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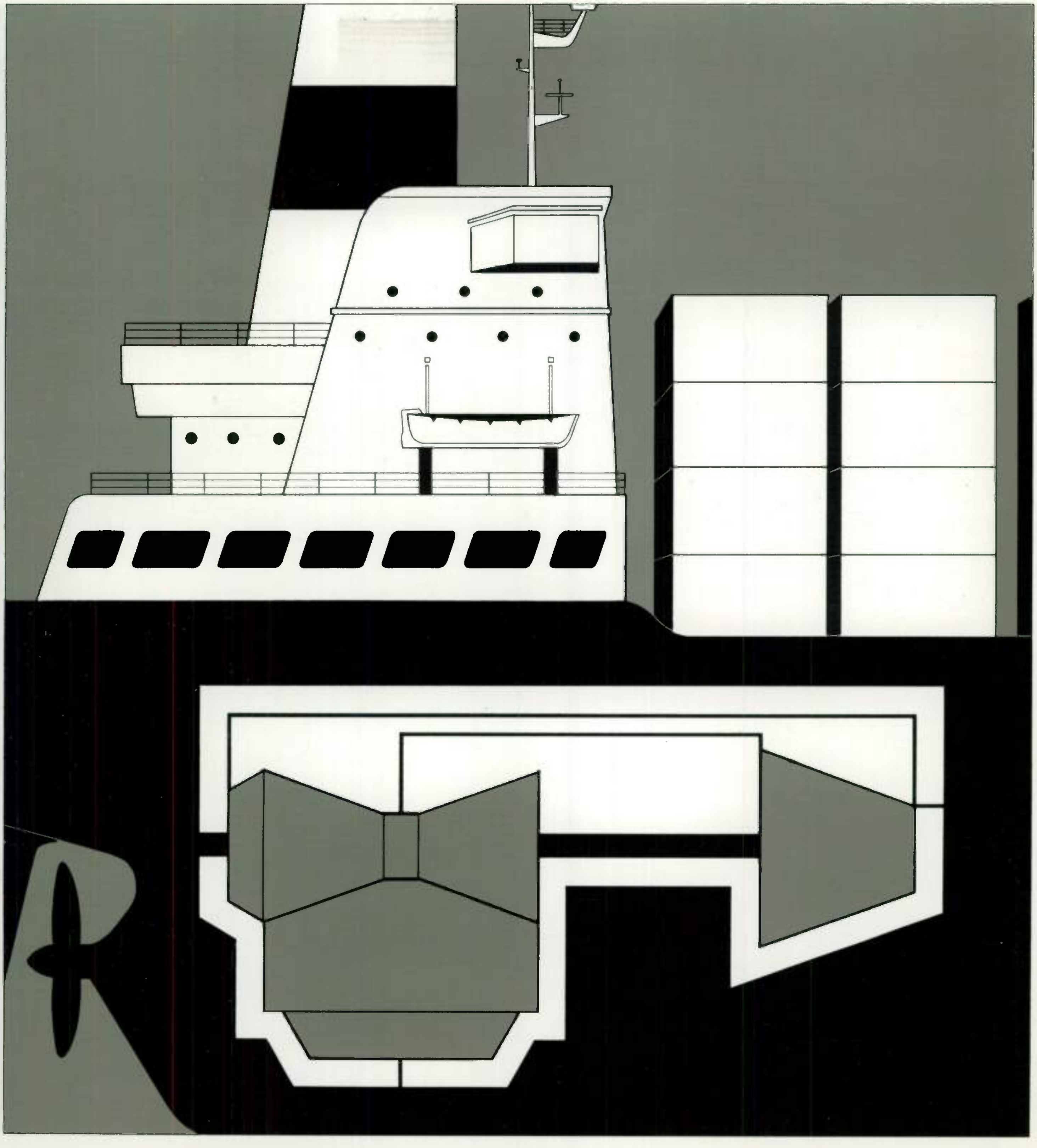

Lake Tahoe Studied with Environmental Monitoring System

Knowledge of such factors as currents, winds, and temperatures is vital to any thorough study of a body of water, but the required measurements have seldom been made by accurate long-term methods. Recently, however, such measurements have been made every 10 seconds over periods ranging up to a month at Lake Tahoe on the California-Nevada border.

An automatic monitoring system gathers and records data that should be helpful in learning how to retain the lake's clarity and its deep blue color. But beyond that, the object of the studies is to determine general effects of local human activity on a lake's conditions.

The long-range study of Lake Tahoe is being performed by the University of California at Davis under a grant from the Environmental Protection Agency. The automatic monitoring system was developed by the Westinghouse Ocean Research Laboratory at San Diego.

The system measures wind speeds and directions, current speeds and directions, temperatures, pressures, and solar radiation on the lake.

Nine channels of information are fed by cable to computer-compatible recording equipment located in a building near the shore. A mast on a pier holds a wind direction indicator and a cup-type anemometer that measures wind speed. Also on the pier are a barometer and a pyrheliometer, which measures the sun's energy radiation on the lake. Three-quarters of a mile offshore, in 600 feet of water, an anchor and flotation gear hold equipment about 75 feet below the surface. The equipment measures current speed and direction as well as water temperature. Another unit, on the bottom in 50 feet of water, provides wave and temperature measurements. Together, the instrumentation gives scientists the "heat budget" of the lake and information about the lake's surface and underwater movement.

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Front cover: A simplified steam plant for marine propulsion that maximizes reliability and minimizes life-cycle costs is the subject of this month's cover design by artist Tom Ruddy. An article describing the plant begins on the following page.

Back cover: Two large drills are being evaluated as part of a coal-mine rescue and survival system that also includes breathing, shelter, and communications equipment. The drills would open passages to trapped men for supplies and rescue. For more information, see page 60.

A Simplified Steam Plant for Marine Propulsion

Allan W. Davis

An extensive simplification of today's marine steam power plant will enhance the reliability of the plants and make them more economical to build and install. These features are essential to the financial success of new merchant marine ships.

In the past decade, the demand for higher productivity has pushed ship displacements and propulsion power requirements steadily upward. Sixteen-knot tankers of 300,000 deadweight ton displacement, and up, are requiring power plants of 40,000 shaft horsepower (shp) and more. Similarly, containerships are growing in speed and displacement; 120,000-shp ships carrying more than 1000 containers are being built. The factors that have brought about these changes—increasing world trade and reduced ship turnaround times—will persist throughout the 1970's.

The life-cycle cost of a complete containership system is in the order of $100 million including containers and a share of the shore facilities. Those high capital investments mean that these ships have high fixed costs, which the shipowner must pay whether the system is operating or not. Since these costs are normally offset by high revenues, the penalty of a day's delay can be very high—figures ranging from $25,000 to $50,000 have been cited for large high-speed containerships and for supertankers. This places a premium on power plant *availability* in new ship designs.

The demand for high ship availability also requires a new look at power plant automation. What appears to be required are power plants that are simple to control, hence, *simple to automate.* This approach inherently requires fewer plant operators.

The low level of fuel costs relative to fixed expenses—about $8 million over the ship's life cycle—means that reduction of fuel consumption is not necessarily the most effective way to reduce operating cost. A 20-percent improvement in specific fuel consumption would reduce total life-cycle cost less than 2 percent (assuming this improvement could be obtained at no expense in capital, maintenance, or availability).

And finally, escalating maintenance costs, and the possible elimination of the subsidy for such costs, require designs for *reduced maintenance.*

These factors led Westinghouse to reexamine the basic design of the marine steam power plant. The scope of this reexamination has been extended beyond the Westinghouse-built turbines, gears, ship's service turbine-generators, and condensers to include the entire power plant, because the availability, maintenance, and operational characteristics of steam plants and their construction costs are affected by all components in the power plant. Furthermore, the physical and operational relationships between those components can have a substantial effect on overall power plant reliability.

One basic design philosophy is used in evaluating each plant feature: the incorporation of any feature that can complicate the plant and reduce its reliability is examined in terms of its potential loss in revenue. Only if the economic advantage of the feature is large with respect to a single day's lost revenue is it used.

The basic power plant discussed in this article is a single-shaft plant rated at 50,000 shp. With small modifications, any rating in the range of 40,000 to 70,000 shp can be provided by the design. The single-shaft plant is suited to large tankers, and large containerships in the 25-knot speed range. The reduction gear is specially tailored to the requirements of the application.

Containerized and roll-on, roll-off cargo places a premium on deck space. Therefore, ship and machinery arrangements are designed to maximize the space availability for container stowage.

A two-shaft power plant rated at 120,000 shp (lower ratings to 80,000 shp and higher ratings to 140,000 shp are possible) has also been designed. The larger plant is suited to large containerships in the 30-knot (and up) range. Since this larger plant design is basically a double-shaft version of the single-shaft design, most of the considerations discussed for the smaller plant also apply to the two-shaft design.

Steam Conditions and Cycle Selection

The first step in selecting steam conditions and the plant thermodynamic cycle is a survey of experience with existing marine power plants to determine the effect of steam conditions, condenser vacuum, and conventional regenerative components (such as the rotary air heater, economizer, and feed-heating equipment) on plant availability and maintenance requirements. Much of this experience is available from the Maritime Administration's Maintenance and Repair Data Processing and Evaluation program, and the Westinghouse study made frequent use of this information.

