and exciter protection. The exciter protection provided a limited degree of overvoltage protection. It was useful on early parallel systems because it afforded selectivity in detecting greatly overexcited generators.

BASIC ISOLATED GENERATOR A-C PANEL

This configuration is considered the present minimum. It would be used only when size and weight were of utmost importance and minimum protection could be tolerated. On such systems the generator feeders and load bus should be short, well insulated, and well protected mechanically.

ISOLATED GENERATOR A-C PANEL

The protection afforded by this typical system is considered adequate for most wide-frequency generator applications. Additional protective devices could be added but since a system of this type usually is not the primary source of electrical power on the airplane, the additional complication and weight of a high degree of protection cannot be justified.

BASIC PARALLEL A-C PANEL

This panel provides control and protective functions for a parallel system where paralleling is accomplished manually. It includes only those functions considered necessary to assure reasonably reliable parallel or isolated-generator operation for constant-frequency (380 to 420 cps) systems.

AUTOMATIC PARALLEL A-C PANEL

This system is essentially the same as the basic parallel panel except that the functions for providing automatic paralleling have been added to the units.

OPTIMUM A-C PANEL

This is an automatic parallel panel that incorporates all of the functions considered necessary for completely reliable parallel or isolated generator operation on constant-frequency systems. The automatic functions of this system are such as to necessitate a minimum of attention by flight personnel. Additional equipment can be added to this panel but it is questionable whether the slight benefits that accrue can justify the addition of such performance.

	EARLY A-C PANEL	BASIC ISOLATED GENERATOR A-C PANEL	ISOLATED GENERATOR A-C PANEL	BASIC PARALLEL A-C PANEL	AUTOMATIC PARALLEL A-C PANEL	OPTIMUM A-C PANEL
1. Generator Control Relay	●	●	●	●	●	●
(a) Trip-Free Operation		●	●	●	●	●
(b) Remote Electrical Reset and Trip	●	●	●	●	●	●
2. Field Flashing		●	●	●	●	●
3. Overvoltage Protection		●	●	●	●	●
4. Overvoltage Lockout		●	●			
5. Over- And Under-Excitation Protection				●	●	●
6. Generator and Feeder Fault Protection	●		●	●	●	●
7. Auxiliary D-C Power			●	●	●	●
8. Emergency D-C Power						●
9. Generator Power Indication				●	●	●
10. Underspeed Protection					●	●
11. Automatic Paralleling					●	●
12. Off-Frequency Protection			●			●
13. Phase-Sequence Relay						●
14. Open-Phase Protection						●
15. Reverse-Power Protection						●
16. Exciter Protection	●					
17. Negative-Sequence Relay						●
18. Quick-Eject Mounting Tray			●	●	●	●
19. Bolt-Down Mounting		●				
20. Approximate Dimensions (inches)	12x14x7*	6x10x5	8x10x5	6x18x4	6x18x5	6x20x5
21. Approx. Weight (pounds)	20*	6	7	7	8	11

*Includes Generator Voltage Regulator

The problem of establishing the proper degree of protection and automatic operation has always been difficult. Although weight is certainly of prime importance, a great deal of consideration must be given to the reliability of components and to the degree of protection desired. A system that provides protection for every conceivable fault, even though light in weight, could be completely useless as a result of the unreliability of overly complicated circuitry. Whether the airplane is a fighter, bomber, or commercial transport greatly influences the design of the electrical system. One extreme would be a fighter plane with little or no standby electrical capacity and in which it would be necessary to maintain electrical power regardless of fault conditions. Protective devices would be few and would serve only to warn the pilot of electrical-system trouble. The other extreme could be the large commercial transports on which the electrical system would be designed primarily for the ultimate in passenger safety and comfort. Air conditioning, coffee warmers, and similar convenience devices are important in this type of airplane; power failures are thus highly undesirable. The luxury transport would have a large standby electrical capacity with a maximum of protective devices. Power would be immediately removed from faulty areas and failure of protective devices would always de-energize that area of the system in which the defective component was located. To assure safe arrival at the airport, means would be provided for powering the equipment essential to the safe navigation and landing of the airplane with only a small portion of the total electrical capacity.

A-c generators usually are driven from the main engines on the aircraft either directly or by air turbines powered by bleed air from jet engines. There are numerous aircraft electrical power installations in which the generator output frequency varies in proportion to engine speed. However, when the electrical power utilization equipment is sensitive to frequency variations, which is often the case, constant-frequency devices must be used between the engines and the generators. Of course, constant-speed drives are essential if the generators are to be paralleled. Isolated operation of generators is often preferred over parallel operation because of the less complicated control and the elimination of reactive and real load equalizing requirements. However, isolated operation often is not practical in large installations because of the necessity of multiple load buses and the complication of load-transfer arrangements that must be provided to assure that power will always be available for essential loads.

Designing the Control Panel

All of the previous factors must be considered in determining the degree of control and protection required for a given application. Then comes the selection of components that best perform the functions required for the system. The tabulation on page 147 indicates the control and protective functions included in typical panels. This tabulation is merely a guide. An a-c control panel as part of a typical system is shown in Fig. 2.

A thorough knowledge of the advantages and disadvantages of each component is necessary to properly evaluate its use in a panel. In making the final selection the degree of risk taken without its use must be weighed against its cost in size, weight, and complication. The following is a brief discussion of the functions of the devices commonly used.

Generator Control Relay—The a-c generator is controlled by a generator control relay (GC) through a set of contacts in series with the generator field winding. This relay is usually a latch-type relay with a reset (close) coil and a trip (open) coil. The latch-type relay stays in position if d-c control power is lost, thus preventing simultaneous loss of a-c power, and it has greater interrupting capacity if it is required to open the large field currents and voltages encountered during fault conditions. A number of auxiliary contacts, used for interlocking purposes, are also actuated by this relay.

Generator control relays are generally electrically and mechanically trip-free or anti-cycling. This means that if the reset coil is energized continuously and a signal is applied to the trip coil, the relay trips and stays open. Without this feature the relay would cycle from open to closed until some part of the system was destroyed.

Generator control relays can be provided with electrical or mechanical reset provisions. The mechanical reset is useful if a-c power is desired when no d-c control power is available. However, seldom are control panels located where mechanical reset can be accomplished in flight, thus limiting the usefulness of this provision. The electrical reset allows easy operation from a remote position.

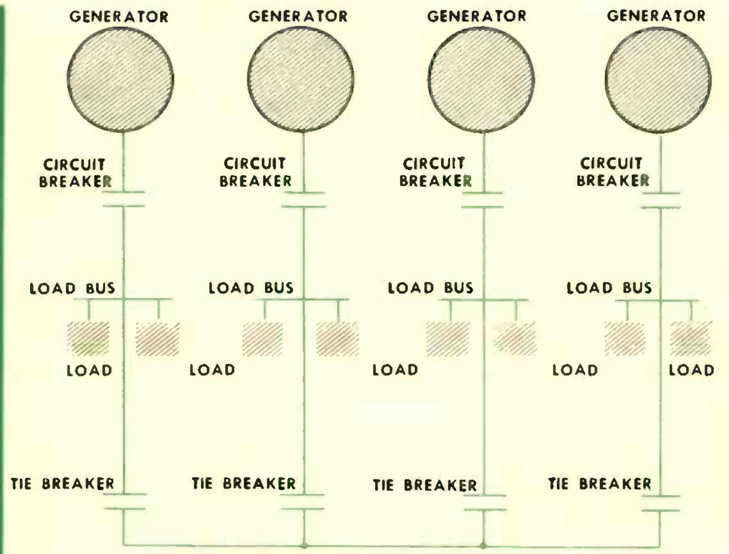
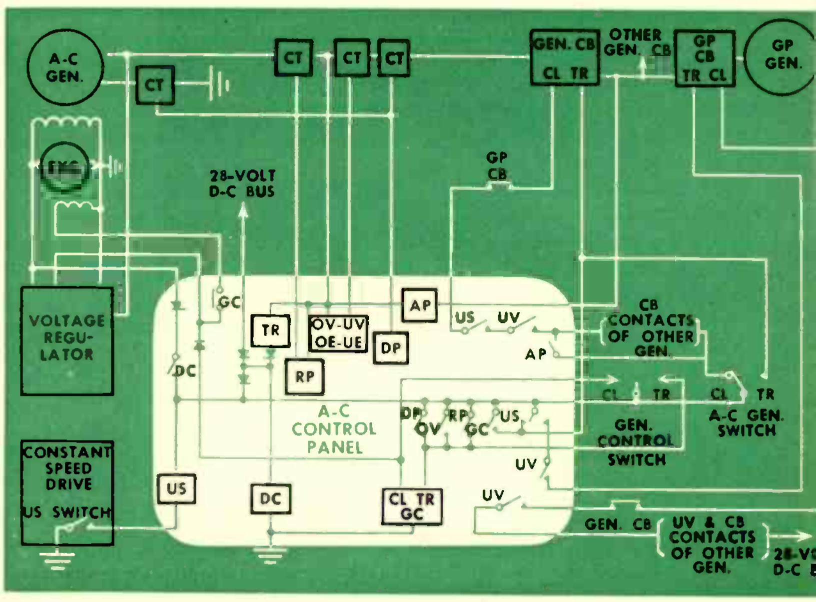


Fig. 1—A line diagram of a typical parallel a-c system.



The generator control relay is an essential component in every type of aircraft electrical-power system. It controls the excitation of the generator and therefore is connected to trip when a generator or regulator fault occurs. Generally a contact on the relay is used to trip the generator circuit breaker every time the generator field is opened.

Field Flashing—Field-flashing circuits are employed in self-excited, a-c generator systems to insure that the generator builds up when its field circuit is closed. Normally enough residual flux (magnetism) is present in this field to cause the generator to build up and no problem exists. However, several possible conditions can prevent build-up. A generator not used for a long time or subjected to normal shipping shocks may not have the necessary residual flux. Also, environmental conditions, including aviation-fuel vapor, can cause films to form on commutators and slip rings, thus preventing build-up. Field-flashing voltages must be sufficient to overcome any of these conditions.

The field-flashing circuit can consist merely of a connection from the d-c voltage supply through a dropping resistor and a set of generator control contacts to the exciter field of the generator. This connection means that field flashing is accomplished every time the relay is reset. Automatic control systems leave the field contacts closed at all times except when a fault occurs; therefore, if a generator fails to build-up on normal starting, the relay must be tripped and reset to obtain field flashing.

Overvoltage Protection—Loads connected to the a-c generator are designed to operate at a certain maximum voltage and minimum frequency. The overvoltage relay (OV) protects these loads from sustained high voltage, but allows normal transient overvoltages to pass. Damage from higher than normal voltage is due mostly to the heating effect and this is a function of voltage and time—the higher the voltage the less time the equipment can withstand it. For this reason the overvoltage relay must have an inverse time-voltage characteristic. Just before the damage point is reached the relay operates to open the generator field.

The overvoltage relay generally senses the average value of the three-phase voltage by rectifying and obtaining a d-c voltage. With this type of sensing a single-phase ground fault, which causes at least one of the other two phase voltages to rise, does not operate the relay. If the relay were sensing only one phase voltage, it would operate on a single-phase fault and not allow the fault to clear itself.

Overvoltage protection is perhaps the most essential on any aircraft power system. It not only protects the over-excited generator and control system but also protects the connected loads from damage.

Overvoltage Lockout—The overvoltage lockout relay (OL) is often used when it is necessary to override the voltage transient that occurs during generator build-up. On single-generator, wide-speed-range systems this transient can be very large at the upper end of the speed range. The ordinary overvoltage relay may trip on this transient, making necessary this extra time delay in some systems. A time-delay relay energized by a generator-control relay contact holds the overvoltage relay circuit open for a small fraction of a second to override the transient. Once the system is in operation the overvoltage lockout relay has no effect on the operation of the overvoltage relay.

Over- and Under-Excitation Protection—When two or more a-c generators operate in parallel, control and protective problems become more complicated. The voltage-measuring circuit of the overvoltage relay or an undervoltage relay reads the average of the generated voltages of paralleled machines and therefore cannot determine which machine is over- or under-excited. This protection can be obtained by measuring the reactive current that flows as a result of the excitation unbalance and using this signal to bias the overvoltage and undervoltage relays. This bias deceives the relays, so that on the unfaulted generator systems they see normal line voltages, while on the system with the faulty machine they see a voltage that is too high or too low.

The overvoltage relay itself has been described previously. The undervoltage relay is voltage-sensing also, but with a fixed time delay to enable it to override engine shutdown and other low-voltage transients. This relay must have a very close operating differential. That is, its drop-out must be very close to its pick-up because to be effective it must drop out on approximately a ten-percent undervoltage and pick up before normal voltage is reached.

Under- and over-excitation protection is necessary on any parallel generator system where the objective is uninterrupted power to load buses. When a fault causes one generator to become under- or over-excited, this type of protection

LEGEND

- GC—Generator Control Relay
- DP—Differential-Protection Relay
- RP—Reverse-Power Relay
- DC—D-C Power Relay
- US—Underspeed Relay
- UV—Undervoltage Relay
- OV—Overvoltage Relay
- OE-UE—Over- and Under-Excitation Protection
- TR—Transformer Rectifier
- AP—Automatic Paralleling Relay
- GP—Ground Power
- CB—Circuit Breaker
- CT—Current Transformer

Fig. 2 (left)—The a-c control panel as a part of a typical system. The legend at left explains the major components of the system.

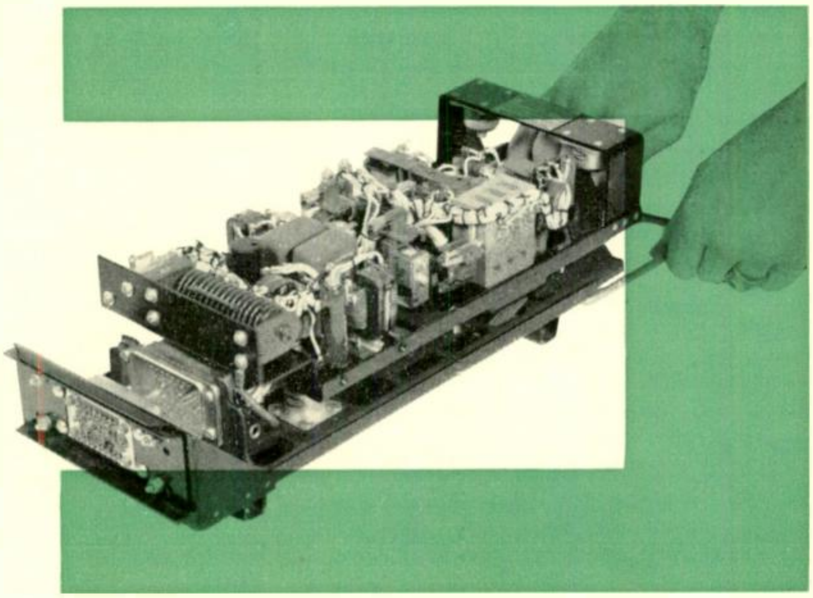


Fig. 3 (right)—The compactness of a typical aircraft control panel is illustrated in this photograph.

selects and removes the faulty generator from the system, while delivering continuous power to the load buses.

Generator and Feeder Fault Protection—The a-c generator and its feeders are protected in case of line-to-line or line-to-ground faults by differential current-measuring relays. Current transformers are located so that any appreciable difference in the current flowing into the generator neutral leads and that flowing through the circuit breaker contacts indicates a fault between them, and causes a differential protection relay (DP) to operate, tripping the generator-control relay. For systems with long generator feeders, two current transformers per phase are required, one at the ground point of the neutral lead and one at the circuit breaker. For short feeders both ends of each generator winding phase are passed through the same transformer.

Differential protection is necessary on any generator system where the generator and its feeders must be protected in case of ground faults. The protected zone generally ends at the generator circuit breaker because bus loads are protected by limiters that disconnect only faulted loads.

An undervoltage relay (UV) provides generator-fault, feeder-fault, and load-bus-fault indication on single-generator systems. However, it cannot be made to provide the sensitivity of differential protection. It has one advantage over the differential-protection relay, in that when used with an overcurrent relay (OC), which senses current at the generator circuit breaker, it can indicate both generator-feeder faults and load-bus faults. Thus the operation of the undervoltage relay alone indicates a generator or generator-feeder fault and the combined operation of the relays indicates a load-bus fault. The undervoltage relay also provides open-phase indication. However, the loads on any system, where undervoltage sensing is used, must be such as not to support the voltage on the phase that is faulted or open.

Auxiliary D-C Power—Aircraft relays, contactors and circuit breakers usually have d-c magnets and solenoids because the d-c devices provide the smallest, lightest and most efficient components. This makes necessary some source of 28-volt, d-c power. Generally this power is supplied by the d-c generator and/or a battery. As back-up protection in case of failure of this supply, it is desirable to have a small source of d-c power located on the control panel. This consists of a transformer and rectifier unit (T-R unit) of sufficient capacity to supply the control power required for its own control panel and associated circuit breaker.

Emergency D-C Power—Another source of d-c power that can be utilized is the output of the d-c exciter on the self-excited, a-c generator. Certain ground-fault conditions can cause the output of the T-R unit to drop below a useful value, and if at the same time the airplane d-c supply is not available the exciter is the only source of d-c power. A d-c relay (DC) can be made to connect the exciter output to the generator-control relay trip coil when these conditions exist.

Generator Power Indicator—To obtain the proper sequence of events in an automatic or even semiautomatic generator-control system, certain quantities must be measured and indicated. One of these is the output voltage of the generator, which is measured by the power indicator relay (PI). One contact on this relay is used to shut down the ground power supply so that the airplane supply can take over. Another contact is used in the circuit-breaker close-coil circuit to prevent the connecting of the airplane generator to the load until its output has reached the proper value.

Underspeed Protection—Another quantity measured is the rotational speed or frequency of the generator. The underspeed relay (US) operates on a signal from the mechanical constant-speed drive and may indicate a loss of hydraulic pressure in the drive, although it usually indicates an actual low-speed condition. Just as in the case of the power-indicator relay, the contacts of the underspeed relay can be used to remove the ground power supply and to close the generator circuit breaker. These contacts are normally used in series with the power-indicator relay contacts so that both voltage and frequency must be correct before loads are transferred from the ground power supply to the airplane supply.

In addition to its control functions this relay may have the protective function of opening the circuit breaker if the power frequency gets low enough to affect the accuracy and safety of the connected loads.

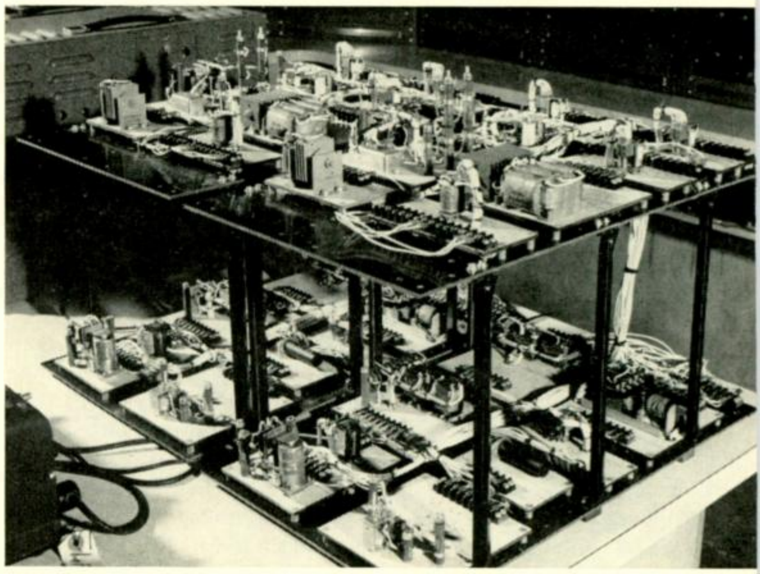


Fig. 4—Complete control assemblies, composed of individual component "breadboards," are tested in the a-c system mock-up.

Automatic Paralleling—The automatic paralleling relay (AP) compares the generator voltage and phase angle with the bus voltage and phase angle, and closes its contacts when conditions are correct for paralleling. An automatic paralleling relay is required for each generator in the system because paralleling is generally accomplished with the generator circuit breaker rather than by the use of a synchronizing bus. The paralleling relay is interlocked with the underspeed and power-indicator relay contacts so that the first generator on the system to reach the proper speed and voltage is connected immediately, while the remaining generators must be connected through the paralleling relay contacts. This relay is necessary on any parallel system that requires fully automatic operation. Random paralleling of a-c generators is possible with no apparent damage to the generating end of the system. However, the ultimate effect of the voltage and power transients resulting from out-of-phase paralleling are not worth the savings from omitting one small relay circuit.

