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Exploring for the Future

Research scientists are in somewhat the same position as an explorer with an infinite territory to investigate. To such an explorer, each mountain scaled, each plain crossed, and each ocean spanned reveals a whole new land. Each step he takes adds to his knowledge of the terrain—but the paths ahead remain numerous. Thus it is with the scientist, whose every discovery adds to his store of knowledge, but where the areas yet to be investigated frequently seem endless.

The scientist is often a pioneer in another sense, in that he must develop the equipment and techniques necessary in his exploration. Without these tools the search for new knowledge would often be impossible. A few examples show the variety of lands yet to be conquered and the pioneering techniques that are helping to clear the way.

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Studying phosphors is much like astronomy, except that it is a younger science. Astronomers, using a variety of tools, have been studying the stars for years; they have learned much, but compared with what remains they know little. While phosphors are the basis of fluorescent lamps, television tubes, and oscilloscopes, phosphors are so complex, so multitudinous in number, with so many dozens of factors affecting their performance that the areas explored are small by comparison.

Phosphor research men, like astronomers, have several different tools and techniques—and each year improve upon them. One new tool somewhat resembles the silvered, double-walled container in a thermos bottle, but with four sets of tubes leading into it. In fact, it is a thermos bottle, but with four walls, not two. When a phosphor is placed on the end of a quartz rod and inserted into this jar, also of quartz, studies of the phosphor can be made at temperatures as low as minus 330 degrees F or at heats up to about 1850 degrees—meanwhile contained in different gases. This new tool has already proved useful in studying the temperature dependence of phosphors.

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Scientists today are making materials of almost fantastic purity. In transistor research, for example, germanium with an impurity content of one part in a billion is now routine. Yet the urge to produce even greater purity is always present, because past experience indicates that even such small increments as a few parts in a billion often have a remarkable effect on a great many of the characteristics of the basic material.

Much emphasis has recently been placed on obtaining ultra-pure semiconductor materials, such as germanium. One technique used is zone refining, in which a bar of the metal is heated progressively from one end to the other. Many impurities have a preference for the liquid state, so that as the molten zone moves from one end of the bar to the other these impurities are swept along, and eventually wind up in one end of the bar, which can then be cut off.

Scientists at the Research Laboratories have recently developed a new technique—called cage zone refining—which enables them to purify titanium and other difficult-to-prepare materials. Titanium is so active at high temperatures that it reacts with any crucible; to get around this, the new process utilizes the titanium itself as the crucible. A square bar of titanium is placed on end on a metal platform, in a low-pressure inert gas. The platform is raised slowly, lifting the bar lengthwise through an induction-heating coil. The corners of the bar do not heat as rapidly and do not melt, and therefore act as a "cage" for the molten center of the bar. The impurities are drawn to one end and the impure corners are cut away. Another important step in the direction of purer metals—but many yet remain.

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For decades electrical engineers have built circuit-interrupters, vacuum tubes, and fluorescent lamps, and have studied lightning. Nevertheless those microseconds of time that elapse between the application of potential and the breakdown of a gas contain much that is mystery. The question is: What physical processes lead to the current build-up?

Some of these processes have long been known. For example, when the potential is applied to opposing electrodes any stray electrons present on the cathode immediately head toward the anode, creating other free electrons enroute by collision with gas atoms. All these electrons in turn progress to the anode, making the passage in a small fraction of a microsecond. However, before breakdown occurs many, many more electrons must be created at the cathode surface. How are these free electrons generated?

Several ways are known—and some of them are known to be applicable in certain situations. For example, electrons collide with gas atoms, knocking off electrons and thereby creating positive ions. These ions are drawn to the cathode and, in a few microseconds, create free electrons there when they strike the surface. Let's call that method A. Then as method B, say, the first electrons bump into gas atoms and instead of kicking off electrons, excite the atoms, which give off their energy as photons. Photons impinging on the cathode can release electrons. This happens fast because photons move with the speed of light, which indeed they are. Then as another method, C, an atom can become metastable by a blow from an electron. That is, it absorbs energy, which it somehow holds for an appreciable period of time and then releases as photons, which then behave as the photons of method B, but after some delay.

There are many other processes that may occur in the breakdown of a gas. To identify them, and to determine which ones are active in any given situation is the purpose of one project at the Research Laboratories.

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Unusual things happen to many materials at extremely low temperatures, i.e., near absolute zero. Normal grades of steel become brittle, and rubber loses its elasticity, for example. To probe a little further into the cause of such peculiar behavior, scientists at the Research Laboratories have been conducting all manner of experiments at temperatures within a few degrees of absolute zero.

One recent experiment is the performance of tensile tests on metals at about minus 452 degrees in a special chamber cooled by liquid helium. Such experiments will, of course, add to the general knowledge about the fundamental behavior of metals. But they will also provide specific information regarding metals best suited for use under extreme temperature conditions. While experiments at temperatures such as these may seem far removed from practical application, oxygen for human consumption during high-altitude flight is already being stored in liquid form in metal containers at temperatures of about minus 300 degrees F. And it is not impossible that aircraft of the future will use fuels stored as liquefied gases in metal containers at extremely low temperatures. Thus while the study is aimed at developing fundamental knowledge, the information gained conceivably could have almost direct application.

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Experiments such as these almost invariably uncover new facts, new knowledge, and help to chart new areas. But beyond any doubt, they often also open up whole new areas of research, and reveal new valleys and mountains to explore. Unlike the explorers of the earth's surface, whose horizons are shrinking, the scientist seems to have no boundaries.

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The Cover

Construction of the rotor of a turbine generator is a careful, painstaking process, from the rough forging to the final precise machining. This month's cover by Dick Marsh suggests the production of such a huge rotor.

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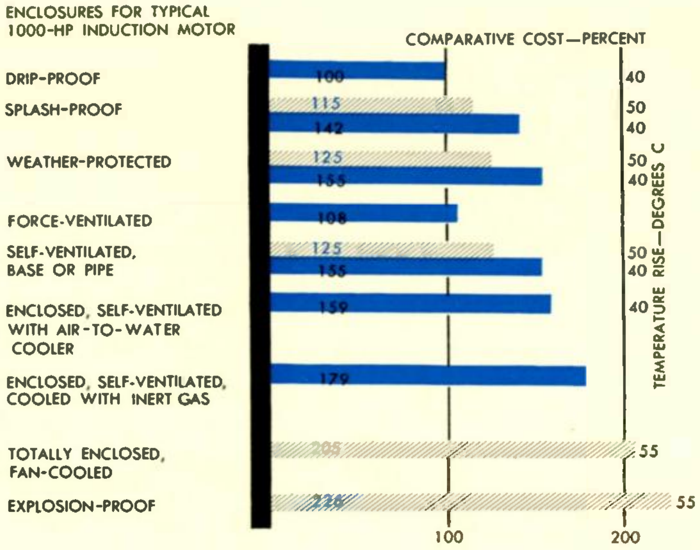
Enclosures for Large Induction Motors



Selection of the proper motor enclosure assures reliable operation and long life, even in the most difficult surroundings.

M. R. Lory, *Manager* and J. F. Heidbreder
A-C Motor Engineering Section, Transportation and Generator Division, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania

All induction motors are subjected to injurious atmospheric conditions, the degree depending on the application. While there are no hard and fast rules as to exactly which type of enclosure should be used for a particular application, general recommendations can be given. The final choice depends on the severity of the damaging conditions, details of location, such as availability of cooling water, and cost. This article applies principally to induction motors larger than 250 horsepower.

Environmental Conditions

Moisture is the most common damaging atmospheric condition. It can enter the motor as condensation when the machine is shut down. Moisture can also run into the motor or be carried in by ventilating air from leaks in steam and water piping, water from plant processes, or from water sprays that are used in cleaning.

Dirt of all kinds is damaging. Conducting dirt is the most dangerous. For example, one common form is the carbon black in rubber mills, which can work into even the most minute cracks in insulation or collect on creepage surfaces, reducing the insulation resistance to a point where the winding will fail.

Abrasive dirt is found in such applications as cement mills and power stations using stoker-fired boilers. It can wear through insulation in a few months. Other forms of dirt or foreign matter are not so directly dangerous to the operation of the motor, but still have adverse effects. For example, it may block the ventilation passages so that the motor fails from overheating. Included in this category are such things as weed seeds and other bits of vegetable matter, insects, dust, nonabrasive fly ash, and many others.

Chemicals, including acids, alkalis, salts, and some organic solvents, have a number of adverse effects. They can attack and destroy the protective films of varnish on the windings. They may even attack the structural parts of the motor. An example of a harmful chemical is salt, which attacks motors located along the sea coast and in steel mills that use salt for descaling. Windings with salt on them have a high insulation resistance when dry, but the resistance drops almost to zero in a short time as the windings absorb moisture.

Oil can get into the motor by leakage from its own bearings, or it can be carried in from the surrounding atmosphere. It may soften and damage protective varnish. It also catches dirt and makes it cling to motor surfaces, thereby making cleaning difficult.

Types of Enclosures

Internally, motors have been designed to protect themselves. Coils are usually given vacuum and pressure impregnations, followed by baking treatments. After the coils have been wound into the machine and all connections made, additional varnish treatments are applied to the completely wound stator. However, even varnishes with superior resistance to water, oil, and chemicals must be given help. This help comes in the form of a variety of enclosure designs, which can provide the additional protection necessary even in the most difficult locations.

Drip-Proof. The drip-proof enclosure is the most common type. A drip-proof motor is protected from water dripping or falling on it from any angle within 15 degrees of vertical. All ventilating air passes through the machine and moisture, dirt, chemicals, or oil in the ventilating air will be carried into the machine, Fig. 1.

The drip-proof motor is the most common type for indoor locations. It is often provided with heaters to keep the motor warm during shut-down periods to prevent condensation.

Splash-Proof. The splash-proof motor is provided with protective covers so that water will not enter the motor when striking it from any direction within 105 degrees of vertical. This protected motor finds wide use in paper mills where it is customary to wash down machinery with hoses. Also, there is considerable water dripping and splashing from the driven machines. The additional enclosures interfere with motor ventilation, so it is customary to give standard splash-proof motors a rating of 50 degrees C temperature rise instead of the 40 degrees C rise that is standard for drip-proof motors. As a result, the splash-proof motor does not have a service factor; that is, it will not carry a continuous overload at a safe temperature. At additional cost (see diagram at left), a splash-proof motor can be provided with a temperature rise of 40 degrees C; such a motor has a normal service factor.

Whenever the amount of enclosure is increased, the accessibility of the interior parts of the motor is reduced. This makes inspection, cleaning, maintenance, and repair of the motor more difficult. As much accessibility as possible is retained in Westinghouse motors by making the enclosing covers of reasonably light steel, and arranging them so they can be removed easily without using a crane.

The use of splash-proof motors, at least in the larger horsepower ratings, is decreasing. Most indoor applications are being adequately served by drip-proof motors. For a time there was a tendency to use splash-proof motors for outdoor applications, but their performance was often unsatisfactory. The splash-proof enclosure does not protect the motor adequately from rain and snow, especially if it is driven into the motor by high winds. For outdoor locations, accepted practice now is to use weather-protected motors.

Weather-Protected. Since the standard splash-proof motor does not give satisfactory outdoor service life, motor manufacturers were called upon to design a motor for these applications. The use of outdoor motors is becoming rather common with the increase in the number of outdoor and semi-outdoor power stations now being built. Of course, totally-enclosed, fan-cooled (T.E.F.C.) motors would be satisfactory for such applications, but the principal reason for the outdoor station is to reduce the cost of construction. And in ratings of 500 hp and above, the large increase in motor cost for T.E.F.C. construction offsets most of these savings.

The weather-protected design is the newest of the standard enclosures, and was developed to give satisfactory performance in outdoor locations at a cost substantially lower than a T.E.F.C. motor. Air enters through four screened and louvered openings in the sides of the motor, Fig. 2. The louvers direct the air sharply downward, so that it must make a turn of almost 180 degrees before it flows upward to the inlet openings. The active parts of the motor are in an inner en-

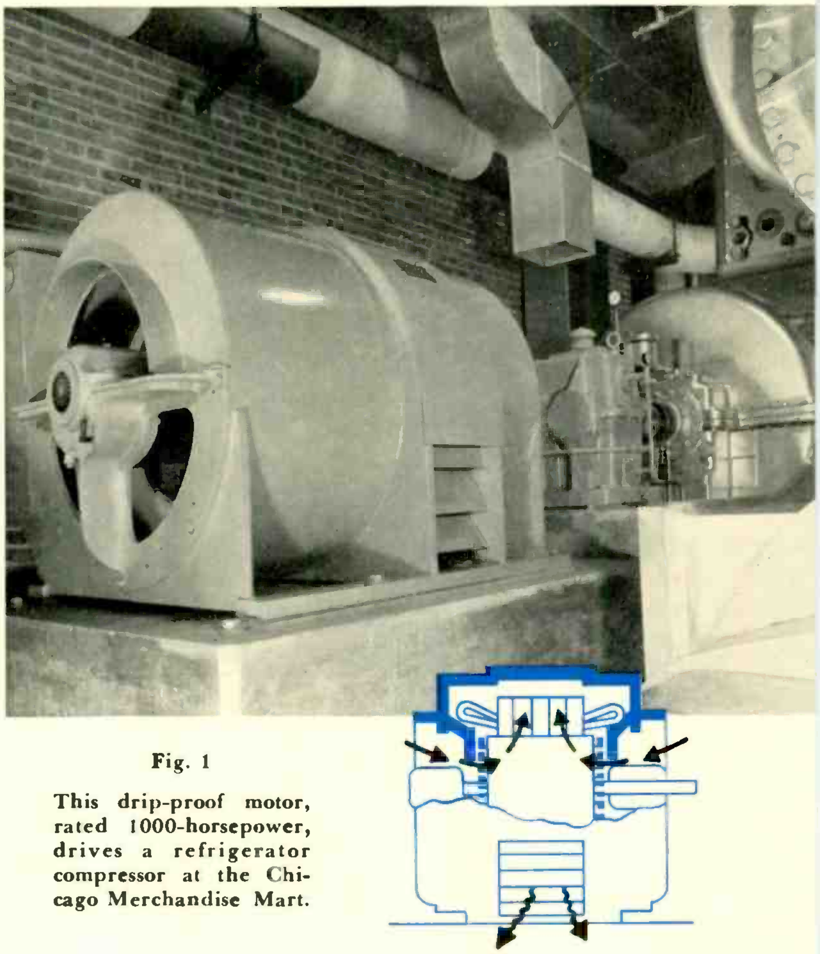


Fig. 1

This drip-proof motor, rated 1000-horsepower, drives a refrigerator compressor at the Chicago Merchandise Mart.

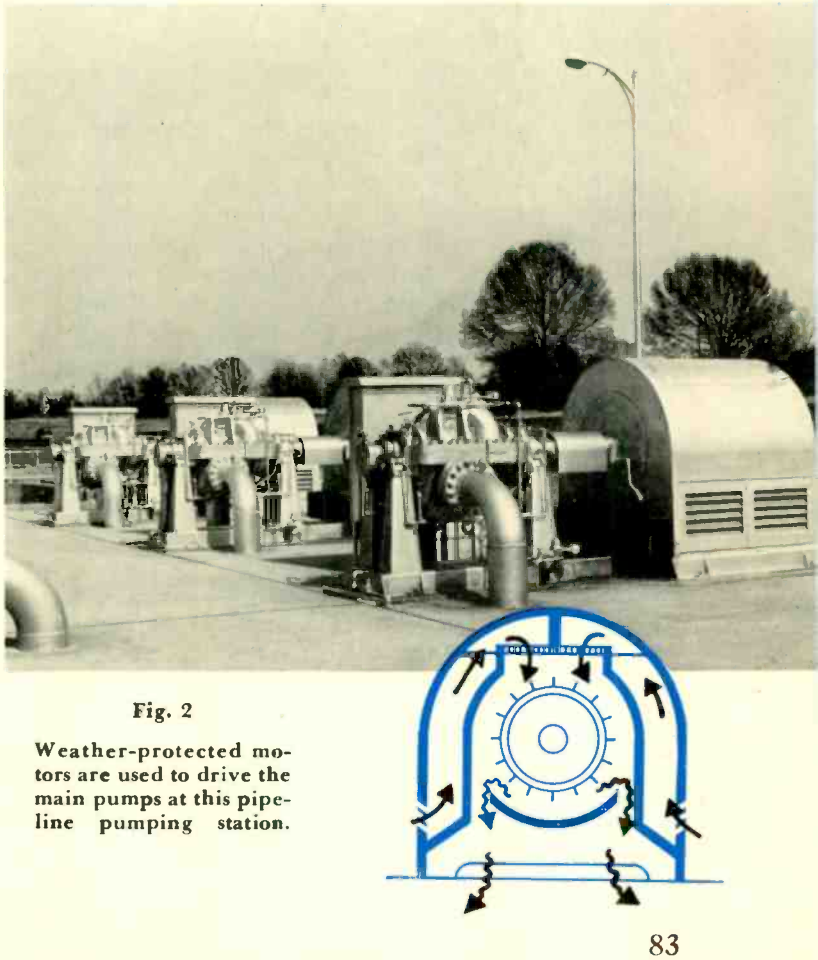


Fig. 2

Weather-protected motors are used to drive the main pumps at this pipeline pumping station.

closure having inlet openings at the top at each end. The space between the inner and outer enclosure is large enough so that the vertical velocity of the inlet air is very low. The combination of a sharp turn, a sudden drop in velocity, and considerable vertical travel upward at low velocity effectively separates out any droplets of water carried by the inlet air.

After the air enters the inner enclosure at the top, it passes down and enters the motor around the shaft. It then passes through ventilating ducts built into the rotor and stator cores as in a standard motor. The air discharged from the stator ducts is collected in the center portion of the inner enclosure and directed downward. It passes around a protective baffle and is finally discharged axially out the two ends between the motor feet.

One of the most difficult atmospheric conditions to which these motors are subjected is rain driven into the motor openings by hurricane winds. To handle this condition, the inlet openings on each side of the motor are connected by a passage straight through below the ends of the inner enclosure, so that wind-driven rain can blow straight through from one side to the other without passing into the active parts of the motor. A baffle is provided at the top of the motor to keep rain from being blown up and through the inlets to the inner enclosure. The restrictions in the internal ventilating passages maintain close to the normal amount of air passing through the machine regardless of wind velocities.

The outlet openings are also arranged so that there is a clear passage from one end to the other. A baffle in the bottom of the frame below the core prevents water from being blown up into the motor, even if a high wind blows rain through from one end to the other under the motor.

This type of motor is suitable for all but the most severe outdoor applications. If dirt is a problem, the motor can be provided with filters. The filters can be changed easily by removing small covers over access openings in the outer enclosure. When filters are added, a Thermoguard or other similar thermostat should be provided, mounted on the stator end turns. This is necessary to give warning of excessive temperatures caused by lack of maintenance of the filter, which can clog and restrict motor ventilation. This can occur even though the filters are of the nonclogging type that simply lose cleaning efficiency but do not obstruct flow of air with any normal accumulation of dirt.

In a vertical weather-protected motor, air enters the outer casing through the two upper openings. It rises a considerable distance at low velocity and passes over a lip in the inner enclosure, thus preventing water from blowing into the motor.

All of the air enters the active part of the motor around the thrust bearing, effectively cooling it. After the air passes the thrust bearing, about half of it enters the motor at the top along the shaft. The other half is carried to the bottom through tubes built into the frame, where it enters along the shaft in the usual manner. The air passes through ventilating ducts in the rotor and stator cores, and then discharges between the tubes through the frame. It goes over a baffle, then to the bottom of the motor where it passes out through two screened openings. These discharge openings are located 90 degrees away from the inlet openings to reduce recirculation of the heated air into the machine again. This motor can be equipped with filters also.

Force-Ventilation. In many installations it is desirable to enclose the motors so that room air does not pass through them. Reasons for the enclosure are to protect the motor from severe atmospheric conditions such as chemical contamination, to reduce noise, to keep explosive vapors out of the motor, and to keep heat from the motor losses from being added to the room air. If a supply of clean ventilating air is available within a reasonable distance, the cheapest form of enclosed motor is the force-ventilated type. Suitable ventilating air must be circulated through the motor by an external fan, as shown in Fig. 3.

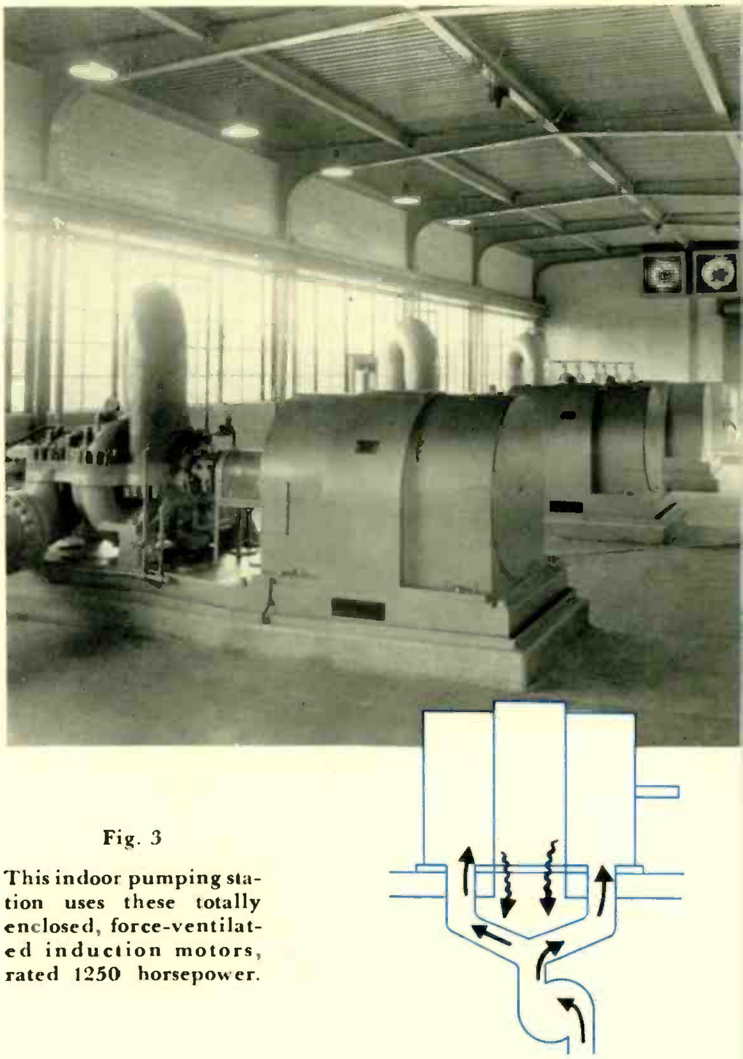


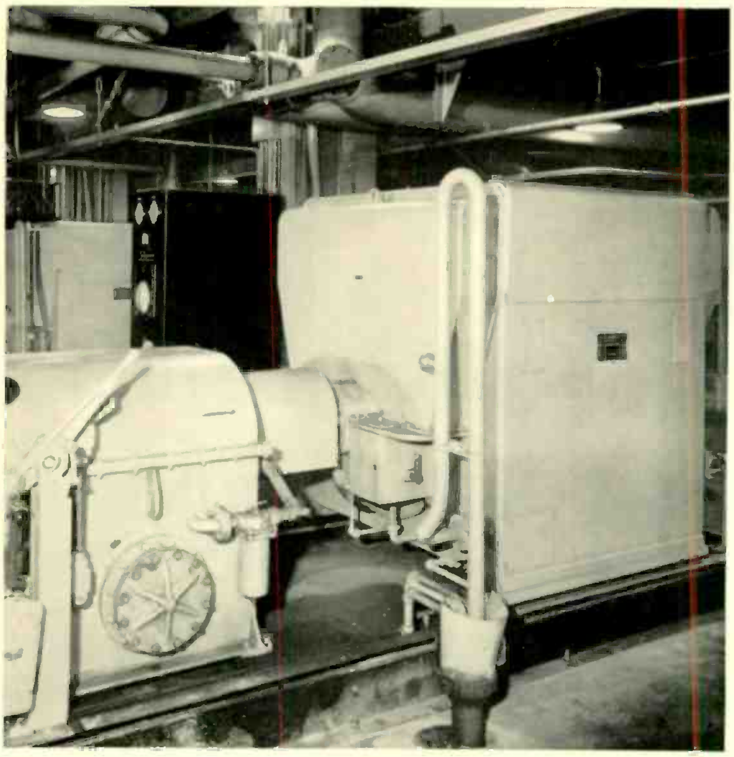
Fig. 3

This indoor pumping station uses these totally enclosed, force-ventilated induction motors, rated 1250 horsepower.