Steam Pressure—Present conventional practice in simple marine power plant cycles is to use a steam pressure of about 850 psia at the turbine throttle. In high-pressure plant cycles, 1200-psia systems are in use. Higher pressure provides improved thermodynamic efficiency, but the fuel cost saving is offset to a large degree by increased first cost. For example, excluding maintenance costs, a 50,000-shp plant operating at 1200 psi would have a net life-cycle economic advantage over an 850-psi system, but the advantage would amount to less than a half day's revenue for a high-speed containership. Furthermore, shipboard experience with 1200-psi steam systems suggests that the frequency of unscheduled plant outages increases with increasing steam pressure. Feed pumps, valves, and boilers in high-pressure systems have experienced a significant number of problems requiring plant shutdown. These problems have resulted not only from the high pressure but

1—The full-power heat balance for the 50,000-shp simplified steam plant is shown on the thermodynamic cycle diagram. With the discounting of fuel costs, the full-power specific fuel consumption is a relatively respectable 0.48 pounds/shp-hr, due in part to the good mechanical efficiency of the large propulsion turbines and the good combustion efficiency of the large boilers.

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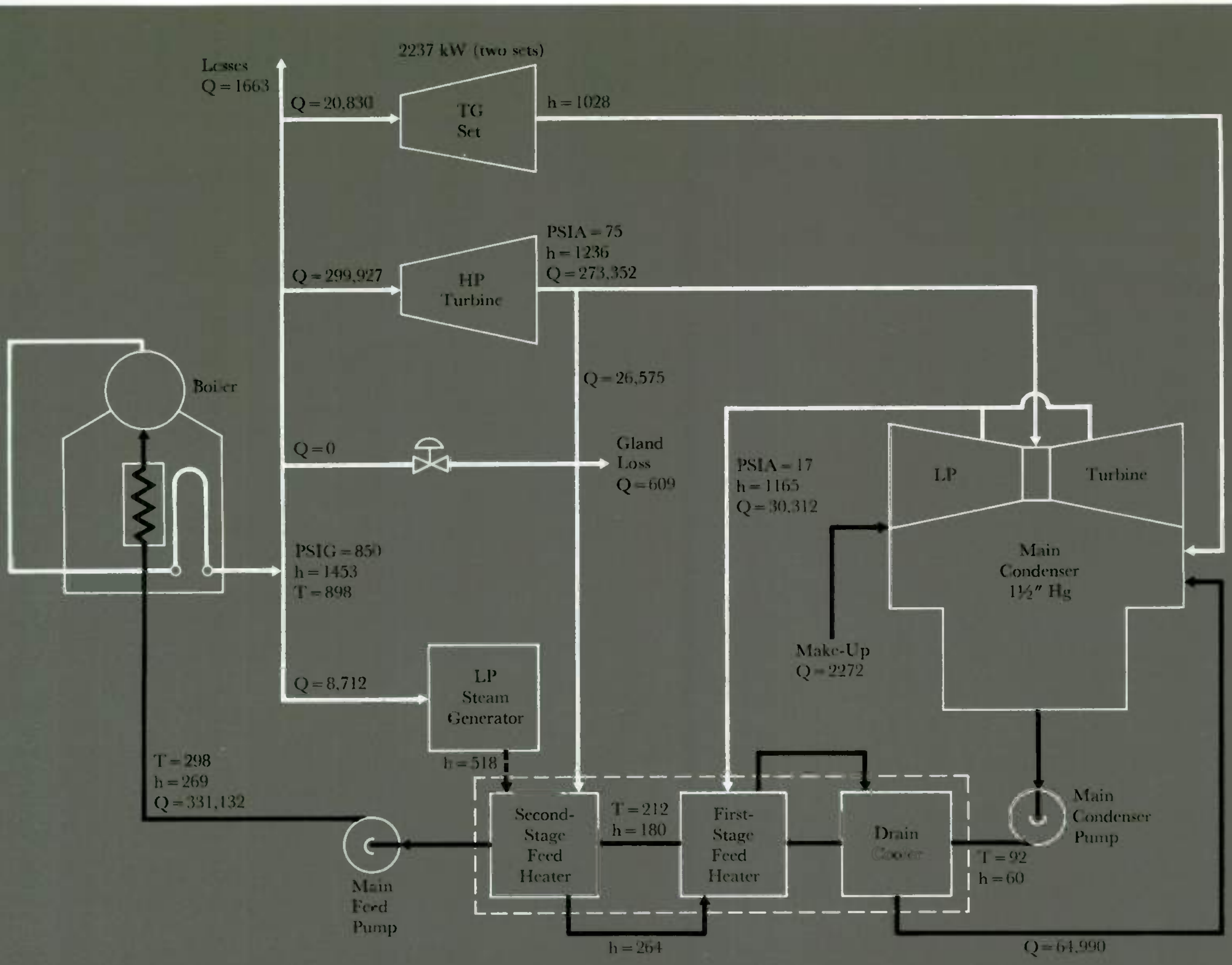


Q	is Flow (lb/h)
h	is Enthalpy (Btu/lb)
T	is Temperature (°F)

Heat Rate: 7838.3 Btu/shp-hr
Boiler Efficiency: 88%
Specific Fuel Consumption: 0.48 lb/shp-hr (hhv = 18,546 Btu/lb)
Drive Train Mechanical Efficiency: 98%

also from the increased sensitivity of the high-pressure boiler to off-design water chemistry.

Therefore, since the loss of a single day's revenue would cancel the entire life-cycle economic advantage of higher pressure, that small economic gain does not warrant the increased risk to ship availability.

Given the economic importance of high availability, pressures lower than 850 psi should also be given careful consideration. Marine plants at 600 psi have, in general, given extremely reliable service. However, examination of Maritime Administration data for boilers in 600- and 850-psi plants indicates that no loss of availability could be fairly ascribed to an 850-psi selection. Furthermore, the increased fuel cost for a 600-psi plant is about $110,000 (present worth) over its life. Since the capital and maintenance cost advantages, if any, for the 600-psi plant are small and would not offset the increased fuel cost for a 600-psi plant, the higher steam pressure of about 850 psi seems the prudent selection.

Steam Temperature—In the past 20 years, steam temperatures in marine power plants have trended slowly upwards; a 950-degree-F superheater exit temperature is typical of a modern plant.

To determine the effect of increased temperature on the reliability of the marine superheater, Maritime Administration data were examined. Data for 125 ships operating for a total of 455 ship years show 27 major boiler outages. Of these, 11 involved failures in the superheater but none involved a superheater operating below 950 degrees F. Thus it appears that selection of a lower steam temperature, say 900 degrees, could reduce the risk of an unscheduled outage.

Again, a 950-degree steam temperature improves overall cycle efficiency, but the life-cycle advantage of 950 over 900 degrees is only slightly more than the potential loss of revenue from a single day's outage. Therefore, a steam temperature of 900 degrees F was selected.

Condenser Selection—Cycle simplification generally means making one component do more than one job. For example, the main condenser can be used as a heat sink for auxiliary turbines as well as the propulsion turbine. Elimination of auxiliary condensers substantially simplifies the condensate and seawater system.

A power plant condenser naturally deaerates, and it is often used to maintain deoxygenated feed in electric utility stations. Using the condenser for this purpose in a marine power plant can substantially simplify the steam plant piping because the deaeration tank, with its long piping runs, can be eliminated.

According to the Standards of the Heat Exchange Institute, a condenser will reliably deaerate provided certain conditions are met: For example, oversized air-removal equipment must be installed; drains and other returns to the condenser must be introduced in a manner to ensure their deaeration; and care must be taken to ensure the tightness of the condenser casing, the hotwell, the condensate pump casing, and the interconnecting piping to avoid in-leakage of air. The condensate pump must not cavitate, even during transients, since cavitation can result in air ingestion. And finally, the heat-transfer area of the condenser must not be too large, because excessive area can subcool previously condensed steam. These subcooled droplets can then absorb any noncondensable gas in the condenser.

To size the condenser, it is necessary to assume a range of injection temperatures. In this case, the assumed range is 32 to 65 degrees F, typical of North Atlantic requirements. The heat-transfer area is then selected to meet HEI deaerating requirements; it will produce a back pressure of 1.5 inches of Hg in 55-degree-F seawater, 2.0 inches in 65-degree water, and 2.5 inches in 75-degree water (the usual MarAd design temperature).

This performance implies that when the ship operates in warmer water, it will burn more fuel than it would if the condenser were sized for 1.5 inches Hg over the full range of injection temperatures. That fuel penalty is chargeable to the deaerating capability of the condenser. But, considering the difference in fuel cost, condenser cost, circulating system cost, and boiler cost, the life-cycle cost of a condenser capable of producing 1.5 inches Hg at 75 degrees is actually higher than that of the 1.5-inch, 55-degree condenser. Therefore, a deaerating condenser producing 1.5 inches of back pressure in 55-degree seawater was selected for the simplified steam plant.

Selection of Regenerative Components

With inlet steam conditions and condenser vacuum established, the regenerative equipment for the steam cycle can be evaluated.

Regenerative Air Heater—Regeneration in the boiler gas path to improve boiler combustion efficiency is accomplished in many modern steam power plants with rotary regenerative air heaters. In a 50,000-shp power plant, such regenerators have the potential for saving more in fuel costs than the first cost of both the regenerator and the high-pressure feed heating necessary to make optimum use of it. However, the maintenance cost of regenerative air heaters is relatively high; because of the corrosive environment, most baskets must be replaced at least once during the life of the ship. Costs of this maintenance are estimated to more than offset the net apparent economic gain of the regenerator. As a result, a regenerative air heater is not used.

Economizer—Another component that could be eliminated from the cycle is the economizer, but, in this case, economic considerations require that it be retained. The increased cost of fuel over the life of the ship for a plant without economizers is nearly $750,000. Furthermore, the maintenance history of this component in recent marine power plants has been good; little trouble has been experienced with economizers when feed temperatures are at least 280 degrees F (eliminating problems with sulphuric acid corrosion). Even with the conservative assumption of an economizer replacement every five years, the net financial advantage remaining in favor of the economizer is about $660,000. However, provisions have been made to bypass the economizer so that trouble with it will not seriously affect ship availability.