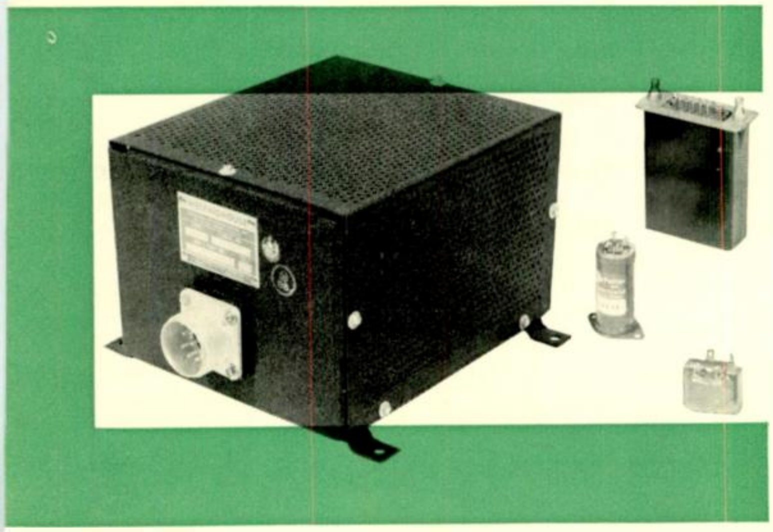
Off-Frequency Protection—The frequency relay senses the frequency of the a-c generator output voltage. Two versions of this relay are in common use; an under-frequency relay (UF), which opens the circuit breaker or merely energizes an indicator light when the power frequency drops into the damage limit, and an off-frequency relay (OF), which operates on both sides of the nominal operating frequency.

The under-frequency relay and the underspeed relay are slightly different in application. The under-frequency unit is commonly used on single-generator systems, which are usually wide-speed-range systems, and whose loads therefore need protection during engine shutdown and idle or windmilling conditions. The underspeed relay is energized by a switch on the constant-speed drive and therefore is applicable only on constant-speed parallel systems. The off-frequency relay is used on constant-speed systems to indicate frequency deviations that may cause calibration errors in load equipment.

Phase Sequence Relay—A phase sequence relay (PS) can be used to prevent the circuit breaker from closing an improperly connected generator onto the load bus. The use of this type of protection is purely arbitrary, depending on the air-frame manufacturer and the application. Reverse phase rotation can result only if an a-c generator is incorrectly connected upon installation, or if two of the three phase leads are accidentally interchanged at a power panel or bulkhead terminal board.

Open-Phase Protection—Protection in case of an open phase in the generator system can be obtained by the addition of circuitry to the phase-sequence relay. The zero-sequence currents in the neutral lead can be measured to indicate when an open phase occurs. An open-phase condition existing before generator build-up or paralleling is easily detected by a three-phase, average-voltage-sensing relay, such as the previously described undervoltage relay. After generators are connected in parallel, an open phase cannot be detected in this manner and therefore a special relay circuit such as that described must be used. Open-phase protection is desirable on parallel systems whose loads could be damaged or made useless by single-phase operation.

Fig. 5—Transistor circuits are a future possibility. Below, an overvoltage relay and the transistor parts required to replace it.



Reverse-Power Protection—Real power flow into one generator in a parallel system indicates a loss of the mechanical power driving that generator. To prevent the loss of power a reverse-power relay (RP) can be used to open the circuit breaker or give an indication of reverse power. A short time delay should be included in this device to override power transfer transients.

The need for a reverse-power signal is questionable. Constant-speed drives contain overrunning clutches and therefore the amount of reverse real power required to drive the generator in case of shaft breakage is small. However, in some cases this device can be justified if it is likely that failures may limit the rotation of a generator and cause an excessive drain of real power from the system.

Exciter Protection—During overload or fault conditions the exciter of the generator may go to ceiling conditions of voltage and current. This condition cannot be tolerated continuously and therefore should be avoided. The exciter protection relay (EP) offers this protection by measuring the d-c exciter voltage in much the same manner as the overvoltage relay measures the a-c output voltage. A thermal time delay gives the relay an inverse time-voltage characteristic for overriding transients. The voltage measured at the exciter, which represents a danger condition, is not consistent enough from one generator to the next to make it possible to use the exciter protection relay as overload protection.

The overvoltage relay on single-generator systems and over-excitation protection on parallel systems give similar protection and are preferred, since they provide a much more direct way to sense the fault. Also, these devices are simple and serve other purposes under other conditions.

Negative-Sequence Relay—A negative-sequence relay (NS) can be used for bus fault protection on multiple-generator systems that make use of a tie bus. This relay senses the three-phase voltages of the tie bus for their negative-sequence components. Any appreciable magnitude of negative-sequence voltage indicates a ground fault on the bus and this signal is used to trip all of the bus tie circuit breakers. If the fault is on the tie bus the system continues to operate as a group of isolated-generator systems. If the fault is on a load bus the negative-sequence relay isolates that faulted system and allows the remainder of the system to continue on isolated-generator operation with only the loads on the faulted bus being lost. If the fault is on a generator or its feeders, the differential-protection relay will remove it before the negative-sequence relay can operate.

Designing with an A-C System Mock-up

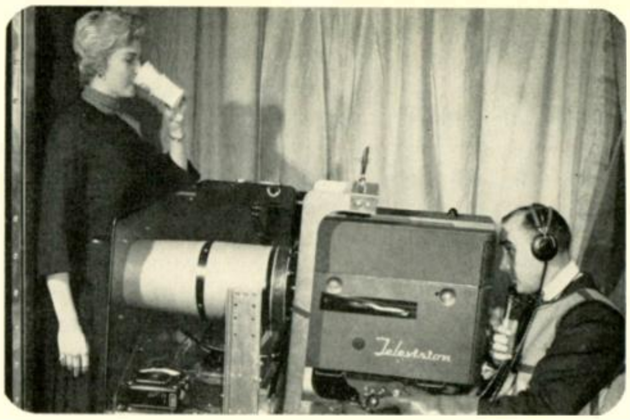
After establishing components to be used in a control and protective panel, it is highly desirable to check out the functions of the system. Shown on page 146 is the control and metering panel for a complete four-generator mock-up. This test facility is designed for complete flexibility in mocking-up any type of system that requires one to four generators.

Future Developments

The equipment described and the functions they perform are typical of the aircraft electrical systems being designed today. Some indication of the direction being taken for the future is apparent in a look at work now in progress.

Transistors—Circuits making use of this small, light and reliable component are being developed to do the same job as devices three to four times larger and heavier. A comparison between a typical a-c overvoltage relay of today and the transistor circuit parts required to replace it is shown in Fig. 5. Not only are transistorized control and protective devices expected to result in smaller and lighter components, they are also expected to be much less sensitive to the extreme environment encountered in military aircraft.

New Types of Control and Protection—In addition to the improvement in existing control and protective devices, new types are constantly being developed. More complete protection is being realized and in some cases is being extended to include electrical-system parts not previously protected.



This developmental model of Video Fluorex was first demonstrated to doctors by means of a closed-circuit telecast in Cincinnati in 1953.

X-ray *Movies* and television

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A conference room in Baltimore was the scene of an event of historical significance recently when a group of doctors, watching a motion picture, saw movements in the human body that they didn't know existed.

This was no ordinary movie. The motion pictures being viewed were x-rays of a patient's soft palate, taken while he pronounced vowels. Every movement of the jaw was recorded on 16-mm film simultaneously with the fluoroscopic examination. Seated in the projection room following the examination, the doctors could study movements of the soft palate as it "slapped" against the back of the throat, closing the passageway to the nose. In normal patients, this closing action prevents air from escaping through the nasal passage and produces normal vocal sounds. In patients with cleft palates, the soft palate does not completely close this passage, necessitating either surgery or the use of appliances that substitute for the soft palate. With x-ray motion pictures, doctors can study repeatedly the motion of the palate and determine precisely what steps must be taken to correct this unfortunate defect.

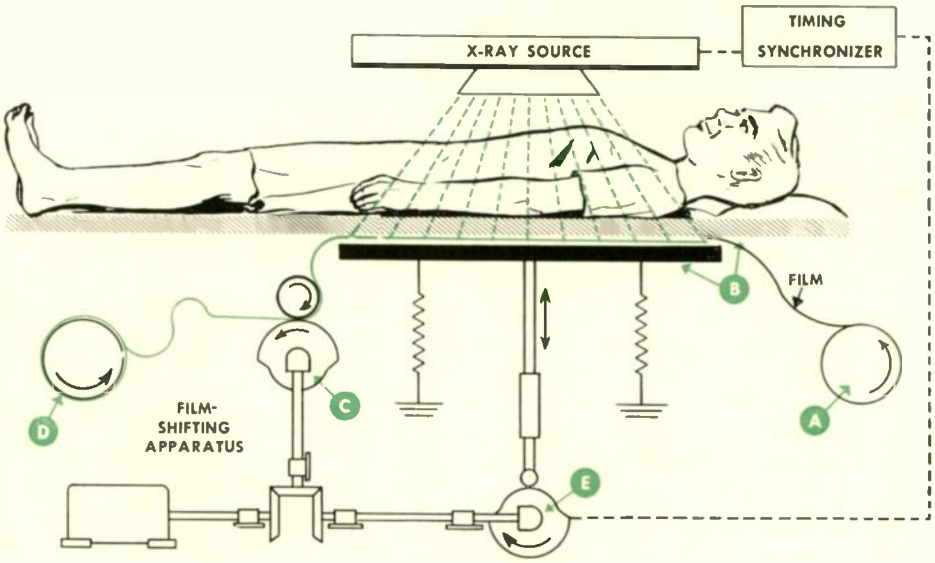


Fig. 1—Principle of film feed as used in cineradiography. X-ray film is pulled from supply spool A by a feed mechanism at C. Exposed film is wound up on spool D. The eccentric E compresses film between screens at B for each exposure.

Need For X-rays In Motion

This is only one of many possible applications for x-ray motion pictures, once a clinical instrument becomes available. With x-ray motion pictures doctors can study the rapid motion of the human body. For example, an infant's heart beat may be as high as 200 beats per minute at birth. Babies with congenital heart disease (or "blue babies") can be studied with x-ray motion pictures by taking these movies at 30 frames per second on 16-mm film; then, by projecting the resulting film at 7.5 frames per second, the single heart beat can be shown sustained for more than a second, providing a slow-motion study of the heart for a better aid to diagnosis.

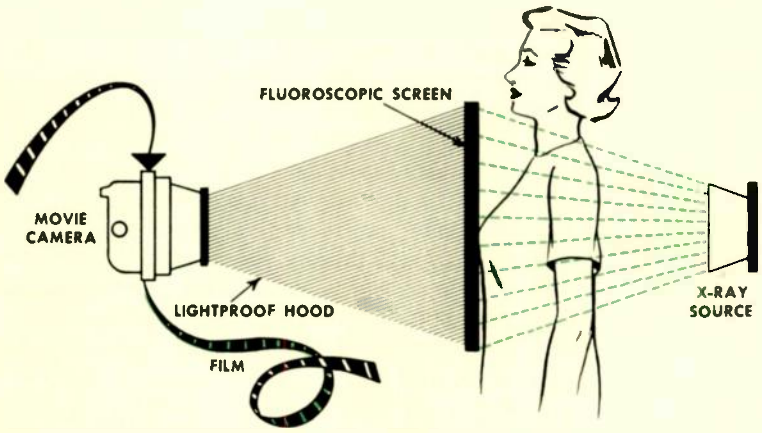


Fig. 2—Principle of cinefluorography. X-rays, arriving from the right penetrate patient and produce a fluorescent image on a screen enclosed in the lightproof hood. The x-ray image is recorded by the camera shown on the left at motion-picture speeds.

X-ray movies of bone and joint movements, swallowing, vocal cords, and the stomach will not only provide doctors with a permanent record of their fluoroscopic examination, but can be filed for comparison with subsequent studies to determine progress of recovery. X-ray movies can be used for teaching anatomy and physiology to medical students. Unusual cases are invaluable records for use in treatment of bizarre pathology.

For industry, x-ray motion pictures will "slow up" motion of rapidly moving internal structures, permitting detailed study of dynamic components. A completed mechanical assembly shrouded in metal is easily studied in motion for weak points. Movies of moving aircraft parts can be retained as a permanent inspection report for possible future comparison against failures.

Producing X-ray Movies

The production of x-ray motion pictures is not new. A year after the discovery of the x-ray in 1895, a Scottish physician succeeded in a technique known today as *x-ray motion synthesis*. This method consists of x-raying a part on individual pieces of film by repositioning the part for each successive exposure. The individual films are then rephotographed onto conventional movie film and projected. This method plays an important part in regular motion-picture production and is currently useful in instructional motion pictures. In fact, the animated cartoons are produced in this manner, substituting a source of illumination for the x-ray beam.

A second method of producing x-ray movies is *cineradiography*. This consists of direct radiography of a moving part, utilizing intensifying screens and x-ray film. Basically, this is conventional radiography repeated at motion-picture speeds and with full-size film. As with x-ray motion synthesis the resulting series of film must also be rephotographed onto standard motion-picture film. Cineradiography differs from x-ray motion synthesis, for in the latter technique, the operator can stop motion for each picture frame, and expose the part at leisure. To produce cineradiographic films, x-ray equipment must be capable of producing high quantities of x-ray energy at the instant of exposure. Furthermore, massive and expensive film-shifting apparatus is required to produce motion pictures, Fig. 1. A further difficulty common to both x-ray motion synthesis and cineradiography is the large quantities of radiation required.

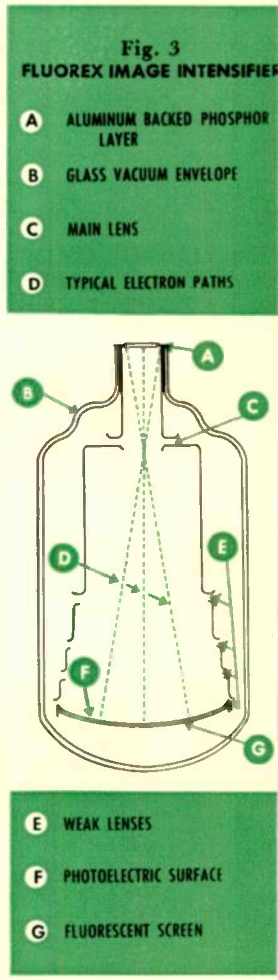
A third method for producing x-ray motion pictures is called *cinefluorography*. This consists of photographing a fluoroscopic screen with a motion-picture camera. This is the indirect method. The patient is positioned in front of a fluoroscopic screen, which is enclosed in a lightproof hood. At the opposite end of the hood, a motion-picture camera is positioned to photograph the image on the screen, Fig. 2. This method requires a lens for focusing the camera on the screen. Due to the small light-collection factor for the lens, and light losses in the lens, as well as low light intensities emitted from the screen, considerable radiation is required for satisfactory results. Radiation exposure can be minimized by obtaining a lens with a large aperture, perhaps as low as f/0.68, and by synchronizing the x-ray generator and camera so that the subject is irradiated only when the camera shutter is open. During film advance, when the shutter is closed, x-rays are not generated. In some cinefluorographic experiments, a radiation output at 100 milliamperes, at 100 kilovolts has made it necessary to limit the total exposure time of the patient to six seconds.

Photographing a fluoroscopic screen is a difficult problem, since 14 to 20 times more radiation is required than with the direct method, accompanied by a loss of fine detail in the image. Therefore, to protect the patient from overexposure to radiation, the brilliance required to produce a photographic effect must be obtained from some outside energy source by a true amplification process rather than from increased x-ray intensity.

About ten years ago Westinghouse scientists began development of a device for intensifying the brightness of fluoroscopic screens. Since the intensifier recently perfected increases the brilliance of fluoroscopic screens several hundred times, the usefulness of such a device for cinefluorography becomes immediately apparent.

This system of screen intensification utilizes an electronic tube principle. In 1950, prototypes of an electronic screen intensifier were put into clinical use for diagnostic fluoroscopy. Finally, in 1953 full-scale production units were installed in hospitals and radiologists' offices. How a screen intensifier augments clinical fluoroscopy today is a separate and dramatic story.

With this system, x-rays pass through the patient and impinge upon a fluorescent screen, where their energy is converted to light as in an ordinary fluorescent screen (right). This light ejects electrons from an



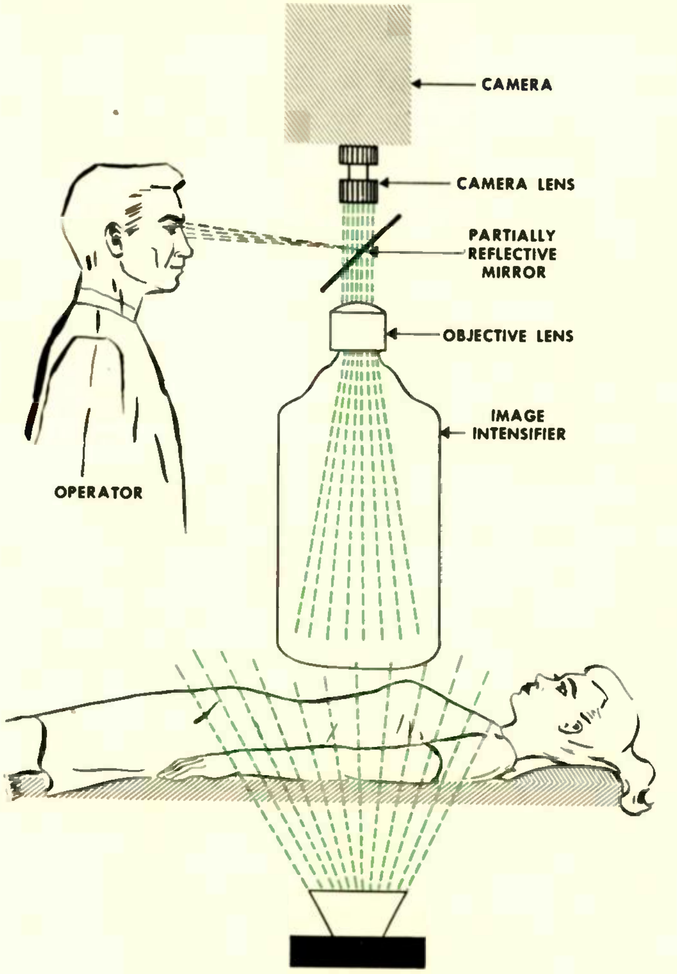


Fig. 4—Laboratory model used to produce x-ray motion pictures.

adjacent photoelectric surface. These electrons are accelerated and focused by a system of electrostatic lenses onto an aluminum-backed phosphor layer. All of the electrons from the input phosphor, which is a circular screen five inches in diameter, are concentrated on a circular phosphor layer, one inch in diameter. Simultaneously, these electrons are accelerated so that they strike the output screen with increased velocity, which further increases the brilliance of this screen. Thus, by concentration and acceleration of electrons, an image several hundred times brighter than the original image is formed, with no increase in dosage to the patient.

The image intensifier is substituted for the lightproof hood shown in Fig. 2. Since the intensified image is several hundred times brighter than an ordinary fluorescent screen, x-ray intensities can now be considerably reduced to obtain the same photographic effect. It becomes entirely feasible and safe to obtain several minutes of cinefluorographic studies on a human subject without danger of overexposure. For example, a sequence taken with the screen-hood arrangement required 100 milliamperes at 100 kilovolts, and was limited to six seconds; the image intensifier arrangement requires but 1-10 ma at 70–100 kv, permitting a three-minute exposure.

A laboratory model is shown diagrammatically in Fig. 4. The intensified image, which is more than 200 times brighter than the initial image produced at the input phosphor, is projected by the objective lens to the camera lens. The final image is then focused onto the film of the 16-mm, motor-driven camera. The operator views the image during the motion picture sequence with a partially reflective mirror, which reflects 5 percent of the light to the viewer and transmits 95 percent to the camera.