Enclosed with Self-Ventilation. If the motor must circulate its own ventilating air, it is said to be self-ventilated, and will not only circulate the air through its own ventilating passages, but also through a standardized amount of external pressure drop. If the inlet and discharge openings are in the bottom it is called a base-ventilated motor. If the air comes into the motor above the floor level, it is called a pipe-ventilated motor. Both the base-ventilated and pipe-ventilated motor are usually rated 50 degrees C rise and hence do not have a service factor. At additional cost the motor can be given a 40 degree C rating and will then have a service factor.

Where a source of clean ventilating air is not readily available, but a source of cooling water and a drain can be provided economically, it is customary to use an enclosed, self-ventilated motor with air cooler. In this enclosure, the cooling air recirculates through the motor and an air cooler, Fig. 4. The pressure to circulate the air is provided by fans mounted on the rotor in high-speed motors. At lower speeds, it is necessary to introduce a motor-driven blower to circulate the air.

Totally Enclosed, Fan Cooled. Although the totally-enclosed, fan-cooled motor is expensive, it may prove to be the



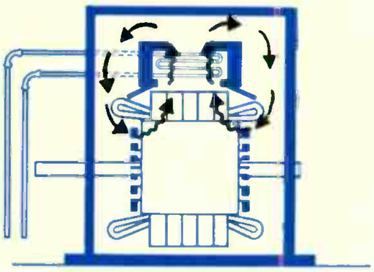


Fig. 4

Boiler-feed pump driven by a 1750-hp motor with a recirculating ventilating system and an air-to-water heat exchanger.

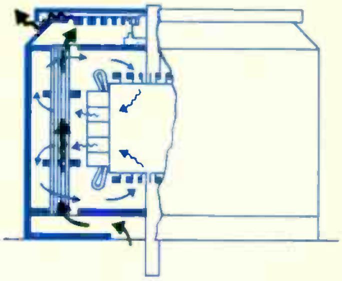


Fig. 5

Vertical totally enclosed, fan-cooled induction motor driving a pipeline centrifugal pump.

most economical for those locations requiring protection for the motor where no source of clean cooling air is available and where it is expensive to provide cooling water and a drain.

A small motor is not so difficult to build totally enclosed because it has a larger surface in proportion to its losses. The losses and the heat to be dissipated are roughly directly proportional to the volume of the active parts of the motor. In order to get an idea of the problems involved in building large T.E.F.C. motors, consider two exactly similar motors except that one is twice the size of the other. The larger motor will have a surface that is four times larger than the surface of the smaller motor, but it will have a volume eight times larger, so that the losses will be roughly eight times as high. Thus, if no artificial means are used to increase the cooling surface, it will have twice as much heat to get rid of from each square inch of surface, and will run at roughly twice the temperature rise of the smaller motor. In order to bring the temperature down, it becomes necessary to provide more surface for heat dissipation. This is done by building a large number of tubes into the motor frame to form an air-to-air heat exchanger, Fig. 5. The room air or outside air is blown through the inside of the tubes by a fan mounted on the shaft outside the enclosure. The inside air is circulated through the motor by fans mounted on the rotor. The heated internal air passes radially outward over the middle portion of the tubes, around a baffle, back radially inward over the end portions of the tubes and into the internal fans again.

Explosion-Proof Motor. The explosion-proof motor is a totally-enclosed, fan-cooled motor that has an external casing sufficiently strong to withstand the pressure of an internal explosion and seals to prevent ignition of the atmosphere outside the motor by an internal explosion. These motors, if type tested by the Underwriters Laboratory, can carry the Underwriters Label for use in a hazardous atmosphere. They are widely used in oil refineries and in pumping stations for oil and gas. They must have special seals at the shaft to prevent flame travel, the leads are carefully sealed where they pass through the outer casing, and all joints are designed to prevent the passage of flame from the inside of the motor.

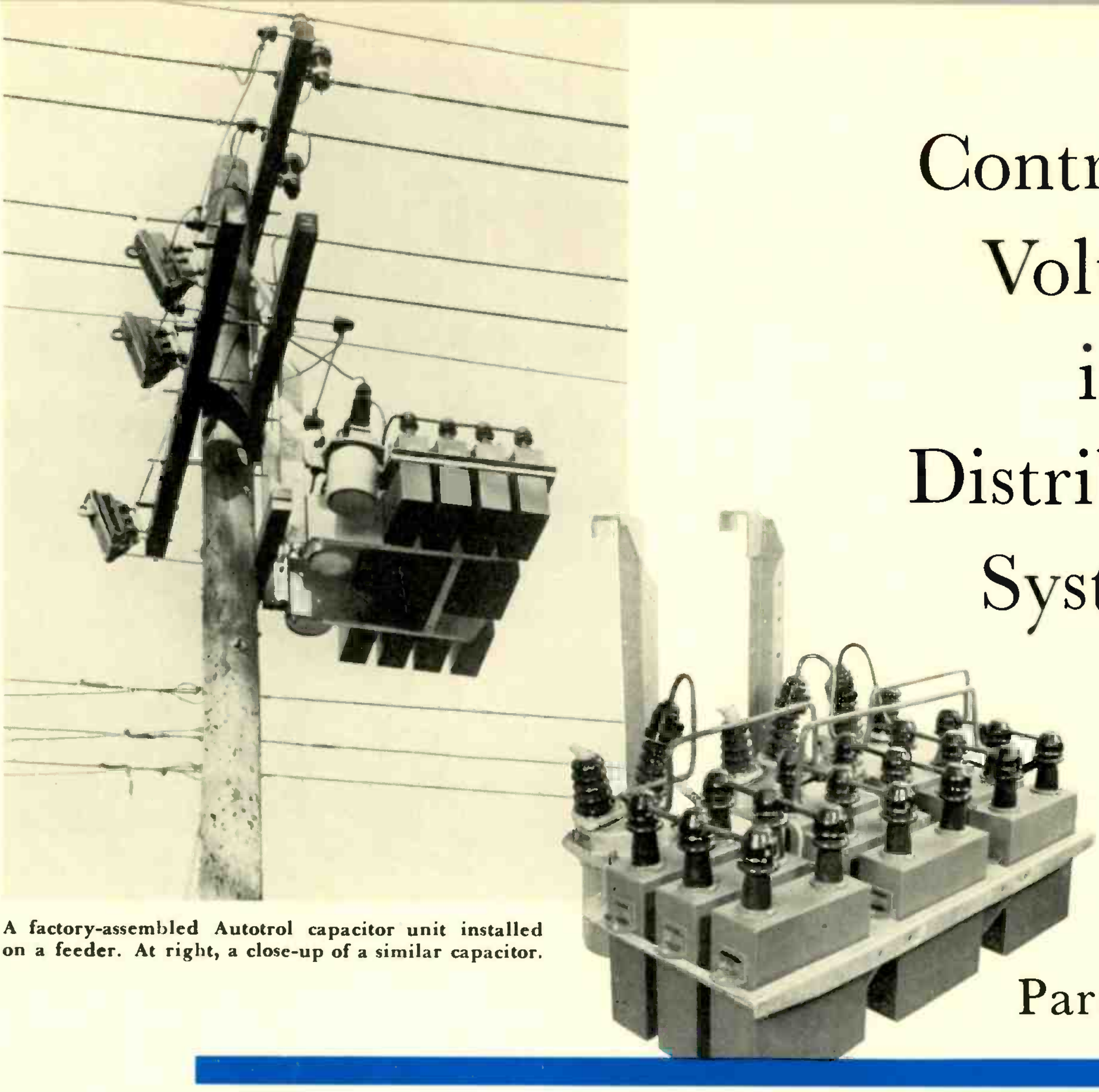
In all totally-enclosed, fan-cooled motors, there is some leakage of room air into the motor. A small amount of moisture can be carried inside and condense in the motor, so it is customary to provide a drain to remove any water that may be inside. When used on explosion-proof motors, the drain must be of a type to prevent flame travel through it. If enclosed motors are to be shut down for appreciable lengths of time, they also should be provided with space heaters.

In addition to the wide variety of standardized types of enclosures, minor variations can be made for special requirements. Close cooperation between motor manufacturers and users will result in the best enclosure to fit the conditions of any difficult application. This involves a balance between the severity of the injurious atmospheric conditions and the extra cost of the enclosure.

Controlling Voltage in Distribution Systems

Part II*

H. E. Lokay, *Electric Utility Section, Industry Engineering Dept., Westinghouse Electric Corp., East Pittsburgh, Pa.*



A factory-assembled Autotrol capacitor unit installed on a feeder. At right, a close-up of a similar capacitor.

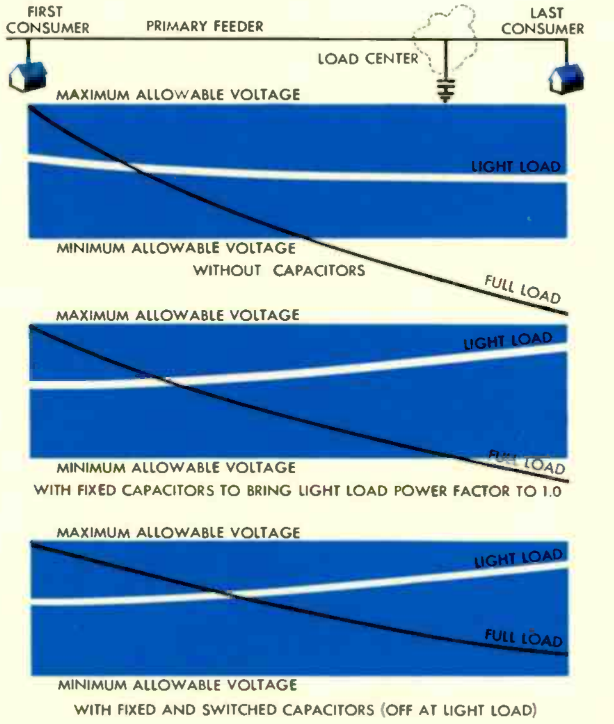


Fig. 1—Voltage regulation is significantly improved by the application of capacitors on a feeder, as shown above.

CAPACITORS offer a convenient method of controlling voltage in the distribution system. Voltage drop along a distribution feeder is a result of the kilowatt and kilovar components of current. For circuits of 0.7 load power factor, the voltage drop due to reactive load is approximately twice that due to the kilowatt portion of load. Capacitors draw a leading power-factor current, and this leading current flowing through the series reactance of the circuit causes a voltage rise equal to the circuit reactance times capacitor current. The voltage rise is independent of load conditions and is greatest at the capacitor location, decreasing proportionally to a regulated source voltage. With capacitors, the circuit voltage can be made relatively flat or even rising at light load. Besides creating a voltage rise, capacitors release system capacity and reduce losses from the capacitor location back to and including the generator.

Fixed capacitors do not effectively improve voltage regulation, but provide a constant increase in voltage level. When capacitors are switched, their effectiveness is often increased because kilovars can be supplied as needed during peak load, thus improving voltage regulation as well as increasing the voltage level of the feeder. The degree of precision of regulation depends upon the number and size of switching steps.

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*The first part of this article, which discussed various types of voltage control and regulators, appeared in the March, 1955 issue on page 50.

The minimum amount of reactive kva and light-load voltage conditions determine the size of fixed capacitors that can be added to the system; generally, they can be added to give approximately unity power factor during light loads. Fixed capacitors can be either primary or secondary capacitors, while switched capacitors are applied only on the primary for economic reasons.

Capacitors can be installed in relatively small banks along the distribution system near inductive loads, thus enabling the line as well as other equipment to handle more real power. If no additional real power is added, capacitors decrease the voltage drop from generator to load and therefore increase consumer voltage. Generally the primary purpose of installing capacitors at substations is not necessarily to control voltage, but to release substation and transmission-line capacity by locating what can be considered a generator of lagging kilovars nearer the loads. If the substation has individual feeder regulation, the capacitors are ahead of any regulators, so the capacitors must normally be switched to avoid overvoltage during light-load conditions. With bus regulation, switching may become necessary to increase the regulator range or reduce to a minimum the amount of substation kilovars at light load. The number of switching steps, important for economic reasons, is kept to a minimum consistent with acceptable voltage change.

With capacitors located at the substation, the voltage drop on a feeder from the substation to the last consumer is not decreased. Power factor of the feeder remains the same, since the total reactive portion of the load is served from the substation; and the voltage level is increased but the feeder-voltage spread remains the same. The maximum voltage allowed at the first consumer limits the voltage rise allowed at the substation bus during full-load conditions. If the feeder voltage spread is too large, the best location for the capacitors is along the individual feeder.

Fixed capacitors on the primary feeder at the load center can bring the light-load power factor to unity, and any additional capacitors needed to improve voltage regulation during heavier load conditions can be switched. Capacitors offer more benefit on long feeders than on short feeders due to the increased line impedance to the capacitor location. The practical limit for increasing voltage on a primary feeder with unswitched capacitors is approximately three or four volts. Improvement of voltage regulation with capacitors located on a feeder is shown in Fig. 1. Automatic control of capacitors is usually economical where the load coming on—when going from light-load to full-load conditions—has a power factor of 0.9 or less. Single-step, factory-assembled units applied on a feeder are shown in the photos on p. 86.

Control

The most common methods of switched-capacitor control and their relative merits are listed in Table I.

The bandwidth, which is most important when using voltage as the intelligence, depends upon the size of the capacitor bank, number of steps, and whether other voltage-regulating equipment will affect its operation. The bandwidth should be larger than the voltage change that occurs when one step is made. The usual step sizes result in a two- or three-percent voltage change. Occasionally a five-percent change is permissible if a switching operation occurs only two to four times daily. The bandwidth commonly falls in the range from four to eight volts.

Primary capacitor units are usually single-phase units of either 15 or 25 kvar, assembled in racks for pole mounting or substation use. Secondary capacitors are all single phase, of either three or five kvar and rated 240 volts. Switched banks of capacitors for pole mounting are complete packages, with capacitor units and switches mounted in the rack and correctly wired for the system voltage. Sizes range from 225 to 300 kvar. Small banks of a few units mounted directly on a pole or crossarm and large banks in substations use similar units. This simplifies the problem of readjustment to meet changes in system conditions.

TABLE I—METHODS OF SWITCHED CAPACITOR CONTROL

Method of control	Relative Cost-Percent	General Use	Advantages	Disadvantages
Voltage	100	Substation and feeder switched-capacitor applications where voltage decreases at least 4 or 5 volts with increasing load.	Will only operate when voltage improvement is necessary. Several switching steps can be used. Only one control potential source required. Independent of daily load patterns. More flexible.	Voltage must decrease with increasing load. Coordination may be required with other voltage-regulating equipment. Bandwidth must be larger than voltage step due to switching operation.
Current	100	On substation and feeder applications serving large intermittent loads that are either on or off. Single step operations. Can be used on feeder with large fluctuating loads if "capacitor off" setting is low enough.	Adaptable where voltage is not a satisfactory signal. Can be located any place in system—flexible. Independent of daily load patterns. Coordination with other voltage regulating equipment relatively simple.	Needs both a current and potential control source. Current transformer must be on load side for fine control. Only single-step control normally available. Examination required to insure bank will not come on when voltage increase results in too high a voltage.
Voltage-Current	140	On substation and feeder applications where system voltage increases with load at capacitor location.	Allows voltage to be used as intelligence at any location on regulated feeders.	Need both a current and potential control source. Increased cost.
Voltage-Time	130	On substation and feeder applications where daily load patterns are generally known but unusual load conditions often occur.	Voltage overrides time control for unusual load or voltage conditions.	Daily load patterns must be known. Increased cost.
Kilovar	180	On substations when voltage conditions are not determining factor and kilovars carried by a system component must be kept to a minimum.	Can have multi-step operation.	Increased cost. Does not consider voltage conditions.
Time-Switch	30	On substation and feeder applications where daily load and system patterns are known.	Inexpensive. Coordination with other voltage regulating equipment not required.	Omitting device required. Carry-over device required. Long system outages require resetting. Unusual load condition may result in too low or too high a voltage.
Manual	0	At attended substations.	Inexpensive. Attendant can follow any load conditions.	Requires attendant.

Switched Capacitors versus Voltage Regulators

Whether a voltage regulator or a bank of switched capacitors is most applicable depends upon the amount of voltage correction desired and the system characteristics. The regulator produces a change in system voltage that depends upon the range of the device. The percent of voltage change per kilovar of capacitors depends upon system reactance.

If a large voltage-regulation range is necessary, a voltage regulator is most applicable, especially where system power factor is high. If a small voltage change is required, a bank of switched capacitors is often more economical. This is especially true if the system power factor is low or decreases as load increases. For fine regulation, a voltage regulator is used, since a bandwidth setting as low as ± one volt is possible. Economies obtained in the reduction of system losses and release of system capacity when using switched capacitors should also be considered. Another factor is the ability of capacitors to support or maintain load voltages during system emergencies. This is generally attainable because during emergency periods the circuit impedance back to the regulated-voltage source increases, causing a greater voltage rise at the capacitor installation.

In many applications, both switched capacitors and voltage regulators are necessary on a particular feeder—for example, when a large range of voltage regulation is necessary and the feeder power factor decreases considerably from light- to full-load conditions. In this case, capacitors reduce losses, release system capacity, and give a rough voltage change, which in effect increases the range of the regulator. Coordination between switched capacitors and voltage regulators is necessary to prevent one from causing misoperations of the other, resulting in improper voltage control.

Coordination is no problem when fixed capacitors on a primary feeder are located ahead of a voltage regulator, or if they are located at or beyond the regulating point determined by the line-drop compensator setting of the regulator controls. If the fixed capacitors are located between the voltage regulator and the regulating point, satisfactory coordination and proper line-drop compensation are obtained by slightly increasing the voltage setting of the voltage-regulating relay in the regulator control.

With switched capacitors located ahead of a voltage regulator or beyond the regulating point, coordination is no problem. If the switched capacitors are located between the regulator and the regulating point, voltage-current control is necessary for the switched capacitors and a slightly higher voltage setting on the voltage-regulating relay of the regulator. The increase in setting would be approximately half of the amount if the capacitors were fixed.

Conclusion

The voltage in a distribution system can be controlled at the source or generator location, at substations throughout the distribution system, and along the primary feeders. Voltage control at the generator location offers the lowest cost method. Control in the system is obtained with voltage regulators and shunt capacitors, with the selection of either or both depending on technical considerations and limitations, individual system requirements, and economics.

First considerations for voltage control in the distribution system should be the use of fixed shunt capacitors throughout the system, up to the system limits of light-load voltage and power factor. Capacitors also generally offer the lowest cost form of supplying leading kilovars to a distribution system. Fixed capacitors can be either primary or secondary capacitors. A method of automatic voltage control with either switched primary capacitors or voltage regulators is then considered, and for any particular application the cost-per-volt improvement should be determined for both.

• • •

Ultra-Safe Punch Press Control

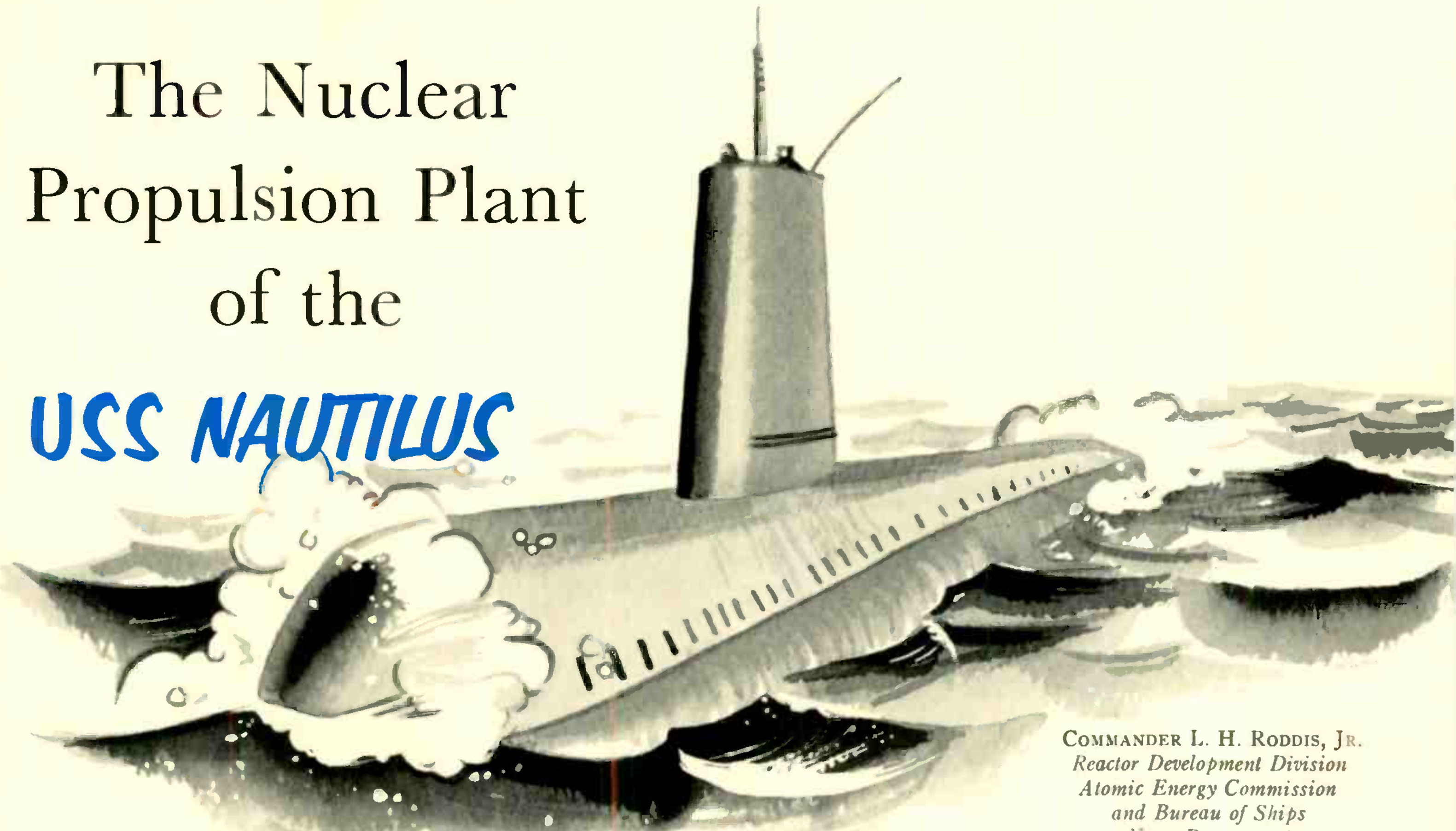
There must be no "ifs" about the control of a punch press. These ponderous machines must make a single stroke and then stop. If due to some malfunction of the control, the press should make any strokes other than those selected, the operator might lose a hand, or an expensive die might be ruined.

A new control, for presses using continuously running motors connected through an air-operated clutch to the crankshaft, presents the ultimate in safety. The control always checks itself for malfunction. Should one relay fail because of a broken coil lead, or weld itself closed, the press stops at the end of the stroke and cannot be further operated. It employs standard break and make pushbuttons (one for each hand); a reset relay prevents operation in the event all "run" buttons are locked out.

New Lathes Produce Klinkii Veneer

If you should visit a furniture shop some day soon and your eye be caught by an unfamiliar, but beautiful, light-textured wood, you may be told that it is araucaria klinkii. If so, it is probably the product of two interesting new veneer lathes recently set up in New Guinea. To make use of this little-known cabinet wood, which grows only in the neighborhood of the New Guinea gold fields, the Commonwealth-New Guinea Timbers, Inc. introduced the two modern lathes. One is used for small logs five feet long, the other for nine-foot lengths. The smaller one is direct connected to a slow-speed d-c motor, which is uncommon for lathes. Both machines are controlled by magnetic amplifiers, the first to be so equipped. Veneer is peeled at speeds up to 400 fpm, and is reeled up as it comes off the lathe.