The use of an economizer establishes the requirement that the feedwater be heated to a temperature of at least 280 degrees F to avoid the risk of sulphuric acid corrosion. If the feedwater temperature is increased substantially above 280 degrees, cycle efficiency is enhanced, but the improvement is more than offset by reduction in combustion efficiency. Therefore, in a plant with an economizer but no air heater, the feed temperature should be maintained close to 280 degrees. For this plant, feed temperature is permitted to vary over the range of 280 to 300 degrees F to allow operational flexibility.

Stages of Feed Heating—Having established feed temperature, the next step is to select the number of feedwater heaters. One, two, and three stages of feed heating were evaluated. It was found that the fuel and capital cost savings resulting from two stages of feed heating versus one stage are substantially greater than one day's outage time. Furthermore, the Maritime Administration failure data indicate that feed heaters are reliable components. However, the addition of a third stage does not appear justified because the additional fuel savings are relatively small.

Feed-Pump Drive—Conventional marine power plants use steam-driven feed pumps. The use of steam drives allows variable control of pump speed so that the pressure differential across the feedwater regulating valves can be maintained at a constant value. In addition, the steam exhausted from the feed-pump drive turbines is conventionally directed to the deaerating tank where it serves as a source of heating steam over the full power range. On the other hand, feed-pump turbines require considerable maintenance. The steam and exhaust piping, and the drains required by the turbines, are relatively more complex than an electric motor drive with its circuit breaker. Furthermore, automation of electrically driven feed pumps is substantially simpler than that of steam-driven feed pumps.

An economic evaluation of electric feed-pump drives indicates that for large marine power plants, electrically driven feed pumps also appear more economical. The electric motor-driven pump has a lower first cost and installation cost, although these first-cost advantages are offset by the increased first cost of the turbine-generator set that must provide the power to the electric motor. However, a cycle efficiency advantage accrues with the electric pump drive because of the better mechanical and thermodynamic efficiency of the turbine/generator/motor drive versus that of the noncondensing turbine drive. The fuel-cost savings of the electric drive offset the relatively small first-cost difference, so the lower maintenance costs of the electric drive give it a net economic advantage.

Steam Air Heaters—Many marine power plants employ steam air heaters. These heaters utilize extraction steam or feed-pump turbine exhaust steam to supply energy to an extended-surface heat exchanger in the boiler intake. Preheating the air improves combustion efficiency, and, in plants with steam-driven feed pumps, a small improvement in net plant efficiency with a steam air heater is often demonstrable. However, elimination of the deaerating tank and steam-driven feed pumps in this simplified cycle alters the economic desirability of the steam air heater; since the heater does not improve overall plant efficiency, there is no economic incentive to install it.

Heat Balance—The full-power heat balance for the 50,000-shp simplified steam plant is shown in Fig. 1.

Steam System Design

Component selection for the simplified steam plant must satisfy reasonable redundancy requirements for all major propulsion plant components—the propulsion turbine, reduction gear, condenser, and boilers. Too much redundancy would increase the maintenance burden and complicate the plant; too little redundancy would risk disruption of the operating schedule by trouble in a single component.

In conventional merchant ships, the use of a single-screw power plant (one propulsion turbine, one reduction gear, one condenser) can usually be justified (vis-a-vis a twin-screw plant) by first-cost and fuel-cost savings. These savings accrue from two sources: elimination of the second shaft's worth of machinery reduces first cost, particularly installation costs; and, in fine-line ships, a single screw generally possesses a better propulsive coefficient, so the plant power required to produce a given speed is reduced and fuel consumption per mile at that speed is decreased. These factors also make single-screw power plants economically attractive for large high-speed container-ships and for super tankers (though to a lesser extent for tankers because of their fuller lines). However, the economic gains of the single-shaft arrangement must be evaluated against the risk (and potential economic losses) of an unscheduled loss of propulsion power.

The record of propulsion turbines, condensers, and gears in the merchant marine service indicates that the risk of a prolonged loss of propulsion power is small; a loss of more than a few hours duration is unlikely to occur during the life of the ship. When this low risk is balanced against the cost savings—potentially several million dollars over the life of the ship—single-shaft power plants are, in fact, applicable to large high-productivity ships.

With respect to boiler redundancy, however, the argument is not so clear-cut. The savings associated with a single-boiler arrangement are in component and installation costs. For a 50,000-shp power plant, these savings are in the $60,000 range. Any means provided for emergency propulsion—an auxiliary boiler, for example—tends to diminish this advantage. Therefore, the cost advantage of the single boiler must be balanced against the risks and costs of a boiler outage. These costs will be significant if the trouble cannot be repaired by the crew, because the ship will then suffer both towing charges and lost revenue. The amount of the loss will depend on the trade route—up to $330,000 is possible for a high-speed containership. Thus, for most of the trade routes on which the high-productivity ships will operate, a two-boiler arrangement is the more logical choice.

With respect to component redundancy in the balance of the power plant, the following criterion served as a basis for system design: redundant components are used as required to allow continued operation of the ship in the event of any single component breakdown. This means there will be at least two of all components vital to plant operation. However, the ratings of redundant components may be less than those equivalent to 100-percent power if the potential loss of revenue due to a component failure is small compared with the cost of increasing its rating to 100 percent.

Other factors also enter into selecting the number of components. For example, Coast Guard requirements set the total installed spare feed-pump capacity at 100 percent. The ability of the ship's service turbine-generator to start a standby component is another consideration. A single 100-percent-rated pump, for example, might be difficult to start, in which case two 50-percent pumps are used.

Main and Extraction Steam System—High-pressure steam from the boilers is directed to four places, as shown in Fig. 2: the high-pressure end of the main propulsion turbine; the two ship's service turbine-generator sets; the low-pressure steam generators; and the augment/reducing valve, which supplies steam to the second-stage feed heater as needed to maintain feed temperature and, through a second reducing station, to the gland-seal system for the turbine-generator sets and main engine. Steam from the augment valve is also used for deaeration at low power. The deaerating steam is directed to the condenser through an orifice and remotely controlled valve to a nozzle immediately above the hotwell. The augment valve is provided with isolation and bypass valves to allow replacement and continued plant operation in the event of malfunction.

Steam from the ship's service turbine-generators is exhausted directly to the main condenser. Steam from the high-pressure end of the propulsion turbine is directed to the dual-flow low-pressure turbine, from which it exhausts through down-flow connections to the main condenser. A single astern turbine is provided at one end of the low-pressure barrel.

Extraction steam to the second-stage feed heater is provided from the high-pressure/low-pressure turbine crossover. At full power this pressure is approximately 60 psig. Steam for the first-stage feed heater is extracted upstream from the third stages of the low-pressure turbines. The two low-pressure extraction points are cross-connected inside the low-pressure turbine casing; a single line connects the extraction steam to the first-stage feed heater.

Drains from the low-pressure steam generators are normally connected to the second-stage feed heater. In the event of a malfunction of the feed heaters, low-pressure steam-generator drains may be connected directly to the main condenser.

The condensing section of the second-stage feed heater exhausts to the first-stage feed heater through a level control valve. The first-stage feed heater includes a drain cooling section. Drains from this section are directed through a deaerating connection into the main condenser.

Feed and Condensate System—The feed and condensate systems are diagrammed in Fig. 3. The main condenser is equipped with an oversized hotwell (by marine standards); approximately five minutes of feedwater supply is contained to ensure an adequate supply of feedwater during steam plant malfunctions. The hotwell is also sized to accommodate changes in water level brought about by the decrease in boiler water inventory with increasing power.

Two condensate pumps take suction from the hotwell. Both pumps are normally operated; each pump is rated at 100-percent condensate flow plus 10-percent margin for recirculation and control. Operating both condensate pumps ensures continuous and adequate feed-pump suction pressure in case of an outage to one.

Fixed recirculation is provided through an orifice downstream from the two condensate pumps. Recirculating flow enters the condenser through a deaerating connection. The main condensate flow is directed from the discharge of the pumps through the composite feed-heater package. This feed-heater package contains the drain cooler and condensing section of the first-stage feed heater as well as the second-stage feed heater. From the composite feed heater, the condensate flows to the suction of the main feed pumps. Isolation and bypass valves are provided around the feed heaters so that the ship can operate on a temporary basis in the event of an outage to either stage.

Two main feed pumps are provided, each rated at 110 percent of rated feedwater flow. The two-pump system meets fluid system redundancy criteria and Coast Guard regulations. Each pump operates at 3600 rpm, is rated at 600 hp, and may be started across the line. During normal plant operation, one pump operates while the other is on standby. In the event of a failure of one of the pumps, more than one and a half minutes is available to start the standby pump before a low-boiler-level alarm occurs.

Feedwater flow to each boiler is controlled by an electrically operated feedwater regulating valve. The valve is designed to provide satisfactory control with a differential pressure across it varying between 300 psi and 100 psi.