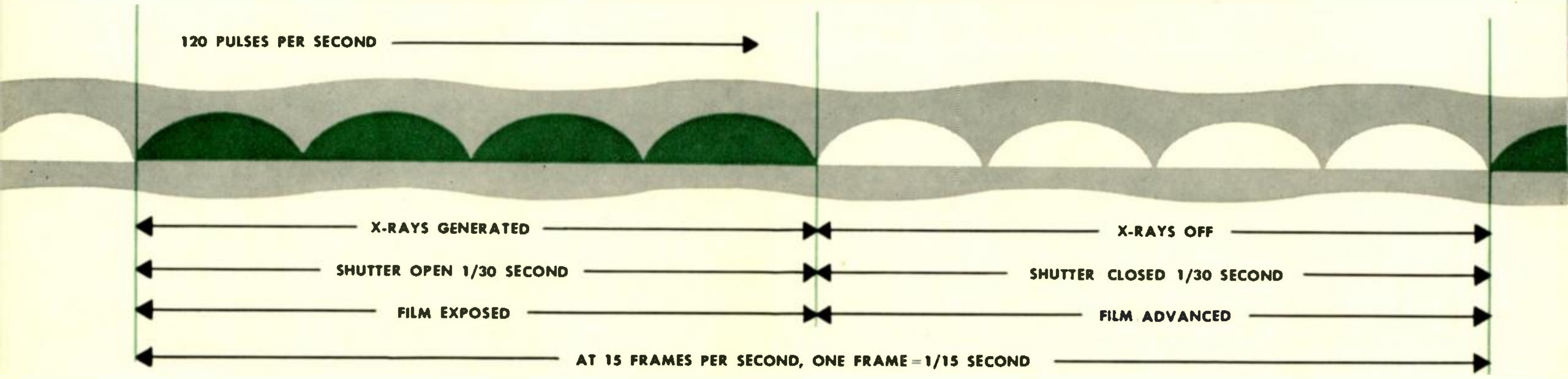
If x-ray impulses are synchronized with the camera shutter, even less radiation is received by the patient, Fig. 5. Suppose the movie camera is set at 15 frames per second; one cycle of shutter operation therefore requires 1/15 second. The shutter is open approximately half that time, or 1/30 second. Likewise, the film advance when the shutter is closed requires 1/30 second. With full-wave x-ray apparatus, 120 pulses of radiation are generated every second. Since no film is exposed during the period of advance, there is no reason to generate x-rays for this 1/30 second per frame, saving the equivalent of four x-ray pulses. By generating x-rays only during the 1/30 second that the shutter is open, four x-ray pulses are utilized for each frame. By synchronization, a total of 60 x-ray pulses per second are generated at the rate of four per frame (four pulses per frame times fifteen frames per second) to coincide with the time when the shutter is open. This results in a 50 percent reduction in radiation per second, or 50 percent for the total cine-sequence of synchronized exposures as compared to a non-synchronized sequence.

Video Fluoroscopy

The Fluorex image amplifier has also made possible a new concept in teaching roentgenology. With the brightness level of the fluoroscopic image increased several hundred times, it becomes practical to televise an image for viewing by medical students in a classroom, located remotely from the x-ray examination. Seated comfortably in a lighted room, students and physicians can observe a fluoroscopic examination on a large-sized television monitor while the operator-instructor explains pathological detail from the examination site.

When used in this manner, the image intensifier performs as a light preamplifier for the television camera. The image is focused onto the sensitive surface of an image orthicon and

Fig. 5—Generating x-ray only when the camera shutter is open reduces radiation by 50 percent.



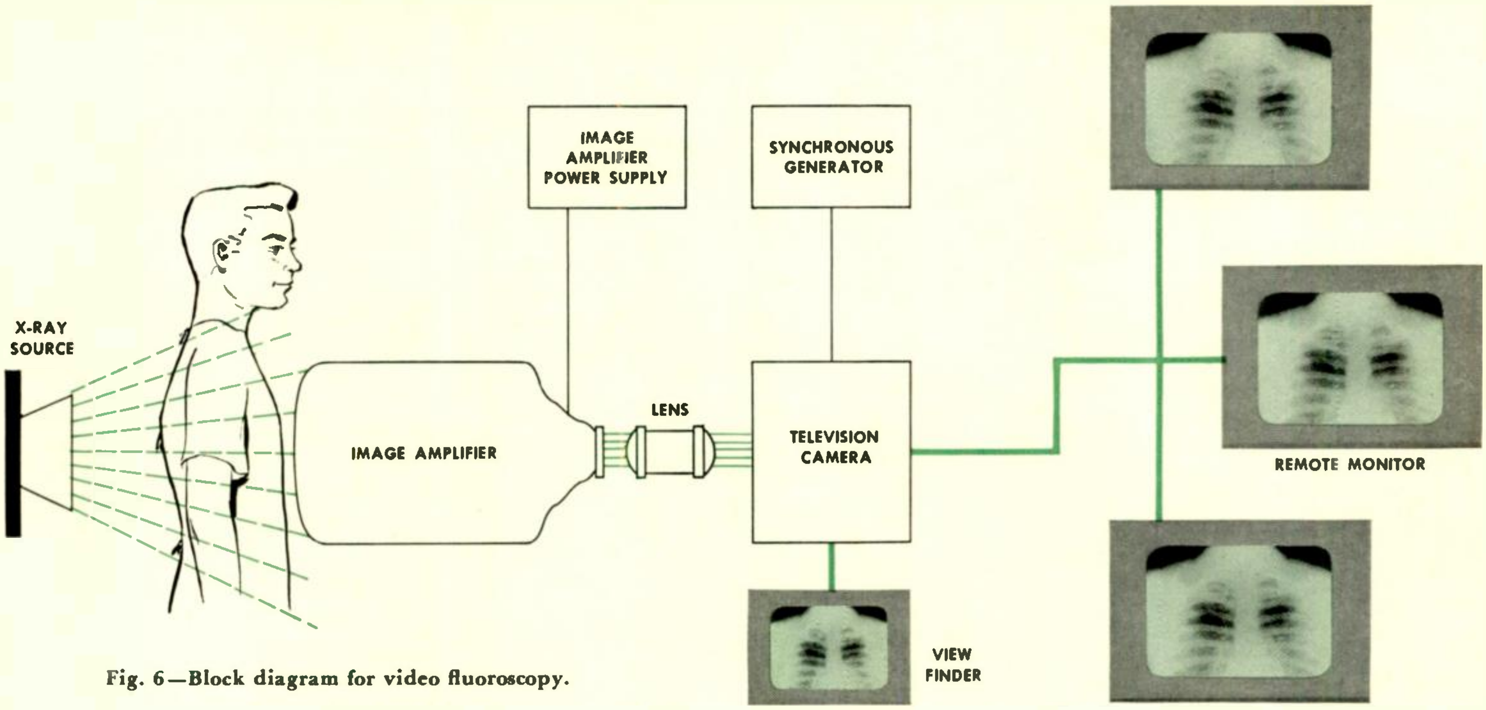


Fig. 6—Block diagram for video fluoroscopy.

transmitted to remote television monitors, Fig. 6. Conventional zinc-sulphide fluoroscopic screens, when irradiated with normal exposure factors, do not emit sufficient light for satisfactory televised images. Although adequate light could be obtained from conventional screens by increasing the quantity of x-rays, this would expose the patient to dangerous amounts of radiation.

In April, 1953, Westinghouse, in conjunction with the American Inventory Program, televised fluoroscopic images over a national network. This was the first time in history that the fluoroscopic and the television camera scanned the entire human body demonstrating swallowing, the stomach and intestinal tract, the chest, and the functioning of a normal and an abnormal heart. As a result of that telecast a packaged unit for use in hospitals and teaching institutions is planned for the future. A prototype of this unit, the Video-Fluorex, has been demonstrated.

An incident that occurred during a demonstration clearly illustrates the value of the instrument. A male patient being used for the demonstration felt dizzy. At this point the Video-Fluorex was trained on the subject's heart, which was now beating at a subnormal rate. One of the doctors on the ninth floor, observing the fluoroscopic image of the beating heart being televised from the second floor remarked, "That boy's going to faint." This remote diagnosis was a visual testimony for this advanced engineering development.

The Future

Within the next year a clinical instrument will be available for taking x-ray motion pictures simultaneously with fluoroscopic viewing. This unit, the Cine-Fluorex, will be packaged for adaption to practically all modern x-ray tables now installed in hospitals and radiologists' offices. The unit will enable doctors to obtain 16-mm x-ray motion pictures of any portion of the human anatomy at the flick of a switch. To maintain constant brightness for the camera, and hence a constant film density as the Cine-Fluorex moves over varying tissue thicknesses, a photo-multiplier tube will be incorporated. This device will feed back to the x-ray control and automatically adjust x-ray tube current to maintain a constant x-ray image brightness.

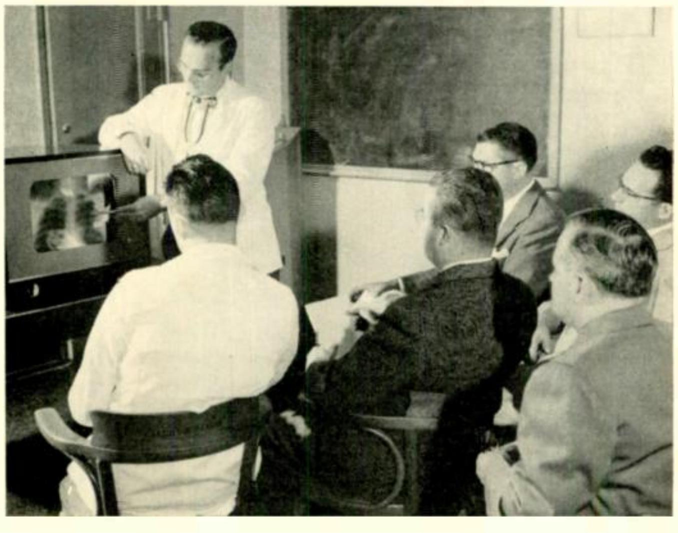
Video fluoroscopy offers many interesting possibilities. Teaching of fluoroscopy today is limited with respect to the number of students who can view the image at one time. Grouped around a fluoroscopic table in a darkened room, the instructor must repeat his dissertation for each student as they come forward to view. Motions occurring in the image, which may be seen by one student, may fail to repeat for subsequent viewers. Video fluoroscopy holds out the prospect of having all students view the image simultaneously on a television screen in a lighted room away from excess radiation, receiving their instructions over an intercommunication system, as in Fig. 7.

Consultation with other specialists is afforded, since several television monitors can be placed in various departments of a large hospital or teaching institution. Indeed, an x-ray specialist will be able to diagnose by "remote control."

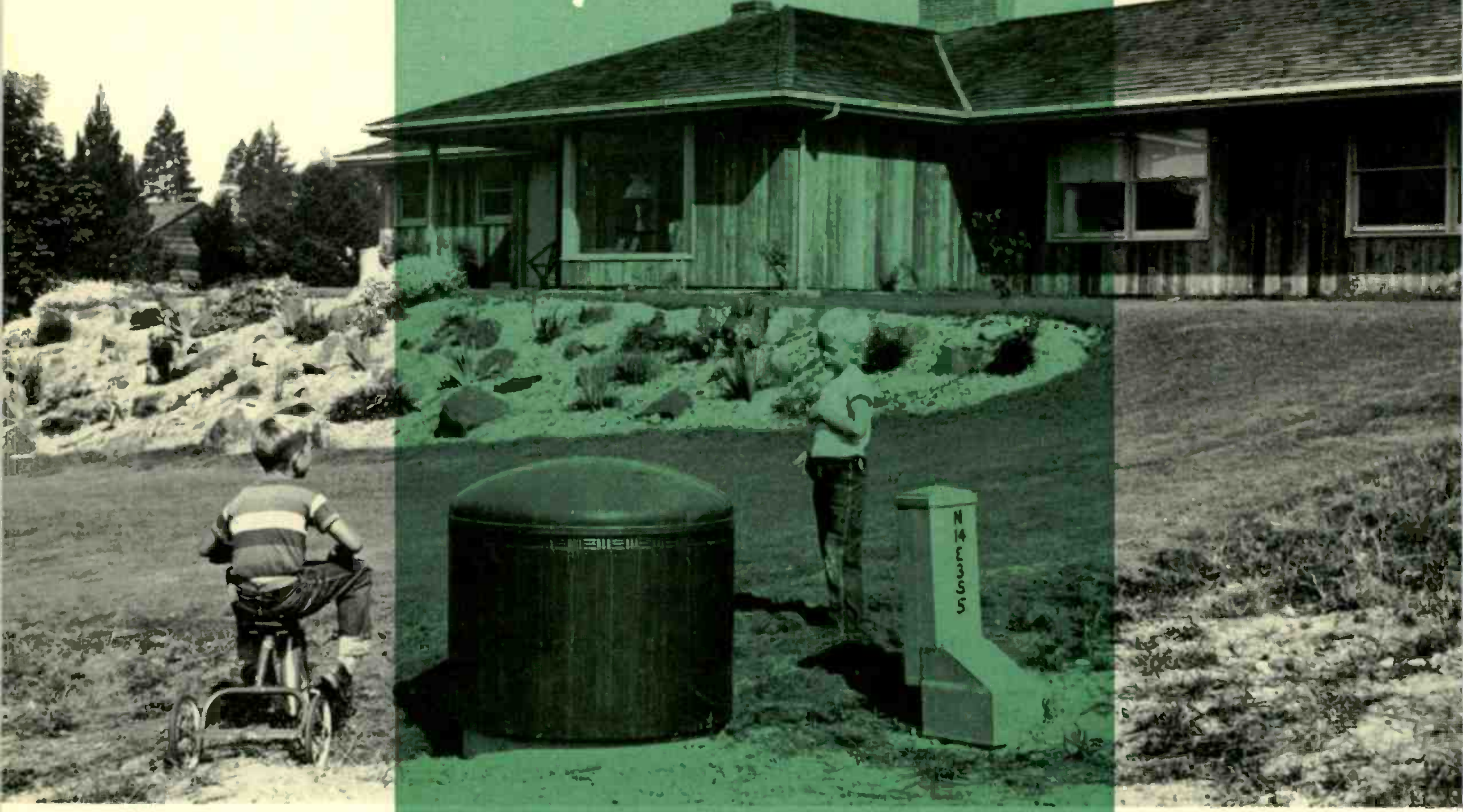
Inherent advantages of television circuitry augment the quality of fluoroscopic images. These pertain to the ability to adjust the television camera and monitor for optimum brightness and contrast, not possible in ordinary fluoroscopy. These advantages will enable one to demonstrate most satisfactorily human tissue of varying density.

Be it x-ray movies or televised fluoroscopy, increased x-ray diagnostic information is offered at low radiation levels.

Fig. 7—Students can be instructed by closed-circuit television.



low-cost *Underground Residential* distribution



Special safety measures have been designed into the transformer housing to prevent any possible injury to children or unauthorized persons.

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A GROWING interest in some type of underground distribution system for new residential areas is due largely to the greatest period of home building this country has ever seen. The desire of many new home owners and real-estate developers to have their areas free of utility poles, and overhead wires and equipment has brought about this increased interest in underground systems.

System Characteristics

The underground system offers some advantages not found in overhead systems. Conductors, equipment, and supporting structures are removed from sight, and are located where the public is least likely to come into contact with them. Better segregation of the different circuits and equipment, usually obtainable in underground installations, provides safer working conditions for electric-utility personnel. The underground system is free of service outages and accompanying expense due to damage by lightning, ice, sleet, snow, rain, and wind storms. The probability of trouble caused by motor vehicles, airplanes, building fires, and foreign objects coming into contact with the system elements is far less than may be expected on overhead systems. Furthermore, the underground system with proper cable will usually have a longer life than the poles and crossarms of an overhead system. The reliability of the residential underground system will be determined, for the most part, by the reliability of the primary-feeder circuits, which will be of overhead construction for at least a portion of their length.

These advantages, however, are accompanied by a greater installed cost. Experience has shown that the residential underground system costs from one and a half to six times as much as an overhead system to serve a given area. The upper end of this cost ratio represents systems approaching the rather elaborate conventional underground systems that serve commercial areas; the lower end represents underground systems where concessions and compromises have been made to obtain a practical installation.

Locating and repairing a faulted conductor usually takes longer in the underground system. However, the total time spent in location and repair of faults on an underground system may be less due to the fact that a smaller number of faults occur.

While the underground system does not have some of the problems associated with overhead systems, it has other problems peculiar to itself: tree roots grow among the conductors; chemical composition of the soil may cause corrosion of the terminals and other metallic parts; ground moisture and freezing may cause trouble; and people or rodents digging in the ground can damage the cables and cause faults.

System Design

The residential underground system cannot have all the refinements and operating advantages of conventional underground systems used to serve commercial areas, and still be a low-cost system. Duct banks, transformer vaults, manholes, and submersible equipment would put the capital investment in the system beyond justification on the basis of anticipated revenue, and must of necessity be eliminated. To achieve the necessary cost reduction and still maintain good practice, the following things must be done:

Primary, secondary, and service conductors must be buried directly in the ground; however, rigid conduit or pipe should be installed at vulnerable locations and street crossings. The distribution transformers must be standard pole type, enclosed in some type of semi-buried or surface-mounted housing. Service boxes or pedestals must take the place of manholes. To achieve further reduction in the installed cost of the system, the cable trench should be shared with the telephone company where possible. If the cable trench is located at the front of the lots, additional economy can be realized by placing the street-lighting circuit in the same trench. Front-lot location also offers the advantage of providing easy access for replacement of transformers, and necessary maintenance work. Locating the system along the back lot line may complicate access to the equipment, but, at the same time, can offer some saving by eliminating street crossings and the longer service runs associated with front-lot location.

In some cases, where residential underground systems have been installed, the cost has been divided between the electric-utility company and the real-estate developer. Generally, the utility bears the estimated cost of a comparable overhead system and the developer assumes the balance. The developer can afford to do this by adding a proportionate amount to the selling price of each dwelling unit. This addition is merely one of several cost increments that the home owner pays for services that are part of an area development cost rather than actually part of the house cost. Actually, this cost is a redeemable asset to the property owner since the improved appearance of the area usually increases the resale value of the property by at least the amount of his contribution to the system cost.

The majority of low-cost residential underground systems now installed are single-phase, radial systems. Actually, this may not be the most economical system. This is especially true where large inrush currents occur in areas having load densities ranging from approximately 30 to 150 kva per 1000 feet of secondary circuit. The advantages of the properly designed single-phase, banked-secondary system over the simple-radial system become more important when the systems are put underground; the banked-secondary system using completely self-protecting transformers then merits serious consideration. The banked-secondary system takes better advantage of the diversity among the loads and permits a smaller installed kva of transformer capacity. It provides better average-voltage conditions at the loads for a given transformer size, conductor size, and spacing between transformers. There is less voltage dip for a given inrush current. The system also provides a higher degree of flexibility with respect to new or growing loads. These factors become very important in an underground system. Once the cables are buried in the ground, the cost of replacing them with larger size cables becomes prohibitive. Actually, the banked-secondary system has adequate capacity in the secondary mains, from the standpoint of current-carrying capacity, voltage drop, and voltage dip, with the same size or slightly smaller conductors for a longer period of time than the simple-radial system.

Underground System Installation

Trenching—The trench should be sufficiently deep to locate cables below the frost line, even though heaving of the ground due to freezing and thawing may not cause damage to the cable insulation. A trench depth of 30 to 36 inches should be adequate for the greater part of the northern half of the United States. Installations in the states of Washington, Nebraska, and Massachusetts have been made using a trench depth of 30 inches. A depth of two feet should suffice in the southern half of the country. The bottom of the trench should be prepared for the cables with several inches of sand or sieved earth. The backfill immediately on top of the cables should also be "prepared" backfill.

Cable Protection—Mechanical protection for the cables is not considered generally necessary. Directly buried cable systems have been used extensively in Europe for many years with satisfactory operation without mechanical protection. However, if the additional expense of mechanical protection can be justified, there are several methods that can be used. A few existing installations in the United States and Canada have used such devices as planks impregnated with suitable wood preservatives, or inverted U-shaped precast concrete channels placed above the cables. In other cases, where the system was installed prior to completion of a new housing

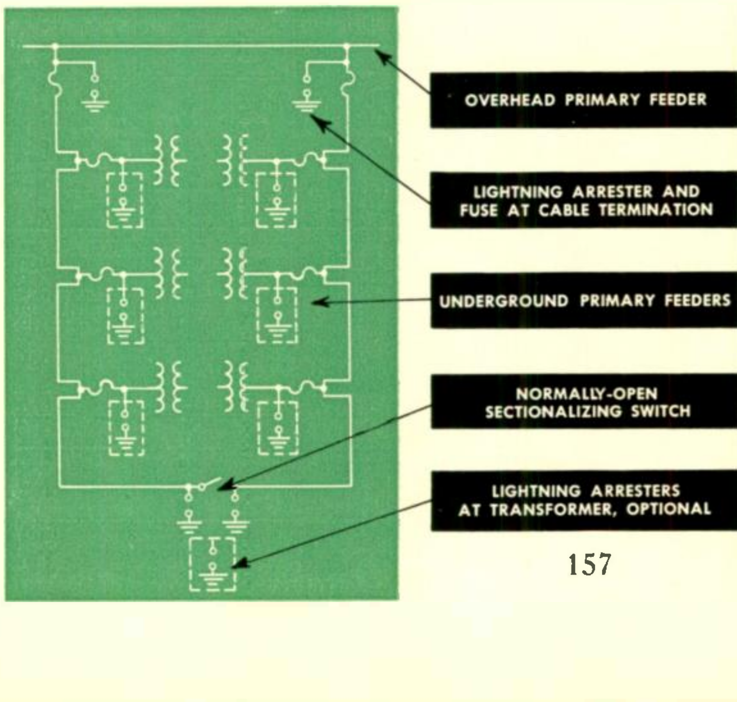


Fig. 1—This single-line diagram shows a primary feeder circuit for a typical low-cost underground distribution system.