The Nuclear Propulsion Plant of the USS NAUTILUS



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PART II—*This article is part of a paper presented at the 62nd Annual Meeting of the Society of Naval Architects and Marine Engineers, held Nov. 12, 1954. Another portion of the paper was published in the March, 1955 issue of the Westinghouse* Engineer.

To start the STR project, it was necessary to make certain arbitrary assumptions and then see what type of power plant would result. The U. S. Navy indicated the speed desired and the basic diameter of the submarine hull. With this hull diameter, the approximate shaft horsepower that would be required was determined, and a study was made as to the size of power plant that would be needed to produce that horsepower. It also was determined that it would be necessary to have two propellers, and preferably two complete sets of main propulsion equipment.

The study showed that the space required for equipment of this size, and space necessary for proper buoyancy prohibited the possibility of using a conventional hull diameter. After a series of design studies, compatible parameters were determined. The project continued at the Argonne National Laboratory. Later, at the Westinghouse Atomic Power Division more accurate equipment designs were obtained and it was necessary to increase the diameter of the hull to meet space, weight, and horsepower requirements.

In a development project of this type, one of the most important facts for consideration was the general status of the knowledge that existed, particularly with respect to whether it was sufficient to give reasonable assurance that a successful nuclear power plant could be produced. This consideration led to the choice of a water-cooled and moderated, highly enriched, heterogenous, thermal reactor. As in all naval vessels, it was necessary to have the plant as small in size, light in weight, and simple as possible, commensurate with reliability of the system, safety, and accessibility.

To capitalize to the greatest extent possible on the use of nuclear power in the propulsion plant, it was necessary to design the reactor plant to have long life, and the longest possible periods between refuelings.

Having selected the basic reactor type, as indicated in the foregoing, it was then necessary to determine the overall plant design parameters. A variety of steam cycles, including various throttle pressures, back pressures, etc., were considered, and the most suitable one—from a weight and space viewpoint—was selected that was compatible with the temperatures available from the primary plant. The reactor heat load was determined and the primary-system water temperature, pressure, and flow, and the maximum fuel-element surface temperature were selected in conjunction with the system study.

The maximum fuel-element surface temperature that could be used was limited by several factors. The temperature had to be below the boiling point of water for the system operating pressure. The temperature also had to be sufficiently low to guarantee a satisfactory lifetime for the fuel elements from a corrosion viewpoint. Obviously, it was desirable to have this metal surface temperature as high as possible in order to get the maximum thermal efficiency in the overall plant. Even though the variation in metal temperature due to power transients and the possible variation in the system pressure were not accurately known, the metal surface temperature was limited by the known data on corrosion re-

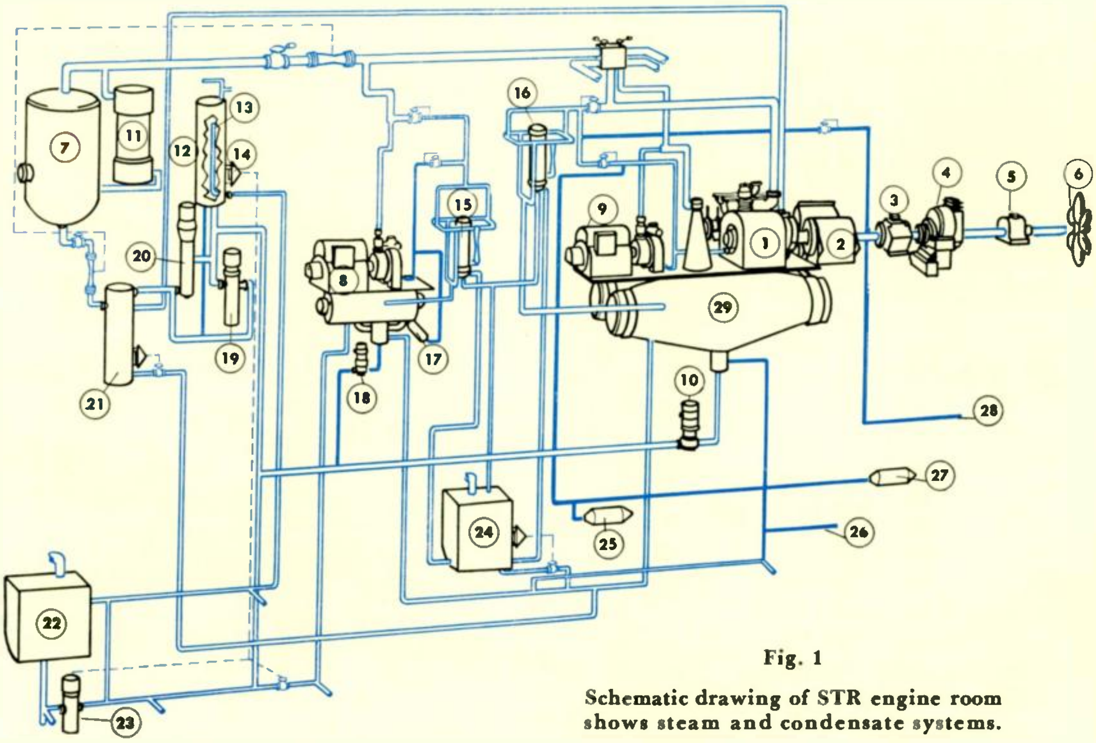


Fig. 1

Schematic drawing of STR engine room shows steam and condensate systems.

1—Main turbines
2—Gear
3—Clutch
4—Propulsion motor
5—Thrust bearing
6—Propeller
7—Steam separator
8—Coolant pump t-g set
9—Ship's service t-g set
10—Main condensate pump
11—Stand-by condenser
12—Surge tank
13—Overflow
14—Lo level control
15—Air ejector
16—Main air ejector
17—Lube-oil cooler
18—Condensate pump
19—Main boiler-feed pump
20—Auxiliary boiler-feed pump
21—Feed heater
22—Feed storage tank
23—Feed distribution pump
24—Drain collecting tank
25—Main lube-oil cooler
26—From 4000-gpd evaporator
27—Shaft lube-oil cooler
28—To 4000-gpd evaporator
29—Main condenser

sistance of the zirconium sheath for the fuel elements.

In determining the average coolant temperature, it is necessary to strike a proper balance of weight, space, and cost of the primary coolant-system components. For a particular steam generator and core design, increasing the average coolant temperature requires a larger and heavier core and reactor vessel. Increasing the average coolant temperature reduces the size, weight, and cost of the boiler.

High flows permit cores that are less complex. Low flow rates permit smaller pipes and valves. In any event, there is a practical upper limit of about 40 fps for coolant flow anywhere in the system.

Core Mechanical and Thermal Design

General Design Considerations—For the necessary heat-transfer surface to be obtained in a nuclear core, the highly enriched uranium fuel must be alloyed with other elements or combined with other materials. The core fuel element not only must have satisfactory nuclear properties but also must be satisfactory from a radiation damage and corrosion viewpoint. It is also desirable to have fuel elements that can be fabricated as cheaply as possible. The clad material on the fuel elements must not only prevent fission products from contaminating the primary coolant but also must itself be corrosion resistant so that radioactive corrosion products do not enter the primary coolant in any appreciable amounts.

The fuel element must be capable of withstanding the effect of the neutron flux throughout the life of the reactor without causing structural damage, distortion, or damage to the heat-transfer properties of the materials.

The materials used in the core must have a low absorption cross section for neutrons in order not to increase the amount of fissionable material required.

Having determined the fuel-element material, it is still possible to design the core with an almost infinite variety of shapes and configurations. The fuel-element geometry must be satisfactory from a nuclear viewpoint as well as from the standpoints of heat transfer reliability, fabricability, and cost. There must be no excessively hot spot in the core occasioned by nonuniform distribution of fuel or coolant, which would cause corrosion damage or excessive thermal stress.

Assembly must be accomplished in such a way that failure to pass inspection at any stage of manufacture requires the minimum loss due to scrapping of material. The entire assembly, of course, must be fully capable of withstanding high impact shock.

Core Materials Problems—It should not be construed from the foregoing discussion that the core mechanical and heat-transfer designers had complete freedom in the selection of materials from among a group whose characteristics were well known, or even that the special configurations and designs they might desire could actually be manufactured. The zirconium and zirconium-uranium alloys that were used for fuel elements were largely unknown from a metallurgical viewpoint, and intense research and development were required before the final design was determined. It soon became apparent that existing sources of supply of pure zirconium would not be sufficient for our needs. To cope with this situation, a zirconium production facility (Fig. 2) was constructed at the Bettis Plant and in a very few months was producing large quantities of pure crystal-bar zirconium (see Fig. 3).

Fabricating methods and quality control of core manufacture entailed an extraordinarily large amount of development work.

Fuel-element samples were made and tested in existing reactors to verify that the fuel elements would be satisfactory from corrosion- and radiation-damage viewpoints.

Core Physics Considerations

Criticality—It is necessary to have the proper amount of fissionable material in such a distribution that the reactor can be made critical. There also must be sufficient reactivity for proper control, not only at the start but throughout the useful life of the reactor. It must be possible to start up when fission-product transient poisons are present in the reactor.

These problems can be solved largely by theoretical calculations. However, during the early phases of the project it was not possible to calculate accurately the nuclear design since the necessary theory and design constants were not sufficiently well known to obtain adequate answers by calculations. For this reason, and to verify the calculations, a series of experiments were performed at the Argonne National Laboratory to determine whether the reactor design would be satisfactory from a criticality standpoint. A series of critical experiments were required to determine wherein the theoretical approximations were in error and to permit corrections to be made so that other properties of the reactor could be predicted. The final critical experiment consisted of an exact nuclear mock-up of the reactor and all of its control. These experiments also were used to determine the neutron-flux distributions for various control-rod positions. In a sense these critical experiments serve as the proving grounds for reactor designs.

Shutdown—In addition to having sufficient fissionable material in the reactor to guarantee its being able to be critical at all times, it is necessary that there be sufficient control means available to shut the reactor down, even in the most-reactive and least-reactive conditions. The difference between the reactivity in the most-reactive and least-reactive conditions is occasioned by changes in temperature, presence of equilibrium and transient fission products, and burn-up of fissionable materials as power is produced.

Control also must be available to decrease the reactivity rapidly enough to prevent dangerous power overshoots effected by possible accidental causes.

Heat-transfer considerations as well as space considerations made it desirable to introduce the minimum acceptable amount of control. This required extensive calculations and experiments to determine the amount that would be suitable under all conditions. The control rods were made of the little-known metal, hafnium. Manufacture of these rods required extensive development in the metallurgy of this new metal. One of the problems that has to be considered with respect to control rods is their nuclear depletion. Control rods perform their function by having an unusually high absorption cross section for neutrons. This very fact, however, causes the atoms of the control-rod material to change gradually to isotopes of higher order. This means that the absorption cross section correspondingly changes, usually decreasing with the absorption of each neutron. The life characteristics of the rods, therefore, must be calculated carefully to ascertain that they will be adequate throughout the life of the nuclear reactor.

Flux Distribution—The heat production in a reactor is proportional to the product of the neutron flux and the absorption cross section of the fuel material. Where the fuel material is uniformly distributed, heat produced at any point is, therefore, proportional to the neutron flux at that point. The neutron flux has the same distribution for the

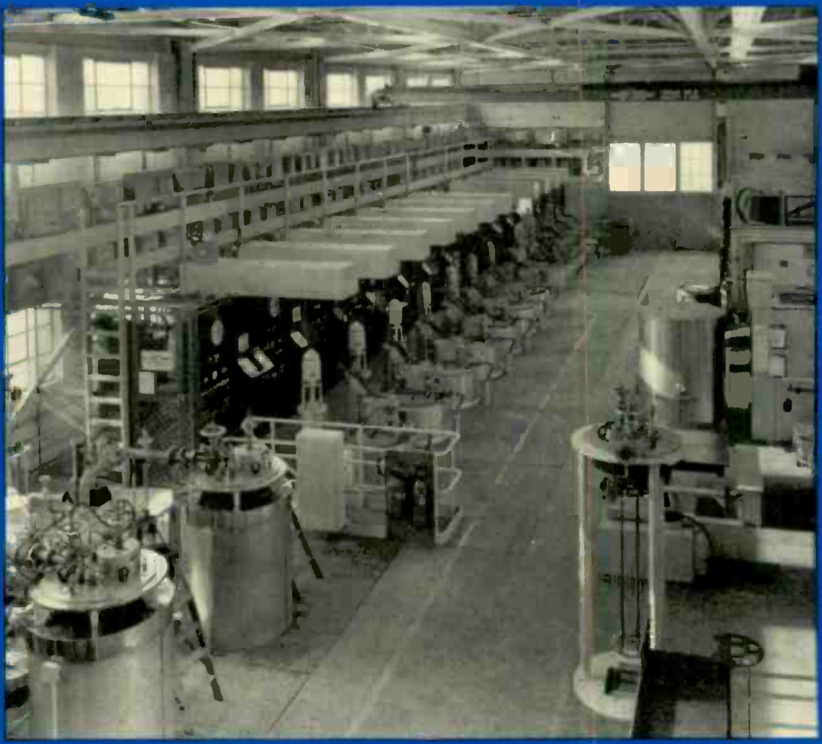
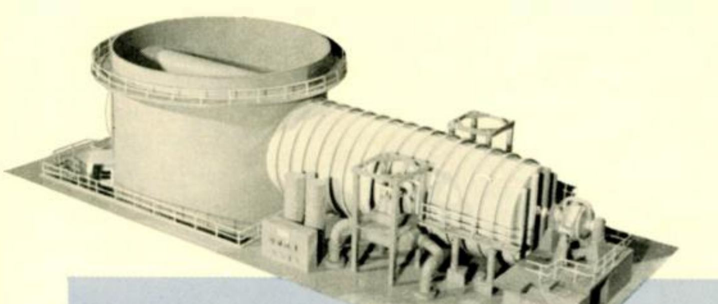


Fig. 2—Zirconium crystal bar production plant at Bettis site.

Fig. 3—Zirconium crystal bars.

same control-rod positions regardless of power level. The neutron flux is, however, a function of control-rod position, inasmuch as the control rods cause local depressions in the flux when they are in the reactor. The power produced by the reactor is proportional to the volume integral of the flux. For a given power level, the location of the thermal hot spots is a function of the gross peak flux due to power level and local perturbations that might cause thermal peaks. Hot spots can cause increased local corrosion, unduly high thermal stress due to the magnitude and gradient of the temperature, or burn-out of the fuel element because of inability to carry away the heat under the boiling condition.

Proper design of the reactor can do a lot to decrease the ration of peak-to-average neutron flux, and thus decrease the peak-to-average temperature. This can be accomplished by proper location and size of control rods, by orificing the coolant flow, and by varying the distribution of the uranium fuel. It must be noted, however, that variable loading and orificing are both largely dependent upon having a fixed flux pattern, as it is a very difficult problem to determine the required orificing or loading pattern if the flux distribution is changed due to changing positions of the control rods.



Test Program

The start-up of new reactors almost always seems to occur in the middle of the night. Whatever the reason, the STR Mark I first achieved criticality at just before midnight, Mountain Standard Time, March 30, 1953. By that time the plant work was essentially complete and most of the plant itself had been tested. The next two months were devoted to completions of the sealing of the primary coolant system and to all final pressure testing and system thermal insulation. The first useful power was generated May 31, 1953.

Beginning in the evening of June 25, 1953, the Mark I was brought to full power for a sustained run needed to obtain information on nuclear physics and reliability of the nuclear plant. It was planned to run for 24 hours. At the scheduled end of the test, the Mark I was performing so well that it was decided to simulate a run across the Atlantic. For the next several days the Mark I "submarine" proceeded at top speed. It was never necessary to shut down the reactor or even to "surface." Only three times during the entire "crossing" did the Mark I slow down. Once it was throttled back to two-thirds power for seven minutes and twice to half-power for a total of less than 1½ hours. In each case the necessary adjustments were made to permit continued operation of the system.

The plant has operated at various powers with relative ease, demonstrating the known conservatism of design of the reactor and primary coolant system. No deliberate attempt has yet been made to operate the plant above its rated power since a large and extensive testing program is being run to obtain detailed design information on all parts of the plant, to permit the better design of future power plants of this general type.

Radiation Damage—The various materials used in nuclear reactors are subjected to various degrees of damage from the radiations to which they are subjected—just as human beings might be. The subject of radiation damage of solids and fluids is another one of those halfway fields lying among physicists, metallurgists, mechanical engineers, and chemists. The surface of these problems and their inter-relationship with each other has only been scratched.

Radiation damage is proportional to the time integral of the flux and is also a function of the type of material and temperature at which it operates. To determine its effects, therefore, requires extensive tests for long periods of time and under conditions simulating actual reactor operating conditions.

Radiation and Heating of Structures—The nuclear core is a source of intense radiation of gamma rays and neutrons as well as alpha and beta particles. The absorption of this radiation creates heat, which is a function of the type and amount of radiation. Because of the amount of absorbed radiation in the material that supports the nuclear core, great care must be taken to have sufficient coolant flow past all of the surface areas.

Instrumentation—The power level is a function of the total number of fissions taking place per unit time within the core. The neutron flux is, therefore, proportional to the power. However, the proportionality constant varies depending upon the peak-to-average ratio of flux. It is also a function of the attenuation of the flux from the core to the instrument that measures it. This is determined initially by calculation, and it is then verified and calibrated by actual operation of the power plant. The variation in flux at the instrument from start-up to full-power presents a very considerable instrumentation problem.

Overall Reactor-Plant Considerations

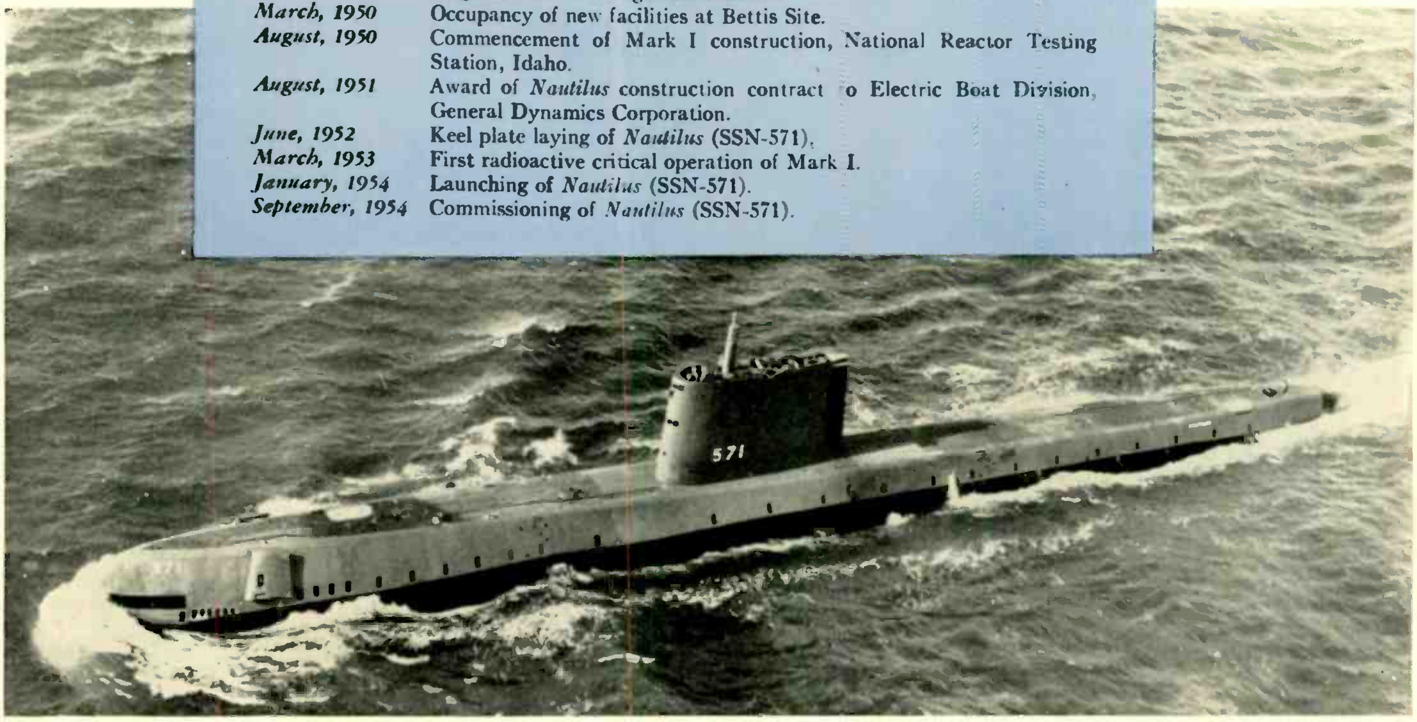
Shielding—One problem that permeates the entire field of nuclear engineering is that of shielding. In the case of mobile plants, shielding is a particularly difficult problem. For stationary power plants where size and weight are not particularly important, one finds ordinary materials such as concrete, iron, and water being used for shielding—economic considerations usually determining the materials. In mobile reactors, for both ship and aircraft application the principal emphasis is placed on weight and space so that more unusual materials are being investigated. Some of the materials that have the best shielding properties do not have good structural properties, so the technique of their possible utilization in reactor-shielding structures is a matter of considerable concern to the nuclear engineer.

In addition to this, it is necessary that the shield be so arranged as to permit the maximum accessibility to the equipment for maintenance purposes.

In the design of the shield, it is first necessary to know the attenuation characteristics of the various materials and combinations of materials that will be used. After this information is known, the problem is still a difficult one, because the radiation does not emanate from a single point source or from even a simple distributed source such as the core itself. Rather, the radiation emanates from the core and from the radioactive corrosion products that are in the coolant, as well as from the radioactive oxygen in the coolant. In addition, these corrosion products over a period of time distribute themselves through-

TIME TABLE OF SUBMARINE THERMAL-REACTOR PROJECT

April, 1948	Formal project established at Argonne National Laboratory.
June, 1948	Original Navy-Westinghouse contract.
December, 1948	Original AEC-Westinghouse contract.
March, 1950	Occupancy of new facilities at Bettis Site.
August, 1950	Commencement of Mark I construction, National Reactor Testing Station, Idaho.
August, 1951	Award of *Nautilus* construction contract to Electric Boat Division, General Dynamics Corporation.
June, 1952	Keel plate laying of *Nautilus* (SSN-571).
March, 1953	First radioactive critical operation of Mark I.
January, 1954	Launching of *Nautilus* (SSN-571).
September, 1954	Commissioning of *Nautilus* (SSN-571).



As this article was in production the USS *Nautilus* underwent her initial sea trials. The vessel got under way on January 17, 1955.

Official U. S. Navy Photograph

out the reactor system, concentrating in certain places, such as crevices. There is an additional complicating factor, which is the self-shielding of the pipes, the core itself, the coolant, and the other pieces of equipment, such as valves and pumps. In addition, the radiation that can be allowed to emanate from the shielded areas depends upon the access required by the crew. All of these factors were taken into consideration in the design and a theoretical solution was obtained. This was checked very roughly by tests made at Oak Ridge National Laboratory. Final confirmation of the shield design could not be obtained until the STR Mark I reactor was actually operated at power at the test site in Idaho.

Another feature of nuclear-power plants associated with shielding is the high degree of leak-tightness required of the coolant systems that must contain radioactive coolant. A degree of leak-tightness and reliability that is unusual in the case of large systems, by ordinary engineering standards, is required. In the case of most of the reactor coolants used, the leakage of a very few cubic centimeters will release enough radioactivity to the surroundings to make the area uninhabitable. An ordinary steam power plant is subject to copious leakage when compared with this standard. Valve packing glands, pump-shaft seals, pipe flanges, and turbine-shaft seals, usually all leak to the extent that it is necessary to add many gallons of makeup water per day to the boiler. The heat exchangers, piping, reactor vessel, and other primary coolant-system components, which make up this necessarily impervious envelope to contain the coolant, generally may be of a heavy rugged structure wherein good engineering practices will insure great integrity. However, it is necessary to transmit through this envelope certain motions, pressures, or considerable amounts of energy; and the points at which these pass through the envelope constitute points of weakness. A great amount of effort is being applied to achieve the necessary soundness and reliability at these points.