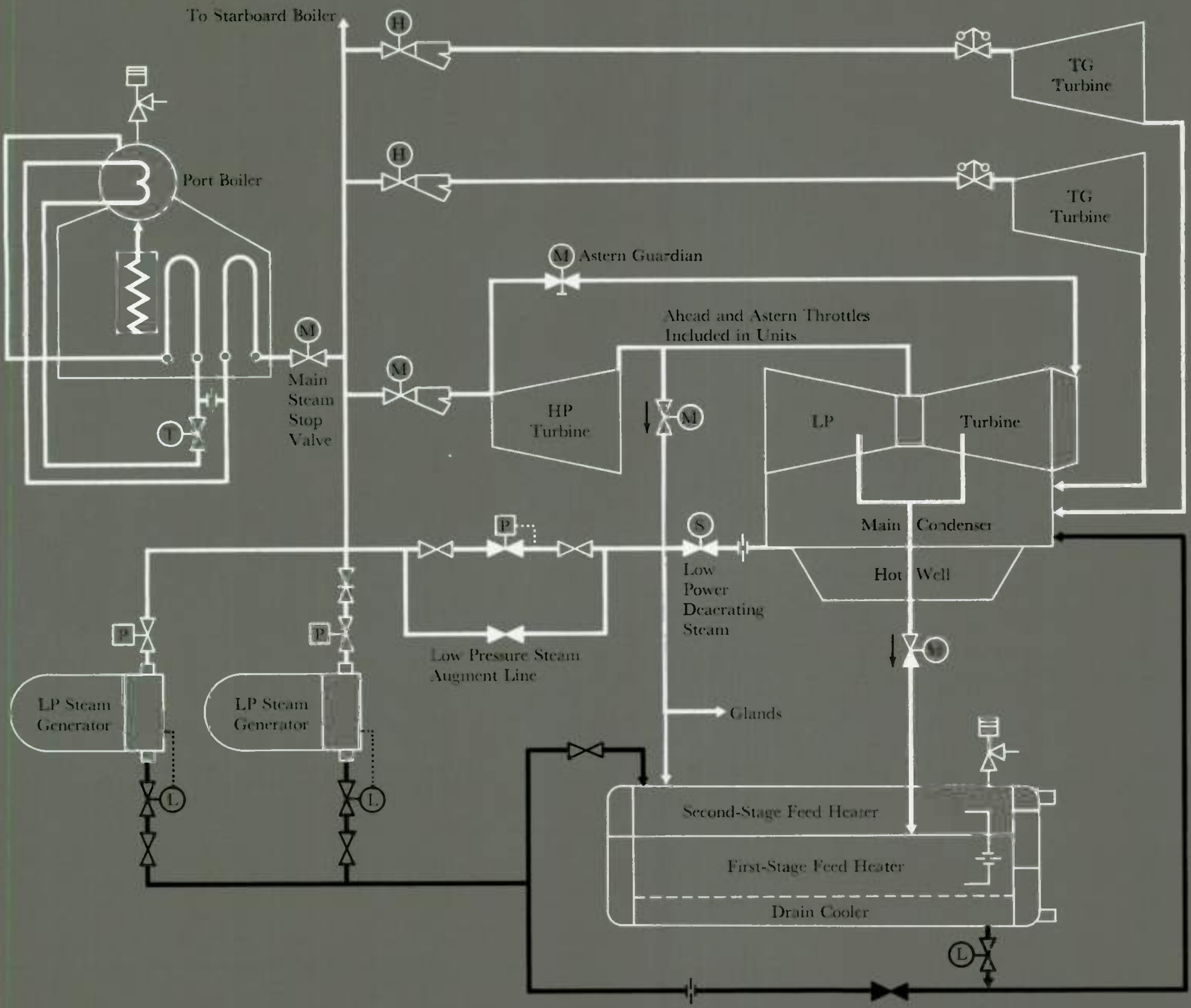
Both the feedwater regulating valve and the economizer are provided with isolation and bypass valves to allow continued operation of the plant in the event of a problem with either component.

Steam plant inventory control is effected by means of high- and low-level switches on the main condenser hotwell. On the occurrence of a high level in the hotwell, such as would exist when the condensate expands during warm-up, condensate is automatically dumped to the feed bottoms from a connection downstream from the condensate pumps. In case of a low level in the hotwell, indicating that make-up is required, make-up feed is introduced through a vacuum drag valve and a deaerating nozzle into the condenser.

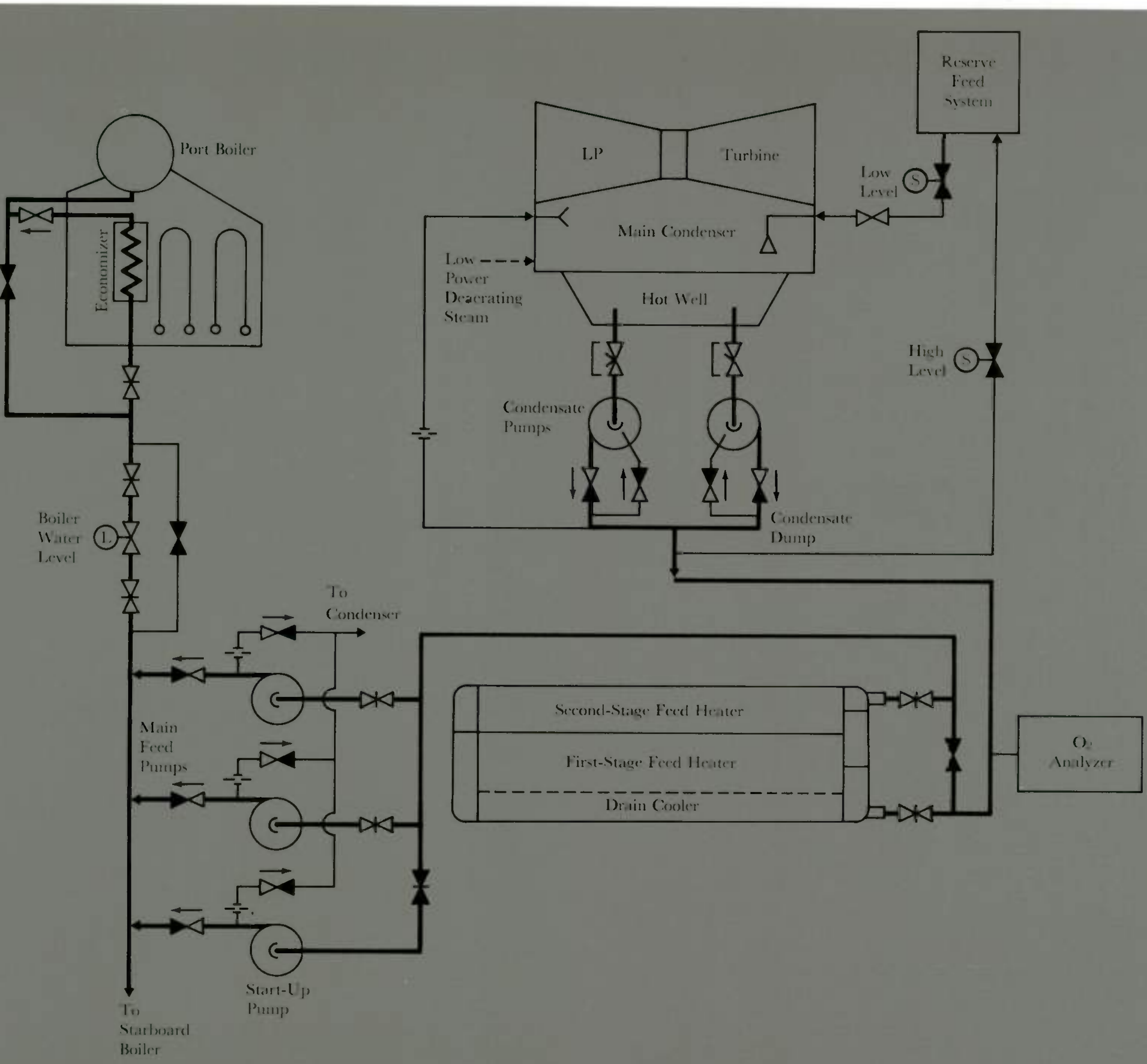
Two vacuum pumps, rated at 7.5 ft³/min at 1.5 inches Hg, are provided for air removal from the condenser. Two pumps are furnished to ensure continued operation of the main turbine with one pump out of service. Air removal capability is such that satisfactory deaeration in the condenser can be obtained with one pump operating. During startup, and at very low power with cold injection temperatures, both pumps can be operated for maximum capacity.

Reliable Boiler Performance

The clear message of marine experience is that to maintain a good availability



2—The main and extraction steam system illustrates the choice of components to satisfy redundancy requirements. The components for the feed and condensate portion of the cycle are shown in Fig. 3.



3—The feed and condensate system for the high-pressure steam circuit is isolated from the low-pressure system to prevent contamination of the boiler feed.

record, attention must be paid to the conditions under which the boiler is required to operate. Unscheduled outages involving failures of boiler pressure parts are often laid to the boiler, when in fact they are the result of off-design water chemistry conditions originating in a component other than the boiler. Benefiting from this experience, some specific measures have been incorporated in the simplified steam plant design to ensure reliable boiler performance.

Low-Oxygen Condensate System—The entire condensate system is designed to minimize the risk of oxygenating the feed. The influence of this factor in designing the condenser to deaerate effectively has already been discussed. Deaerating in the condenser carries a bonus with respect to plant oxygen level; it minimizes the rate of formation of corrosion products in the low-temperature end of the condensate system. Such corrosion products deposit in the boiler and can eventually lead to tube burnout.

Other steps to minimize oxygen problems have also been taken. For example, all drains are directed to a deaerating nozzle in the condenser instead of a drain collecting tank to avoid the possibility of oxygenation in an atmospheric drain tank. Elimination of pumped drains involves a small penalty in cycle efficiency but is easily justified in terms of reduced maintenance.

Minimum-Makeup High-Pressure Circuit—Makeup to the steam plant is minimized because large and frequent additions of water from the evaporators can introduce oxygen, carbon dioxide, and trace quantities of calcium and silicon compounds, which can cause corrosion and scale on the boiler tubes. Moreover, makeup perturbs plant water chemistry and requires that chemicals be added to maintain the feed within specifications. Frequent addition of chemicals in itself involves some risk of a boiler casualty. In the simplified steam plant, makeup requirements are minimized by reducing the outflow from the plant. In conventional plants, such outflow is due to three principal causes: steam for atomizing the fuel, steam for soot blowing, and leakage from the steam and feed systems, including removal of boiler water for sampling purposes.