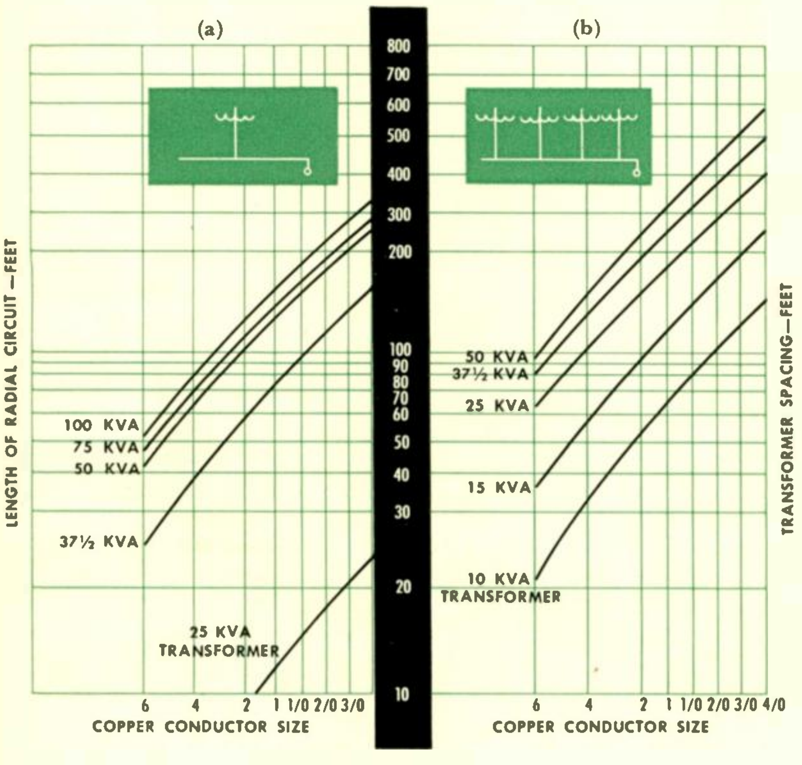
development, cables were laid below the edge of the proposed sidewalk location. The sidewalk provides the desired vertical protection and the cables are still accessible for maintenance by digging down at an angle. The possibility of damage to the cable can also be reduced by using some type of armored parkway cable.

Cables—The concensus of leading cable manufacturers is that both the primary and secondary conductors should be insulated with a good, tough, moisture-resistant insulation. The best cable insulation should be used for direct burial, inasmuch as the small initial savings of a relatively poor insulation is false economy in the long run. The system should be designed for approximately 30-year life and therefore the insulation used becomes critical. A good insulation, meeting these requirements, is a neoprene jacket over either rubber or an oil-base compound insulation. Both primary and secondary circuits should be composed of single-conductor cables rather than three-conductor cables. This reduces the probability of phase-to-phase faults, and facilitates making transformer connections, installing sectionalizing devices, and service take-off connections. In the case of a cable fault, a single-conductor cable is simpler to repair. The neutral conductor, which can be a common neutral, can be bare.

Sectionalizing—Most low-cost underground systems now installed serve small areas. They have a relatively small amount of buried primary cable, which is usually supplied from adjacent overhead open-wire circuits. Because of the system size, sectionalizing is often done as shown in Fig. 1. When the system is more extensive, further sectionalizing means are desirable to limit the amount of load dropped in the event of a cable fault.

Conductor Size—The primary conductor size depends upon primary voltage, length of the cable, and magnitude of anticipated load. A primary-circuit design for a maximum load of

Fig. 2—Correlation curves for a 120/240 volt, single-phase, three-wire, single-conductor underground system show (a) maximum length of a radial secondary circuit, and (b) maximum spacing between transformers for a banked-secondary system for a 2.5-percent voltage dip caused by inrush current to a 5-hp motor.



approximately 300 to 500 kva should be adequate for the majority of residental underground-installations.

Operating practice in the underground system parallels overhead practice in many respects. Initially, voltage regulation is the limiting factor in the secondary circuit. As the loads increase and more transformers are added, the spacing between transformers is reduced and current-carrying capacity rather than voltage regulation becomes the limitation. However, at any time, these two limitations may be superseded by the voltage dip caused by motor-inrush current and system design must be based on the tolerable voltage dip.

The use of single-phase, 220-volt, 5-hp motors in residential areas is not a thing of the distant future, but is here today in the form of heat pumps and central air-conditioning systems. Because this motor load is a definite possibility in almost any new residential development, it has been chosen as the basis for transformer and secondary main correlation. Typical curves showing correlation in a simple radial system and banked-secondary system are shown in Fig. 2. Since these curves show a condition of maximum severity, systems designed on this basis have sufficient current-carrying capacity in the mains, and voltage regulation is not a problem.

The service cables should be fused at the points where they tap off the secondary mains to protect the secondary from faults in a service cable. This is especially desirable inasmuch as the majority of faults due to mechanical damage are likely to occur in the service cable through the consumer's digging in his yard.

Service Connections—Service boxes or pedestals, containing three separate buses for the connection of the service cables, are the practical way to make service connections. Service boxes have been fabricated on the job using pre-cast concrete sections and a steel cover with provisions for locking. The box is set down in the ground with the cover flush with the ground level. The service pedestals must be of hollow construction to allow the cables to be brought up to make connections. The pedestals have to be rather bulky to give desired segregation between the buses. So, from the standpoint of appearance as well as cost, the flush-mounted service box is preferable.

Transformer Application—Conservative practice dictates that transformers installed in a housing or enclosure should be derated by 10 to 15 percent, since air temperature inside the housing is somewhat higher than that of the air external to the housing. However, when the actual load cycle under which the transformer operates is considered, derating probably will be unnecessary. This is because of the appreciable thermal time lag before the transformer reaches maximum temperature for any given load. Theoretically, the life of semi-buried transformers applied without derating is somewhat less than that of pole-mounted transformers, but whether this difference will be recognizable is questionable.

Street Lighting

Many possibilities exist for handling street lighting in a low-cost underground distribution system. The constant-current transformers, oil switches, and protective relays can be installed in semi-buried housings similar to those used for the distribution transformers. If the underground system, as will usually be the case, serves a relatively small area supplied from adjacent overhead primary circuits, this equipment can be located on poles in the overhead area adjacent to the underground area. The problem of locating the necessary street-lighting equipment and circuits is very much simplified if multiple rather than series street lighting is used. When using multiple street lighting, the buried secondary circuits need only be run to the street lighting poles or standards and then up to the lights. Control relays for the lights are mounted in or on the poles. One possibility is to use a light-sensitive relay built integrally with each lighting unit. If the light-sensitive relay, time clock, or other type relay is used to control several street lights, the control relay can be mounted on one pole and pilot circuits run underground to the other poles where lights are to be controlled.

Fault Location

The use of single-conductor cable in the low-cost underground distribution system will probably eliminate all faults but the single-line-to-ground fault. The location of these faults will be facilitated through the use of a standard test procedure. Such a procedure might be as follows: (1) Make a preliminary analysis to determine the fault location based on customer complaints and information concerning the operation of system protective devices; (2) Inspect the cable route for physical evidence which might indicate a fault location. Such evidence may be in the form of recent construction involving excavation; (3) Determine and isolate the faulted cable section through sectionalizing procedures; (4) Use tracer-current or surge type of equipment to determine exact fault location.

Surge Protection

Nonmetallic-sheathed cables buried in the ground are not immune to surges and possible damage due to lightning. Lightning surges get into these cable circuits in two ways. The first, and most frequent manner, is through the overhead primary-feeder circuits. The cables and the distribution transformers connected to them usually can be adequately protected by applying lightning arresters at the termination of the overhead circuit and at the opposite end of the underground cable. However, if the cables are relatively long, additional lightning arresters may be required at intermediate points along the cable. The arresters can be located at the transformers.

The second way in which lightning surges can get into the unshielded cable circuits is through lightning currents in the soil. If the soil has relatively high resistivity, these currents may seek the cables because of the better current-carrying path they provide. Damage to the cable and connected equipment can result. Arresters at each end of the cable cannot protect the cable and the connected equipment from such surges. If the soil has high resistivity and the number of lightning strokes per year is relatively high, the application of lightning arresters at all distribution transformers or the use of metallic-sheathed cable may well be justified. In low-lightning-density areas where the soil resistivity is low, the omission of arresters at the distribution transformers may be a good calculated risk, assuming, of course, that adequate protection is provided at the cable terminations.

Transformer Installation

Over the years, various utilities have devoted a considerable amount of thought as to how they might provide for the transformer installations for a low-cost underground system. Requests for recommendations were received by Westinghouse as early as 1939. The most promising housing developed uses a partially buried hollow concrete cylinder, with the upper portion above ground level. This arrangement lessens the difficulty of installation and maintenance over that of a completely buried unit, and makes the completed installation less conspicuous than a surface-mounted unit. The superstructure, a steel housing and cover, can be fabricated at the transformer factory. This offers the advantage of providing a degree of uniformity and economy not possible when individual power companies make their own housings. The design has come to be known as a *semi-buried* transformer installation.

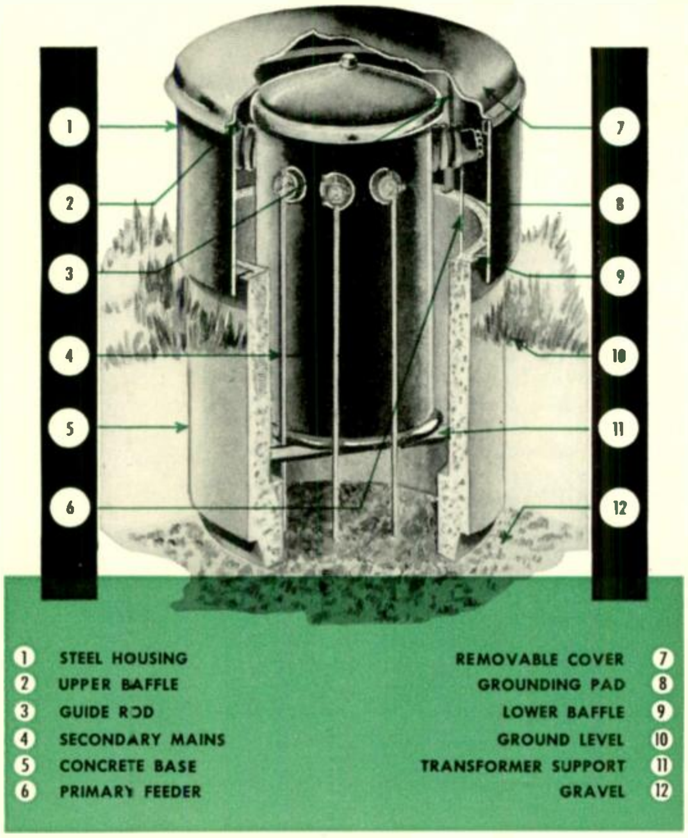
During the last five years, a number of design changes have been made, based on the accumulation of experience, and all aimed toward greater simplicity and safety. The latest designs have three component parts; a cylindrical concrete pipe, a cylindrical steel shell, and a domed circular sheet-metal cover. Standard concrete pipe dimensions are utilized in the design of the base, shown in Fig. 3.

The steel housing is of larger diameter than the concrete base, to permit cooling air to be drawn into the enclosure. Near its top, a section of grillwork allows heated air to escape to the outside. A mounting ring is welded to the steel shell near the bottom. The domed cover is flanged to fit snugly over the steel housing and provided with fittings to permit padlocking to the housing. A survey of the transformer ratings and types indicated that two sizes are required using a 36-inch and a 48-inch diameter housing. With these housings, single-phase transformers through 50 kva, 7200 volts, and through 100 kva, 2400 and 4800 volts, and three-phase transformers through 75 kva, 2400 and 4800 volts, can be accommodated.

Conclusions

The use of underground systems has not been extensive. However, recent use has been sufficient to be recognized as a trend in new residential areas. While this trend will probably not grow to large proportions, a gradual increase in the number of these systems installed each year is anticipated. Underground systems using the equipment described have been installed in 18 widely spread states, the Virgin Islands, Hawaii, Alaska, and Puerto Rico. Operating experience has been entirely satisfactory, and has shown that low-cost underground distribution can be achieved in residential areas.

Fig. 3—A cutaway view of the semi-buried transformer housing.



Stories of

Dirt Gets Tagged

What physical and chemical forces hold dirt to cloth, and how do such things as detergents, mechanical agitation, and water temperature break down these forces? These factors are not well understood. Scientists are currently trying to find out how dirt sticks to various objects by tagging dirt with radioactive carbon and tracing it through a cleaning cycle.

In this project, samples of cloth are stained with a standard dirt containing carbon black, a fat, and a protein—the essential ingredients of dirt in clothes. Any one of the three ingredients can be tagged by adding radioactive carbon. The beta particles given off can be counted with precision. Thus if one ingredient is tagged, and the radioactivity of the stain is measured before and after washing (see photo), the difference in beta-particle emission gives an accurate measure of the amount of that type of dirt removed.

The new technique already has revealed several facts that contradict common beliefs about removal of dirt from cloth. For example, the standard method of judging the amount of dirt removed in laundering has been to compare the whiteness of the cloth, by measuring the amount of light reflected by the stain before and after washing. Some of the tracer tests show that removing as much as 42 percent of the carbon black in soiled cloth brings only a 16-percent increase in whiteness. A common belief is that grease or fat is the culprit in dirt that causes it to stick. Experiments show, however, that dirt removal is not that simple. In certain cases, 76 percent of the fat in dirt must be removed to increase reflectivity and whiteness of cloth by only 14 percent.

A new insulating enamel for copper wire—shown here being prepared in the laboratory—promises smaller, longer-lived, and more efficient electrical equipment. Life tests of the new enamel show that electric motors using it can operate for ten years at a temperature of 325 degrees F. The new insulating material is a modified polyester-type resin containing about 20 percent silicone.

Super Power X-Ray Machine

X-ray machines are a basic tool of the research scientist. This new one at the Research Laboratories is the most powerful and versatile crystallographic x-ray machine in the world.

The key element in this new apparatus is a radically improved crystallographic x-ray tube. Such a tube yields a narrow intense beam of x-rays; the beam is directed through a crystalline material and the rays fall on photographic film. This gives a pattern that tells the arrangement of atoms in the crystal. The usual x-ray tube for this purpose yields x-rays activated by a continuous current of 15 or 20 milliamperes at 45 000 volts, compared to 120 milliamperes at 45 000 volts for the new tube. This additional power is especially important in research because it permits x-ray photographs in one sixth the usual time, collapsing months of normal x-ray work into a few days or a few weeks.

The high power output of the new tube comes from a unique water-cooled rotating metal anode. This anode, about five inches in diameter, resembles a hollow metal wheel and rotates at about 1000 rpm. X-rays are generated when a stream of electrons from a special type of cathode strike the rim of the whirling anode. Cooling water is pumped through a cavity in the anode.

When bombarded with electrons, different metals give rise to different kinds of x-rays. The new x-ray tube has extra anodes, each plated with a different metal, which can be interchanged in a few minutes. This versatility has already proved its value. New and unique radiations have been produced using anodes plated with such metals as gallium, which has such a low melting point that it cannot be used as a target in any conventional x-ray tube.

Pure and Perfect Iron

Little is known about metals that are completely free of impurities and imperfections—simply because they are never found in nature, and until recently could not be prepared in the laboratory. Theoretically such metals should exhibit fantastic properties. Pure and perfect iron, for example, has an ultimate tensile strength of more than a million pounds per square inch—which is at least ten times the strength of ordinary iron that has been hard drawn into wire, and at least three times the strength of the kind of steel used in making piano wire.

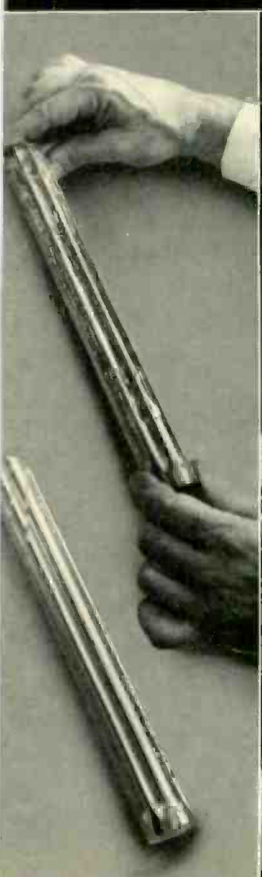
Scientists at the Research Laboratories have recently produced pure and perfect slivers of iron on an unprecedented scale; these exhibit tensile strengths approaching a million pounds per square inch. These slivers, or "whiskers," are each pure iron crystals, so perfect that no defects can be detected in their structure. The crystals are as much as two inches long and a thousandth of an inch thick; previous attempts to produce such "whiskers" have rendered crystals that could only be observed with the aid of a microscope.

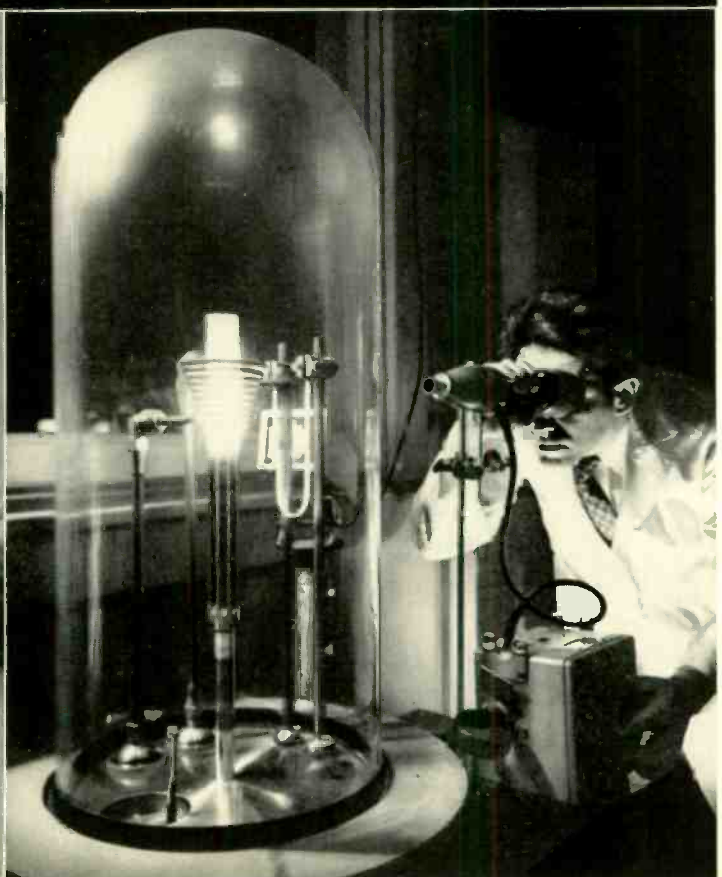
This pure iron resulted from the perfection of a new "whisker growing" technique, originated at the Laboratories about two years ago. Highly purified iron chloride, a common salt of iron, is heated in an atmosphere of hydrogen gas inside a special furnace at a temperature of about 1100 degrees F (see photo at left). By rigid control of temperature and flow of hydrogen the chlorine atoms in the iron chloride are allowed to unite chemically with the hydrogen at a certain precise rate. This leaves unattached atoms of iron, which migrate slowly toward each other and deposit one upon another in perfect arrangement. Thus billions of iron atoms grow, without any observable defects, into a single perfect crystal of pure iron, exactly square in cross section, and often attaining a length of two inches (see inset photograph at left). Direct mechanical tests show these crystals have strengths approaching a million pounds per square inch.

Pure and perfect iron will not emerge tomorrow as a brand new construction material; but this method produces the metal on a scale large enough to permit a realistic study, as well as being another forward step in an attempt to gain a broader understanding of the fundamental properties of metals.

research

Titanium Purified by Zone Refining





Scientists at the Westinghouse Research Laboratories are purifying titanium and other hard-to-get metals by imprisoning the molten metal inside a cage of its own making. The process, called cage-zone refining, uses a unique method to melt a bar of metal while the metal acts as its own crucible, thus preventing contamination by any containing vessel. Object of the process is to prepare super-pure metals.

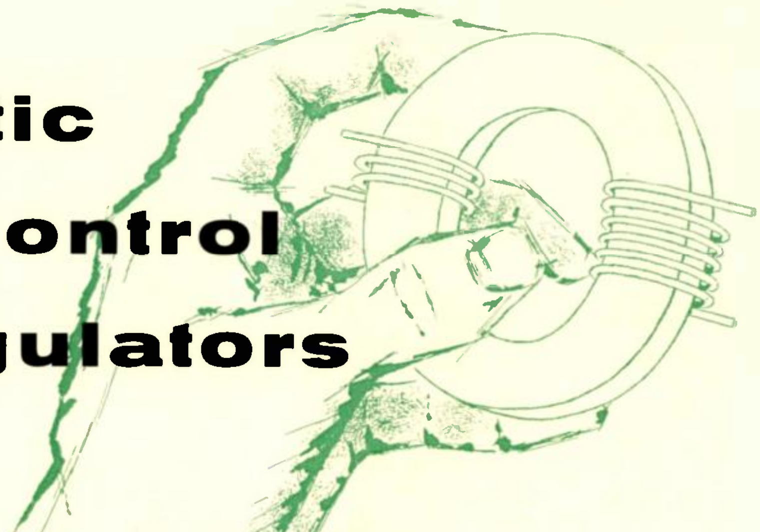
The success of zone refining depends upon the fact that most impurities in metals have a preference for either the liquid or solid state of the metal. Iron, a common impurity in titanium, has a preference for the liquid state of titanium. When a bar of impure titanium is melted progressively from end to end, the iron concentrates in the liquid titanium and follows the molten zone to the end of the bar. This end is then cut off and discarded, leaving the rest of the titanium bar more pure. Each time the process is repeated, more impurities are removed.