Another problem associated with radioactivity and shielding is that of maintenance. In the development of shipboard nuclear-power plants, there are some extremely difficult problems in insuring that one can do something about all parts of the system in case it becomes necessary. Sometimes this involves various ingenious mechanical devices to perform remote operations. It always necessitates plans for repair as part of designing due to the fact that, once any part is radioactive, it is difficult to take it back to the machine shop for alterations. This requires a much greater than normal attention to details of design and installation.

General Materials Problems—A great many new and unusual materials are employed in the design of nuclear reactors. The need for their use comes from the requirement that structural materials, heat-transfer fluids, shielding materials, and nuclear fuel and moderating materials must have certain nuclear properties in addition to the chemical and physical properties normally required. There are numerous materials that, in the past, have been rare and little known from the standpoint of engineering properties, which are now being used in varying degrees.*

Installation, Operation, and Maintenance

In a development program of the magnitude of the submarine thermal-reactor program, many dozens of items completely new in concept and design and many hundreds of newly designed items are combined to form a final power plant. The principle of individual tests for each item was followed to the maximum extent possible so that the final assembly represents a test of the complete power plant rather than the test of individual items. In addition, where secondary service systems were involved, the systems themselves were tested individually before inclusion in the final plant. Finally, the entire nuclear power plant was tested at the Mark I facility, as a whole. This extensive test program has proved its worth in that the power plant as finally installed in the Nautilus will be a plant similar to the one which has had over a year's actual operating experience.

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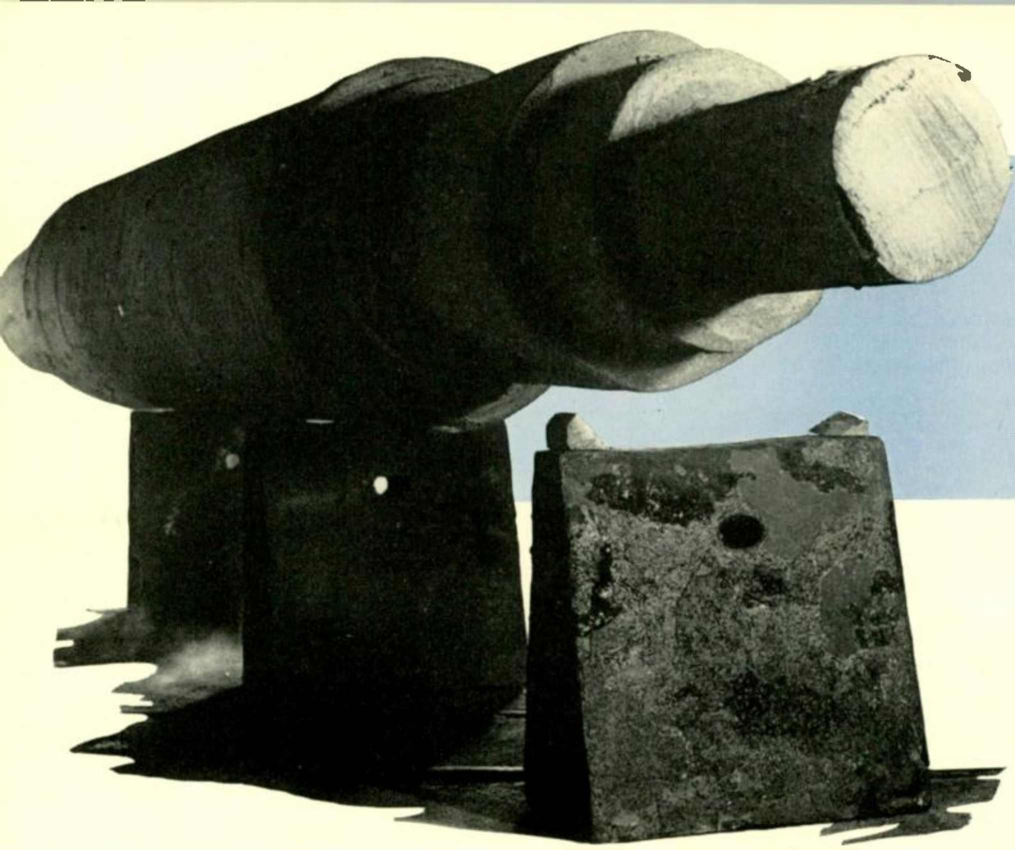
*For a discussion of materials problems for the submarine reactor, see "Materials Development for the Submarine Thermal Reactor," by William A. Johnson, *Westinghouse* ENGINEER, November, 1954, p. 208-12.



HIGH-SPEED

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The principal forged components of 3600-rpm turbine-generator rotors are the rotor body, retaining rings, and blower hubs—of these, the large rotor forging is, literally, the heart of the turbine generator. The available size and quality of this forging determines the maximum generator size that can be built for a given rotational speed.

To insure maximum reliability of this important component, the most modern manufacturing and inspection techniques are employed. All turbine-generator rotor forgings are made to strict specifications, and are given a complete and thorough inspection at the forging plant by both the supplier and Westinghouse. This close cooperation with the supplier results in improved methods and procedures for producing reliable forgings. Specifications designate the kind and amount of alloying materials, general manufacturing and forging methods and procedures, and such physical properties as tensile and yield strengths, and ductility. Also specified are size and location of test samples taken from the forging for determining these physical properties, and for obtaining material character with respect to grain structure, uniformity, freedom from defects on external and bore surfaces, and freedom from injurious internal defects. After inspections and tests have verified the high quality of the forging, further checks are made periodically during manufacture to assure a smooth-running generator rotor.

Rotor Inspection

In addition to making the usual analysis of the material, and physical tests to determine yield strength, tensile strength, percent elongation, etc., the rotor forging is given several special inspections:

Borescope Examination—After the rotor has been forged, rough machined, and in some cases partially heat treated, a hole is drilled completely through the forging, from end to end along the axial center of the shaft. After further heat-treatment and machining operations, the bore hole is finish machined to the diameter specified. The bore is then polished, and as part of the final inspection, examined visually using a periscopic device known as a borescope. In this way, the complete length of the forging in the section where a defect would be most likely to occur can be examined, and a bore that will be completely free of harmful defects is definitely assured.

Magnetic-Particle Tests—Magnetic-particle tests assure the absence of harmful flaws or defects on the forging surfaces. The test can locate any discontinuity open to the surface, but too fine to be seen with the naked eye, and some defects slightly below the surface. In this test, a magnetic field is set up in the object being tested. Fine magnetic powder is then applied to the surfaces. If a flaw exists, it is detected by a collection of the powder at the defect.

Ultrasonic Examination—Ultrasonic examinations of the complete forging are made in both the axial and radial directions. A high-frequency mechanical wave (both 2¼ and 1 megacycle are used) is transmitted through the material, reflects from the opposite side, or from any discontinuities in its path, and returns to the source. Time of travel is measured, and by comparison of the elapsed time for portions of the returning wave, any discontinuity would be located immediately. If there is an indication that is questionable because of size, shape, or location, it is further investigated by taking out core samples, or enlarging the bore hole, so that the condition of the material at that point can be determined. If the investigation discloses any harmful flaw or discontinuity, the forging is considered unsatisfactory.

New ways of utilizing ultrasonic signals for checking forgings are continually being investigated, which may result in even further improvements in inspection techniques and procedures for these large rotors.

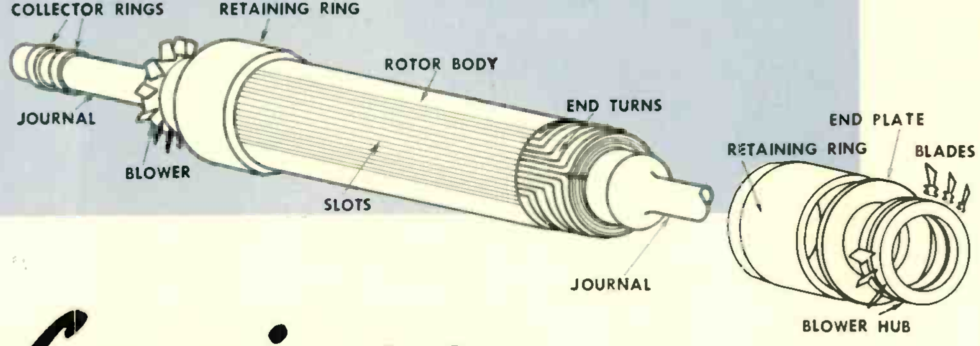
Component-Parts Testing

To assure maximum reliability, all component parts of the rotor are given a separate proof test at a load corresponding to a stress larger than that obtained at the maximum generator overspeed.

Particular attention is given to the retaining rings, which are forged from high-strength steel and subjected to the same requirements as the rotor forgings. Physical tests are made on test pieces taken from an extension of the forging. All mechanical surfaces are examined visually and by magnetic-particle testing. The ring material is checked ultrasonically in the radial and circumferential directions. As an additional quality check, the retaining rings are hydrostatically tested before

Modern manufacturing facilities and specialized inspection techniques have made possible today's high-quality rotor forgings; more recently, inner-cooling has contributed an even greater margin of reliability to the new, large-sized generator ratings.

Major components of a high-speed generator rotor are shown in the exploded view below.



generator forgings

being assembled on the rotor, at stress loadings appreciably higher than those that occur at 20-percent overspeed, the maximum speed of the assembled rotor.

The blower hubs, which are relatively thick in the radial dimension, are given the same inspection and test as the rotor retaining rings, except that they are mounted on a mandrel and rotated at 25-percent overspeed instead of being subjected to the hydrostatic-pressure test. The physical properties and ductility of the blower hubs are determined in the same careful manner as the rotor forging. Prototypes of new blower designs are also subjected to tests corresponding to operation at full speed in air, where the aerodynamic load on the blades is much higher than for normal operation in hydrogen.

The blower blades are assembled on the blower hub or on a test tool and given a 25-percent overspeed test before being mounted on the rotor for operation. Furthermore, the blower-blade section is fluorescent-penetrant tested to assure freedom from cracks and flaws both before and after overspeed.

After the rotor is complete, it is run in a seasoning and balancing rig over a range from zero to 110 percent of normal speed. As a final test, a 120-percent speed run is made with the rotor assembled in its own stator and with its own bearings.

Contribution of Inner-Cooling

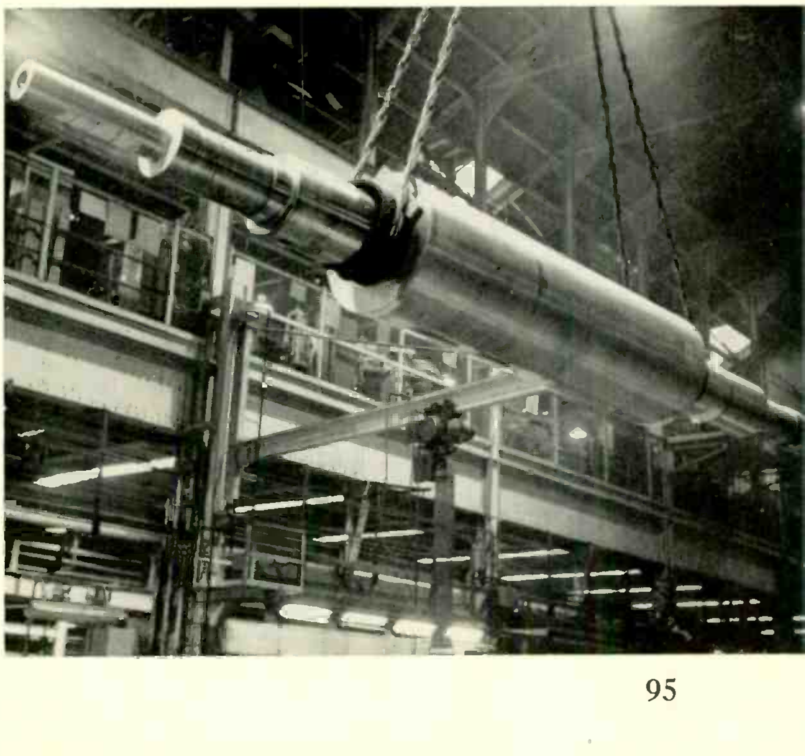
Increased mechanical reliability of the rotor is the greatest contribution of inner-cooling. For rotors with a central bore, the maximum stress occurs at the bore surface, and for different rotor diameters this stress varies approximately as the square of the diameter. For example, the bore stress for a 43-inch diameter rotor is approximately 50 percent greater than for a 34-inch rotor, and approximately 35 percent greater than for a 37-inch rotor. Therefore, the yield strength of the material must also be increased approximately as the square of the rotor diameter, and the strength increments will be on the order of 50 and 35 percent, respectively, in going from 34- and 37-inch rotors to the 43-inch rotor.

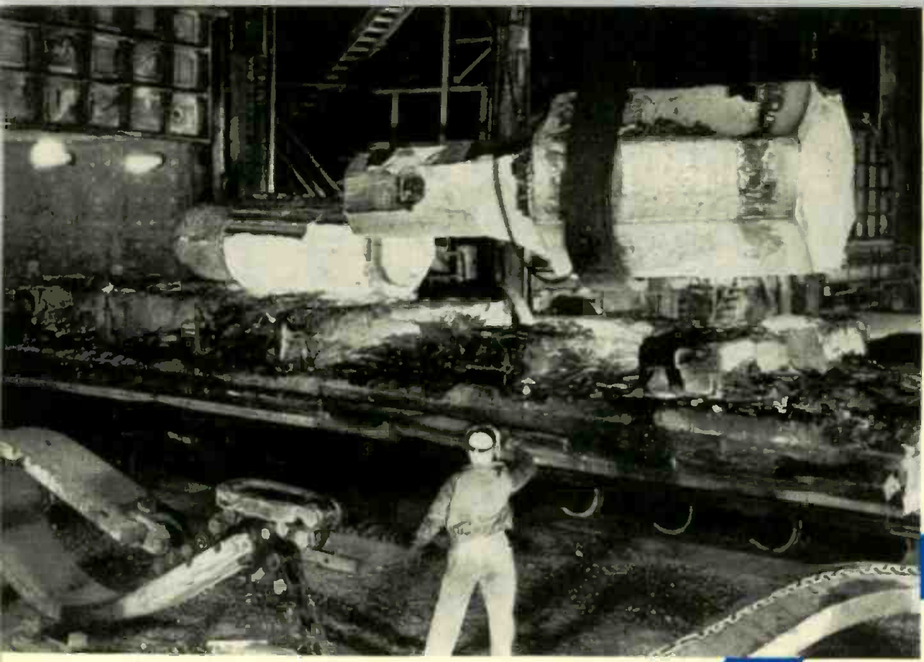
Inner-cooling makes possible a reduction in rotor diameter up to six inches (two sizes), and the rotor weight approximately 50 percent for 3600-rpm generator ratings up to 300 mw. This means that ratings ranging from 125 to 300 mw can be given the same margin of mechanical reliability that is now available on the 60-mw generators of conventional design.

The question is sometimes raised as to the desirability of using cross-compound turbines for the large unit ratings. From the generator viewpoint, inner cooling has made possible the construction of single-unit, 3600-rpm generators for ratings up to at least 450 mw with the same safe margin of mechanical reliability now present on 60- and 100-mw units of conventional design. The advantage of a lower operating speed of the 1800-rpm unit for the cross-compound machine is offset by the smaller diameter forging required for the 3600-rpm tandem machine. Consequently, for ratings up to 450 mw, the need for the cross-compound unit construction should be based on the efficiency performance of the steam turbine and the overall cost of the unit for the particular rating, steam conditions, fuel costs, water temperature, and other pertinent factors.

Text continued on p. 98

This rotor forging has been turned to size, ready for slotting.





U. S. Steel Corporation photograph

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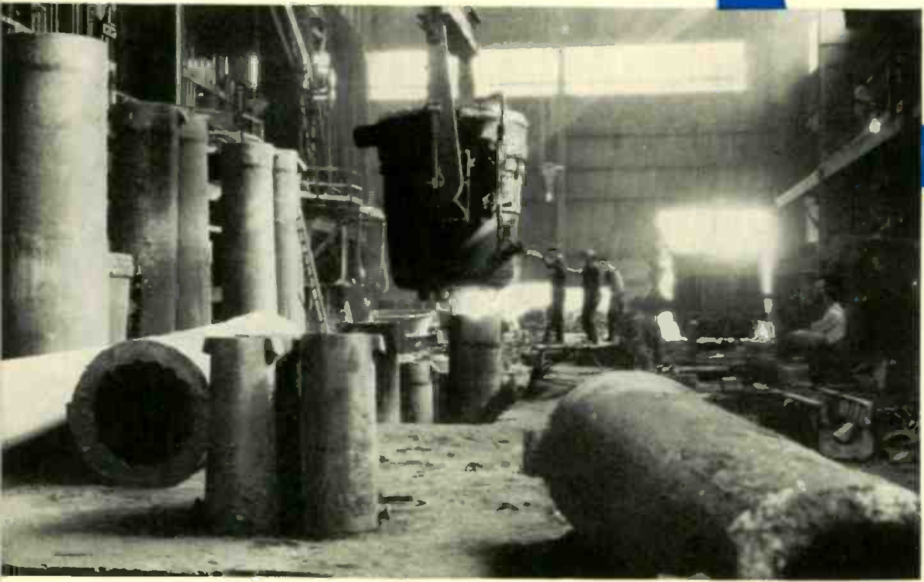
Bethlehem Steel Company photograph



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Erie Forge & Steel Corporation photograph

generator rotors

production and testing

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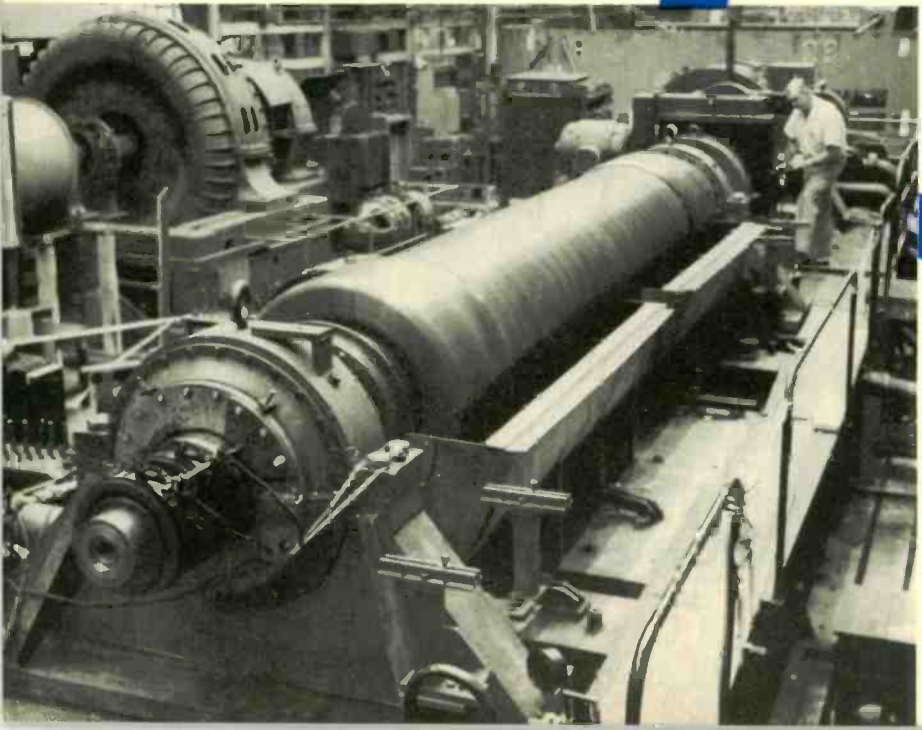

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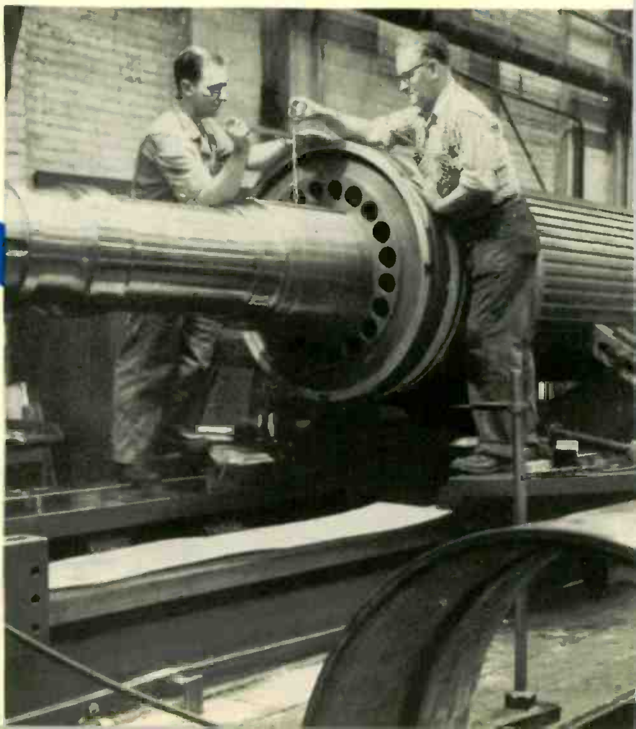

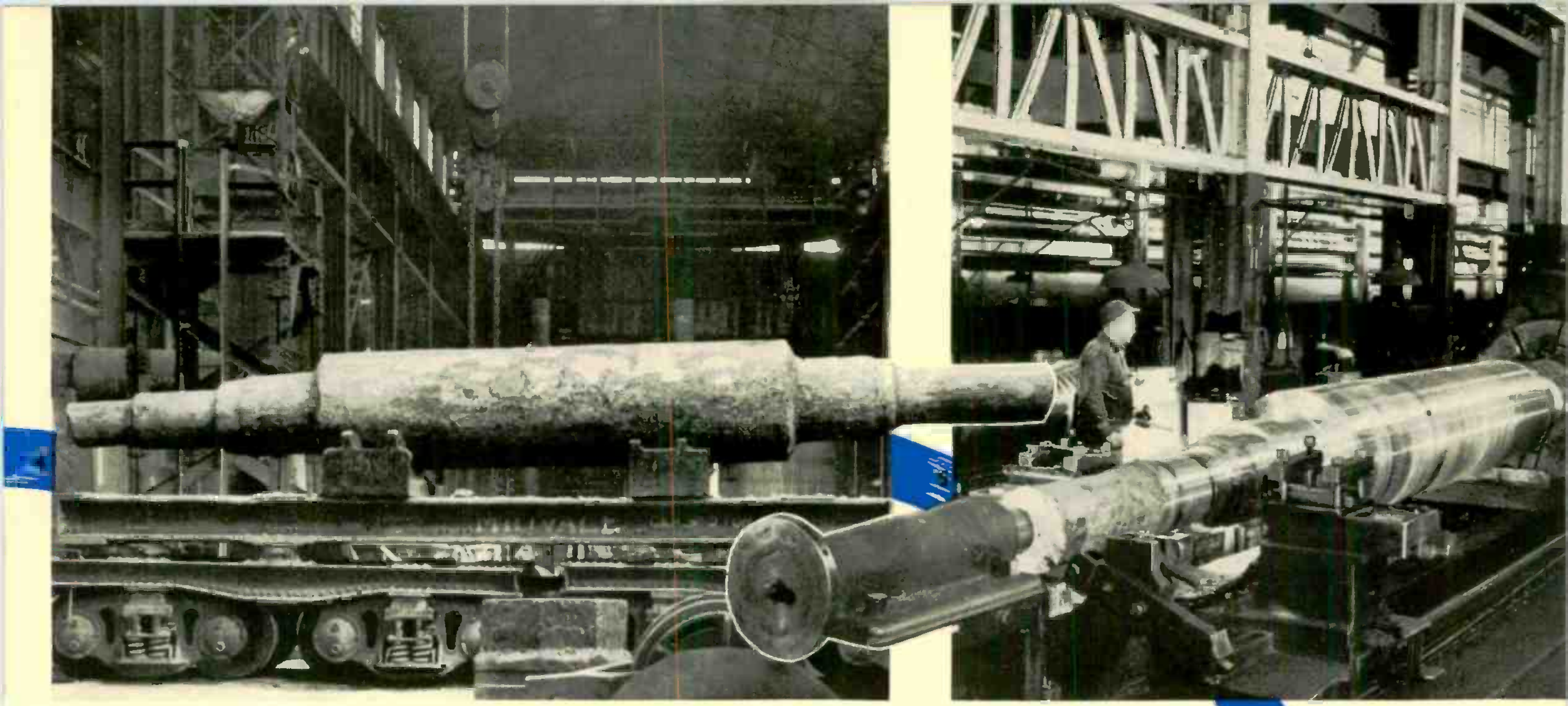

Midvale Company photograph

Bethlehem Steel Company photograph

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4—Following forging, and prior to any machining, the forging is partially heat-treated. In the photograph shown above, heat treating was done in a vertical furnace.