The outflow in the simplified steam plant is drastically reduced. Steam for atomizing and soot blowing is supplied from the low-pressure (300-psi, saturated) steam generators (Fig. 2). The low-pressure fluid system is completely isolated from the high-pressure circuit. The temperature of the low-pressure steam is low, so the risk of oxygen pitting is small. Scaling of the low-pressure side of the low-pressure steam generators results only in a reduction of steam pressure, not a burnout. Thus, the high-makeup low-pressure circuit is substantially less sensitive to the chemistry of its makeup water.

Only two functions besides propulsion, electric power generation, and low-pressure steam generation are performed by steam from the 850-psi circuit: (1) An augment system maintains the temperature of the feed flow from the second-stage feed heater above 280 degrees F; this minimizes the chance of economizer corrosion when the plant is at low power. (2) The gland seal system maintains positive pressure seals on the shafts of the propulsion turbines and the ship's-service generator turbines.

With soot blowing and atomizing steam supplied by the low-pressure steam circuit and leakage minimized, the need for frequent sampling of boiler water is greatly reduced.

Clean High-Pressure Circuit—Many boiler incidents start with large-scale contamination of feedwater. Several measures have been taken to avoid such incidents in the simplified steam plant.

All necessary precautions have been taken in the design of the condenser to minimize the risk of a seawater leak. To further reduce the likelihood of seawater contamination of the feed, the evaporators are supplied with steam from the low-pressure steam system. The penalty to cycle efficiency has again been justified by the reduced risk of an unscheduled plant outage.

Heating steam for fuel oil is supplied by the low-pressure steam generators to avoid the chance of contaminating the main feedwater system with fuel oil.

The gland-seal steam drains are directed to the drain-collecting tank of the low-pressure steam system. This has the effect of increasing the net outflow from the high-pressure circuit, but reducing that from the low-pressure circuit. However, the chance of oil contamination in the more sensitive high-pressure circuit is reduced by this provision.

In Port

The short turnaround times of modern ships make it desirable that the propulsion turbine be operated on the turning gear and that condenser vacuum be maintained while in port. Thus, the use of the main condenser for the ship's-service turbine-generator set exhaust constitutes no particular operational inconvenience in port.

The 50,000-shp plant is equipped with a 600-kW diesel-generator set to allow cold startup without resorting to shore power. The diesel-generator set is also capable of providing hotel loads, steering power, and other ship's loads while maintaining the power plant in a hot standby condition.

Conclusions

Each feature of the simplified steam plant has been selected by tradeoffs of capital and fuel costs against potential future maintenance costs and losses due to unscheduled outages so that the overall plant will have near minimum life-cycle costs. Although the economic analyses are based on a high-speed containership system operating on a four- to five-day North Atlantic trade route, the conclusions of the analyses are generally applicable to other containership systems and to tankers. Of course, the specific results of some of the economic tradeoffs on component sizing may change for other applications.

A New Parametric Device for Filtering and Voltage Stabilization

R. J. Spreadbury

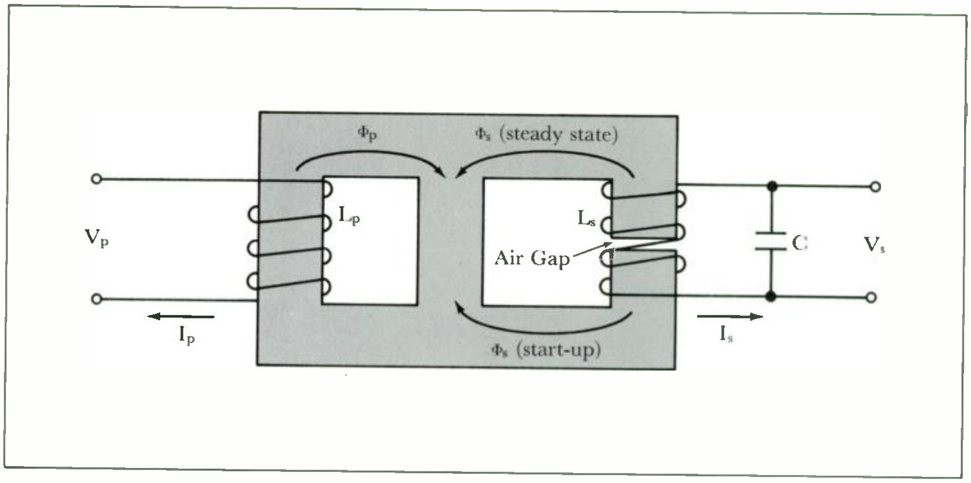
A unique power conditioner consisting entirely of passive elements combines the stabilization and filtering ability of a parametrically energized oscillator with the advantages of a conventional flux-coupled transformer.

To insure dependable performance, electrical control equipment often needs a constant-voltage power source that is free of harmonic and transient distortion. These requirements are met in an unusual parametric transformer that provides several unique electrical characteristics coupled with an input power factor, efficiency, and size comparable to that of conventional ferroresonant voltage stabilizers. It provides a sinusoidal output of low harmonic content even if the input waveform is grossly distorted with harmonics, random high-frequency noise, or with high- or low-voltage transients. While the new parametric transformer was originally designed as a power filter, it also provides load voltage stability within plus or minus one percent of its rated output for input power line swings as much as ten percent.

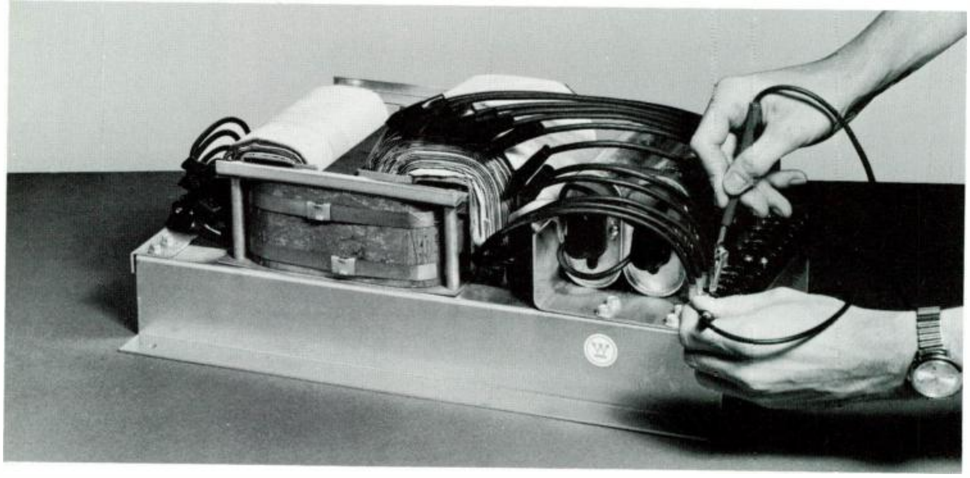
The parametric transformer was developed at the Westinghouse Research Laboratories in conjunction with the company's Specialty Transformer Division, which also manufactures the units. It is suited for protecting and stabilizing such diverse apparatus as industrial control systems, medical electronic devices, and power supplies for laboratory equipment and photographic processing equipment. In all those areas, equipment and circuitry are sensitive to power-line interference caused by lightning strokes, load switching, and electrically noisy loads such as phase-controlled dc motors.

Description

The nonlinearities of the new transformer's magnetic core provide its unique performance characteristics. While its operation is consequently more complex than that of a conventional transformer,



1—Shown schematically are the main elements of the parametric transformer. The device is started by increasing the primary voltage (V_p) until it is sufficient to drive some primary flux (Φ_p) through L_s in the output leg. Once in operation, Φ_p traverses the input and middle legs, and secondary flux (Φ_s) traverses the output and middle legs.



***Photo*—The new parametric device, called the SW Transformer, acts as a power filter and voltage stabilizer. Its output voltage deviates no more than ±1 percent for input variances of up to ±10 percent. From left to right are the primary winding, secondary winding, capacitor bank, and terminal strip for different voltage taps.**

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a simplified qualitative explanation can be given. The device is basically a three-leg laminated iron core with a primary winding of self inductance, L_p, and a secondary winding of self inductance, L_s, that has a capacitor connected with it in parallel (Fig. 1). For normal operation (input frequency = output frequency), the L_sC tank circuit is tuned to resonate at the operating frequency:

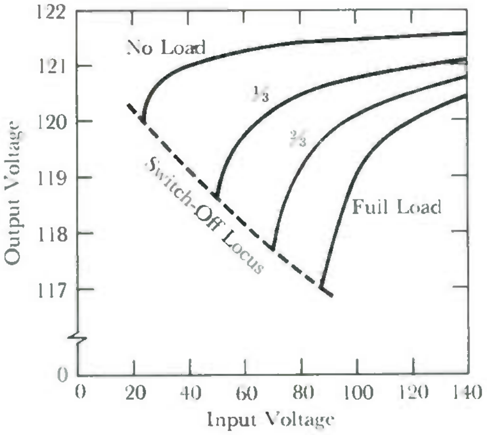
$$f = 1/(2\pi\sqrt{L_sC}).$$

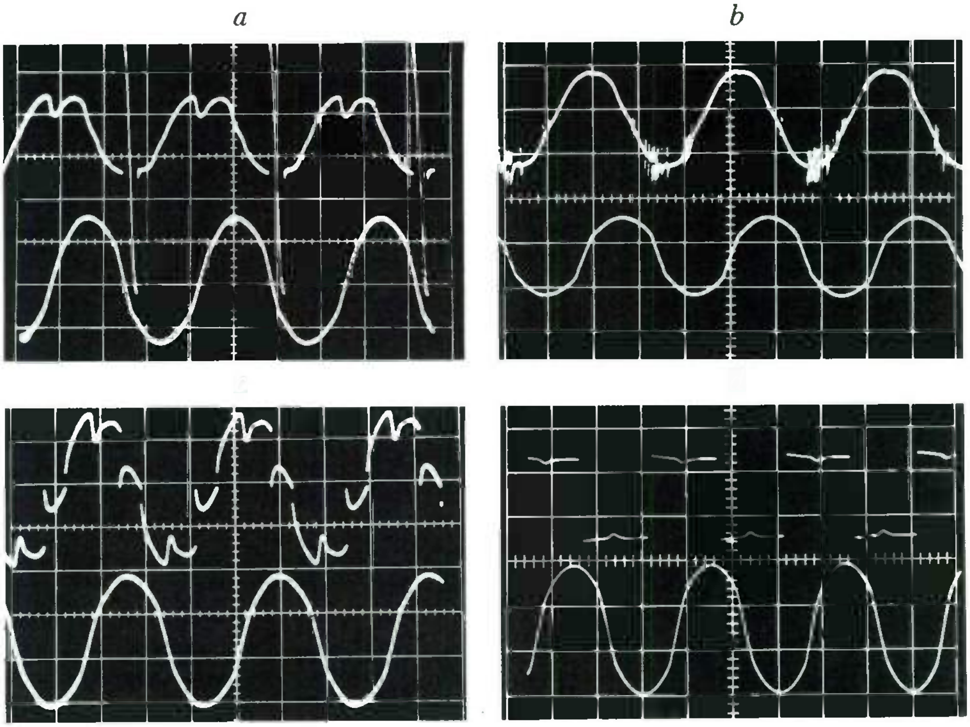
As long as the input voltage is below the minimum starting voltage, the primary flux, Φ_p, follows a closed path through the input and middle legs because the air gap in the output leg presents too much opposition (reluctance) to the flow of primary flux. As the input voltage is increased, the primary flux density in the middle leg increases until that leg approaches saturation, thus forcing some of Φ_p into the output leg and across the air gap. Once some of Φ_p is circulated through the output leg, the L_sC tank circuit becomes energized and the transformer provides load voltage, V_s. For a more detailed discussion, see "Parametric Transformer Operation" on page 44.

The purpose of the air gap in the output leg of the transformer is to help provide a virtually sinusoidal output voltage. Gap length generally varies with the transformer's volt-ampere rating and is adjusted to give the best output waveform at full load. The gap could be eliminated to provide a virtually square output waveform that is ideally suited for rectified outputs (dc power supplies). The output voltage would still remain locked at approximately 90 degrees to the input voltage.

Performance Characteristics

Unlike conventional transformers and ferroresonant voltage regulators, the new parametric transformer does not "start" (provide load voltage) unless the input voltage is within a predesigned range, generally 95 to 135 volts. If the input voltage is at or above the minimum, the unit starts, as the output voltage rises in a few cycles from almost zero to a specified value. Once started, the unit maintains output voltage even with a transient loss





2—(*Top*) **Regulation of the parametric transformer is illustrated in this typical family of curves of the unit under various load conditions. The switch-off locus indicates how much the input voltage can drop before the unit stops producing load voltage.**

3—(*Bottom*) **The general filtering ability of the new transformer is demonstrated in this series of input/output waveforms. All voltages are 60 Hz, 115 V rms. In (*a*), 600-volt transients on the input are attenuated over 60 dB in the output. No discernible breakthrough occurs with high-frequency input interference in (*b*). The effects of discontinuities from cyclically switched loads are completely eliminated in the output of (*c*). A sinewave output results in (*d*) even with a square-wave input.**

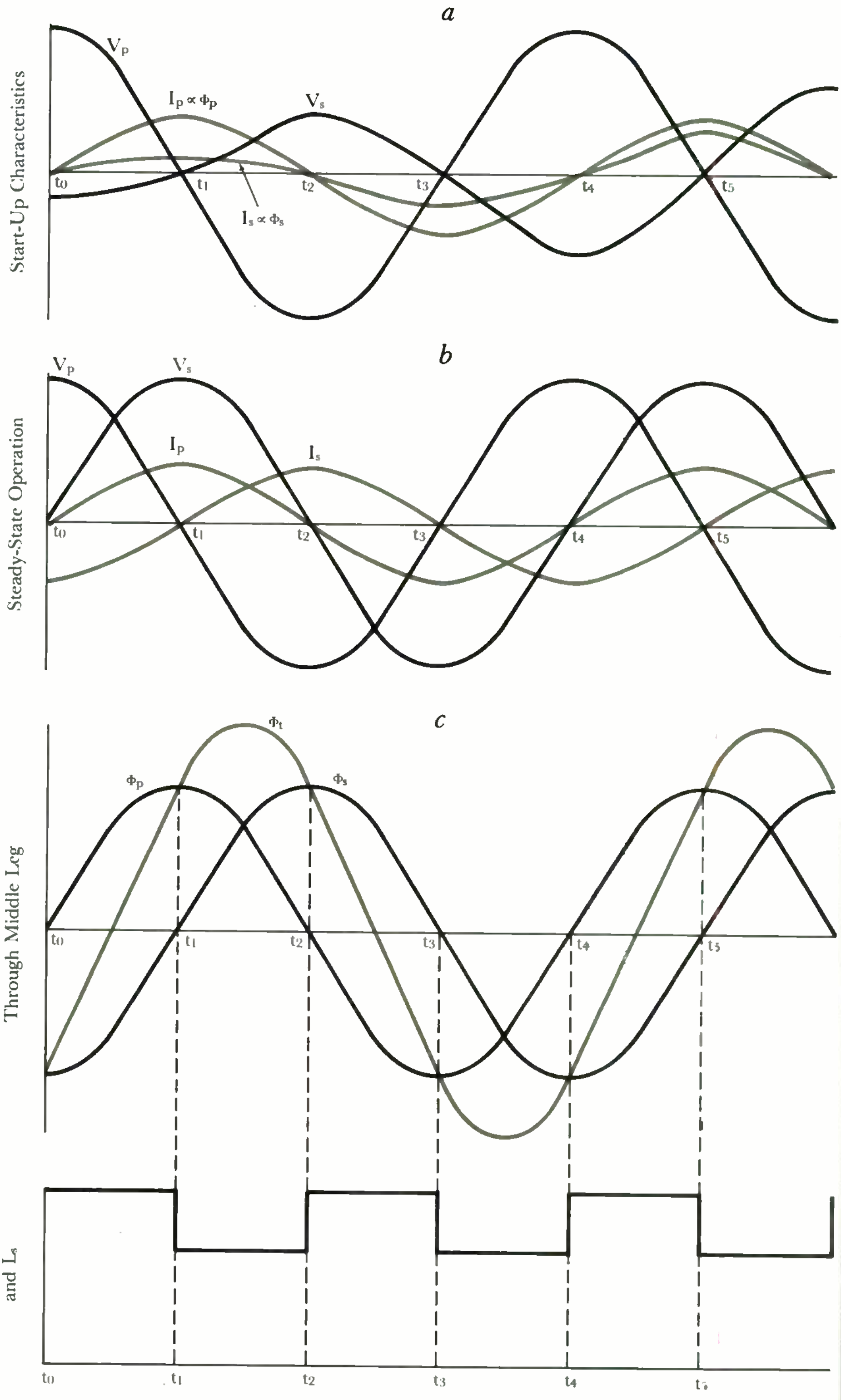
Parametric Transformer Operation

The parametric transformer (Fig. 1) appears to provide the designed output voltage, V_s, almost instantaneously once V_p is brought up to the minimum starting voltage. However, several cycles are needed for V_s to reach its proper value (*a*). Whenever some primary flux, Φ_p, begins traversing the output leg, a small secondary current, I_s, is induced in coil L_s. The capacitive load causes I_s to lead V_s by 90 degrees, thereby placing the flux produced by I_s in phase with Φ_p. Thus, Φ_s aids Φ_p as they traverse the output leg of the transformer. After I_s reaches a maximum value at time t_1, it starts to decay, charging the capacitor with voltage V_s at time t_2. During the next quarter cycle, the capacitor discharges, sending current back into L_s to restore Φ_s. Since Φ_s is aided by Φ_p, their interaction produces a net increase of total flux through the output leg and a corresponding growth of secondary current at time t_3. As the increased I_s decays during the next quarter cycle, the capacitor is charged to a new V_s maximum at time t_4.

Secondary current, flux, and voltage continue to grow in this manner until V_s reaches its operating value. Once this value is obtained, the device prevents further growth by automatically displacing the secondary voltage 90 degrees from the primary so that minimum phase interaction occurs between them (*b*). The fluxes become similarly displaced, but the direction of Φ_s is reversed so that flux addition only occurs in the middle leg (*c*). For simplification, all functions in (*a*), (*b*), and (*c*) are represented by sinusoids. With the tank circuit now resonating in the steady state, the capacitor draws only enough power from the input source to overcome losses, supply voltage for L_s to produce secondary flux, and maintain constant load voltage.

Unlike a conventional three-leg transformer, the parametric transformer, in the steady state, does not transfer energy to the secondary circuit by direct coupling with primary flux. Instead, it transfers energy parametrically, i.e., by periodically varying (pumping) one of the circuit parameters, which in this case is inductance. The inductance of a coil is given by $L = N^2 A\mu/l$, where A is the area of the core's cross section, N is the number of coil turns, l is the mean length of the flux path through the core, and μ is the core's permeability. All terms are physical constants except μ, which is a function of the flux density in the core. Thus, a change in the flux density in any part of a coil's flux path causes a change in the core's μ, and hence the coil's inductance.