Titanium has a high melting point—over 3000 degrees Fahrenheit. At this temperature it is one of the most active metals known; it not only oxidizes rapidly but it reacts chemically with metal, graphite, or ceramic containers. The new process eliminates such sources of contamination in a unique way. In a low-pressure, inert atmosphere of either argon or helium gas, a bar of impure titanium stands upright on a metal platform (see photo at left). The platform is slowly raised, lifting the bar through the heating coil. A high-frequency current (10 000 cps) flows in the coil and induces currents inside the bar, causing the bar to melt from the inside. Thus the corners of the bar are less affected by the induced currents and rapidly lose what heat they possess to the surrounding atmosphere. The corners remain rigid and act as a cage in which the molten titanium is "imprisoned."

In a variation of the new process, a round bar is machined so that several ridges or fins run lengthwise along its surface, much like those on the fluted columns of certain buildings. These unmelted ridges then form the cage, and since they can be placed at will, they permit longer bars of larger diameter to be purified. Photo at far left shows such bars before and after refining. Scientists foresee the technique being applied to bars as much as three inches in diameter and of any desired length.

Magnetic amplifiers have moved into still another field, this time in a new control for voltage regulators. They bring with them the advantages of no moving parts and increased reliability, while maintaining accuracy standards of present controls.

static control *for* regulators



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The rapid growth of new loads makes proper voltage control in distribution systems an increasingly important factor for economic and efficient operation. The degree to which the voltage regulator performs this function depends upon the accuracy and reliability of its controls. In a new control for induction and station-type step regulators, and tap-changing-under-load transformers, magnetic amplifiers perform the functions previously handled by moving parts. In addition to the increased reliability thus afforded, the new control maintains the accuracy standards and operating features of present controls, and is arranged so that all control settings can be made from the front of the panel using calibrated dials.

Control Requirements

The basic function of the regulator control is to maintain the voltage at some point in the distribution system. A simplified diagram of a step-regulator control system is shown in Fig. 1; this system maintains the load-center voltage within predetermined limits with varying load conditions or incoming-bus voltage variations. The diagram for an induction-regulator control system is identical, except that no time-delay element is used.

For a regulator control to be applied in a variety of distribution systems having different requirements, many operating settings are necessary. In addition, the accuracy of the control to hold the voltage within a given bandwidth must meet ASA specifications for Class I operation, which limit the error in balance voltage to not more than one percent for variations in temperature, frequency, and line-drop compensation.

Step-Regulator Controls

Voltage-Regulating Element — The voltage-regulating element is the brains of the control system, in that it directs all control operations. Present control systems use some form of electro-mechanical voltage-regulating element, generally consisting of either a solenoid or induction-disc type device. The voltage-regulating element has a voltage bandwidth setting that determines the voltage spread of the regulated system. This element energizes the time-delay element every time the voltage swings outside the set bandwidth. On some distribution systems this can lead to excessive operation of the conventional regulating relay, thus shortening its life and decreasing the reliability of the entire control system.

Time-Delay Element—The time-delay element limits excessive operations of the tap changer due to momentary disturbances that cause the voltage to go outside the set bandwidth of the voltage-sensing element. The time-delay relays presently used are generally of the thermomechanical or motor-driven types. The component operation of either type depends, basically, upon the timing and reset characteristics desired: that is, whether integrating, inverse, or straight timing of an error signal is required, and whether or not the time-delay relay is to be reset immediately following an operation.

Regardless of the features designed into the timing element, any operation of the voltage-regulating element operates the timing element, to either run a timing motor, operate a motor clutch, energize a heater element, or operate auxiliary relays used to provide particular operating features of the time-delay relay. Therefore, while the output contacts of the delay element operate only to initiate a tap change, the timing components are operating to some degree for every fluctuation of voltage outside the set bandwidth of the voltage-regulating element. Again, as in the voltage-regulating element, the components of the time-delay element are subject to many operations for each tap change, and failure of this element affects the entire control circuit.

Static Control System for Step Regulators—Since only the voltage-regulating and time-delay elements in the control are subjected to excessive operation—the motor contactor and motor operate infrequently in comparison—a control system that can perform these functions with static devices has considerable merit.

The basic components that make up the static control system are shown in Fig. 1. Both the voltage-regulating element and the time-delay element are magnetic-amplifier devices.

The voltage-regulating element is actually composed of two circuits: a *sensing and reference* circuit and a *voltage-regulating* magnetic-amplifier circuit. The operation of these circuits is shown in Fig. 2.

The time-delay element that works with the voltage-regulating element is likewise static, except for a small relay, which operates infrequently. The operation of the time-delay element is shown in Fig. 3.

Operating Features—All settings required for specific applications are electrical settings made from the front of the control panel. Continuous voltage level setting from 105 to 135 volts can be made with the dial calibrated for 1-volt steps. Line-drop compensator settings are continuous, being made with a dial calibrated in 2-volt steps. Reverse reactance is obtained by merely selecting one of two positions with the reverse reactance switch. Bandwidth is set by a rheostat and has a minimum setting of ±1 volt and a maximum setting of ±3 volts. Only one time-delay setting in 1-second steps is required for both "raise" and "lower" operation to give delays ranging from 5 seconds to 90 seconds. The delay is on the basis of an error voltage existing for the full time set on the dial.

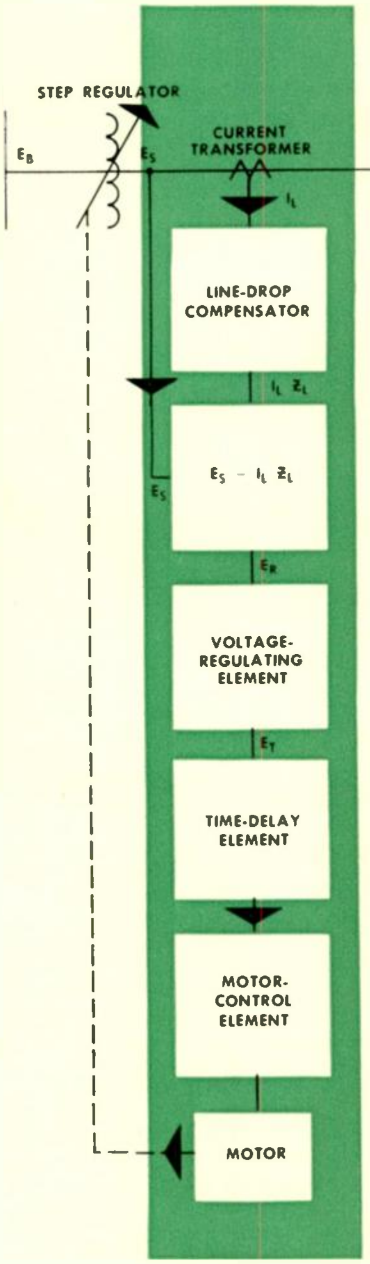
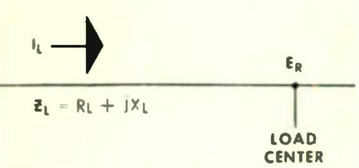



Fig. 1—A voltage proportional to the line drop is obtained in a line-drop compensator circuit and then subtracted from the sending-end voltage, E_S (output voltage of regulator). The resultant voltage, which is proportional to the load-center voltage E_R, is fed into some form of voltage-regulating element. Here, it is compared with a constant reference where a predetermined change in E_R due to either E_S or I_L will energize a time-delay element. The time delay is inserted to override minor fluctuations and hence reduce unnecessary operations of the tap changer. If the error exists for the set time of the time-delay element, the motor is energized and operates the tap changer to correct the voltage.

Voltage Reference and Sensing Circuit

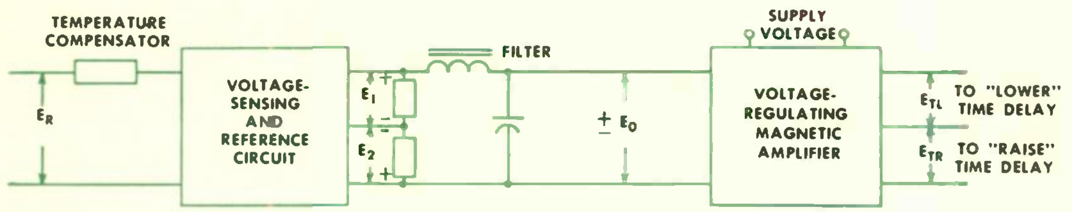


Fig. 2—The voltage reference and sensing circuit consist of a saturating transformer and rectifiers that measure the average value of the load-center voltage (E_R) applied to it. The circuit combination has two outputs. At the set balance voltage, the two outputs (E_1 and E_2) are equal and hence no error voltage (E_0) appears. Any departure from the balance level produces an error voltage of a polarity to indicate the direction of voltage change from balance. This error voltage is applied as a signal to a voltage-regulating magnetic amplifier, whose output energizes the time-delay element when the load-center voltage (E_R) departs from the predetermined voltage band.

Two magnetic amplifiers with their control windings connected in opposition make up the voltage-regulating magnetic-amplifier control into which is fed the error voltage from the reference and sensing circuit. A positive error voltage resulting from an increase in E_R above the bandwidth setting causes the "lower" unit to conduct giving an output d-c voltage E_T of one polarity, which is applied to the time-delay element. Compounding is provided by the positive feedback, so that once the error voltage has exceeded the bandwidth setting, the error will have to decrease by some definite amount before the input to the time delay is removed. This insures stable operation and permits the system to properly interpret a step correction of E_R that step regulators inherently provide. Similar operation takes place for a negative error voltage, which occurs when E_R drops to a value below the set bandwidth, thus giving an output d-c voltage E_T of opposite polarity.

Indicating lights are provided to show when the voltage has gone outside of the bandwidth setting. Potential test terminals and 5-ampere current test terminals are available on the front of the control panel.

Static Control System for Induction Regulators

Operation of an induction regulator usually takes place without time delay when the voltage swings outside the set bandwidth. This method of operation results in a large number of voltage corrections. The induction regulator is inherently capable of such operation since there are no main circuit contacts and the mechanical operation is simple, requiring only a means of positioning the rotor. Continuous efforts have been made to develop control elements that have operational life equal to that of the regulator itself. However, in general, control elements have continued to be a limitation on the serviceability of the regulator; and, in some cases, it has been found desirable to limit the number of operations by allowing a time delay after the voltage exceeds the bandwidth setting before operation of the motor control relays is permitted.

With the development of the completely static automatic control, however, operational life of the control element is removed as a limitation on the number of regulator operations. All time-delay apparatus has been omitted from the controls and the regulator operates to correct voltage as soon as it departs from the preset band. This static control system is similar to that for the step regulator except for the omission of the time-delay circuit.

The voltage-regulating element is similar in design and operation to the voltage-regulating element for the step regulator. When the applied voltage departs from the balance voltage, a differential or error voltage exists. This error voltage, applied as an input signal to a voltage-regulating magnetic-amplifier circuit, is amplified and applied as an input signal to the motor control element.

The motor then repositions the regulator rotor so that the regulated output voltage returns to the middle of the bandwidth setting. Compounding is provided by positive feedback so that once the error voltage has exceeded the bandwidth setting, it must decrease to near the center of the bandwidth before the input to the motor-operating stage is cut off. This feature has a high degree of importance in the economics of regulator application. Causing the output voltage to return to the balance point setting as often as a voltage correction is required reduces the effective bandwidth on the distribution system to a minimum. Achieving minimum effective bandwidth with feeder-voltage regulation allows an appreciable return in utility revenue, which, in most cases, more than justifies the investment in an induction-regulator installation. Both the permissible bandwidth of voltage variation and the return of the voltage to a mid-value are adjusted simultaneously by means of one knob on the front of the panel.

The motor control element is a single-stage magnetic amplifier of the self-saturating type. It acts as a static "on-off" switch to apply power to or remove power from the operating motor according to the signal received from the voltage regulating element. As power is applied, the motor repositions the regulator rotor so that the regulated output voltage returns to the middle of the band.

The adjusting and manual control features are similar to those previously used. The value of the balance voltage is set by calibrated dials and the sensitivity or permissible bandwidth of ±½ to ±3 volts approximately is likewise set by a single dial to a value best suited to the voltage characteristics of the system. Compensation for reactance and resistance drops in the line between the regulator and the load are set individually by means of calibrated dials on the front of the panel.

The use of the all-static control on induction regulators opens a new field of trouble-free operation, with more economical operations as a result of the narrower effective voltage bandwidths made possible. By its use, the usual program of inspection, maintenance, and repair of control parts will be greatly reduced.

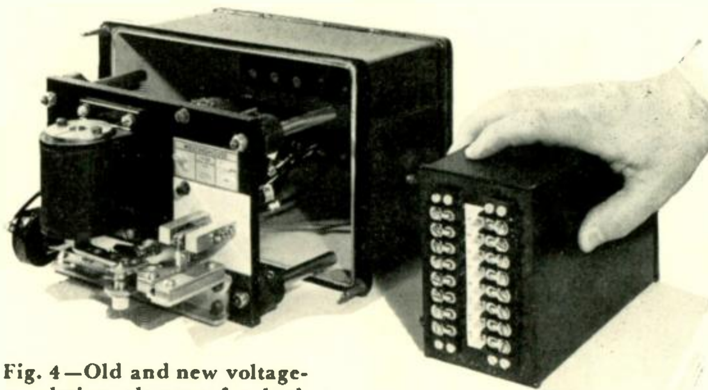


Fig. 4—Old and new voltage-regulating element for both step and induction regulators.

Time–Delay Circuit

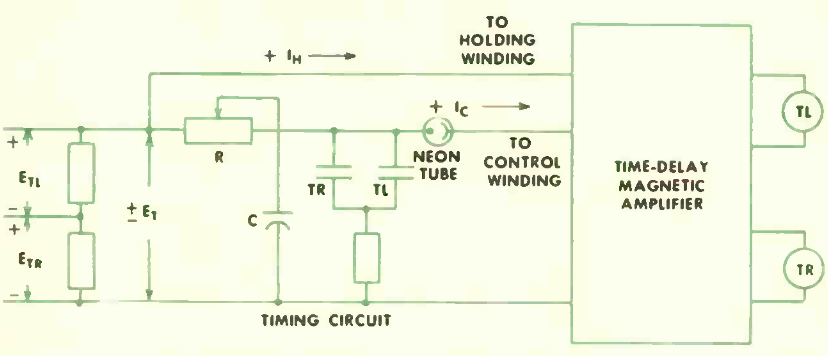


Fig. 3—The timing voltage, E_T, from the voltage-regulating magnetic amplifier is applied to an RC delay circuit controlling another bi-stable magnetic amplifier. The basic timing circuit with its timing characteristic is shown at left. The voltage, E_T, of given polarity (depending upon the direction of unbalance voltage) is applied to the RC network as shown. For the large delays required, the charging current through the resistor of the RC network is too small to be utilized. However, by charging the capacitor slowly, a neon gas tube measures the voltage across the capacitor, and when the tube breaks down it discharges the capacitor rapidly, giving a pulse signal current (I_C) into the control winding of a magnetic amplifier. Another signal current (I_H) applied to the amplifier directly by E_T keeps the amplifier conducting. When E_T is removed, the amplifier output drops to its cut-off value.

an *Engineering* Personality

C. B. Campbell

WHO IN WESTINGHOUSE has the most experience with steam turbines?

When this question was recently put to the Company, *C. B. Campbell* was named without taking time for a second thought. Thus it was that Campbell found himself one of the few engineers representing the Steam Division aboard the atomic-powered submarine *Nautilus* when she made her first dive.

Likewise, Campbell's assurance that a 5000-pound, 1200-degree steam turbine is a venture as engineeringly sound as it is forward looking was a major factor in Philadelphia Electric's decision to have Westinghouse build this epoch-making machine, which will generate more than a quarter-million kilowatts.

Such is Campbell's reputation in the industry. It is a standing based on 35 years of intensive work with public-utility, industrial, and ship-propulsion steam turbines, in which his judgments have become internationally known as being progressive and reliable, cautious yet forward looking. He has always been anxious to take the next step in turbine progress but has been determined not to take it until the experience of the last step has been consolidated.

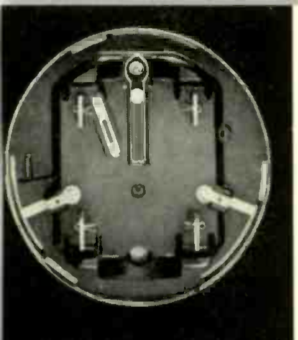
While an undergraduate student at the University of Michigan (BS-ME 1919), Campbell developed an affection for steam turbines, and a determination to participate in their development. Acting on the advice of his university faculty mentor at Michigan, he came to Westinghouse and started on the apprentice course.

After a year in various sections at the shops, there came a year and a half on the drafting board. This was followed by nine on the design of industrial steam turbines, during which time the "process-steam, by-product power" industrial-turbine field was vastly expanded. Early in this period, Henry Schmidt was developing his now famous oil governor. Campbell was assigned to help in the development, and then to establish the basic principles upon which present hydraulic-control systems are built. Campbell has several patents to show for this work. During the last several of those years he began working more on the big powerhouse machines—which fact was recognized in 1930 when he was placed in charge of Central Station Turbine Engineering. Four years later he was given the larger assignment of manager of Land Turbine Engineering, the position he held until 1944 when he was made manager of the Engineering Department of the Steam Division. He is now Chief Engineer of the Steam Division. His long and varied experience with steam turbines serves him well in advising and directing engineers in all phases of steam turbine and power plant engineering. When anyone has a turbine problem, the immediate thought is, "Let's call 'C.B.'"—and they usually do.

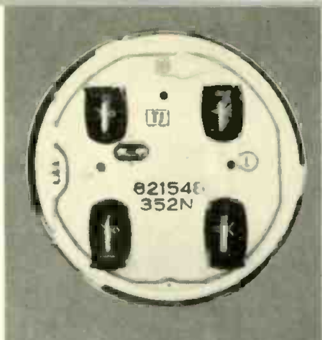
Campbell has dealt with many interesting turbine developments. For example, his activities have spanned the major development of the high-speed turbine, in which Westinghouse pioneered. When he came into the picture, the largest 3600-rpm turbine-generator unit developed was only 6000 kw. He took a principal part in ushering in the super-posed turbines, which were built in large numbers in the late 30's. The 165 000-kw, 1800-rpm unit—"Big Ben"—installed in 1935 in Richmond Station of the Philadelphia Electric Co., is still the world's largest single-shaft, 1800-rpm machine. Campbell supervised its design. His activity also includes machinery for ship propulsion—most noteworthy have been the U.S.S. *United States*, the aircraft carrier *Forrestal*, and the current nuclear-powered ships for the Navy.

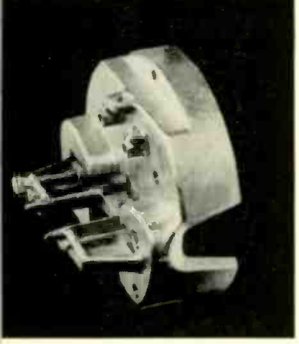
Many honors have been rightfully his. He was elected fellow of the ASME in 1953, and has served on many of its national and local committees. He is a member of Sigma Xi and Tau Beta Pi. For the World Power Conference in London in 1950, Campbell presented a summary of U.S. developments in central-station turbines. He has recently been elected a member of Franklin Institute's Committee on Science and the Arts. He was awarded the Westinghouse Order of Merit in 1942, and received a citation from his alma mater's College of Engineering in 1953.

Campbell writes well, perhaps an ability traceable to the days when he helped his father run a daily paper. "C.B." admits to doing everything in the shop from sweeping floors, to setting type, to reporting. (One of Campbell's two sons is a successful trade-magazine editor—the other has recently joined Westinghouse.) We suspect, too, that Campbell would have made a good teacher. This is evidenced by the great personal interest he has taken in the young engineers, who over the years have come under his influence. He is gifted with great patience, and has an unusual ability to explain technical matters. And furthermore, it appears that he enjoys it, for his discussions are punctuated with the broad, winning smile and chuckle that everyone knows as a Campbell characteristic. In spite of greying hair, he is as youthful in appearance as he is in his ideas. One could appropriately say of "C. B." when it comes to steam turbines, "You can be *sure* if Campbell says it's so."