5—The first rough machining cut on the forging shown above is followed by final heat-treating to obtain the desired physical properties. After final heat-treatment, the forging is machined to within one-eighth inch of the final dimensions.

6—The forging is carefully inspected, and properties verified by a variety of tests—physical, chemical, borescopic, magnetic-particle, and ultrasonic; ultrasonic testing is shown.

7—The forging is shipped to the Westinghouse East Pittsburgh plant for further machining. First operation is in a lathe, where the forging is turned down to its final diameter. It next goes to the special slotting machine shown, where the slots for the windings are machined.

8—Cutting the slots in the rotor forging is an intricate machining operation, particularly in inner-cooled rotors where the slots are tapered. All machining must be accurate to within a few thousandths of an inch to insure a smooth-running generator. Each slot is carefully checked with these special gauges.

9—After windings and end-rings have been assembled on the shaft, blower hubs are shrunk into place. Each hub ring is heated and placed in position; the shaft is rotated while the ring cools so that the hub will shrink uniformly.

10—The assembled rotor is balanced both hot and cold, so that vibration during operation will be reduced to a minimum. Following the balancing operation, the rotor is subjected to overspeed tests. As a final check on rotor operation, it is assembled in its stator frame on its own bearings, and given a 120-percent speed test.

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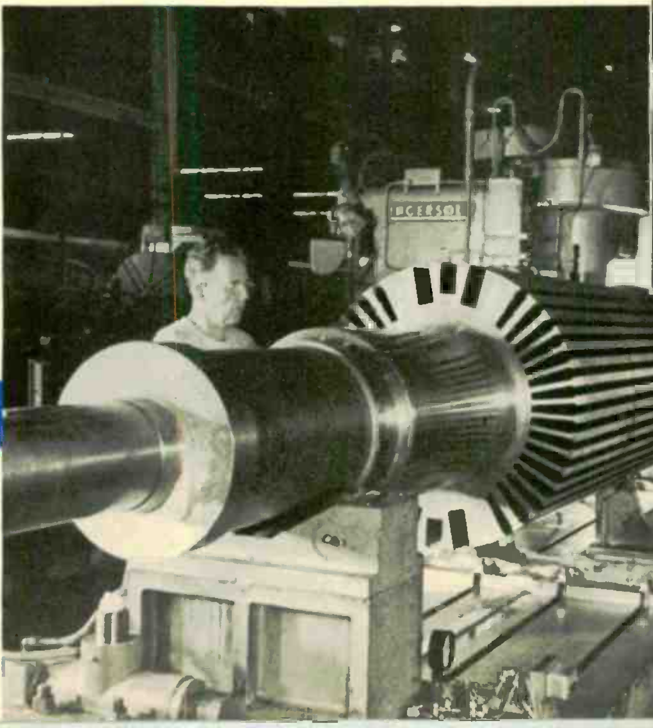


Rotor-Forging Inspection on Completed Units

If desired, forging inspection techniques can be applied to the rotors after manufacturing and testing operations have been completed, and at periodic intervals after the unit is in service. For turbine units now in service or under manufacture, visual and magnetic-particle inspections can be made at any time on the surface parts of the rotor that are available, or that can be made available without undue effort, time, and expense. The rotor bore surface can be reached by removing (1) the lathe center plugs at the extreme ends of the rotor, (2) the magnetic filler pieces in the rotor bore, and (3) the rotor field-lead assembly. Both borescope and magnetic-particle inspection can be made on the bore surface following a reasonable amount of cleaning.

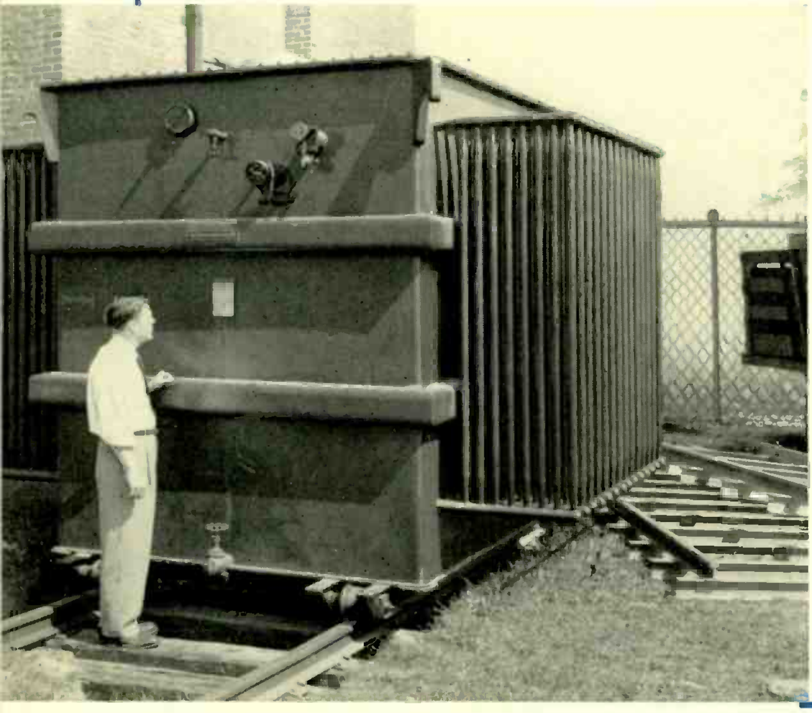
Ultrasonic inspection can be made on the shaft ends but not on the rotor body, due to the small, closely spaced grooves machined in the surface to reduce surface losses. Practically complete ultrasonic inspection of the rotor body can be made by machining two shallow, crescent-shaped axial grooves in the surface of each pole center, and using a circular-shaped, adjustable angle crystal. The indications thus obtained probably will be different from those obtained initially on the solid forging by the conventional method, and some reconciliation may be necessary. Indications from subsequent inspections should be compared to results obtained by previous inspections made under similar conditions.

The rotors of generators now under manufacture can be machined so that ultrasonic inspection can be made at any selected time after the unit is in operation. In cases where this kind of inspection is desired after the unit is in service, a reference bench-mark inspection record should be made after the rotor balancing operations are completed and just prior to the time the rotor is to be assembled in its stator for unit manufacturing tests. If rotors are removed from the stator for shipment, the reference check can be made after the unit is dismantled for shipment. The present Westinghouse inspection and maintenance program for large generating equipment can be extended to cover ultrasonic inspection of the generator rotor-forging elements.

Summary

The development and introduction of new and specialized inspection techniques, and the improvements in the forging art during the past several years have made possible the production of large, high-quality rotor forgings for turbine generators. More recently, inner-cooling has enabled large reductions in rotor-forging diameters and weights, so that generators can be built for ratings up to 300 mw using rotor forgings of the same diameter as have been used on 60-mw units of conventional design. The improved ductility due to reductions in diameter and weight gives an increased margin of mechanical reliability, which is of much importance in connection with high speeds attainable under loss-of-load conditions. Inner-cooling makes it feasible to build tandem-compound, 3600-rpm units for any rating desired in the foreseeable future with assurance of ample mechanical reliability.

Reactor System Breaks Low-Frequency Radio Traffic Jam



The number of teletype messages the Navy can transmit over its high-power, low-frequency transmitter has been increased five-fold. This big transmitter is part of the Navy's system of communication to its many centers throughout the globe. Because it operates at the extraordinarily low frequency of 15 000 to 34 000 cycles, it puts out an extremely powerful ground wave but very little sky wave. Hence it is virtually immune to atmospheric disturbances.

But at that frequency it is inherently sluggish. The impedance of the antenna is so high that changes in signal strength take place slowly. Hence the on and off pulses of the transmitter cannot be closely spaced.

The trick is to frequency-shift key the transmitter, and simultaneously shift the antenna tuning exactly in step with the keying pulse. This is done by a huge saturable reactor controlled by a special pulse transformer. And we do mean huge. The reactor alone weighs 46 000 pounds and is filled with 23 000 pounds of oil. It occupies a space bigger than a normal room. But this is small compared to what it would have been without the recently available ferritic core material, which has low loss at these frequencies. The core is made up of bricks of magnetic ferrite. The reactor is wound with special cables, about a half-inch thick but containing 4500 strands. Each strand is insulated from the others, and in winding the strands are transposed for minimum eddy-current loss.

The special pulse transformer is used to modulate the saturable reactor. This cuts down the driving power, if the "brute strength" method had been employed, from about 100 to 10 kw.

Industrial Magamp Systems

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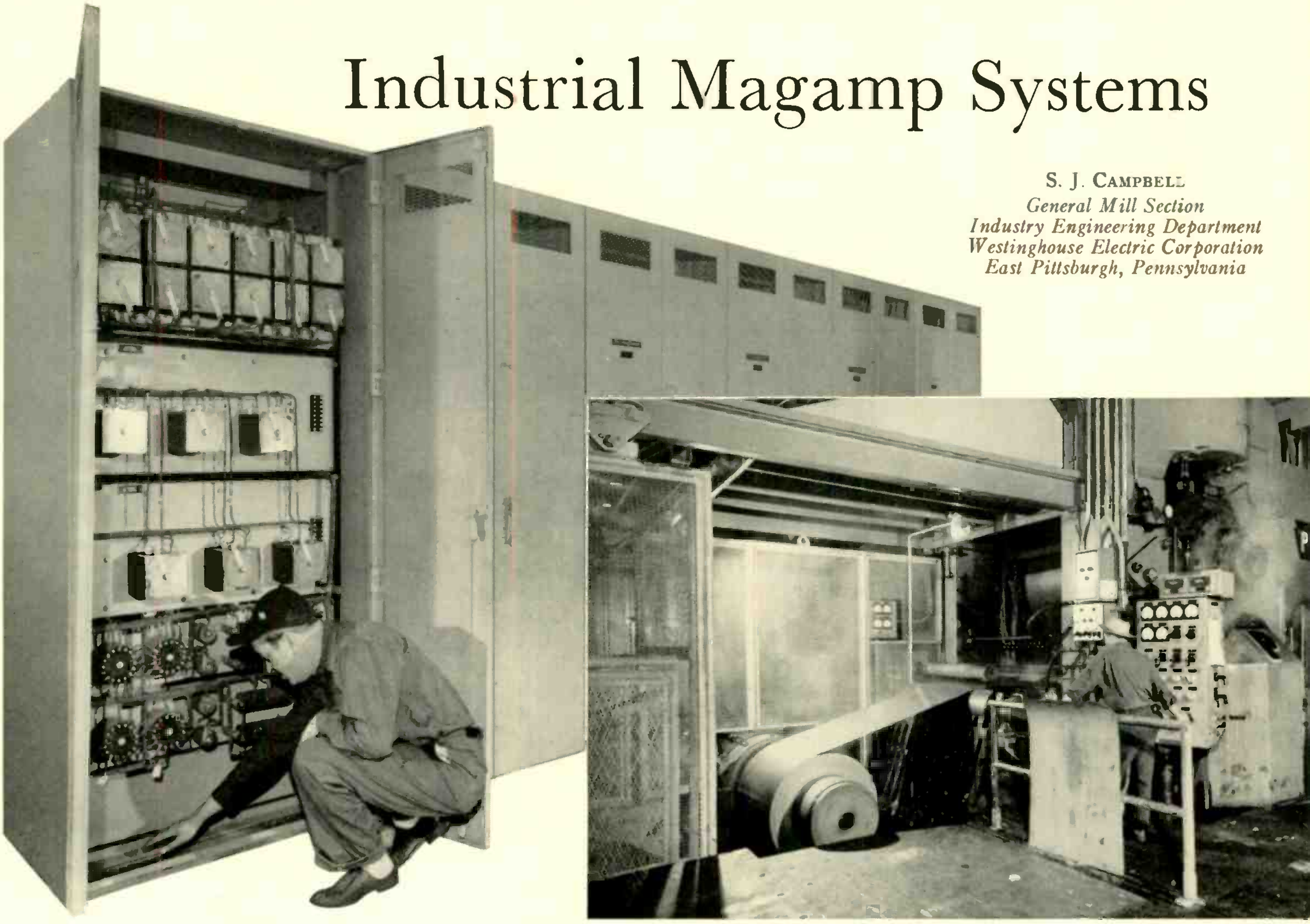
Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania



At left, the Magamp control cabinets for the stands, 400-cycle supply, and reel of a tandem cold strip mill. Above, the mill's delivery end.

The magnetic amplifier gets around. Since it first was introduced to the industrial field, the Magamp has become a familiar part of regulating systems in most industries—and its circle of acquaintances is still increasing rapidly.

THE MAGNETIC AMPLIFIER, which made its bow in modern form but a few years ago, has quickly won itself an enviable place in industrial control. Based on an old, but relatively obscure principle, it was given a new lease on life by the development of applicable new materials and circuits. Since that time the Magamp has found extensive use for many control functions in such industries as paper, steel, lumber, textile, mining, machine tool, and material handling. Despite the variety of tasks it performs, however, the magnetic amplifier itself and the basic circuits required in its application remain relatively simple and straightforward. Minor variations in the basic Magamp circuits enable their application in a large number of different situations.

Brief Magamp Theory

A Magamp is essentially a controlled impedance in series with a load, both connected to an a-c source. When the load requires direct current, a bridge-type rectifier is connected in series with the Magamp. The controlled impedance is in the form of a square-loop core material whose flux is controlled or preset by external means.

A simple half-wave circuit that illustrates the theory of operation of a Magamp is shown in Fig. 1a. Assume that control current is such that initial magnetic intensity (H) is at point 1 (Fig. 1b) when the supply voltage begins to rise. This assumption is valid because for negative half cycles, the rectifier blocks any reverse current, so that the only ampere-turns on the core are those from the control winding. As the supply voltage rises from zero, a small magnetizing current flows, and the flux in the core begins to increase. The dotted lines from points 1 to 2 in Figs. 1b and 1c show the core flux and resulting load voltage for this condition. When the flux reaches point 2 the core saturates, so that its impedance is essentially zero. The supply voltage then appears entirely across the load, as shown by point 3 on Fig. 1c. The ampere-turns of the load current cause the operating point after saturation to move out on the B-H curve to some point as 3, Fig. 1b. When the supply voltage decreases to zero, the operating point on the B-H curve moves to point 4. During the negative half cycle, the core flux is reset to the value determined by the control-winding ampere-turns.

For a given supply voltage, the point at which the mag-

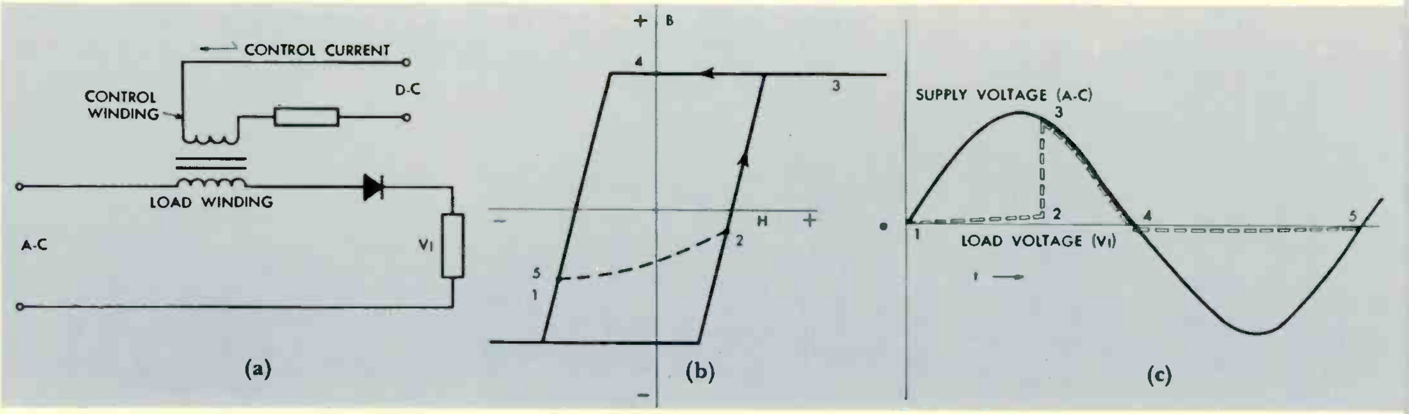


Fig. 1—(a) A simple half-wave Magamp circuit; (b) the B-H curve; and (c) the resulting load voltage.

netic amplifier core saturates is determined entirely by the control-winding ampere-turns.

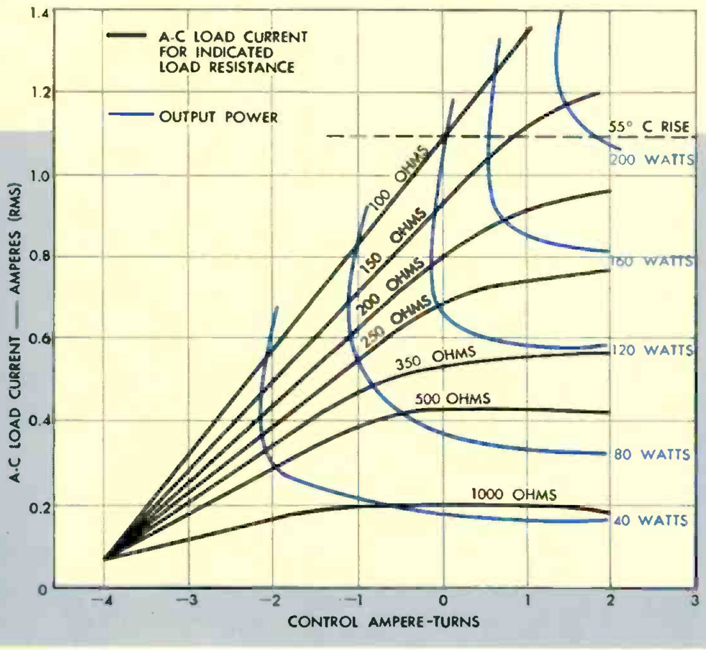
The relationship between the load voltage and control ampere-turns is known as the *transfer curve*, or *transfer characteristic*. A typical transfer characteristic for a Magamp having an idealized square loop core material is shown in Fig. 2. Note that when there are no control ampere turns, output is a maximum. The effect of adding a separate control winding to apply a net negative, or bias, ampere-turns to the core, is shown by the dotted lines.

The bias winding has the effect of shifting the transfer curve to the right, so that in the case of Fig. 2, the output is a minimum when the control ampere-turns are zero.

Note that this transfer curve does not reach zero output volts. This is because even so-called square-loop core materials used in Magamps have a finite permeability. That is, a definite magnetizing current is required in the load winding to overcome the reluctance of the magnetic circuit.

Transfer curves such as this show load voltage versus control ampere-turns. This method of showing output versus input is useful in understanding the theory of magnetic amplifiers; however, usual practice is to indicate the transfer curves of Magamps in terms of control ampere-turns versus load amperes for a given load resistance (Fig. 3). By showing the performance characteristics in this manner, the effect of the load-winding resistance on load voltage can easily be determined. Also, for a given Magamp load-winding design, various temperature-rise lines can be plotted for different values of load resistance. This permits plotting a curve of output watts superimposed on the transfer curve for various load resistances. Also, for a given load resistance and load winding, the system gain can be determined quite easily. The effect of changing the load resistance can also be examined easily in terms of output watts and system gains.

Fig. 3—Typical performance curves for a standard design Magamp, i.e., control ampere-turns plotted against load amperes.

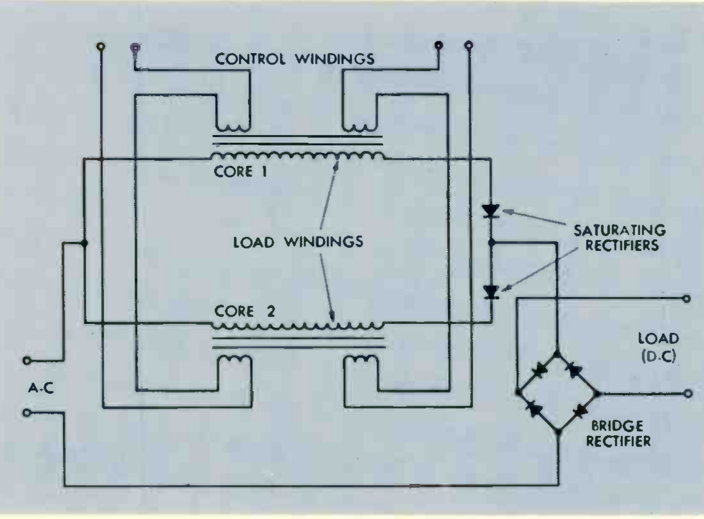


The circuit shown in Fig. 1a is not practical for several reasons. First, the output is half wave, which means that the circuit has a definite limitation regarding output power and efficiency. Second, the control winding is, in effect, the secondary of a transformer as seen by the supply voltage. The induced voltage in the control winding would tend to nullify the effect of the control ampere-turns. For this reason, the control winding impedance must be quite high. Third, the self-saturating rectifier must be designed to withstand the entire negative supply voltage, with minimum back leakage.

Basic Industrial Circuit

Several circuits can be used to overcome the limitations of the simple half-wave circuit. The one finding greatest usage

Fig. 4—The basic doubler circuit common in industrial usage.



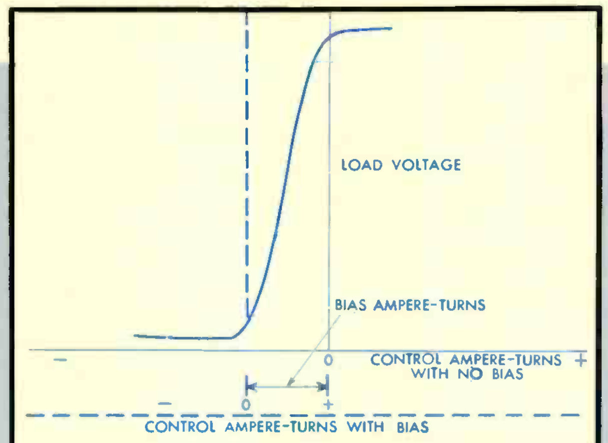


Fig. 2—A transfer curve for a Magamp with an idealized square-loop core material; dotted-line axes show effect of adding a bias to the Magamp.

in industrial applications, known as the *doubler circuit*, is shown in Fig. 4. The name comes from its similarity to the doubler circuit used in d-c electronic power supplies.

This circuit consists of two separate cores with load windings, control windings, a self-saturating rectifier for each core, and a bridge-type rectifier to supply direct current to the load. The circuit is arranged so that one core conducts while the other is cut off, for alternate half cycles of supply voltage. This permits the use of a bridge-type rectifier to obtain a full-wave output. The control windings are connected in series between cores so that the fundamental and odd harmonics are cancelled in the control windings. This eliminates the need for high control-circuit impedance.

Use of a Self-Energizing Winding

Single-stage magnetic amplifier units are used wherever possible. For applications requiring higher system gains than obtainable in a single-stage unit, the designer is left with two alternatives. The first is to use a two-stage Magamp, which generally increases the overall cost of the regulator, or second, to use a single-stage Magamp with a positive-feedback system, which will increase the Magamp gain.

The simplest way of increasing the Magamp gain is to use a self-energizing or self-saturating winding. The self-energizing winding feeds back cumulative ampere-turns to the core proportional to the load ampere-turns. This means that less ampere-turns are required in the control windings to obtain a given Magamp output. The self-energizing winding increases the steady-state system gain but has little effect on the dynamic gain (transient response). This is because the self-energizing effect is proportional to load amperes, which in turn respond to a transient as a function of the time delay of the load itself.