In the steady state, the phase relationship of Φ_p, Φ_s, and the total flux ($\Phi_t = \Phi_p + \Phi_s$) through the middle leg is shown idealized in (*c*). At time t_1, the density of Φ_t becomes



great enough to substantially increase the reluctance of the middle leg. This high reluctance condition causes a drop in the middle leg's μ, which reduces the inductance presented by L_p and L_s. A quarter cycle later at time t_2, Φ_t declines, reducing the flux density sufficiently to revert the inductances of L_p and L_s to their original higher values. Thus, the inductances are pumped at twice the operating frequency, undergoing transitions each quarter cycle at t_1, t_2, t_3, etc.

When inductance L_p drops to its low value at t_1, Φ_p attempts to drop, but it is counteracted by the primary winding drawing additional current from the source. The net affect is an increase in L_p's electromagnetic energy ($U_B = LI^2/2$) at t_1. At this instant, the secondary current is zero, so the energy in L_s is zero. However, the rate of rise of I_s from t_1 to t_2 becomes a little greater than shown because L_s is attempting to oppose the low inductance condition instilled in it at t_1. When Φ_t becomes low enough to allow L_s to revert to its high value at t_2, the increased secondary current, gained by the faster rise, induces an extra emf ($e = -L\,di/dt$) that helps the secondary voltage, V_s, increase from zero at that time. Finally, at time t_3, V_s reaches its maximum, so the electrostatic energy in the capacitor is maximum ($U_E = CV^2/2$), and the energy transfer chain from primary to secondary circuits is complete. This entire sequence now repeats itself and continues to do so every half cycle.

Although this describes the basic operating principle, actual operation differs in that the period of time when inductance is low amounts to only about 15 degrees each half cycle instead of 90 degrees as illustrated. This is due to the somewhat abrupt, nonlinear magnetizing characteristic of the iron core, which causes the current and flux waveforms to become more pulse-shaped than those approximated with sinusoids. Thus, the device has excellent filtering ability, since interference can only be passed between primary and secondary magnetic circuits whenever they are coupled (the low-inductance interval). Stable operation can be obtained when the inductances are pumped at any multiple or submultiple of the tank's resonant frequency, but maximum efficiency is gained by pumping them at twice the resonant frequency as shown.

Under light or no-load conditions, any tendency for the resonating capacitor to charge up to an excessively high voltage is counteracted by the transformer. The device automatically adjusts the timing at which the inductances are pumped with respect to the phase of the corresponding currents, so that the energy in the capacitor reaches a fixed maximum each cycle. This results in a highly stable ac output voltage.

of the input voltage. Sustained reduction of input voltage does, however, cause an abrupt switch-off at some value dependent on the load. The standard line of parametric transformers has been designed for a 120-volt output at a tolerance of ±1 percent for an input variation of ±10 percent. (Other voltage ratings, however, can be designed if required.) *IR* drops in the windings produce some change in the output voltage with changing load (regulation). For the standard transformer line, load regulation is better than ±1½ percent no load to full load (Fig. 2).

The fact that the new transformer is a parametric device indicates an inherent degree of filtering ability. Parametric devices are noted for their ability to selectively operate at only one preset frequency, with high rejection of all others. Another reason for the unit's excellent filtering ability is that the input is effectively coupled to the output for only about 30 degrees each cycle. Typical attenuation of high voltage transients generally exceeds 63 dB; for high-frequency high-voltage interference, there is no discernible breakthrough. In addition, the effective decoupling of the input and output circuits for the major part of each cycle means that the output voltage waveform is virtually independent of the input. A sinusoidal output results whether the input is square, distorted with transients, or even multipulsed, so long as the input frequency is correct (Fig. 3).

Application Areas

The new parametric transformer is called the SW Transformer by its manufacturer, the Specialty Transformer Division. It is particularly useful in areas where sensitive equipment must operate from the same power lines as heavy industrial apparatus. Control computers, data-processing computers, and numerical controls are especially vulnerable to voltage variations of any kind; an SW Transformer used as a preregulator to the power supply helps provide the stable voltages needed for dependable operation.

Unwanted interference in the power line can often distort the results of laboratory experiments that use sensitive test equipment such as digital meters. The SW Transformer functioning as a voltage stabilizer and power filter eliminates this problem and frequently provides an extra degree of accuracy.

Another application lies in industrial lighting. Besides providing a constant light output, the transformer removes the interference that some lighting systems introduce back into the power line.

The new stabilizer also improves the consistency of exposures for photographic enlargers, and it has many uses in the medical industry where sensitive equipment must monitor and support human life. Other applications are use as an output transformer in a dc-to-ac inverter (which automatically provides sinewave filtering, output voltage stabilization, and short-circuit load protection) and as an ac-to-dc power supply or preregulator. The stabilizer may also be used as a one-to-three-phase converter by Scott-connecting input and output voltages, which are in quadrature, or even as a frequency changer (from 60 to 20 or 30 Hz).

Polyphase Induction Motors and Noise

P. K. Shenoy

Noise standards can be confusing without some basic understanding of the different ways in which noise is measured. With that understanding, the standards can be applied rationally.

Noise has become an increasingly important factor in the design and application of mechanical devices because of the growing realization that exposure to high levels over a long period can cause undesirable effects, including hearing damage. This growing concern with noise as an environmental hazard is reflected by the provisions on occupational noise exposure of state, local, and federal legislation, such as the Walsh-Healy Public Contracts Act.

Electric motors are the workhorses of the mechanized world, and the bulk of them are polyphase induction motors run on ordinary 60-hertz power. Consequently, the National Electrical Manufacturers Association (NEMA) has established recommended limits for the noise produced by these motors. Most standard induction motors meet the NEMA recommendations.

What Noise Is and How It Is Measured

Airborne noise, which is the subject of this article, is composed of sound waves of different intensity and frequency. A complete description of a noise should specify both sound pressure level (also called sound intensity) and frequency composition.

Sound Pressure Level—Sound pressure level is the measure of pressure exerted by the sound waves at any given location. It is expressed in a logarithmic unit called decibels (dB):

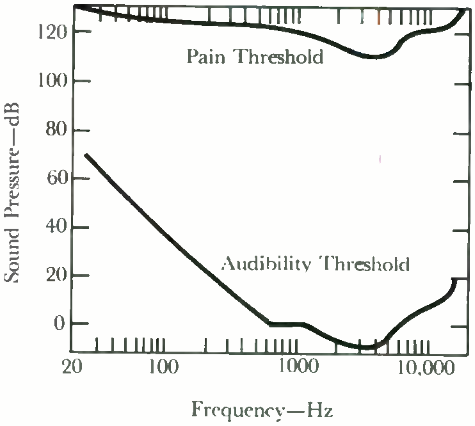
$$\textit{Sound Pressure Level} = 20 \log \frac{P}{P_{\text{ref}}},$$

where P is the actual measured pressure of the sound waves and P_{ref} is the reference pressure level equal to 0.0002 microbar. (This reference pressure level is the lowest pressure audible to the average person at 1000 hertz). Zero dB corresponds to a pressure level of 0.0002 microbar, or reference pressure level; a negative value indicates a level below the reference point, while a positive value indicates a level above it.

Frequency—The human ear is capable of responding to frequencies up to about 20,000 hertz, but its sensitivity varies with frequency as indicated in Fig. 1. The lower curve shows the minimum noise level, in decibels of pure tones of a given frequency, audible to human ears. For low frequencies, the threshold audible level is well above 0 dB, which happens to be the threshold level for a 1000-hertz pure tone. The threshold falls below 0 dB in the range between 2000 and 5000 hertz. The upper curve shows the threshold where the ears start feeling pain.

It is impractical to measure sound level at all frequencies, so for practical purposes the audio frequency range is divided into frequency bands. Each band is identified by a center frequency, a lower cutoff frequency, and a higher cutoff frequency. An octave band is a particular case of division such that the ratio between any two consecutive band center frequencies, or between the edge frequencies of the same band, is 2 to 1. Standard octave bands used for acoustical measurements are given in Table I. The first part shows the current standards; the second part, 1953 standards now superseded.

Sound pressure levels for each octave band can completely describe the noise of the device. However, a single value that takes into consideration the frequency composition is more desirable because it is simpler to measure and to use. Such a value is overall sound level, as read from standard sound-level meters with proper weighting. "Weighting" refers to a particular frequency response built into the measuring electronic circuit to provide predetermined gains over the whole audio range. The American National Standards Institute (formerly USA Standards Institute and, before that, American Standards Association) has provided three types of weighting networks, designated A, B, and C. In addition, there is a linear or "flat" scale in



1—(*Above*) The response of average human hearing for pure tones varies with frequency. The lower curve shows minimum audible sound levels; the upper, levels at which the ears start feeling pain.

2—(*Right*) Frequency response characteristics of standard sound-level meters illustrate the built-in circuit responses that produce the A-, B-, and C-weighted values. The A-weighted curve is especially useful because it closely approximates the response of the human ear to noise.

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which no gain is provided for any frequency. The frequency characteristics of the ANSI Standard weighting networks for sound-level meters are given in Fig. 2.

Of particular interest is the A-weighted curve because it closely simulates the actual response of the human ear. In it, large attenuation is provided for low frequency, none at 1000 hertz, and some gains between 1000 to 5000 hertz. This curve is a "flipped" image of the audibility threshold curve of Fig. 1 about the 0-dB axis. Use of A-weighted values is becoming more common for describing sound levels of all devices.

Sound Power Level—The sound pressure level for an overall or octave-band reading should also specify the location of the measuring point, since sound pressure varies with the distance from the source. Moreover, most practical devices such as motors, transformers, and machine tools do not radiate noise uniformly in all directions, so any single location does not give a true picture of the sound field around the device. To solve this difficulty, sound pressure level readings are taken at several points located on a well-defined geometrical contour such as a hemisphere. An average pressure level is determined and, from it, the average radiated sound power level (in decibels) is calculated:

$$\textit{Sound Power Level} = 10\ \textit{log}\frac{W}{W_{\text{ref}}},$$

where W is average sound power level and W_{ref} is reference power level equal to 10^{-12} watts. Sound power level readings are independent of the locations of the measuring points.