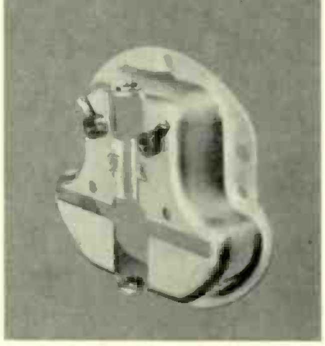


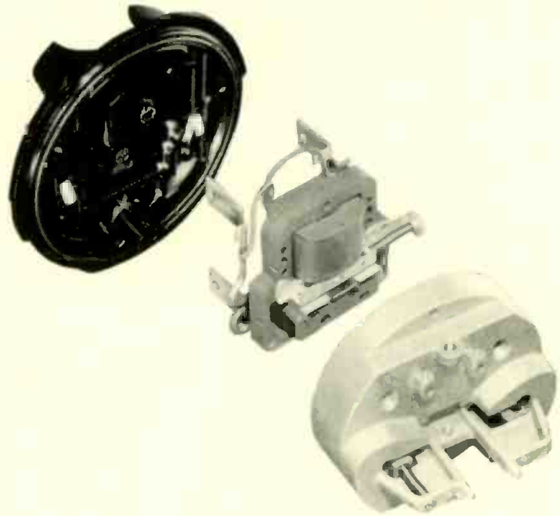
Left, the Micarta base-plate assembly of the new DS meter, showing the De-ion arresters. Right, the metal base-plate assembly of the older CS meter.



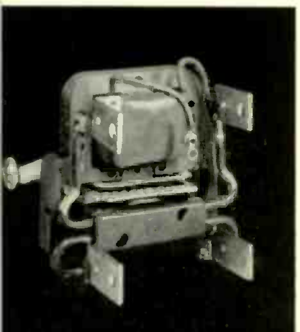


Left, a die-cast movement frame of the new DS meter holds all components in alignment. Right, the pressed-steel movement frame of the old meter.

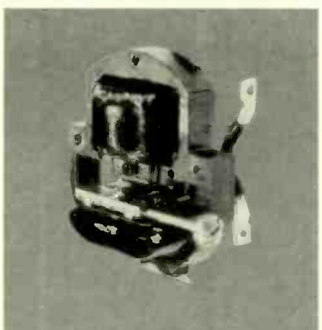




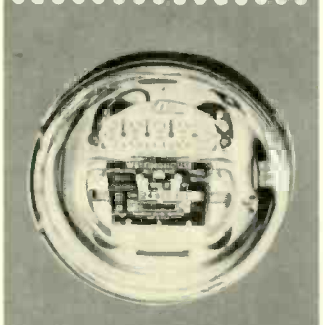
design considerations



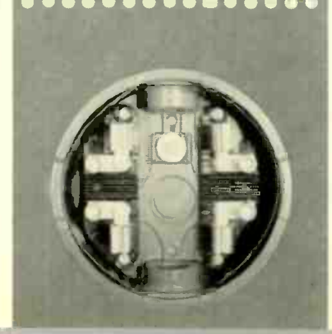
Left, the electromagnet assembly of the DS meter, showing form-wound, polyester-insulated current coils. Right, the CS meter assembly; note hand wound coils.



Left, a front view of the new DS meter. Dials have specially developed permanent finish designed to resist discoloration. Right, the CS meter.



Left, the new 100-ampere socket. Note the self-aligning terminals. Right, the old socket. New design achieves maximum corrosion resistance.



No matter how good they are,
few devices ever quite reach the point where no further improvements can be made.
Changing requirements also often make room for more improvements.
As a result, major design changes
occur periodically; such has happened in the case of the
watthour meter, with significant results.

for the Lifetime Meter

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and Ray Forrest
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Few devices operate as continuously with as much precision as the watthour meter. Yet despite its already high degree of reliability, the watthour meter has recently undergone a major design change to produce even further improvement. The result is a new meter, appropriately called the Lifetime meter, which has accurate load registration over a broader range, greater electrical and mechanical stability, and a longer life expectancy, among other improvements.

Range of Load Registration

Prior to 1924, all commercial watthour meters showed a pronounced decrease in accuracy of load registration beyond their rated capacity. During the early 1920's the widespread increase in domestic appliances taxed the average household meter to its fullest, and beyond. The potential loss in revenue to power companies led to the development of meters accurate to 200 percent of their nominal rating. Excessive retarding torque, produced by overload, had caused the lowered registration. This was compensated for by saturable magnetic shunts, which redistributed the electromagnet current flux on overloads, thereby extending the effective range.

By 1940 the flat load-curve characteristic had been extended to 400 percent of nominal rating. Thus a meter rated at 15 amperes could record with precision up to 60 amperes, which was adequate for most single-phase domestic service.

During 1953 the average annual home consumption of electric energy climbed to over 2500 kilowatthours. So alarming was the increase, both actual and potential, that the installation of meters below 100-ampere rating no longer seemed justified, since such meters would probably outlive their usefulness long before their normal retirement age.

A second method of extending the overload range had long been known. This was to reduce the disc speed at full load by increasing the strength of the damping magnets. The result was an increase in the ratio between the total retarding torque and that produced by the increase in current flux due to overload. The design problem revolved around two factors: low starting watts must be maintained, and high side-thrust on the bearing systems should be avoided.

In the new Lifetime meters, disc speed at rated load has been lowered from 30 to 16⅔ rpm. By careful balance of the magnetic components, side thrust at the bearings is actually lower than the previous higher speed meter. Single-phase and polyphase meters now have an effective range from starting watts to 667 percent of rated load.

Electrical and Mechanical Stability

Stability in a meter is its inherent ability to maintain its initial accuracy over years of continuous operation. This includes sufficient ruggedness to withstand severe or prolonged mechanical shocks, such as might be experienced during shipment across the country by rail, without affecting the calibration of the meter.

In place of a steel stamping, a new rigid, die-cast frame holds all operating components in precise and permanent alignment. Upper and lower bearing mounts are precision machined to close tolerance in the casting itself, thus eliminating bushings and inserts. Tapered dowels position the electromagnet and prevent shifting. As before, potential coils are fabricated into a single solid unit by vacuum impregnation with a thermosetting polyester resin. Instead of hand-wound current coils, the new meter uses form-wound current coils enclosed in a polyester insulating matrix solidly molded around the laminations.

Adjusting screws are spring loaded to hold calibration settings without shift, instead of depending on friction between the parts, as in previous meters.

All coils are wound for ample current-carrying capacity, and brazed terminals are used instead of the former screw connections. As before, the electromagnet laminations are treated to prevent development of internal "sneak circuits" that might affect calibration.

To prevent any variation in accuracy due to changes in strength of the damping magnets, a high coercive alnico alloy is used. The new magnet is practically immune to stray demagnetizing fields from d-c or a-c sources, and the magnets are shielded against lightning surges up to 40 000 amperes, 20- by 50-microsecond wave.

Life Expectancy

The enemies of long meter life are corrosion, wear, and burn-out. Corrosion resistance was a principal consideration in the design of the Lifetime meter, and all materials were selected and treated for maximum chemical stability. Replacing the former lacquered-steel base plate, the new socket-type meter base is high impact-strength Moldarta. Even at high temperatures, the insulating materials used do not emit corrosive vapors that might attack metal parts. All aluminum parts are protected by an iridite finish, and all register gearing is gold plated. Electromagnet laminations are individually bonderized, and the whole electromagnet assembly is lacquered. White dials have a new specially developed permanent finish that does not discolor even after the severe test of 24 hours at 330 degrees F. Instead of a hard flat gasket, a foam neoprene ring, recessed into the base, compresses to a smooth snug seal when the glass cover is in place.

The moving element rotates on a chrome-steel ball between two sapphire cup jewels, which are virtually free from friction even after years of continuous service. Careful balance of driving and damping torques gives a low resultant side thrust at the upper guide bearing, and negligible bearing wear.

To protect against burn-out damage due to lightning, De-ion arrester gaps are used. Arranged to discharge outside the meter, these flash over at approximately 7000 volts impulse, which is safely below the 10 000-volt minimum impulse insulation level of the coils.

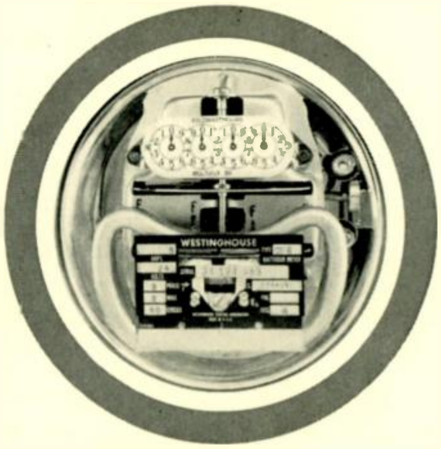
The Lifetime meter is essentially maintenance-free, except for the usual cleaning of jewels and bearings at scheduled testing periods. In many states these periods are now at eight-year intervals, and may be further extended in the future. The normal trouble-free service life of the new meter is estimated to be at least 30 years.

Components, such as bearings, registers, and moving elements are common to both single-phase and polyphase meters, thus reducing the inventory necessary for normal servicing.

The Single-Phase Meter

Single-phase Lifetime meters are designated as type DS for socket mounted, and type DA for bottom-connected panel mounting. The three-wire meter is designed in a 15-ampere rating suitable for loads up to 100 amperes, and in a 30-ampere rating good up to 200 amperes, as compared to the 60- and 120-ampere ranges of their corresponding predecessors.

Calibration adjustments are readily accessible and arranged for either finger or screwdriver operation. To simplify adjustment, both full-load and light-load adjusting screws have practically linear sensitivity of approximately one percent per



Above, the old CS-2 polyphase meter; note the two discs. At left is the new single-disc meter, designated the DSP-5.

Right, the new DSP polyphase meter dismantled. As can be seen, adjusting screws are accessible from front of the new meter.

turn. Range of calibration for both adjustments is plus or minus ten percent. The power-factor adjustment, formerly a hand-soldered loop of wire, has now become a permanent, preset factory calibration.

Surge-protection gaps are arranged to discharge outside the meter. The De-ion principle minimizes burning of the contacts even by repeated surges. Should the outer electrode become damaged, it can be replaced easily without removal of the glass cover.

New disc guards are cast into the frame to prevent damage to the disc or bearings if the meter is laid on its face during inspection or maintenance. As in all Westinghouse meters, the register is bayonet mounted and needs no adjustment for correct mesh.

The full complement of standard accessory equipment includes four- and five-dial clock-type registers, a new large numeral cyclometer-type register, and both indicating and cumulative mechanical-demand registers.

The Polyphase Meter

When three-phase, three-wire circuits were first introduced, they were measured by two single-element meters, each having an individual register. The algebraic sum of the register readings gave the energy consumption of the system. In 1896 Shallenberger designed a single meter in which two elements, acting on a single disc, actuated a single register that integrated the combined readings.

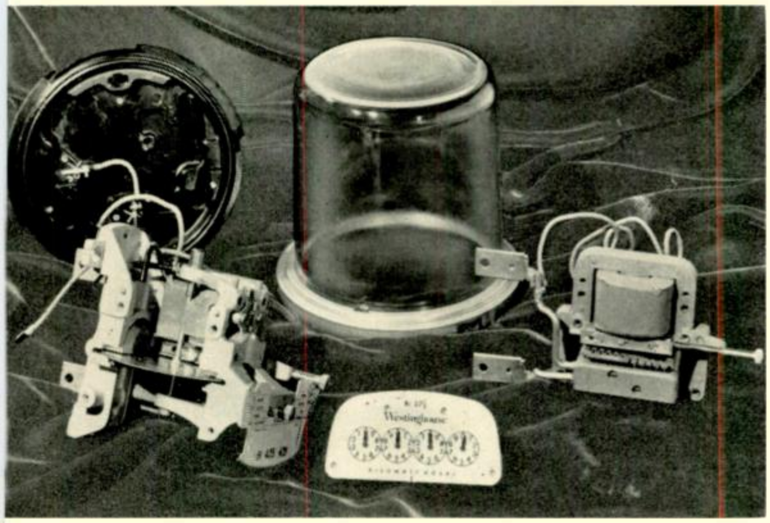
When more than one electromagnet is applied to a single disc, the currents induced in the disc by one electromagnet react with the fluxes induced by the others, causing faulty registration. In the Shallenberger meter a large-diameter disc reduced this interference to a minimum, but the problem was far from solved. A simpler alternative was to use a separate disc for each element.

Early in 1898, the first multi-disc polyphase induction meter was patented. The use of two separate discs operating on a common shaft effectively eliminated the interference, and this meter was the first to operate correctly on unbalanced loads. A principal disadvantage was its large size and weight.

Engineers, therefore, turned their efforts towards producing more compact, simpler, and less-expensive polyphase meters. Through the years these attempts have followed two main lines; improvement of the multi-disc meter, and development of single-disc meters incorporating means for eliminating the interference between elements.

By 1936 the double-disc polyphase meter had been reduced to a size comparable to the single-phase meter. Single-disc polyphase meters were also available, but required laminated or radially slotted discs to reduce interference by localizing the eddy currents.

Completion of the design of the single-phase Lifetime meter in 1954 focused attention on the need for a companion polyphase line incorporating the new features, including extended range. Retention of the advantages of the basic electromagnet structure of the single-phase meter seemed desirable. In this case a multi-disc design would be prohibitive in size. Therefore, single-disc construction was selected, to keep the size of the polyphase meter small and permit reduction in the number of adjustments.



Before going further, a solution to the problem of voltage and current interferences had to be found. Up to this time several methods of compensation were in use. Among these were laminated discs, magnetic shielding, slotted discs, and magnetic bridges to carry a compensating flux across from one electromagnet to the other. But a new and unique scheme offered better possibilities.

Reduced to its simplest terms, interference can be considered as arising from three separate interactions between eddy currents in the disc and fluxes from the electromagnet poles: First, voltage interference, caused by voltage-pole flux interacting with eddy currents induced by the opposite voltage pole; second, current interference, caused by current-pole flux interacting with eddy currents from the opposite current pole; and third, voltage-current interference, caused by current-pole flux interacting with eddy currents from the opposite voltage pole, and vice-versa.

The first and second sources of interference were found to be largely due to a condition of asymmetry between the two electromagnets and the disc. This can be corrected by a symmetrical arrangement of the electromagnet poles with respect to the center of the disc, which directs the forces caused by the undesired interaction towards the axis of rotation.

The third interference, due to voltage-current interaction, is eliminated by a novel arrangement of cross-connected windings on the voltage poles. By correct proportioning of the ratio of compensating turns to main-winding turns and proper phasing, the interfering torques are completely cancelled. Once determined, the compensation holds for any phase relationship between the two electromagnets and for any condition of loading. This solution permits using a single-phase, solid-disc assembly in the polyphase meter.

Once the single-phase interference problem was solved, a functional design evolved. The die-cast frame is split into a front and a rear component. These are joined by the two electromagnets into a rigid, box-type assembly, which securely holds the operating components in precise alignment. The disc, bearings, and register from the single-phase design are retained without change.

To simplify the calibration problems inherent in a polyphase watthour meter, a simplified system of adjustment was developed. For a given load, each element of a polyphase meter obviously must produce the same torque on the moving system. Because two identical torque-producing units are virtually impossible to produce using standard manufacturing processes, balancing adjustments were always provided on each electromagnet. In the new meter, however, only one torque adjustment is required. This is made possible by applying a fixed preset torque reducer to the nonadjustable electromagnet. An additional feature of the new design is the compensation of the torque adjuster so that it does not disturb the relationship between full load, light load, and power factor.

Conventional polyphase meters have commonly employed a separate light-load adjuster on each electromagnet. This practice is a carry-over from early designs, which were essentially two or more single-phase electromagnets driving one or more discs on a common shaft. By designing a light-load adjuster to perform the specific function of calibrating a two-element polyphase meter, it was possible to use a single adjuster instead of the conventional two. This was accomplished by incorporating additional lag compensation in the non-adjustable electromagnet, and doubling the range built into the variable adjuster.

The total number of adjustments has thus been reduced to three; one each for full load, light load and phase balance. Lag calibration for power factor is preset. All adjusting screws are accessible from the front of the meter, and can be set by hand or screwdriver. As in the single-phase meter, adjustments feature a sensitivity of one percent per turn, and are spring loaded. Calibration of the new polyphase meter is, therefore, simpler and faster than ever before possible, without sacrifice of either accuracy or stability.

To complete the picture, companion 100-ampere sockets have been designed with maximum corrosion resistance and ease of wiring. New self-aligning, bus-type terminals accommodate either aluminum or copper conductors up to No. 0, assuring adequate capacity for tomorrow's loads.

The watthour meter, which is nearly as old as the electric-utility industry itself, has undergone many changes in the past half century. The new meter represents the latest major effort to improve its characteristics and reliability. As its name suggests, the Lifetime meter is mechanically and electrically designed for long service, and to have maximum dependability and accuracy throughout its useful life.

propulsion equipment for the U.S.S. Glacier...

the U. S. Navy's Newest Super Ice Breaker

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THE PROPULSION REQUIREMENTS OF an ice-breaking vessel are peculiar to the nature of its operation. Since passages cannot be "broken" through heavy polar ice floes, the ice breaker must take advantage of open leads, or force floes apart by applying sufficient thrust to form a lead. This calls for a vessel of short length and maximum maneuverability. The ship's hull must be extremely strong and the installed power plant of sufficient power to force a lead. Also, since the ship may be frozen in for long periods of time, and its voyages may be of such nature that refueling is practically an impossibility, the power plant must be economical on fuel during long periods of full-power operation, as well as during enforced idleness. The economy in space and fuel consumption offered by diesel-electric propelling machinery, together with its flexibility of operation, are important factors in its choice for this exacting service. The need for rapid maneuverability and constant shaft horsepower over a wide propeller-speed range has led to the use of d-c motors and generators for propulsion power on ice breakers.

Although only 310 feet long, the U.S.S. *Glacier*, the Navy's newest and fastest icebreaker, is powered by 21 000 horsepower—in the form of two 10 500-hp motors that drive the twin screws. Electric power is supplied to each motor by five diesel-generator sets in parallel. Magnetic-amplifier control is used to maintain constant horsepower automatically from ice-breaking to open-water operation.

Propulsion Motors

The requirements of the *Glacier* called for propelling motors on each of the twin screws capable of 8450 shaft horsepower continuously, and 10 500 hp for four hours over a propeller-speed range of 120 to 175 rpm. For flexibility and reliability, a double-armature motor would have been desirable. However, weight and space restrictions made it necessary to use a single-armature machine. As a result, the two motors are the largest single-armature d-c motors, in horsepower rating, that have ever been built.

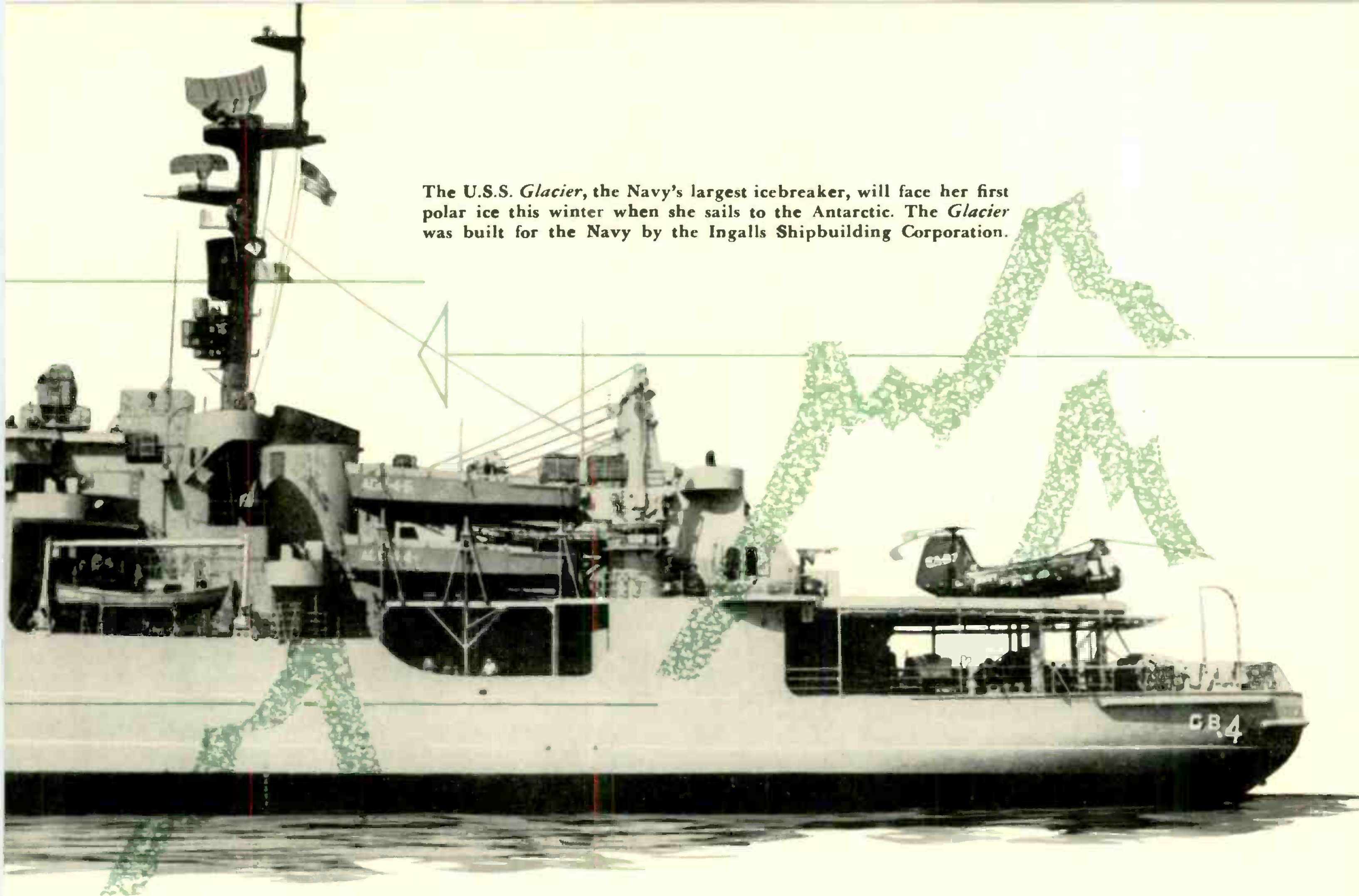
The motors are shunt-wound, separately-excited, compensated machines. Each motor is force ventilated by two bulkhead-mounted, axial-flow fans. The forward and after ends of the motor are separated by a bulkhead in which the fans are mounted. The after chamber is under pressure so that air is forced through the motor and exhausted through a surface-type water-to-air, double-tube cooler and air filter into the forward chamber, where it is again picked up and recirculated by the ventilating fans.