Basic Systems

Consider now the basic types of regulators and their corresponding Magamp circuits. Some of these regulators are of the single-stage, self-energized variety, some are single stage without self-energizing windings, and the remainder are two-stage regulators.

Simple Current Regulators

The simplest Magamp regulator is one that regulates for constant armature current in a d-c drive. This can be done by regulating the generator voltage or by controlling the excitation of a booster in series with the motor armature circuit.

A simple current-regulator circuit using a Magamp is shown in Fig. 5. The bias winding is adjusted for minimum Magamp output with no other signals in the control windings. The pattern field winding is cumulative and is adjusted for the desired armature current. The control winding is excited proportional to the armature current and is differential in its effect. The regulator operates to keep the difference between the pattern and control ampere-turns to a minimum, and therefore maintains essentially constant armature current for a given pattern-field setting.

Such a current regulator is applied to maintain constant torque on a d-c motor connected to a machine whose speed is set by some other means, such as wet-end helper drives on paper machines, and tension rolls preceding a windup stand.

Voltage Regulators

Voltage regulators can be either single stage or two stage, depending on the required power output and the necessary system accuracy. In general, when accuracy on the order of one-half percent of top voltage is required and when the power output is to be 200 watts or more, two-stage magnetic amplifiers are used.

A typical two-stage voltage regulator, shown in Fig. 6, can be designed for a system accuracy on the order of 0.1 percent at top voltage, assuming no variation in the system reference.

Fig. 5—A simple current regulator utilizing magnetic amplifiers.

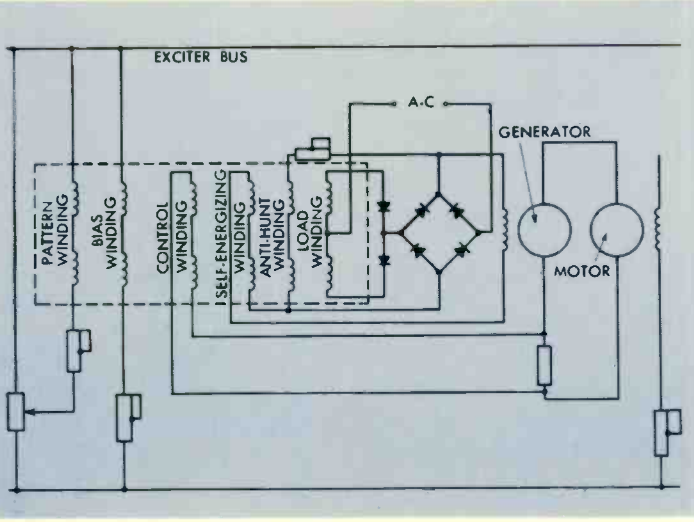
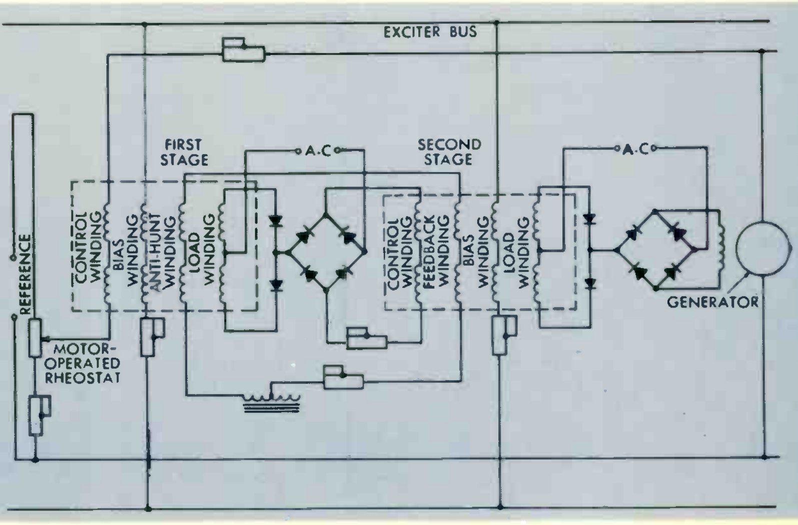


Fig. 6—A two-stage voltage regulator that uses fixed reference.



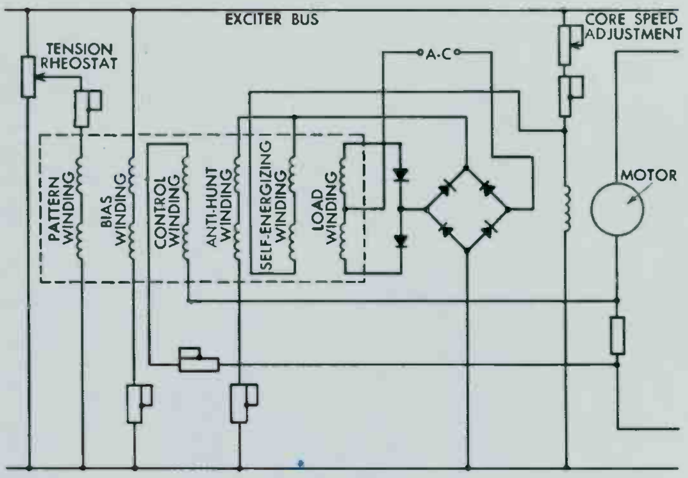


Fig. 7
A reel-drive Magamp system for a paper machine.

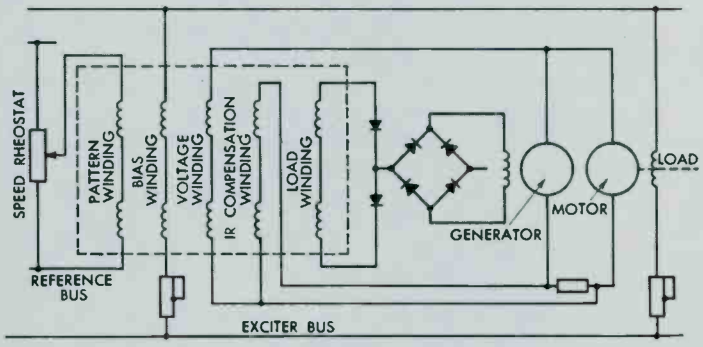


Fig. 8
A typical counter-emf Magamp speed regulator.

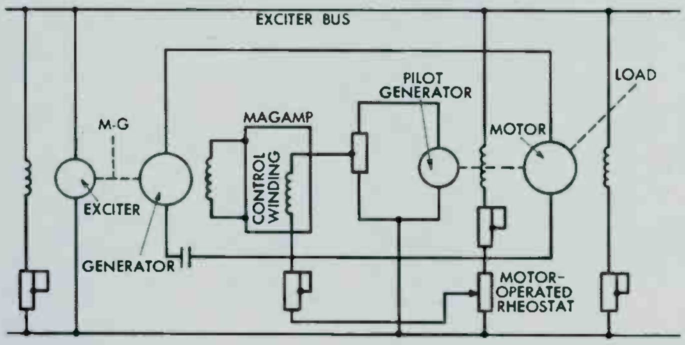


Fig. 9
Basic circuit of a pilot-generator feedback regulator.

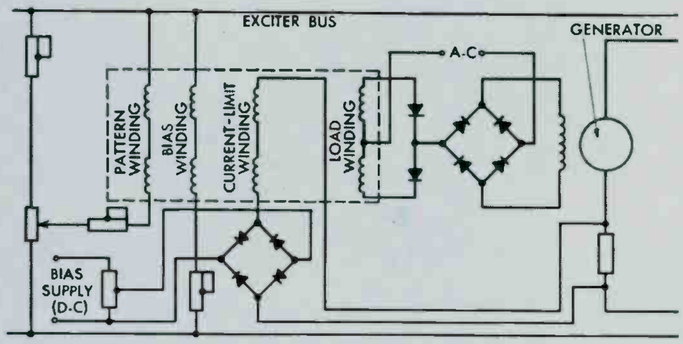


Fig. 10
An over-ride current-limit Magamp system, with bias.

This regulator controls the generator voltage corresponding to a production speed range, usually by means of a motor-operated rheostat. The reference voltage is obtained from a suitable constant-potential source.

Note that self-energizing windings are not used with this regulator. This is because the required system dynamic gain cannot be obtained unless a two-stage Magamp is used, in which case the self-energizing winding is unnecessary.

Typical applications of such a voltage regulator are sectional paper-machine-drive power-supply generators, and bus voltages used as references in coordinated drive systems.

Constant-Tension Regulators

Windup- or unwind-stand reel drives, in which the driving motor is direct connected to the core, must maintain constant sheet tension over the range of roll diameters. This means that the motor must operate at constant horsepower, since the sheet speed is constant, and horsepower is proportional to the product of the sheet tension and its speed.

A reel-drive system for the windup at the end of a paper machine is shown in Fig. 7. In this system, the motor armature voltage is established proportional to machine speed. Constant sheet tension is maintained by regulating for constant armature current. Constant armature current, in turn, is maintained by controlling the excitation to the motor shunt field as the roll diameter builds up.

Note that the control windings are arranged similar to those for the simple current regulator. However, in the case of a windup drive, the pattern-winding ampere-turns are differential, while those of the current winding are cumulative.

Speed Regulators

Speed regulators are of two basic types, counter-emf and tachometer feedback. The simplest is the counter-emf type. Here the Magamp supplies excitation to the generator to control its terminal voltage in proportion to the desired speed. The total cumulative ampere-turns are those supplied by the pattern winding and the IR-drop compensating winding. The differential ampere-turns are supplied by the voltage-feedback winding. Such a counter-emf speed regulator using magnetic amplifiers appears in Fig. 8.

The most common speed regulator is the tachometer feedback type. In this regulator, the tachometer output voltage, which is proportional to the machine speed, is matched to a reference voltage through the magnetic amplifier. The Magamp, in turn, supplies controlled excitation to provide the correct speed.

The basic circuits of an adjustable-voltage speed-regulated drive using tachometer feedback and a Magamp are shown in Fig. 9. A typical circuit of this type has an accuracy of about ± one-half percent of top speed, no load to full load.

Note that the single control winding compares the pilot-generator voltage to the reference voltage. The difference between these two voltages supplies the control ampere-turns necessary to provide the required Magamp output. In general, a single control winding is used when only two quantities are to be compared and when it is not necessary to maintain circuit isolation.

Current-Limit Systems

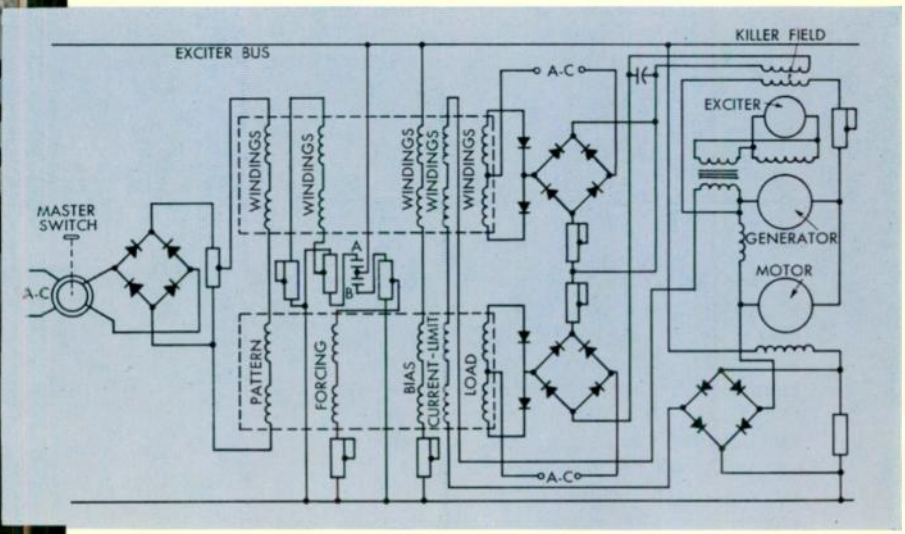
The two basic current-limit systems use magnetic amplifiers. These basic systems are: current-limit over-ride and current limit with field forcing.

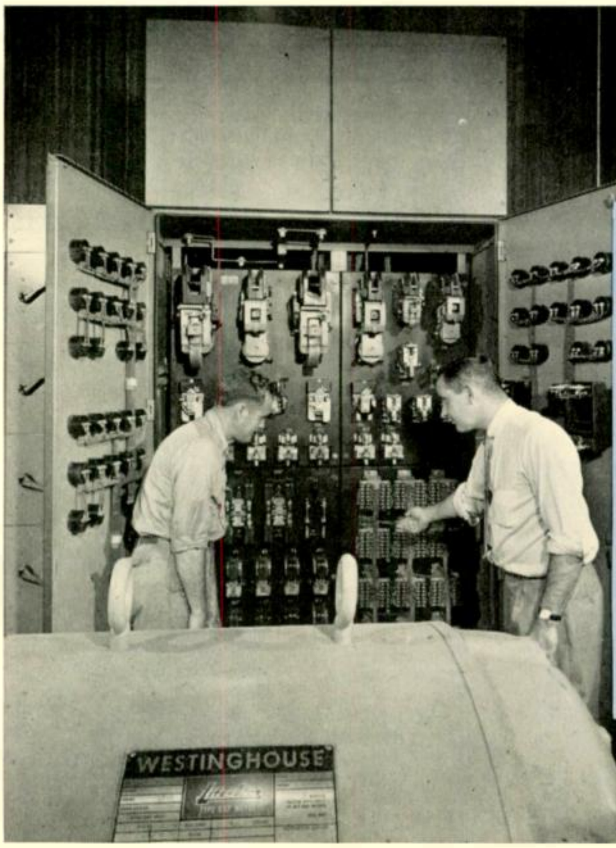
The simplest form is the over-riding type. This is applied when manual or preset control of speed is used for acceleration and deceleration. The over-riding current limit is used primarily to protect the rotating equipment and to give smooth operation during acceleration and deceleration. An over-riding current-limit system using Magamps is shown in Fig. 10. The current limit comes in only when the speed-adjusting rheostat is moved rapidly, or when the load inertia is large enough so that the motor cannot change speed fast enough so that its counter emf will keep up with the change in generator voltage.

This is also known as the bias-type current limit, since the system is biased so that no current limit takes place until the armature current exceeds the value set by the bias voltage.

The watt input across the bias resistor is made intentionally high, so that the signal from the armature circuit has little effect on the bias-voltage setting. The bias power must be a low-voltage source since its voltage is compared to the signal voltage from the armature-circuit resistor. Bias power can be obtained from a separate three-phase transformer and rectifier or from the series dropping resistor in a motor or an exciter shunt field.

Fig. 11—A field-forcing current-limit Magamp for a reversing drive. Points A and B are the forward and reversing cams on the master switch.





A Magamp cubicle for a coal-unloading tower. This is a current-limit override system with voltage feedback.

The simple over-ride current-limit Magamp can be modified to include a voltage-feedback winding and an IR-drop compensating winding. The Magamp is then a voltage, or cemf regulator, with current-limit over-ride. However, the addition of feedback windings, since their effect is differential, requires that the system gain be increased to provide the same sharpness in current limit. Thus, with voltage-feedback current-limit systems, it is usually necessary to add damping circuits and to use two-stage Magamps to obtain sharp cutoff current limiting.

When a load must be accelerated and decelerated at rates up to the maximum capability of the drive units, the regulating system must provide both current limit and field forcing. Field forcing overcomes the time delay in the generator field and at the same time forces the armature current to the maximum value. The current limit monitors the amount of field forcing to protect the armatures and commutators.

With nonreversing drives, current limit and field forcing can be obtained on acceleration and deceleration by using a single Magamp. For reversing drives that require field forcing and current limit, two Magamps are necessary—one for forward and one for reverse operation.

These Magamps can operate on individual fields in the generator or in the shunt field of a small reversing exciter that supplies reversible excitation to the main generator. It is usually more economical to use the reversing exciter system. The resulting smaller Magamps usually offset the increase in cost that would be due to the addition of the small reversing exciter. A typical field-forcing, current-limit regulator, as used with log-carriage drives, is shown in Fig. 11.

The log-carriage-drive master-control switch consists of an inductor unit with an a-c output. The a-c output is obtained from the rotor unit. Its magnitude is a function of the rotor position, along one quarter of a sine wave. This permits essentially stepless control over the speed range.

The a-c output is rectified and fed to the Magamp pattern windings. On log-carriage drives the inductor output is differential so that its maximum output provides minimum generator voltage. This differential system is used to give smoother speed control of the carriage at the lower or sawing speeds.

Special Circuits

The circuits described so far cover the majority of the basic industrial drive systems. There are a number of special circuits that have been designed for particular systems or to provide a particular type of output characteristic.

Ignitron Voltage Control—A Magamp system is used to control the output voltage of an ignitron that supplies adjustable voltage to the drive motors for a hot-strip mill. The Magamp operates as a voltage regulator by controlling the ignitron firing angle. The Magamp is provided with a cumulative pattern winding, set to give the desired voltage, a voltage-feedback winding, whose ampere-turns are compared to those of the pattern winding, and bias and damping windings. The Magamp output controls the impedance of reactors in the firing circuit of the ignitron.

Sectional-Drive Regulator—A special Magamp circuit is used in conjunction with a differential error-detecting unit on a paper-machine sectional drive.

This regulator operates on the position principle, that is, the revolutions of the regulated section are matched to the revolutions of a master set. The matching is done through a differential gearing system. The mechanical output from the differential gearing system is translated into electrical signals by an inductor unit and a d-c pilot generator. The inductor provides the steady-state position cue by virtue of its rotor position. The pilot generator provides the necessary forcing signal to maintain the correct paper-machine-section speed under transient conditions.

A two-stage Magamp is used. The steady-state, forcing, and damping signals are fed to separate control windings in the first, or voltage-amplifier stage. The output of the first stage is fed to the second, or power-amplifier, stage. The power amplifier supplies the entire excitation requirements of the section generator.

Relay Magamps—A Magamp with a self-energizing winding can be calibrated so that its operation is similar to a relay. That is, it can be arranged to pick up, or conduct at a certain value of control ampere-turns, and drop out, or cease conducting at a reduced value of control ampere-turns. The calibration is made by adjusting the ampere-turns of the self-energizing winding.

This type of characteristic is used in dead-zone regulators such as a tension-monitoring device. The relay Magamp can also be used to initiate a sequencing system such as a stopping circuit when the initiating control signal is very small and is nonrepetitive. A typical application would be an automatic stop of a core-driven reel on a sheet break. The initiating signal in this case could be a capacitor discharge into the relay Magamp control winding.

A-C Supply Considerations—Variations in both a-c supply voltage and frequency affect the output characteristics of Magamps. For a given total control ampere-turns, an increase in the supply voltage causes an increase in output volts and vice versa. In general, supply-voltage variations should not exceed ± five percent for optimum performance in a closed loop system. When the variations in the a-c supply are expected to exceed ± five percent, a regulating supply transformer should be used in place of the conventional supply transformer. In the case of a two-stage Magamp, it is usually necessary to use a regulating supply transformer only for the first stage.

An Engineering Personality

There are at least two ways of getting at the nucleus of any complex problem. One is by striking out in whirlwind fashion, solving all incidental or orbital problems as they are encountered, literally overcoming all obstacles by sheer energy, and eventually finding a path to the destination. Another is to analyze the situation more precisely before starting and then strike straight at the nucleus, following as direct a path as possible to the solution of the problem.

Of the two, there is little doubt as to which scientist Dan Alpert prefers. Nearly everything he does shows ample evidence of a high degree of analytical thinking and a carefully considered direct approach. As one of his associates puts it: "Dan is a master at reducing problems to their barest essentials." And, we might add, this is demonstrably true whether the subject be a complex scientific question, or an equally complex administrative problem. As a scientist at the Research Laboratories since 1941 and as manager of the Physics Department since 1950, Dr. Alpert has proved himself adept as both a physicist and an administrator.

Alpert's record in research shows participation in a number of significant developments. While still in college he was part of the group that developed the klys-

Changes in supply frequency affect the value of saturation voltage primarily. In general, Magamp operation is satisfactory as long as the supply-frequency variations are within ± one percent of the nominal value.

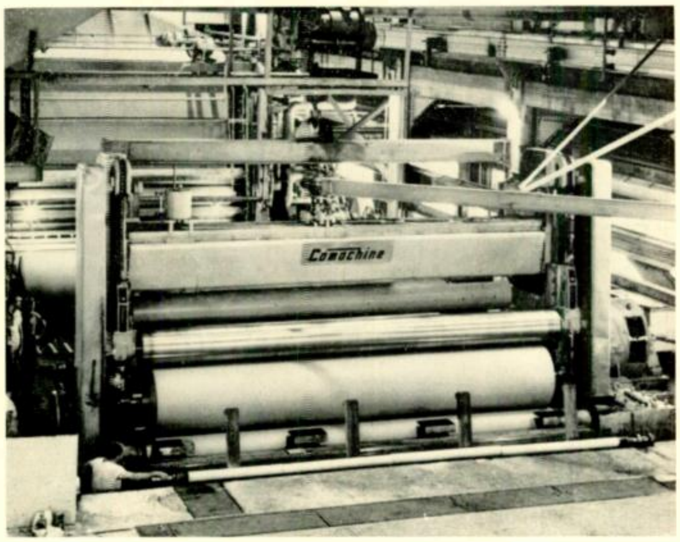
A Magamp is a carrier-type amplifier. That is, its response to a change in control signal is carried on the frequency of the a-c supply. This means that the response time cannot be less than one half the period of the supply frequency. Also, the Magamp size for a given power output is determined by the supply frequency in much the same manner as it is for transformer size.

Therefore, when extremely fast response is required, and when a large number of Magamps are to be used for a complete system, a separate high-frequency power supply is usually advantageous. Usual practice for these types of systems is to supply a separate 400-cycle alternator.

However, the majority of Magamp regulating systems operate satisfactorily at the common supply frequencies from 50 to 60 cycles. The simple over-riding current-limit system can be used with a supply frequency as low as 40 cycles.

A typical industrial Magamp regulator includes a supply transformer to step down the plant voltage to the required Magamp voltage. Relays are also included to assure d-c bias voltage before alternating current can be applied, and to assure having the alternating current on before the drive can be operated. A-c disconnects in the form of fuses, knife switches, or AB breakers are also usually included with the Magamp. The connections, type of overload, and type of interrupting circuits to the a-c supply transformer are usually applied by the mill in line with their own practice for transformer circuits.

The basic Magamp systems described have already been used on a large number of different applications. Undoubtedly, as the use of these static devices increases still further, new variations or new circuits will appear. However, the systems mentioned or combinations thereof are applicable to the vast majority of present industrial regulating systems.



This Magamp-controlled paper winder operates at 5000 fpm.

DANIEL ALPERT

tron, a radar tube later to be widely used during the war. At Westinghouse he was a key figure in the development of the TR switch for radar in 1943, and in 1944 the beacon reference cavity, a microwave tube still in use—which is unusual considering the tremendous advances in the microwave art since that time. In 1945 Alpert became part of a group who worked on isotope separation at Berkeley for the Manhattan Project.

Since he returned to the Laboratories in 1946, Alpert has concerned himself largely with fundamental research in physics, particularly in the fields of gaseous and physical electronics. His most recent activity has been in the field of ultra high vacua; one by-product of this research is the Bayard-Alpert ionization gauge, which is capable of measuring considerably lower pressures than could be accomplished with previous devices. Armed with this gauge and other vacuum equipment they developed, Alpert and his co-workers have been able to explore the structure of matter under conditions never before achieved. Applications for some of the information and techniques developed have already found their way into such widely different fields as electron tubes and geologic age determination.

Alpert's analytical approach and organizational ability result in a high degree of succinctness and clarity of expression both in the written and spoken word. One indication of this is the award he recently won for presenting the most noteworthy paper at the annual meeting of the American Association for the Advancement of Science. The subject—high vacua.

As a department manager, considerably less of Alpert's time is spent in actual experimentation. As he puts it, "Until six years ago my work was physics and my hobby administration; now, in a sense, my work has become administration and my hobby, physics." But Alpert's approach to his administrative tasks is as characteristically thorough as his scientific approach. He believes strongly that the atmosphere in which scientists work determines to a large degree what they accomplish. While this is by no means an unusual theory, Alpert extends the word "atmosphere" to cover considerable territory. He is, for example, as careful and thorough about some of the seemingly minor tasks, such as laying out the workbenches and tools for his laboratories, as he is about advising and encouraging a young physicist in his selection of a scientific problem.

Despite his analytical and thorough approach to all situations Alpert is not deliberate; his reactions are often immediate, occasionally even blunt. He obviously believes in meeting all situations directly rather than circuitously.

Alpert is a New Englander, a native of Bloomfield, Connecticut. The valedictorian of his high-school class, he entered Trinity College where he followed the same pattern, graduating magna cum laude in 1937. The recipient of a graduate fellowship, he spent four years at Stanford, and earned his Ph.D. in 1942. In 1941 he joined Westinghouse as a Research Fellow, and shortly became a member of the Electronics Department. In 1950 he was named manager of the Physics Department, his present position.

Despite his many professional interests, Alpert manages to take an active part in community affairs; he is, for example, currently president of the school board in his township. A ski enthusiast, on many a winter weekend he can be found with his wife and two daughters on a nearby slope; in the summer his sports interest turns to the tennis courts, at which game he considers himself "no better than fair."

All of his activities considered Alpert leads an active, well-rounded existence. As one associate admiringly put it, "Dan Alpert extracts about as much out of life as any individual can."

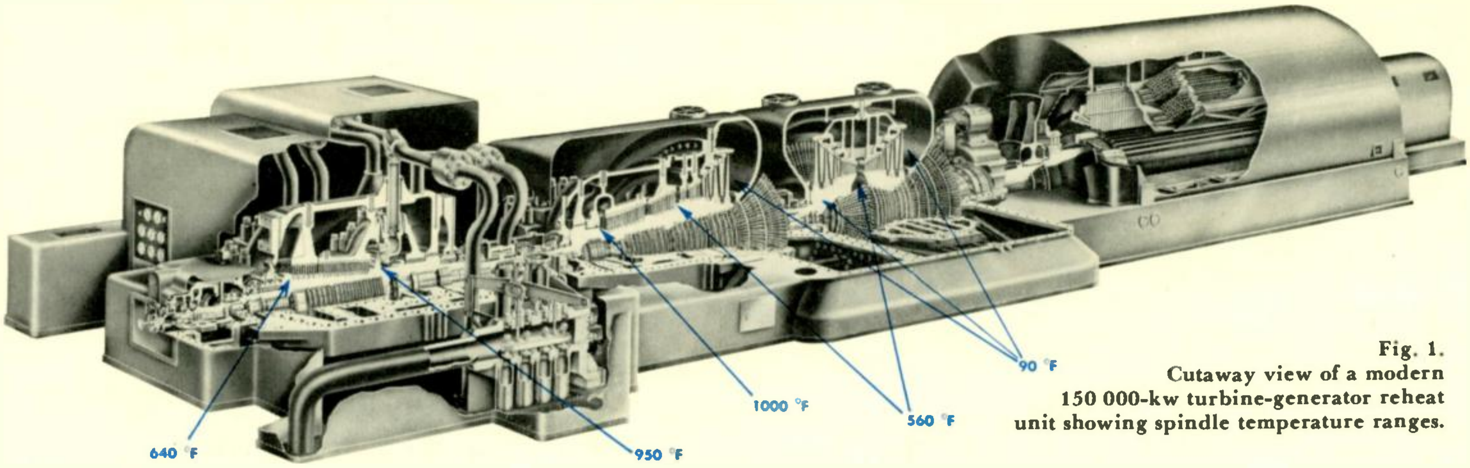


Fig. 1.
Cutaway view of a modern 150 000-kw turbine-generator reheat unit showing spindle temperature ranges.

Smooth Running Turbines...

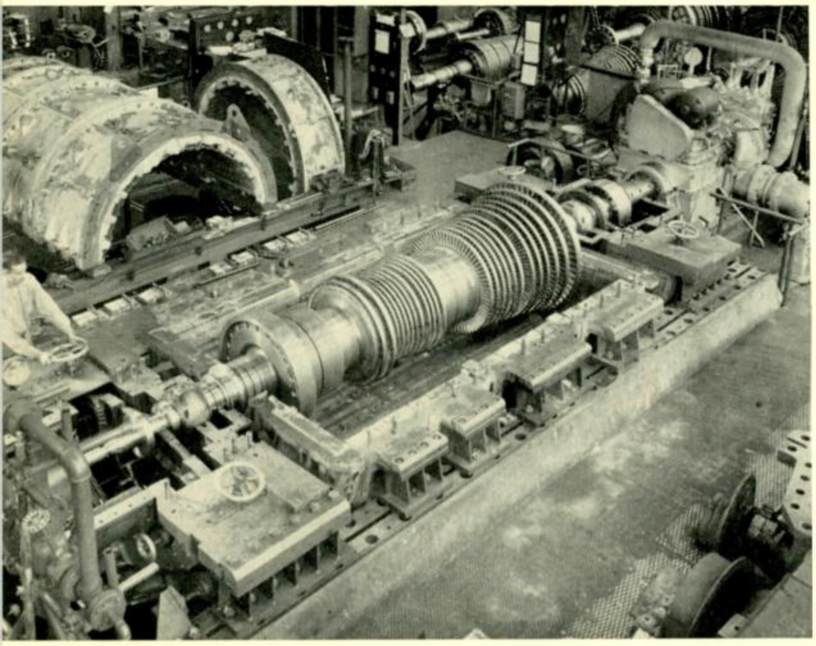
. . . are assured by more stringent test procedures for high-speed, high-temperature turbine spindles to make certain that permanent bowing is detected and corrected before the turbine leaves the factory, thereby eliminating additional field balancing.

P. C. WARNER and F. C. EATON, *Steam Division, Westinghouse Electric Corp., South Philadelphia, Pa.*

THE MODERN central-station steam turbine is an amazing machine. The story of its large output and high efficiency is well known. Less appreciated, perhaps, but certainly of equal importance is the high degree of reliability required. Many turbines, when placed in service, operate at or near full load for as much as a year before being taken off the line. They carry load day in and day out for their entire life with a minimum of attention; in some cases, inspections may be as infrequent as every five years.

One important aspect of this reliability is the low level of machine vibration tolerated. For large Westinghouse turbines, total shaft motion near the journals is held to less than 0.002 inch, or roughly half the thickness of the paper on which this article is printed. The exacting nature of this requirement can best be appreciated by considering that to achieve this goal, turbine spindles, which weigh from five to twenty tons, must remain straight within 0.001 inch, despite a combination of spindle temperatures up to 1000 degrees F, and high centrifugal stresses due to 3600-rpm operation.

Fig. 2—High-temperature spindles are put through their paces in this heater box. The spindle being tested is driven by a shop turbine through a flexible length of shafting. The box can be heated or cooled to provide the desired test temperature. Vibration readings can be taken near the journal at each end of the test spindle.



Westinghouse policy is to manufacture and test turbines so that they can be placed in commercial operation without field balancing, thereby eliminating a costly and time-consuming field operation. Standard Westinghouse procedure has been to test all turbine spindles after final machining and blading by spinning them at rated speed (usually 1800 or 3600 rpm) to check the mechanical balance, and at 20 percent overspeed to verify the design and manufacture with respect to centrifugal stresses. After successful completion of these checks, all high-temperature (over 900 degree F) spindles are run at design speed and with spindle temperatures equal to or greater than those encountered in service. These tests at temperatures are made in facilities such as that illustrated in Fig. 2 at left.

Permanent Spindle Bowing

Within the last few years, field experience has indicated the need for more stringent test procedures. The advent of larger machines with more flexible rotors and rising steam temperatures has greatly intensified the problem of spindle stability. This perplexing problem, which consists of permanent spindle bowing, generally becomes apparent during initial high-temperature operation. The resulting unbalance causes heavy spindle vibration, which is readily detected by the accurate vibration-measuring equipment now in use.

A typical indication of the need for additional shop testing came in a machine where, after initial installation, the vibration level gradually increased until after a few weeks rebalancing was mandatory. When the machine was opened for inspection, the troublesome spindle was found to have a permanent bow. The spindle in question was rebalanced and returned to service, and has performed satisfactorily since. However, the fact that the spindle had passed the original shop tests indicated that more stringent testing was required.

At first, mechanical forces set up during manufacture appeared to be the cause of this instability, but later developments indicate that the difficulty is of a metallurgical nature, and is probably associated with volume changes that take place during certain transformations. However, non-uniform first-stage creep has not yet been definitely dismissed as a possibility.

New High-Temperature Test Procedure

The re-evaluation of the shop-test procedures has resulted in the full-temperature run for high-temperature spindles being extended from about two hours to a minimum of twelve hours at the maximum design temperature of the spindle. Any vibration changes have acquired added significance, since the longer period makes it possible to separate short-time transients from steady-state operation, and spindle vibration can be given much more careful scrutiny. Vibration data, which include amplitude and phase angle of the motion of each journal, are recorded at half-hour intervals throughout the test. From these data, a spindle is judged to be either satisfactory for commercial operation, or to need further treatment depending on the steadiness of the vibration. That the new test procedure has been successful is evidenced by the fact that over the past two years, less than three percent of the turbines placed in service have required field balance to produce smooth-running operation.

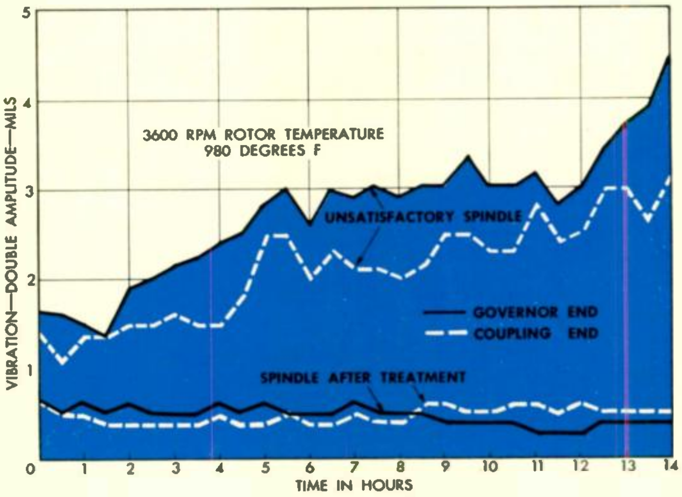


Fig. 3—Vibration record of an unsatisfactory spindle on test prior to treatment is shown by upper curves; the satisfactory record after treatment by the lower curves.

With this more stringent test program, six spindles have been detected out of the last forty processed that probably would have required rebalancing in the field. The troublesome spindles generally show up during initial phases of the full-temperature run. The spindle balance changes slowly, resulting in increased vibration, as shown in Fig. 3. The spindle is then balanced, and the test repeated. After each test, the spindle body is indicated for truth, and the deviation from straightness along the main body of the spindle recorded (see Fig. 4). If repeated tests indicate additional bowing, then further corrective measures are necessary.

Correction of Permanent Bowing

Corrective measures to eliminate the condition consist of one or more runs at turning-gear speed with spindle temperatures at 1100 to 1150 degrees F, which is 100 to 150 degrees above normal design temperatures and approximates the final stress-relief temperature, interspersed with full-temperature runs at design speeds. The experience to date indicates that both of these measures are necessary. As soon as tests indicate that the spindle has attained its full permanent bow, the journals may be machined if necessary to reduce the outage, and the remainder of the unbalance eliminated by usual balancing procedures.

The response to the treatment is indicated in Fig. 3. The spindle previously mentioned and others similarly treated have been in commercial operation for periods up to twelve months and have shown no further evidence of any vibration abnormality. Only one spindle has not responded satisfactorily to treatment. It was placed in service with temperature limitations and operated under these limitations for approximately five months. When the temperature restrictions were lifted, the spindle again evidenced the slow but steady balance shift that characterized the shop tests. Therefore, it was necessary to replace the spindle. However, the advance notice of potential trouble given by the shop tests makes possible replacement of the unsatisfactory spindle without undue expense or unit outage.

The investigations thus far have been principally directed towards determining and applying procedures to eliminate difficulties in the spindles that do not pass the tests, although the test data are being analyzed continually for information as to the fundamental causes.

Improved Test Facility

Unfortunately, spindle temperatures and distortion are difficult to measure with accuracy. For this reason, the basic cause must ultimately be determined as a result of carefully planned experimental programs, in conjunction with the information obtained from shop tests. Additional facilities are currently being built to augment present processing and testing programs. For example, a new high-temperature, high-speed box (Fig. 5) is under construction and is expected to be in operation in the near future.

In this facility, the spindle being tested is driven by a shop turbine through a flexible length of shafting. The box is capable of being heated with electric heaters or cooled with steam to provide the desired temperature level, and is so arranged that vibration readings may be taken near the journal at each end of the test spindle. The box will have partitions so that actual rotor-temperature conditions can be more

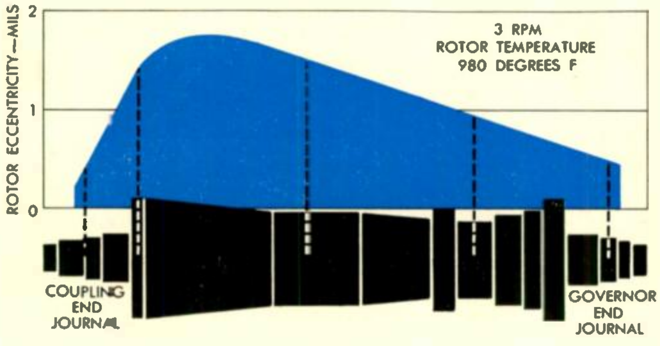


Fig. 4—Permanent rotor bowing is shown by this outage chart.

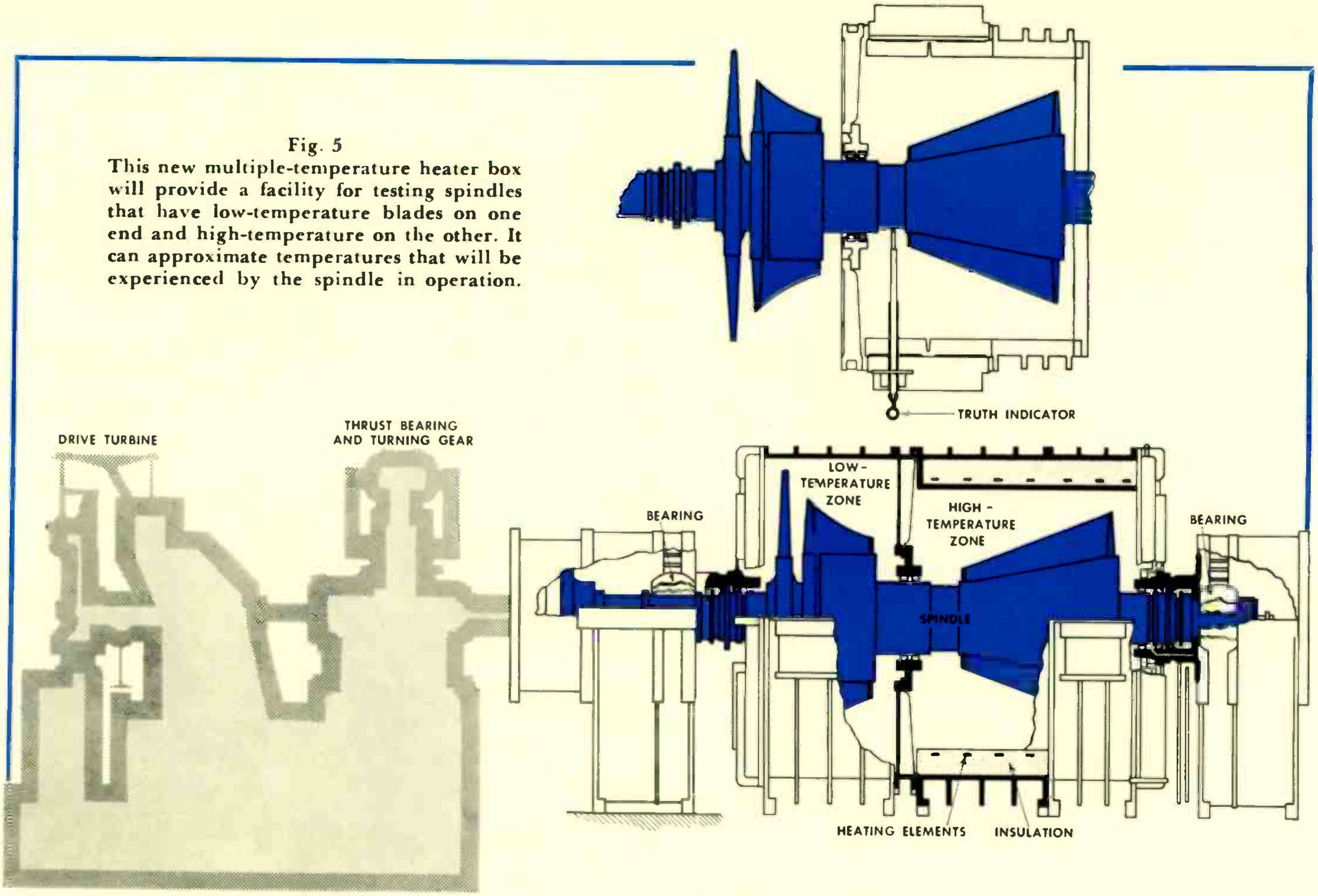


Fig. 5
This new multiple-temperature heater box will provide a facility for testing spindles that have low-temperature blades on one end and high-temperature on the other. It can approximate temperatures that will be experienced by the spindle in operation.

closely approximated. It will accommodate a wider range of spindle sizes, and temperatures can be obtained as high as 1300 degrees, which is considerably above the present design temperatures.

Furthermore, the vibration and outage-recording equipment is being improved. A new automatic vibration recorder will be used, and will record up to four sets of unbalance-vibration readings (each including phase angle, amplitude, and speed) every 40 seconds. Thus more data will be available than with the present high-temperature, high-speed boxes, and by eliminating the human element in recording, will give more consistent readings.

With the additional facilities and more precise measurements, the experimental program planned should yield not only improved processing procedures, but also knowledge of the basic phenomena involved.

• • •

What's NEW!

Improved Control for Better Sawing

About three years ago a basically new control and drive system for log carriages was introduced. On these, logs—some of tremendous size—are carried back and forth through a saw and reduced rapidly to lumber.

The control system has been recently refined to provide a simpler installation and better performance. Reactors that work from less energy and have higher gain are applied in the magnetic-amplifier circuits. This allows omission of the armature resistor, which reduces the heat from the control cabinet and increases the efficiency. The higher gain provides a better current-limit characteristic, which, of course, means that the machines can be operated closer to their peak-rating limits with safety, and a better acceleration characteristic for the drive. Space-wise the new reactors are considerably smaller and permit use of a wall-mounted cabinet for the control panel, in place of the previously required floor-mounted cubicle. A new master switch employs an inductor for supplying the control signal to the Magamps and thus truly provides the sawyer with a stepless speed control of an infinite number of points. Since the inductor involves no moving contacts or resistors, there are no wearing parts or adjustments required, which minimizes the maintenance problem.

The new drive also employs type MC mill motors as the propulsion unit and as the generator and, therefore, incorporates the inherent characteristics of these machines. Since the machines are duplicate, the problem of spares is minimized.

Ferryboat Gear Drive

A pair of destroyer escort motors have been drafted for peacetime duty—escorting passengers and automobiles across the Puget Sound. They will serve their "hitch" on the *Evergreen State*, a passenger-automobile ferry that is operated by the State of Washington.

Each of the tandem three-bearing motors has been rebuilt into a pair of two-bearing motors. Instrumental in the conversion is a twin-pinion speed-reduction gear drive; each of the two motors is coupled to a pinion, which drives a common bullgear. Two motors and a gear drive are located at each end of the ferry.

The unit is rated at 2500 hp, and reduces 600-rpm motor speed to 180 rpm for the propellers. A roller bearing built into the gear case carries the propeller thrust.

To Design a Precision Snap Switch Is No Snap

A SNAP SWITCH! One of the simplest of all electrical devices. It has only to open and close a low-voltage, low-current circuit.

The requirement in the design of a snap switch used as an individual or component part of a limit switch, float switch, relays, and other control schemes is precision in operation; contacts must be opened and closed with surety millions of times, and occupy the absolute minimum of space.

A new snap switch designed to these goals belies in its appearance the hundreds of engineering man hours that went into it. Its case is molded plastic and in two forms, for front or for rear connection. Its toggle mechanism and plastic operating button are disarmingly simple. In total size, it is about equivalent to a penny match box.

The new snap switch occupies an inconspicuous place in the world of electrical equipment, but it has a job to perform and, to enable it to do so, requires engineering skill no less than to produce a machine conspicuous because it is ten-thousand-fold larger.

More for Your Money

HIGH SPEED x-ray tubes—we're speaking now of exposures in the vicinity of a millionth of a second or less—must be considered expendable items. Depending upon type of service, the tube may last for as few as fifty or a hundred exposures. Therefore, anything that can be done to decrease tube price is welcomed. A new Micronex tube recently developed will accomplish the same job as its predecessor, yet is only half the size and of simpler construction. Although the tube also operates at a lower voltage (30 to 90 kv), a thinner bulb permits a high output. The per-exposure expense will be cut approximately by half.

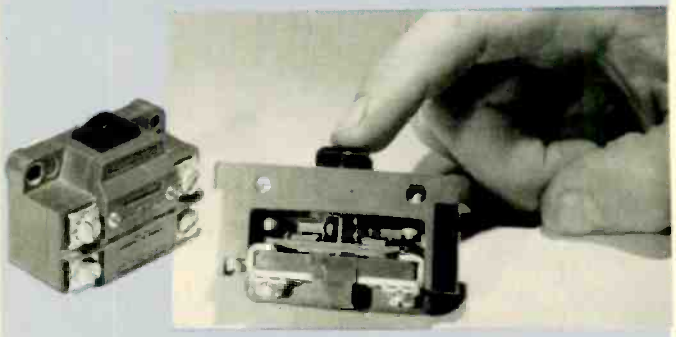
Improved Coal Unloading Towers

MAGNETIC amplifiers now help unload coal. On two important coal unloading towers last year magnetic amplifiers were used in the regulating system to provide the necessary current limit. This effects the simplification possible when a rotating device is replaced by a static one.

The coal unloader of the Jersey Central Power and Light Company operates on a 33-second cycle to handle 600 tons of coal per hour. Bucket operation is managed by two 155-hp d-c motors, and a 44-hp d-c motor operates the trolley. This installation is the first unloading tower or bridge in the world to use magnetic amplifiers and the first to use the high-speed (3600 rpm) Rototrol speed regulator. Also, the m-g set runs at 1800 instead of 1200 rpm. These machines, because of their higher speed, weigh much less and reduce the problems involved in supporting the equipment in the machine room, which is located at the top of the tower.

The coal unloader of the Will County Station of Commonwealth Edison Company is larger and operates slightly faster. It handles 1200 tons per hour, making two round trips per minute. This unloader departs from usual practice in that the hoisting and bucket closure are completely separated. One 640-hp (actual) d-c motor is used for all hoisting and lowering, and a second smaller motor is used only to open and close the bucket. This unloading tower uses adjustable-voltage control. This system insures that the bucket remains fully open on lowering until it is ready

The tubular-shaped, 3-kvar capacitor now has a big brother, one good for 5 kvar. The swift rise in induction-motor loads has created a need for corrective capacity in the same lightweight, cylindrical form, but larger in amount. The 5-kvar unit is 24 inches long and about 4 inches in diameter. As it weighs only 25 pounds the capacitor can easily be carried by a lineman to a pole top, and mounted on the pole or cross-arm in any position. In an insulating sleeve covering the connection to one capacitor terminal is a special fuse. When it blows, the conductor drops free—but its end still remains insulated.



Design of the snap switch was not an engineering "snap."

Precision-hobbed, fine-pitch, case-hardened gears have been developed for a family of a-c and d-c gear-head motors for aircraft use that are extremely light, compact, and quiet. The two gear widths, for different loadings, add but 1.6 and 1.85 inches respectively to the length of the standard motors to which they are applied. The smaller gear head adds only 2½ pounds to the motor; the larger one, 3 pounds. Gears are treated with zinc phosphate and molybdenum disulphide, which lubricate and provide corrosion protection. The gear cases are vented to allow operation at low pressure (high altitudes). The gears are oil-lubricated, allowing operation at −55 degrees C. Used with either d-c or 400-cycle motors, output speed reductions of 0.4 to 0.105 are available.

for loading. Also the mechanical structure, including the counterweight system, is simplified. The regulating system is a combination of magnetic amplifier and high-speed Rototrol.