Propulsion Generators

Five diesel-driven propulsion generators supply power for each of the propulsion motors. Each generator has a continuous rating of 1340 kw, 837 volts, 1600 amperes; a four-hour rating of 1700 kw, 900 volts, 1890 amperes; and an additional four-hour rating of 1700 kw, 760 volts, 2240 amperes. The latter rating is required to make full use of the available engine horsepower when the vessel is stalled under a condition of three-engine operation. It is based on preventing engine overload by reducing full-field motor speed by lowering generator voltage, but simultaneously maintaining rated engine and generator output.

Each generator is totally enclosed and self ventilated by a shaft-mounted blower. The air is recirculated and cooled by means of a top-mounted, double-tube cooler. A mechanical filter is provided to prevent recirculation of carbon dust from the generator brushes.

Each generator is protected and has mounted adjacent to it an electrically operated circuit breaker. The circuit breakers



The U.S.S. *Glacier*, the Navy's largest icebreaker, will face her first polar ice this winter when she sails to the Antarctic. The *Glacier* was built for the Navy by the Ingalls Shipbuilding Corporation.

also serve as generator set-up switches and permit the use of any combination of from one to five generators for supplying power to the propulsion motor. An individual rheostat is in series with the shunt field of each generator. These rheostats are provided as a means of dividing load equally among the paralleled generators on the bus, since there is no provision for individual adjustment of engine speeds.

Motor Field Control

The power required to drive the propeller of a ship in open water varies approximately as the cube of the propeller rpm. This means that if propeller speed is to be doubled, the power must increase eight times. Putting it another way, the vessel can be propelled at 80 percent of rated speed with only 51 percent of rated power.

If forward motion of the vessel is retarded or brought to a stop by ice or a heavy tow, the power required to drive the propeller at a given speed increases a great deal over that required when the vessel is running free. In other words, a given horsepower is reached at a lower rpm. This is shown graphically by the curves in Fig. 2 (p. 173).

In an ice-breaking vessel such as the *Glacier*, it is desirable to obtain maximum available output from the power plant with any number of engines in operation, from stalled to free-running condition. To do this, all of the engines must be kept running constantly at rated speed; therefore, to provide the necessary flexibility, the motor field must be adjusted according to load conditions.

The propeller of the *Glacier* may load the propulsion motor to its maximum-rated output with the speed varying over a range of 120 to 175 rpm, depending on whether the vessel is completely stalled or running free. When the propulsion motor is developing rated (10 500) horsepower at 900 volts, the full-field or minimum speed of the motor is 120 rpm and the weak field or maximum speed is 175 rpm. Once these voltage and speed points are established for a given motor design, the same range of motor field adjustment can be used for lower motor speeds and lower power levels by lowering the bus voltage applied to the motor. For example, to load the plant at normal continuous output of 8450 hp, the motor full-field speed should be 112 rpm and the weak-field speed 163 rpm. The correct bus voltage is in direct ratio to the propeller speed, or in this case 837 volts. In a similar manner the correct bus voltage for a propeller load corresponding to four-engine and three-engine plant output would be 777 and 706 volts, respectively.

By selecting the bus voltage in this manner, the required range of propeller speed from stalled-ship to free-running condition can be covered entirely by motor-field control, keeping the plant output constant. During ice breaking, conditions change rapidly from one extreme to the other; therefore, provision is made to automatically regulate the motor field strength to keep the motor load at the rated output of the propulsion plant.

Constant-Horsepower Regulator

The curve in Fig. 3 (p. 173) shows what the motor armature current should be for constant-horsepower motor operation at any given value of bus voltage. To hold these loads, it is necessary to control the motor speed by automatically adjusting the motor field current until the load current corresponding to the voltage is obtained. Thus, as the ship's condition changes anywhere from completely stalled to running free, the generator voltage is held constant while the motor field is adjusted to hold the motor load constant. The plant power output will also remain constant as the propeller

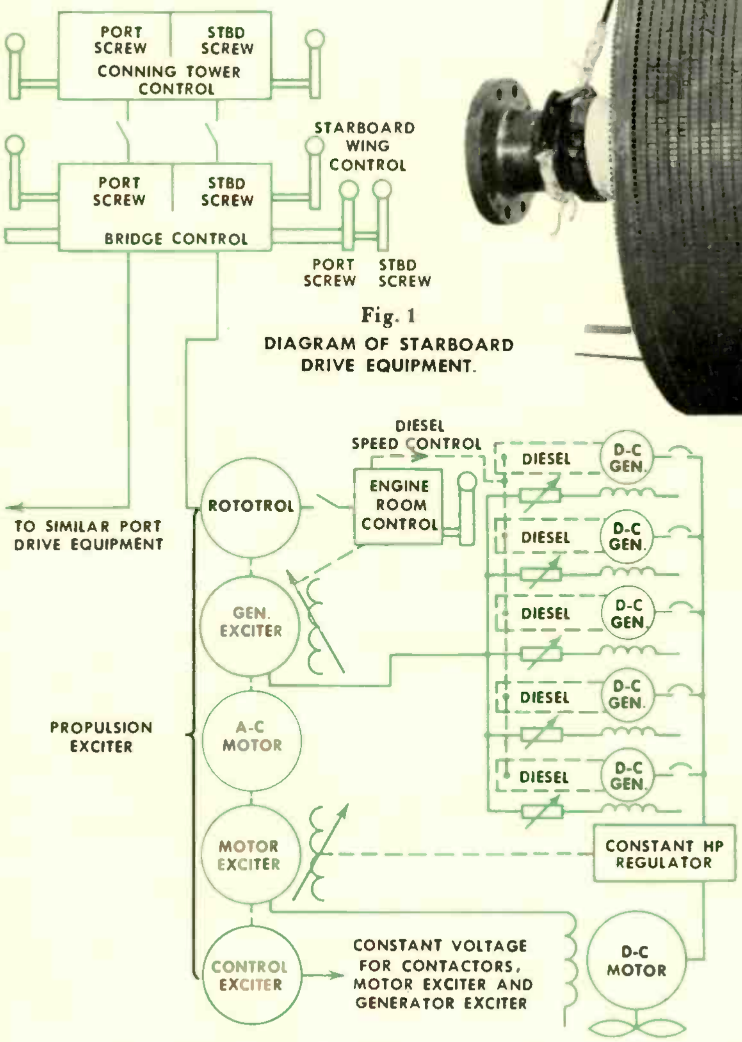
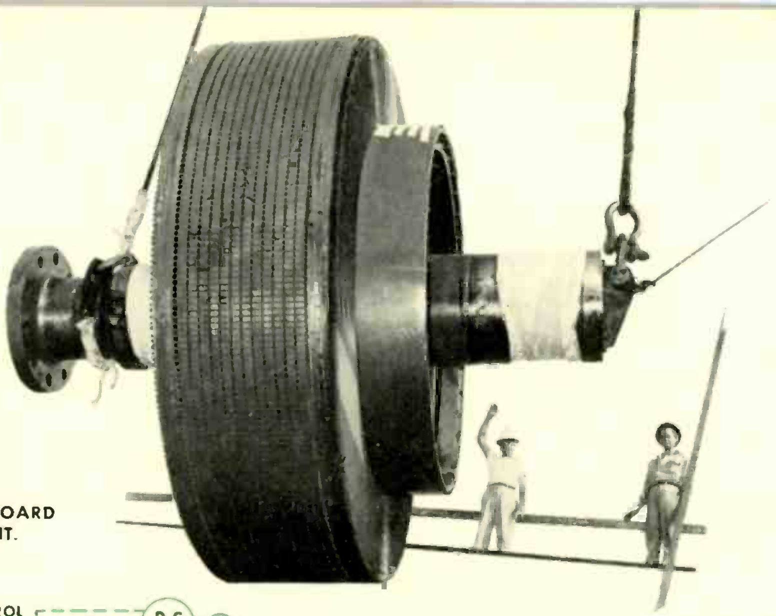


Fig. 1
DIAGRAM OF STARBOARD DRIVE EQUIPMENT.



The huge d-c propulsion-motor armature being lowered into place. (U.S. Navy photograph)

speed varies up and down to meet the varying operating conditions.

Under ideal conditions, the propulsion power plant operates at a constant output and the propulsion motor develops constant horsepower, while its speed varies over the full range to correspond to all operating conditions from stalled ship to free running. This, in effect, is like moving back and forth on a constant horsepower line between the two curves in Fig. 2. For each value of bus voltage, there is a corresponding value of propulsion power that the propulsion motor is designed to develop, and at which its full-field speed corresponds to the stalled-ship propeller load and its weak-field speed corresponds to the free-running propeller load.

Since it would be impractical to construct a load regulator that would make an ideal adjustment for every conceivable operating condition, the constant-horsepower regulator has been designed for best performance in the range of operation where three or more engines are in operation at either normal or four-hour power rating and in the ahead direction only. At bus voltage much below 700 volts, and at all speeds astern, the regulator will tend to apply full field to the propulsion motor at all times.

Reduced-Power Operation

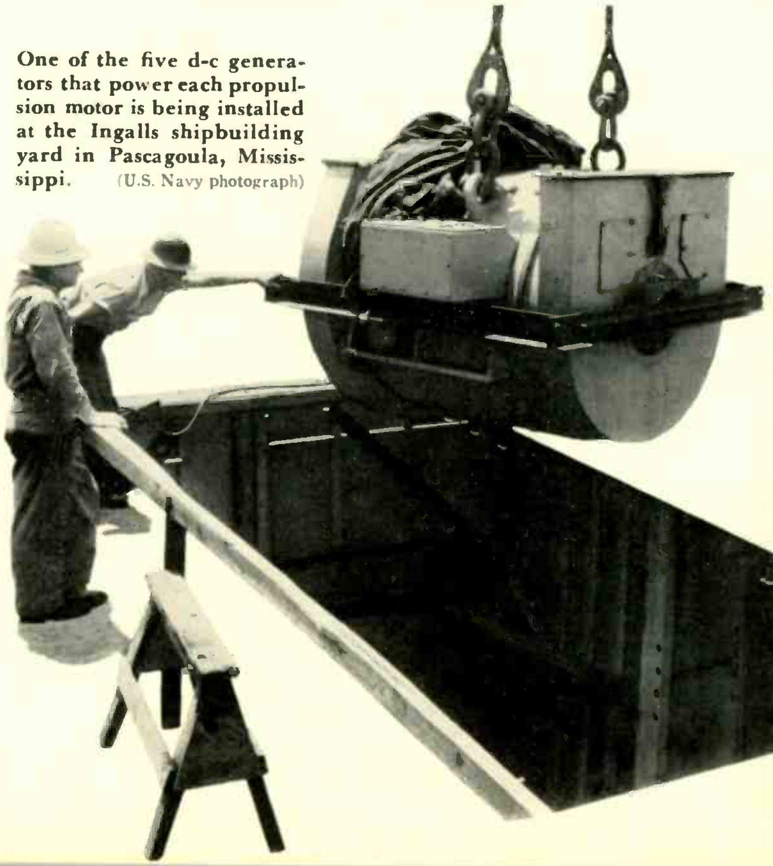
In all previous discussion, it has been assumed that the vessel will be operated with three or more generators connected to each motor and with the motor operating at constant horsepower over the speed range from stalled-ship to free-running. Under less severe conditions of operation, when the vessel is running free in open water, satisfactory performance of the power plant can be obtained with only one or two engine-generator sets connected to the propulsion bus.

The propeller speed corresponding to full power of one engine, in open water, is 95 rpm, which corresponds to a full-field motor voltage of 710 volts. With continuous generator rating of 1340 kw, the generator load is 1890 amperes, which is well within its rating. For the two-engine-generator condition, the free-running speed is 120 rpm, which corresponds to a full-field motor voltage of 900 volts and a generator load of 1490 amperes. Therefore, to fully load two generators and their engines, the motor field must be reduced.

Vessel Speed Control

Fundamentally, control of propeller speed is obtained by just one variable, generator voltage. Of course, it can be said that any adjustment of the motor fields affects the propeller speed, but adjustment of motor fields is made only to compensate for some new condition of operation. For any one condition of operation, the motor field should be held constant and the motor speed changed by varying the bus voltage. Even the direction of rotation of the propeller is controlled by generator voltage, since the motors are reversed by reversing the generator polarity.

One of the five d-c generators that power each propulsion motor is being installed at the Ingalls shipbuilding yard in Pascagoula, Mississippi. (U.S. Navy photograph)



The generator voltage of the *Glacier* is controlled by two methods: changing engine speed, and changing generator field strength. All five of the generators driving one propulsion motor are connected in parallel through electrically operated circuit breakers. These breakers will trip on overcurrent, short circuit, or engine overspeed, or can be tripped manually. The overcurrent trip is set for currents higher than any peaks that can be expected in normal service, and is adjustable from 3000 to 5000 amperes. Protection against moderate current overload is not necessary, since the engine cannot exceed its maximum rating long enough to seriously overload a generator. At low propeller speeds, the engines are run at their idling speed of 300 rpm and the generator voltage is controlled by varying the generator excitation.

When the speed control is in the "stop" position, the field current in the generator exciter is reduced to zero. However, due to residual flux in the exciter, enough voltage may be applied to the generator exciter field to produce an undesirable voltage on the propulsion bus. This voltage may be enough to keep the propulsion motor turning even though the control is turned to "stop." To prevent this undesirable voltage from building up on the propulsion bus, a strong differential winding is provided on the generator exciter. This winding, known as the "killer field," is connected to the propulsion bus when the controls are in the stop position. This field, taking voltage from the propulsion bus, acts to reverse the polarity of the generator exciter and forces the propulsion bus voltage down to zero.

Remote Control—Remote control of the propulsion-motor speed is basically a system for remotely operating the master speed controller on the motor-room control board. The remote control is arranged so that a small potentiometer with three connecting leads is all that is needed to control propulsion from any point in the ship. The master speed controller in the motor room is the device that actually controls propulsion speed at all times. Regardless of where the remote control may be originating, the motor-room operator can take over control at any time by disconnecting the remote control.

Provision is made for remote control from two points, the pilot house and aloft conning station. The control pedestals provided on each bridge wing are actually mechanical extensions of the pilot-house control stand and can be quickly disconnected at any time by the pilot-house operator. The bridge operator selects the station to be used.

System Fault Protection

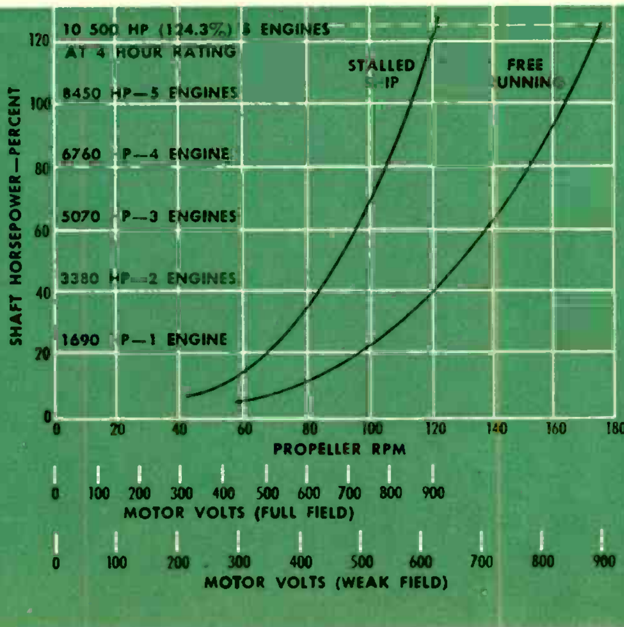
To protect the system against a fault on the propulsion bus, which could conceivably exceed the individual generator circuit-breaker ratings, the generator and motor fields must be de-energized. The simplest way of de-energizing fields would be a contactor in the exciter fields. Unfortunately, however, if the generator and motor fields remain connected to the exciters, the time constant of the field circuit is quite long, in the order of three to four seconds. During this length of time, considerable damage could be done to the d-c machines. To reduce the length of time required to bring the field current, and consequently the short circuit, down to a safe value, the field circuit itself must be opened, thus separating the field from its exciter. A field contactor is furnished with specially designed long arc-chutes and double blow-outs to make it capable of producing arc voltages of more than 1000 volts when interrupting field currents. Two poles are used in series for each field so that a maximum arc voltage of 2000 volts can be attained. The use of this special contactor, together with a high-resistance discharge resistor, makes it possible to reduce the motor or generator field in about one-tenth of the time it would take if only the exciter field were opened. The field contactor is controlled by a sensitive overload relay, which picks up and drops out the contactor when a short circuit occurs on the propulsion bus.

Heeling System

An unusual application, which occurs only on ice breaking vessels, is the use of fully reversible propeller-type pumps to transfer large quantities of ballast water between wing tanks, located high and outboard, in a timed cycle. This shifting of ballast gives a continuous rocking motion, which is used, under certain conditions, to prevent the vessel from becoming frozen solidly in the ice.

A total of 320 tons of sea water can be transferred from one side of the vessel to the other in about 85 seconds by the three heeling pumps, which are each powered by a 100-hp squirrel-cage induction motor. Power for operation of the three heeling motors is taken from one of the 400-kw ship-service generators. To perform this service under reversing-motor operation, the cycling control has a $2\frac{1}{2}$ second time delay in the "off" position, in which the reverse flow of water, due to gravity, will stop the motor and tend to reverse its rotation. The three pump motors are sequence started to reduce the total inrush kva. In addition, the generator field is highly over-excited for seven seconds while the motors are being accelerated. When a generator is segregated to heeling duty, its direct-connected exciter is de-energized, and excitation is obtained from a motor-generator set of sufficient capacity to provide the necessary field forcing. Operation of the heeling pumps can be by either manual or automatic control.

Fig. 2
PROPELLER POWER REQUIREMENTS FOR U.S.S. *GLACIER*.