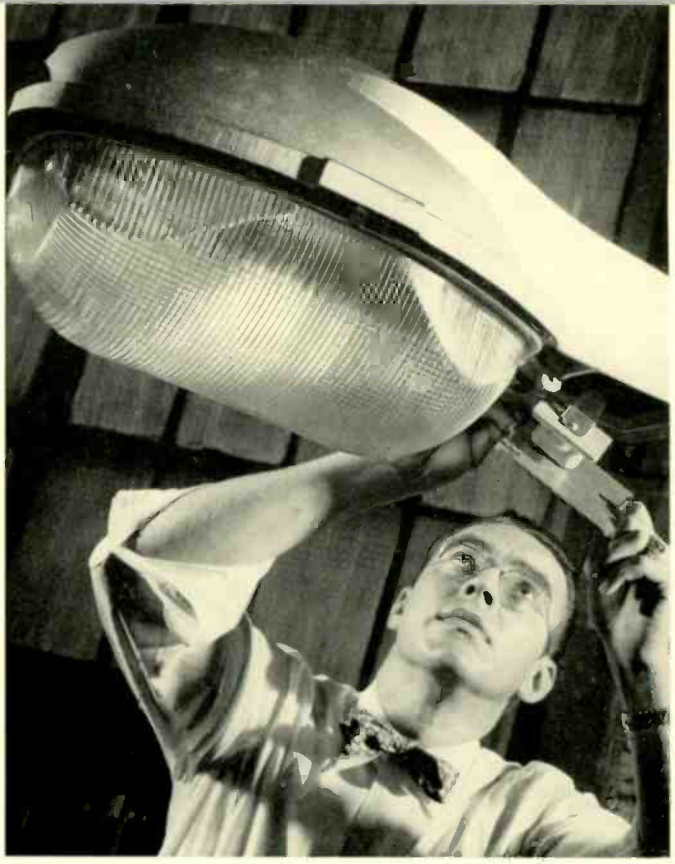
For Better Air-Minded Bearings

Bearings have always been a major problem to designers of aircraft apparatus. With the mounting severity of loads, the widening spread between the extremes of heat and cold, and the ever-present requirement for less weight, there is slim prospect that bearings and lubricants will ever cease to be a problem. In fact, like Alice in Wonderland, bearing engineers have to run fast to keep from standing still—or even going backwards. Recently they have a new tool that enables them to do some pretty fast running. This is a bearing tester possessing several novel features. It provides for independent variation of four parameters: load (both thrust and radial), speed, temperature, and vibration.

A horizontal table has space for two sets of 24 bearings. The table is spring-mounted so that its own natural frequency is low. A circular vibratory motion (similar to that experienced in aircraft service) is imparted to the table by a motor driving through a connection with an unbalanced weight. A force of 3380 pounds at 10 000 rpm can be thus developed. Eleven different frequencies from 86.4 to 287.5 cycles per second are obtainable.

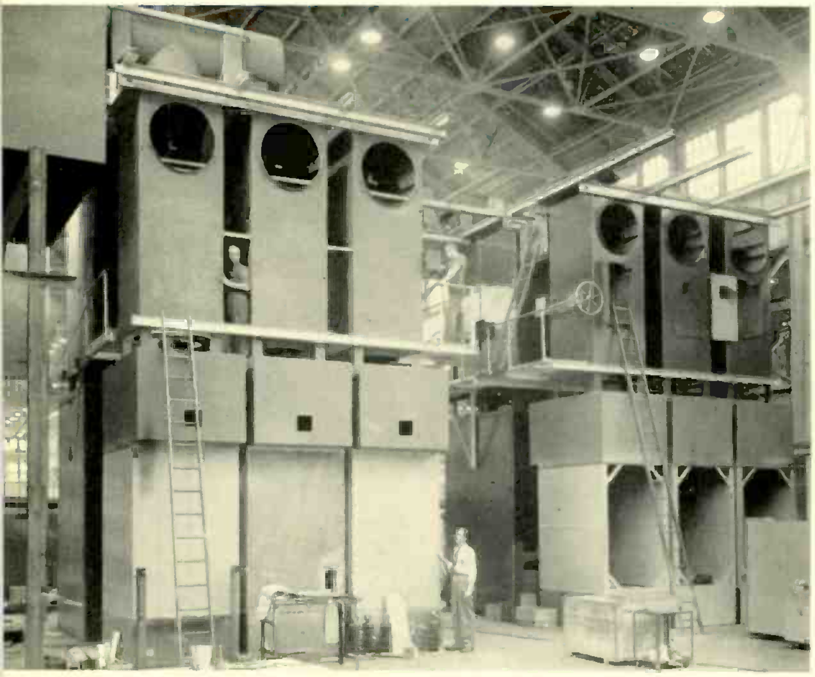
In aviation-bearing applications, vibration is very critical. Lubricants normally adequate under comparable conditions of load, speed, and temperature fail in a short time under aircraft vibratory conditions. In some applications near large jet engines, particularly during afterburner operation, the lubricant and the bearings are being subjected to supersonic maltreatment at tremendous energy levels by air-transmitted vibration.

While the tester described is not yet fitted for supersonic research, it will reproduce the other environmental conditions likely to be encountered on aircraft. To isolate the effect of temperature, one set of bearings can be held at any convenient temperature while that of the set is varied at will up to 160 degrees C, all other conditions of load, speed, and vibration meanwhile being held common. On this device, as various designs of bearings and various types of lubricants are studied, a great forward step is being taken in bearing application for high-speed aircraft.



A slight modification of the standard mercury-lamp street-lighting housing makes possible its use on 3.3-ampere series circuits without individual transformers. The filter of the unit is made slightly longer, which provides space for a well to contain the film cutout holder, receptacle, and integral terminal blocks for line connections. Polyester glass materials are used to provide the necessary high-voltage insulation. Access to the film cutout chamber can be had through a removable door without opening the lamp housing. This street-lighting system is now receiving field-service trials.

Switchgear comes big these days. This is a portion of the air-insulated switchgear for a 69-kv substation being erected in the heart of downtown Pittsburgh. All equipment meets full-impulse test requirements. The idea of metal-enclosed, air-insulated substations supplied by underground cable is growing, as it permits bringing blocks of power at high voltage close to the heavy loads.



Crane Control De-Contactored

It has always seemed anomalous that it is easier to make something complicated than simple. Thus it is that right after a fundamentally new device or scheme is turned loose, engineers—often the same ones who dreamed it up in the first place—find ways to simplify it.

The Load-O-Matic control for cranes with a-c motors, which was introduced only four years ago, has been getting this treatment. Originally the control required two reversing contactors, two contactors for the reactors, and four for the motor wound-rotor secondaries, for a total of eight contactors. Now Load-O-Matic gets along with only one reversing contactor, no reactor contactors, and but two for the motor secondaries. Down from eight to three. We were bold enough to ask an engineer, "What are you going to do about the remaining three? Won't they be lonesome?" He thought for a moment and said, "I've been thinking about those too. They have to go eventually. But that will take a bit of doing."

The trick to the elimination of the five contactors is to make the reactors bigger and do the switching by wider control of direct current for saturation of the reactors. This principle isn't new, but the size of it is. Engineers are learning more and more about the versatility of reactors.

Also a further simplification was effected by reducing the control points for both hoisting and lowering from five to three. This sacrifices only the control of speed between 25 and 100 percent of maximum speed—where it is never needed (infinite control of speed up to 25 percent is obtained.) This gives somewhat better control of speed of an empty hook downward, and more uniform (linear) speed control on the different control points.

New Devices Take a Transformer's Temperature

Both the devices that evaluate a transformer's remaining load-carrying capacity and that measure its hot spot have been improved. The relay (TRO) takes into account present and recent load history and ambient temperature. It has been made smaller (space is becoming scarce on a transformer tank), and has a new bimetal powerful enough to drive the pointer directly (i.e., gears before). A much more rugged switch has been provided. It can now be used on d-c as well as a-c, and on control voltage up to 250. The relay has three main contacts for successive operation of fans, pumps, an alarm, or circuit-breaker trip. The relay can be disconnected in the time it takes to pull out a plug-type terminal.

The new hot-spot indicator uses many of the same elements and mechanical arrangements of the TRO but is modified in circuit to read the highest temperature in the windings. Both relays occupy wells in the transformer case and hence require no opening into the oil.

Stations of 2500-Mile Pipeline To Be Remotely Controlled

A start has been made to equip one of the nation's principal and longest oil pipelines with means for controlling remotely some of its 30 pumping stations. This program also includes selective transmission of displacement-meter register readings from a similar number of delivery terminals. This line transports refined products over a vast system.

The stations will be controlled from dispatching offices. The start was made last year with the installation of supervisory control for operation of six pumping stations. Equipment will be installed this year for the control of nine more pumping stations with displacement-meter register readings from delivery terminals. The supervisory control will operate over telephone-line carrier channels in some locations and over existing microwave links in others.

This is the most extensive use yet made of supervisory control for pipeline operation.

Radiation-Monitoring Systems

A common practice of radiation health physicists has been to determine the condition of an area exposed to a radiation field by making a survey with a portable instrument. As the use of radiation-emitting devices became more complex, the need arose to monitor some areas continuously, and as the areas became more numerous the idea was conceived to present all the monitored information in one place.

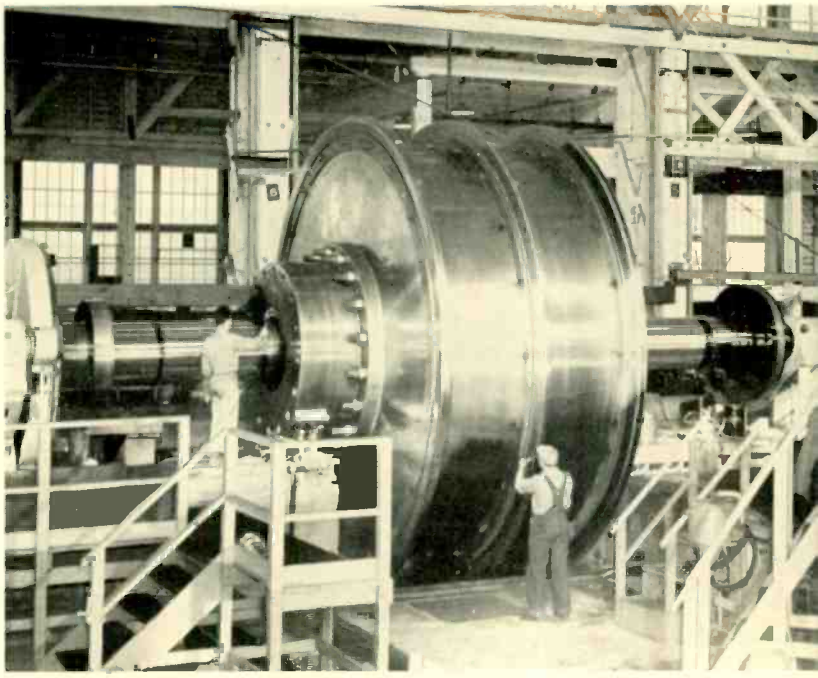
One of the first such radiation-monitoring systems was for a naval vessel, the equipment being designed to detect emanations from a radioactive cloud and the resulting contamination that it might spread about the ship. The information was brought from a number of detectors to a central location where it was indicated, sorted, and recorded.

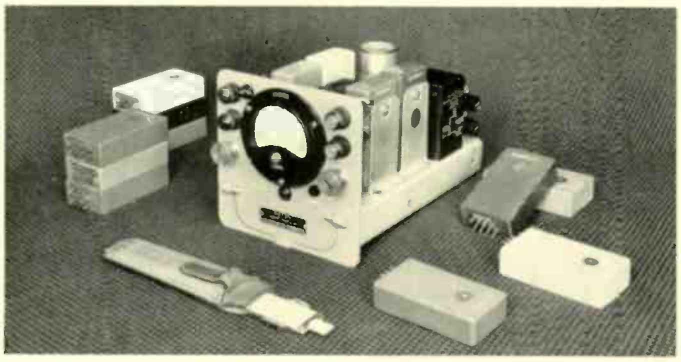
This was the forerunner of a radiation-monitoring system for the nuclear-powered submarine, *Nautilus*. In contrast with the earlier system, here the radiation to be detected originates in the installation itself, giving rise to new problems.

The monitoring set meets this challenge with five different types of detectors, all feeding information into a central console

The John H. Kerr Dam on the Roanoke River in Virginia now has six 33 555-kva waterwheel generators and one of 13 333-kva. The machines run at 85.7 and 138.5 rpm respectively and hence are physically large. Because of the nature of the stream flow, and the variable character of some of the major loads served, the machines are started and stopped frequently, sometimes several times daily.

This 18-foot-diameter compressor rotor now undergoing final tests, is the largest of its type ever built. It will be installed in the U. S. Air Force's new Propulsion Wind Tunnel, Tullahoma, Tenn. This compressor, plus four supersonic compressors, will be powered by a 216 000-hp, single-shaft drive. When the 1200-pound blades are added to the discs, the compressor rotor will weigh 180 tons.



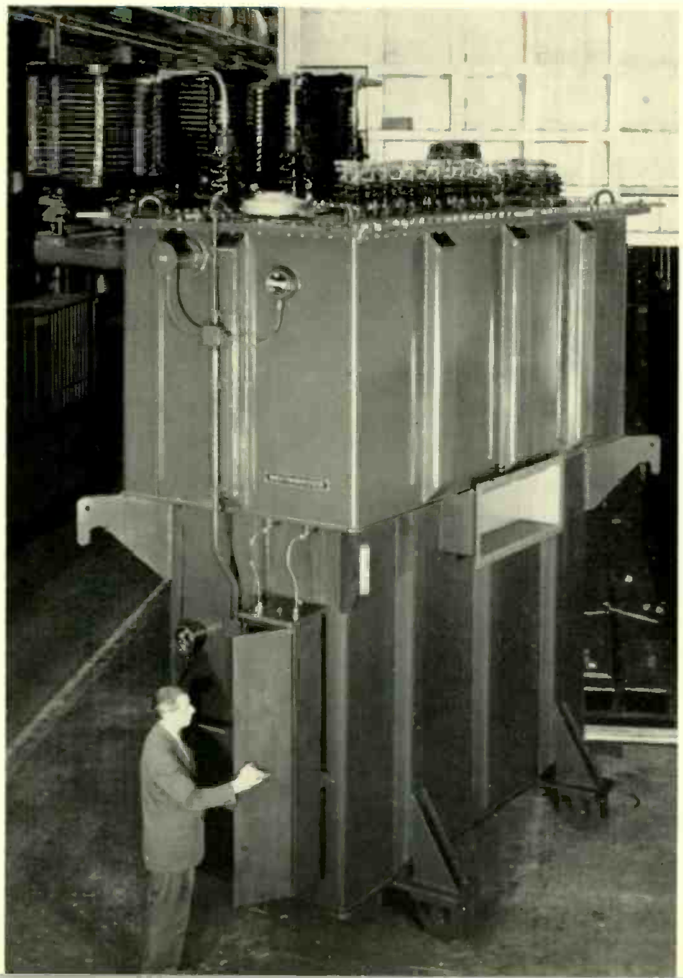


Plug-in components are color coded according to circuit function.

in the form of impulses initiated by the radiation to be measured. Here a simple computer-indicator presents the information from each channel so that the operators are continuously informed of conditions at all monitored locations. Remote indicators provide a second center with the same information.

A previously determined permissible radiation exposure level can be set into each computer circuit so that a visual and audible alarm will be sounded if this value is exceeded. A glance at the console informs the operators of the location and degree of the hazard so that corrective action can be taken to stop or reverse a dangerous procedure. If damage has occurred, a decision can be made quickly to disperse personnel and institute decontamination procedures.

This is the first water-cooled transformer serving the rectifiers of an aluminum electrolytic line. It is one of sixteen 12 500-ampere, 700-volt transformers for a new aluminum plant in Montana. By eliminating the huge radiator required on large-capacity oil-to-air rectifier transformers, water cooling effects a reduction of 40 to 60 percent of floor space and about 40 percent of the weight, with large consequent reductions in the building size, foundation cost, as well as a 15-percent reduction in the transformer initial cost.



Philosophy of the monitoring set design is speed and ease of maintenance together with ruggedness and reliability. Plug-in components and subassemblies have been extended to include a whole electronic function, with as many as four subminiature tubes encased in plastic with a plug-in base, the whole being no larger than a ten-cent ice cream bar.

A unique feature of these components is pigmentation of the plastic to "color code" and thereby speed identification of these circuits; a color dot on the chassis matches each plug-in unit to its proper place in the circuit. Imprinted on the unit is complete functional and numerical identification plus a serial number to facilitate keeping records of service life.

Open Season on Weevils

Grain inspection by x-ray permits the inspector to detect weevil infestation during its early stages, thereby minimizing damage to grain.

X-RAY is well known as a useful tool for detecting faults in metals, thereby insuring perfection of machines and structures; now it is on the verge of improving the quality of the bread we eat—via a new x-ray inspection unit for examining grain.

Bugs called weevils may enter a grain bin, eat into the grain, and deposit eggs. As the normal life cycle repeats, the original eggs produce bugs, the bugs produce more eggs, and an "avalanche" results, causing undesirable grain quality and spoilage. The ill effects can be minimized by rejecting or down-grading grain showing infestation and by use of suitable fumigants at the proper time.

X-ray has proved a more reliable means for grain inspection than previous methods employed. It permits an inspector to virtually see inside the grain to determine which phase of development the insect is in. Consequently, such thorough inspection results in improved quality of wheat (hence more pure bread), and also turns out to be a cost saver to the miller and grain elevator by placing grain in the proper price category and suggesting fumigants at the proper time.

In order to insure radiographs of high contrast in a minimum of time, the x-ray tubehead has a beryllium window and a filmholder, both highly transparent to x-rays. The operator is completely protected against stray radiation by the cabinet walls and an interlocking door. Only a few minutes instruction is required to train an operator in the proper operation of the unit.

Kansas State College proposed and developed this method of x-ray inspection. Cooperative treatment of samples by Kansas State College and the Food and Drug Administration indicated it was a better method than any in use or proposed. Westinghouse cooperated with the Food and Drug Administration by supplying x-ray equipment initially and later supplied them with a unit, the predecessor of the model shown.

Personality Profiles

The name of *C. M. Laffoon* is undoubtedly a familiar one to our readers in the electric-utility industry, many of whom know him personally. Others know him through the innumerable technical articles and engineering society papers that have borne his name.

Laffoon has been associated with large rotating machinery almost since the day he joined Westinghouse in 1916. A graduate of the University of Missouri—with an E.E. degree in 1914, and an M.S. in 1915—Laffoon was fortunate enough to have tutelage from B. G. Lamme.

About a year afterward he began his career in a-c generator engineering. In 1936 he became manager of that department, and in 1953 was made assistant manager of the Transportation and Generator Division. In the course of these years, Laffoon has played a part in almost every phase of turbine-generator development; particularly he played an important role in the development of high-voltage insulation, ventilation systems, and rotor construction, of which he writes in this issue.

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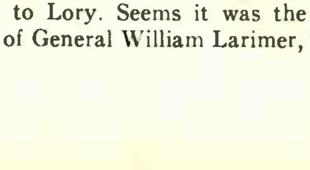
M. R. Lory has been continuously associated with a-c motors, particularly the large synchronous variety, since he arrived at the motor design section from the Graduate Student Training Course in 1928. He was a design engineer until May 1946, when he was made section manager. During this time, Lory has been involved in the largest motors ever built—both in size and in horsepower. Largest physically were the 65 000-hp, 200-rpm drive motors for irrigation pumps at Grand Coulee; largest in power were the two 83 000-hp, 600-rpm motors for the wind-tunnel drive at Tullahoma.

When queried as to other activities, Lory replied that since he is living in one of the few remaining three-story log houses—it was built in 1790—"living in a house of this age has to be a hobby in itself!" But the house has a special significance to Lory. Seems it was the birthplace of General William Larimer, founder of the city of Denver. Mr. Lory, a graduate of Colorado A. and M., comes from Larimer County, Colorado, just north of Denver.



J. F. Heidbreder, who teams with Lory in this issue to write about motor enclosures, has often joined with him in motor-design jobs. Possibly their most notable collaboration was the Tullahoma wind-tunnel drive. Heidbreder designed the two 25 000-hp, wound-rotor induction motors, which go in tandem with Lory's aforementioned giant synchronous motors.

"But Heidbreder really got the toughest job at Tullahoma," reminisces Lory. "His 'little' motors have to start and stop that big compressor rotor—mine just give the 'push' once it's on its way."

Heidbreder came to Westinghouse from the University of Michigan in 1929. From the Graduate Student Course, he went to circuit-breaker engineering, and in 1932 to materials engineering. Induction motors have been his specialty since coming to the a-c motor design section in 1942.

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When *S. J. Campbell* authored his first article for the ENGINEER, he was all wrapped up in magnetic-amplifier applications for lumber and paper mills. Now, a year and a half and many applications later, he's still devoting a large proportion of his time to the Magamp. A member of the general-mill section of Industry Engineering, he has helped design many of the systems he describes in this issue.

A native of Wisconsin, Campbell grew up in a papermaking and lumbering area. After he graduated from the University of Wisconsin in 1950, he came directly to Westinghouse. After completing the Student Course, he became a member of his present section, which handles the application of electrical equipment to a wide variety of industries.

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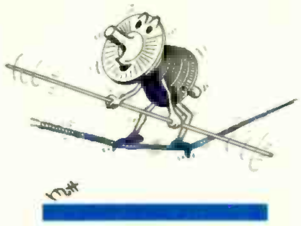
P. C. Warner and *F. C. Eaton* are the "Mr. Outside—Mr. Inside" combination for turbine-spindle testing.

Warner, the "outside" man, does most of the field test work at the turbine installation. He came to Westinghouse from Cornell in 1946 via the Graduate Student Training Course. Warner went directly into the mechanical design section of the Steam Division at South Philadelphia, and has been there since. Most of his time is taken up with rotor vibration and stress studies in both blades and rotors.

The "inside" man, F. C. Eaton, handles shop vibration testing, and applies results to spindle design. He has likewise spent all his Westinghouse time in the mechanical design section. He came on the graduate student course from Virginia Polytechnic Institute in 1948.



Besides collaborating at work, and on articles, Warner and Eaton play on the same softball team—fittingly enough, Warner plays outfield and Eaton infield.

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Three of our authors in this month's issue are winding up articles started in the March issue. *H. E. Lokay* of the electric utility section at East Pittsburgh finishes his discussion of voltage regulation with a section on capacitors. ***Commander Louis H. Roddis*** and ***John W. Simpson*** also complete their story on the USS *Nautilus*.

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An Engineering Highlight

High Light Output from Miniature Flash Lamps—More light! Smaller bulb! This is the continuous insistence of the millions of camera enthusiasts. To the great credit of the lamp designer, that difficult request is now being met.

A new miniature flash lamp (1¾ inches long by ¾ inch in diameter) gives out a total of 5200 lumen-seconds. The best any previous lamp of this small size has been able to do is 4200 lumen-seconds. This is made possible by the seemingly anomalous stunt of making the bulb bigger without exceeding any of its previous dimensions. Whereas other lamps of this size (designated M-2) are tapered, this new one is almost cylindrical. It thus has more volume for foil.

By proper control of the primer, the pattern of light output also is made better. Although all of the light occurs before 25 milliseconds the peak output occurs between 18 and 20 milliseconds, which makes this the only M-2 lamp with class M timing. This gives the bulb practically universal synchronization—from box cameras to cameras with *x* and *f* settings at 1/50 second, *M* settings of 1/200 second and less, and even most focal-plane shutter cameras. For all of this a packet of a dozen bulbs is small enough to slip into a shirt pocket.

Tensile tests on various metals are being conducted in this special chamber—at temperatures as low as minus 452 degrees F. Liquid helium is used to attain these temperatures.