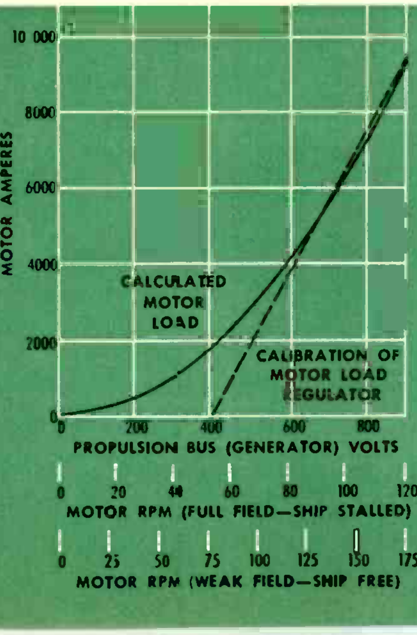
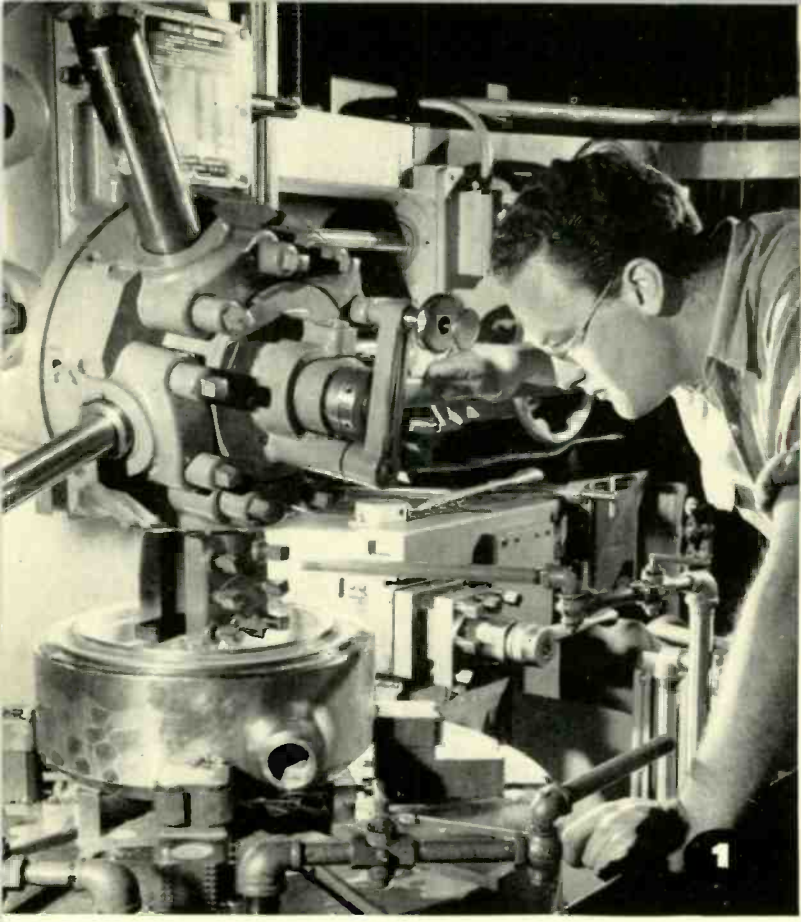
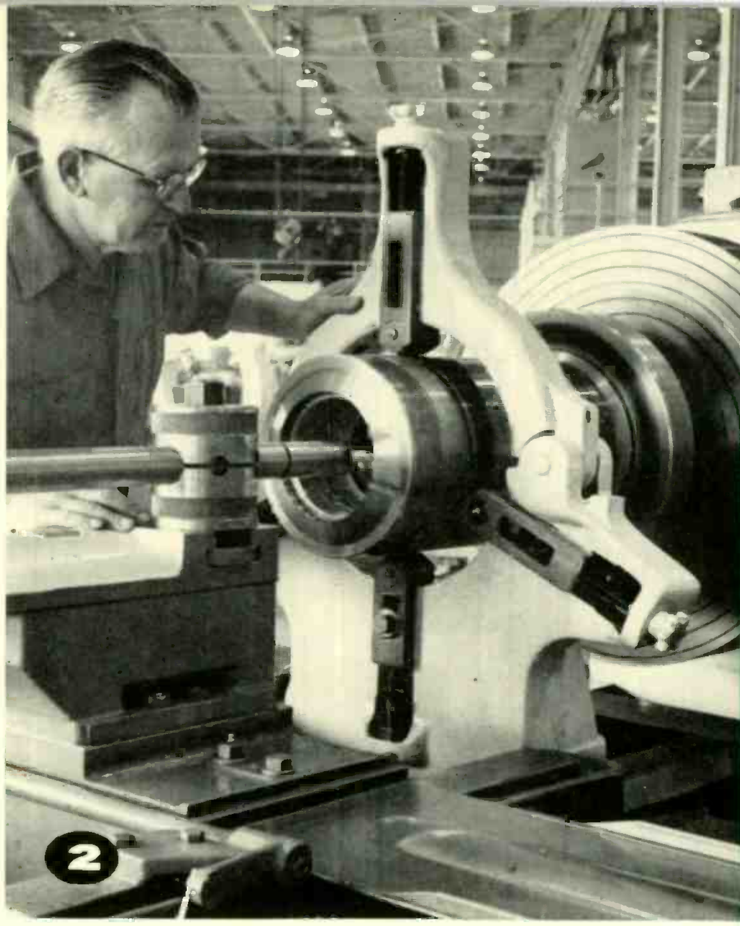
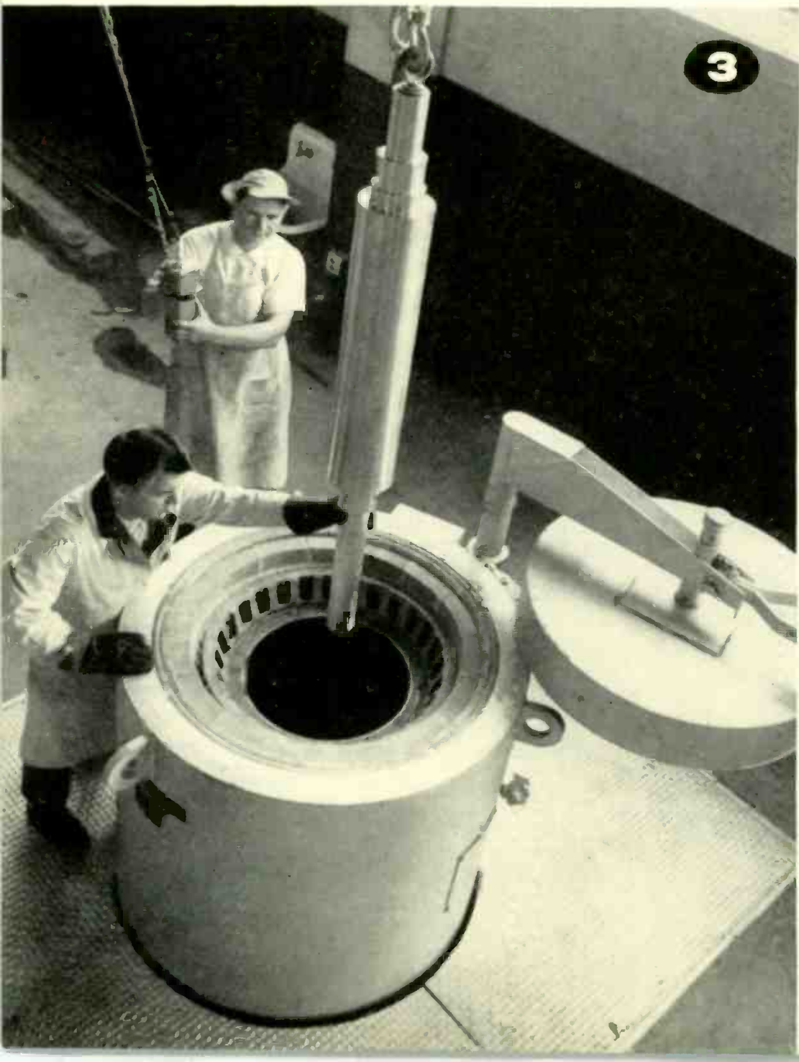


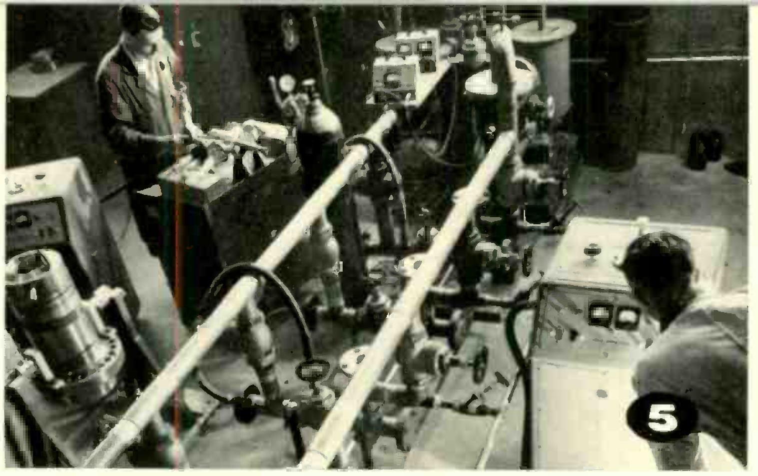
Fig. 3
MOTOR LOAD CURRENT FOR CONSTANT-HORSEPOWER OPERATION.





precision "Canning" for motor-pumps





Because canned motor-pumps will be in direct contact with radioactive water, extreme precision is the rule rather than the exception. Here a machinist watches carefully as his vertical boring mill takes a cut in the stainless steel volute of a pump.

With the precision of a watchmaker, a machinist puts the finishing touches on the threads of the stator end ring of a canned motor-pump. This motor-pump, like smaller and larger models, will pump fluids through loops of hermetically sealed systems.

Prior to finish machining, the rotor of the electric motor is heat treated in a vertical, 15 foot deep furnace. The rotor will be heated to a temperature of 1350 degrees F for ten hours, then allowed to cool under controlled conditions.

Canned motor-pumps derive their name from the nickel-alloy cylinders that line the bore of the stator and surround the rotor core—literally "canning" each. This photo shows the nickel-alloy liner being put into the stator.

The stator undergoing a gas leak test with a mass spectrometer using helium at 2000 psi. This test facility is capable of detecting a helium leak as small as 8 x 10^{-6} cc/sec with a 15-psi pressure differential on the spectrometer.

The rotor for the electric motor of a canned motor-pump must operate vibration-free. To assure such operation, all rotors are given a static as well as a dynamic balance test. Here a balance-machine operator dynamically balances a large rotor for a pump.

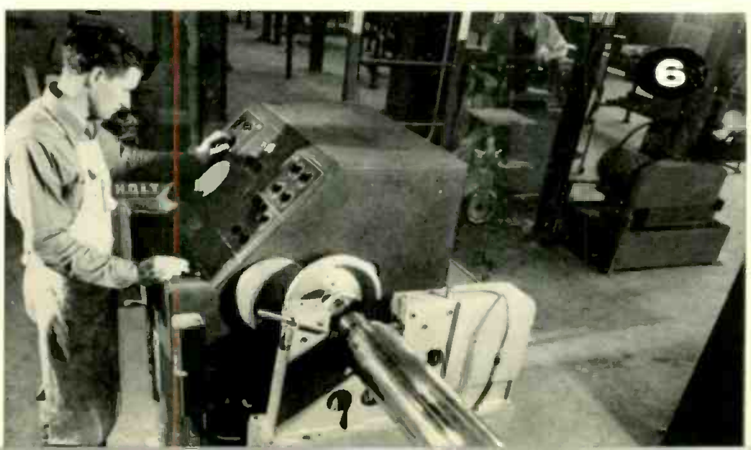
Above, at far right, a completed canned motor-pump. The unit shown is capable of delivering 150 gallons per minute.

THE "CANNED MOTOR-PUMP," developed by Westinghouse under its contract with the Atomic Energy Commission for carrying out the atomic submarine engine project, is being made with watchmaking precision in the Atomic Equipment Department plant at Cheswick, Pa. This is the first privately-financed plant built exclusively for production of components for nuclear systems.

Developed to meet the need for a means of circulating a liquid coolant in an hermetically-sealed system, such pumps are used in a closed hydraulic circuit or loop. Such loops include the primary coolant system for nuclear reactors, a steam system where controlled or forced circulation is required, and certain process applications in the chemical and petroleum industries.

The design for the canned motor-pump is unique in concept, as the pump impeller and its electric drive motor are encased within a single pressure-tight vessel. Thus, the fluid being pumped circulates throughout the drive motor—through its bearings, about its rotor, and around its sealed stator. The stator windings are protected from the hot fluid by jacketing the ends and outside diameter in stainless steel and then lining the inner bore with a cylinder or "can" of thin nickel alloy sheet, welded leak tight at each end. The outer surface of the rotor is "canned" in a similar manner.

These canned motor-pumps range in capacity from 5 to 17 000 gpm. Each can handle liquids at system pressures up to 2500 psi and temperatures as high as 650 degrees F. Special designs are available for handling liquid metal at system temperatures as high as 1000 degrees F.



what's NEW!

Heaters Boost Oil-Well Production

An electric heating device for oil wells is intended to revive or improve oil production from plugged-up wells. Lowered into a well to depths of previous production, the long Corox tubular heaters raise the temperature of the oil, thereby melting the wax-like plugging material lodged within the oil-bearing "sand."

The effectiveness of oil-well heating has been proven in Montana, where a total of 24 heaters have been operating for the past 12 months. Oil production from most of these wells was doubled after only a few hours of heating. Most prior attempts to boost production by heating the oil were unsuccessful due to early burn-out of the heaters. In many cases, heater failure occurred within several days or a few weeks.

Geologists estimate that over 50 percent of the oil around old oil wells remains in the ground, stubbornly resisting the most up-to-date methods of recovery. One obstacle to the complete removal of all oil is paraffin—similar to the substance used by the housewife to seal jelly glasses. So long as the oil remains at the usual high subsurface temperatures, the waxy paraffin stays in the oil as a liquid. However, the temperature at the bottom of an oil well drops after a number of years of production and then the paraffin starts to solidify.

Oil companies have long used metal scrapers to remove the paraffin that was deposited on the sides of the steel pipe through which the oil flowed to the surface. But it was obvious that paraffin also solidified within the oil formation itself—thereby preventing oil from even reaching the pipe and pumps that would carry it to the surface.

The new Westinghouse heater assembly is threaded onto a standard length of two-inch pipe and lowered into the well. Succeeding sections of pipe are added at the surface until the heater reaches the desired depth. A single conductor cable to power the heater is clamped at intervals to the outside of the two-inch pipe as the heater and pipe are fed into the hole. The heating assembly consists of four steel-sheathed Corox elements supported at the top by a steel terminal box and at the bottom by a protective steel nose. Each of the heaters is grounded to the bottom steel nose, thus power is returned to the surface through the two-inch pipe. The Corox element heaters can be varied in length from 4 to 14 feet to provide 5-, 7½-, 10-, or 20-kw output.

Movie Reveals Historic Scenes of Atomic Engine Construction

A new movie, "A Dawn's Early Light," filmed in both color and black and white, shows publicly for the first time actual scenes taken during construction by Westinghouse, under AEC contract and supervision, of the nuclear power plant for the first atomic submarine, the U.S.S. *Nautilus*.

One portion of the film shows the shipment of the reactor core—that section containing the uranium fuel elements—from the AEC's Bettis plant near Pittsburgh to the Idaho installation, where it was installed in a full-scale, land-based model of the power plant in the sea-going *Nautilus*. Another scene shows a part of the installation of the pressure vessel for the reactor in the hull of the land-locked version of the submarine.

The picture stars Fred MacMurray and features Fay Wray and Jack Dimond. Mr. MacMurray portrays a Westinghouse nuclear scientist whose son, a college freshman, is worried and confused over the job that he and his generation will inherit in putting a social harness on atomic power.

"A Dawn's Early Light" is suitable for showing to social, service, and school groups, civic organizations, and professional groups. It is available on loan without charge, and can be purchased outright.

For information about booking or buying "A Dawn's Early Light," write Westinghouse Film Division, Westinghouse Electric Corporation, P.O. Box 2278, Pittsburgh 30, Pa.

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This new self-diffusing lamp being installed by an NBC electrician at Radio City employs an internal coating of silica powder to diffuse light from its incandescent filament. Developed for studio lighting, the 1000-watt lamp eliminates the need for spun-glass diffusing scrims. Light output is about one-third greater than that from fixtures equipped with scrims, and color quality is virtually perfect for either television or theatre lighting.

personality profiles

J. A. Wasmund • *C. L. Mershon and N. F. Schuh* • *D. Steinweg* • *R. Forrest and W. Schmidt* • *William A. Sumner and Robert A. Zimmerman*

• Although this is the first appearance of *J. A. Wasmund* in the ENGINEER, writing is certainly not a new experience for him. He has written more than a dozen articles for marine magazines, as well as several technical society papers.

Wasmund came with Westinghouse on the Graduate Student Training Course with a degree in E.E. from the University of Nebraska in 1929. However, by the time he had finished Design School in 1930, the depression had hit; jobs for graduate students were scarce. He left Westinghouse to become an instructor in electrical engineering at the University of Pittsburgh. During his stay at Pitt, Wasmund got his Masters Degree in Engineering. In 1939 he rejoined Westinghouse, going directly to the Marine Engineering Department of Industry Engineering.

Wasmund has been associated with all forms of electric-driven ships, including tankers, Coast Guard cutters, dredges, tugs, ferries, and ice breakers, of which he writes in this issue.

• *C. L. Mershon* and *N. F. Schuh* are the "co-pilots" of this month's article on a-c control systems for aircraft. Mershon, a native of Alabama, is a graduate of Alabama Polytechnic Institute, class of 1941. He came to Westinghouse shortly afterward, and following the usual time on the Graduate Student Course, joined the Porcelain Department. Here he worked on the development of radio-interference-free transmission-line insulators. In 1943 he transferred to the Aviation Engineering Department, to work on aircraft electrical equipment. His assignments there have since largely covered the full range of this type of equipment, from electromagnetic engine torque meters to Magamp voltage regulators. In 1951, Mershon became assistant manager of the control section, and has since been made acting manager of the section.

Schuh came to Westinghouse from the campus of the University of Florida, where he received his electrical engineering degree in 1949. Like Mershon he spent time on the Graduate Student Course, and then joined the control section of the Aviation Engineering Department. His present activities involve transistors, which he is adapting to aircraft control equipment. Schuh is active in association activities, currently being chairman of the local AIEE section in Lima, Ohio.

• To be a musician or an engineer? That was the choice *Don Steinweg* faced in 1943. He had completed his first year at Cornell University, and had the choice of furthering his musical education in the Navy band, or finishing college in the Navy V-12 program. He chose the latter, and obtained a B.S. in Electrical Engineering from Northwestern University.

Steinweg came with Westinghouse on the Graduate Student Training Program in 1946. Following a four-month x-ray engineering course at Baltimore, he went to Cleveland as an application engineer for the X-ray Division.

In 1953, Steinweg returned to Baltimore, and has since been in application engineering for special-purpose x-ray apparatus—some of which he describes in detail in this issue.

Although he has forsaken music as a career, it has always been a factor in his spare-time activities. Steinweg is particularly enthusiastic about work he has done with young people's groups, especially in directing their musical talent shows.

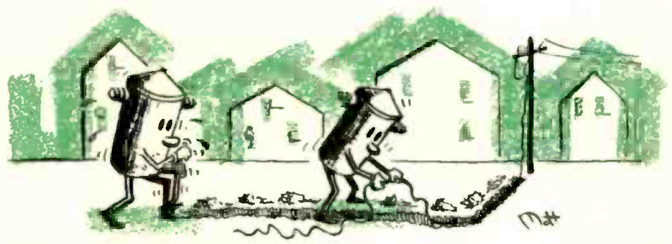
• Our authors on the new watthour meter in this issue are *Ray Forrest* and *Warren J. Schmidt*. Forrest, a native of Newark, is a graduate of Montclair State Teachers College; he came to Westinghouse shortly after graduation in 1940, and first worked in the instrument section of the Meter Division. During the war he worked on many different instruments for the Navy and Air Force. Since that time he has spent five years in the relay section, and the remainder in the meter sales department, which gives him a well-rounded view of the Meter Division's activities.

Schmidt is a mechanical engineering graduate of Pratt Institute. Shortly after his graduation in 1950 he entered the Westinghouse Graduate Student Program, and in early 1951 joined the Meter Division as an assistant design engineer. Here he worked on several design projects for the new single-phase meter before becoming project engineer in charge of the new polyphase-meter design in 1954. Schmidt has since become supervising engineer of the long-range development section.

• *William A. Sumner* and *Robert A. Zimmerman* have been collaborating on the application of low-cost residential underground distribution systems since 1950, and are therefore a fitting team to author an article on the subject.

Sumner is a native of Connecticut. He graduated from the Yale School of Engineering, then the Sheffield Scientific School in 1917. After a year of graduate work at Yale and a short enlistment in the U.S. Signal Corps, he came on the Westinghouse Graduate Student Course in 1919. He became a design engineer on distribution and instrument transformers in East Pittsburgh. When the Transformer Division was moved to Sharon, Pa., Sumner went along to become a development design engineer on distribution transformers. In 1932, he was made a section engineer, and in 1940, manager of distribution engineering.

Zimmerman came directly into the distribution group of electric utility engineering at East Pittsburgh following his graduation from Purdue University in 1949. Since that time his work has been primarily concerned with system design, fault studies, and load studies of electric utility, industrial plant, and commercial building distribution systems.



Bob has what may be termed a "well-rounded" education. Shortly after he entered high school in his home town of Louisville, Ky., his father answered the Army's call for doctors and the travels began. Upon graduation from the fourth high school he attended, he started college in the Army ASTP program—first at the University of Nebraska and then at Texas A.& M. Back home once again after the Army, he attended the University of Louisville briefly and then went to Purdue. Since joining Westinghouse, he has done some graduate work at the University of Pittsburgh.

This beam of light—believe it or not—is an effort to minimize noise near heavily populated areas. One of the most powerful searchlights ever built, it serves as a skyway "traffic light" to direct departing planes over a more sparsely settled takeoff route near La Guardia Airport. A 2500-watt short-arc mercury lamp produces a shaft of light of some 300 million beam candlepower, equivalent in light intensity to approximately 10 000 automobile headlights.