Induction-Motor Noise

The range of ac motors for which noise-level limits are presently available as NEMA authorized engineering information is shown in Table II. The motors are tested under no-load conditions at rated voltage and frequency. (Full-load noise tests are impractical, since one cannot isolate the noise of the driven load.) The test specification[1] allows for a single point measurement, a complete octave-band sound pressure analysis, or a complete octave-band sound power level analysis

*Table I. Octave Bands**

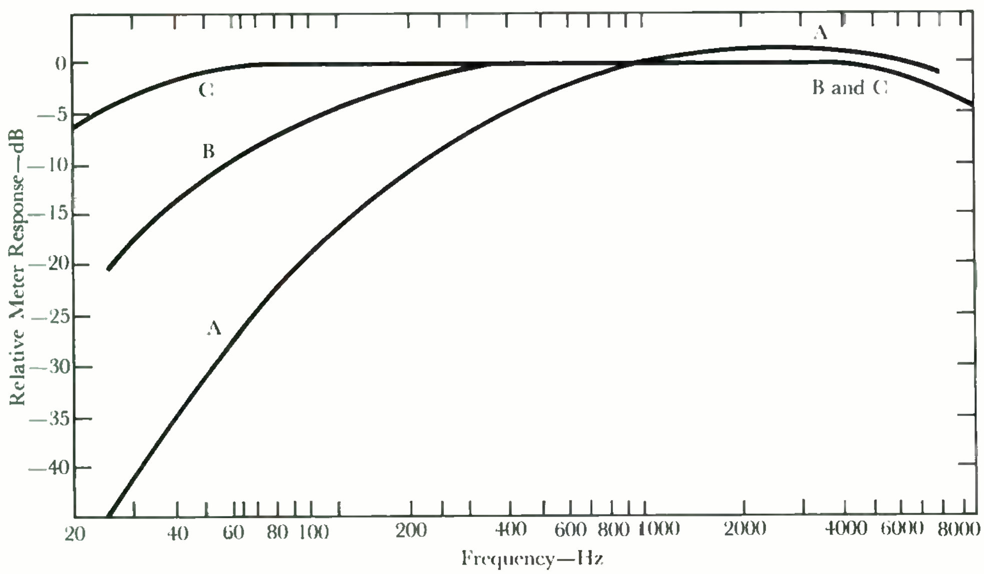
ANSI S1.6-1960, Preferred Frequencies for Acoustical Measurement		*ANSI Z24.10-1953, Octave-Band Filter Set for the Analysis of Noise and Other Sources*	
Band Edge Frequency	*Center Frequency*	*Center Frequency*	*Band Edge Frequency*
45/90	63	53	20/75
90/180	125	106	75/150
180/355	250	212	150/300
355/710	500	424	300/600
710/1400	1000	848	600/1200
1400/2800	2000	1695	1200/2400
2800/5600	4000	3390	2400/4800
5600/12,000	8000	6780	4800/9600

**Test Procedure for Airborne Noise Measurements on Rotating Electrical Machinery*, IEEE No. 85, Feb. 1965.

Table II. Motor Ratings Covered by NEMA Noise Information

Horsepower	*Speed (r/min)*	*Enclosure**	*Standard*
1.5—250	3600	DRPR	NEMA MG 1-12.49, Feb. 1970
1.5—150	3600	TEFC	
1—200	1800	DRPR	
1—150	1800	TEFC	
0.75—150	1200	DRPR	Being established by subcommittee
0.75—150	1200	TEFC	
0.5—100	900	DRPR	
0.5—100	900	TEFC	
All Other Ratings		All enclosures	No information established

*DRPR stands for "dripproof," TEFC for "totally enclosed fan-cooled."



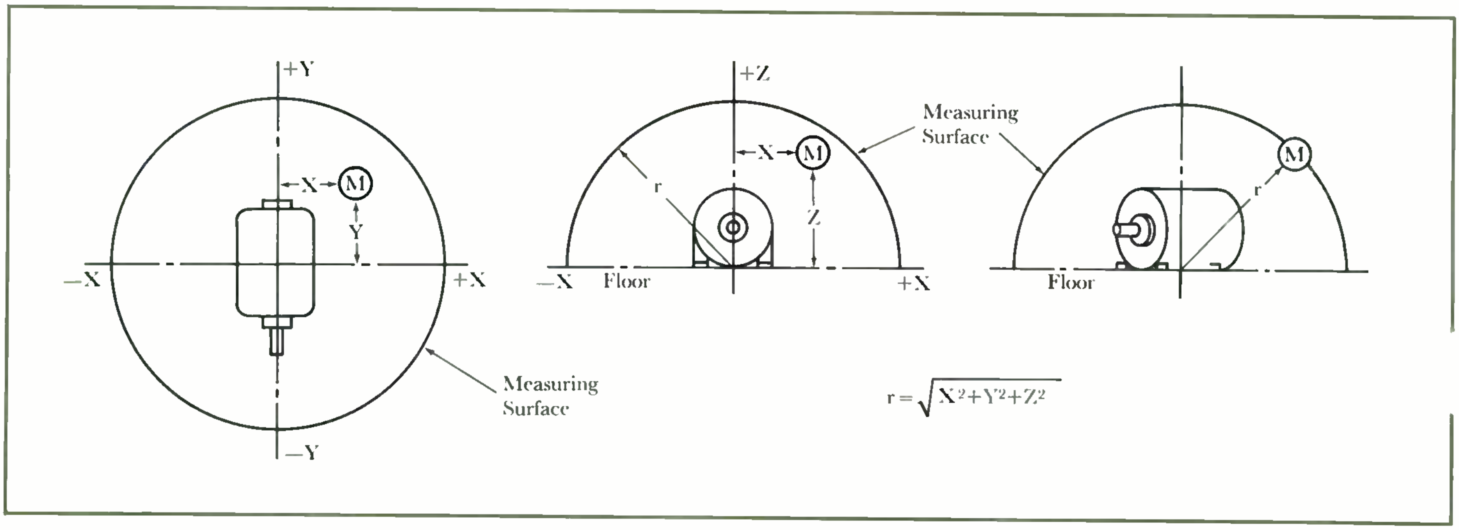


Table III. Noise Levels of Polyphase Squirrel-Cage Induction Motors

Horsepower	*Enclosure Type*	*Synchronous Speed (r/min)*	*Sound Power Levels (decibels, reference level = 10^{-12} watts)*							
			Octave Bands (center frequency, hertz)							*Overall Noise (A weighting)*
			125	*250*	*500*	*1000*	*2000*	*4000*	*8000*	
1.5, 2, 3	Dripproof	3600	57	65	73	71	68	66	61	76
5, 7.5		3600	64	71	79	75	72	68	64	80
10, 15		3600	73	79	82	79	76	70	68	84
20, 25		3600	77	83	85	82	79	74	73	87
30, 40		3600	82	87	88	85	82	77	77	90
50, 60		3600	87	92	92	89	86	80	81	94
75, 100		3600	92	95	96	94	90	84	85	98
125, 150		3600	96	97	100	97	93	87	88	102
200, 250		3600	99	99	103	101	97	91	91	105
1, 1.5, 2	Dripproof	1800	51	61	67	64	62	61	48	70
3, 5		1800	57	68	69	66	66	63	52	72
7.5, 10		1800	61	73	72	70	70	66	56	76
15, 20		1800	66	79	76	75	74	69	61	80
25, 30		1800	70	82	78	78	77	71	64	83
40, 50		1800	76	85	81	82	80	73	67	86
60, 75		1800	79	88	84	85	82	75	70	89
100, 125		1800	82	91	88	88	84	78	73	92
150, 200		1800	85	94	92	89	86	80	75	94
1.5, 2	Totally Enclosed Fan-Cooled	3600	69	75	81	84	82	76	72	88
3, 5		3600	72	79	85	87	85	80	77	91
7.5, 10		3600	75	82	88	90	89	84	80	94
15, 20		3600	79	87	92	93	93	88	84	98
25, 30		3600	82	89	95	95	95	90	86	100
40, 50		3600	85	92	98	98	97	93	88	103
60, 75		3600	87	95	100	100	99	95	91	105
100		3600	88	97	102	101	100	97	92	106
125, 150		3600	90	99	103	102	101	98	94	107
1, 1.5, 2	Totally Enclosed Fan-Cooled	1800	58	65	66	71	67	60	55	74
3, 5		1800	62	70	72	75	73	66	60	79
7.5, 10		1800	66	74	78	80	78	70	65	84
15, 20		1800	72	80	84	86	83	75	69	89
25, 30		1800	76	83	88	89	86	78	72	92
40, 50		1800	82	88	94	94	89	82	75	97
60, 75		1800	86	92	97	97	92	85	78	100
100		1800	89	95	99	99	94	88	80	102
125, 150		1800	92	99	101	109	97	90	82	104

The no-load sound power levels of Design A, B, and C polyphase squirrel-cage motors in Frames 143T to 445T, inclusive, generally do not exceed the values given when measured in accordance with the Feb. 1965 edition of IEEE Publication No. 85.
From NEMA MG 1-12.49, Feb. 1970.

3—(*Left*) Sound measurements are taken at several points around a motor and an average pressure level determined. The IEEE test specification used requires that microphones be located on a hypothetical hemisphere.

obtained from the pressure level readings. The tests are conducted in a controlled environment. Because motors do not radiate sound uniformly in all directions, the microphones are located on a hypothetical hemisphere as shown in Fig. 3, with 4, 6, or 12 measuring points on this contour. Tests are conducted in free-field (essentially echoless) or semi-free-field conditions, or in reverberant- or semi-reverberant-field conditions. The photos (page 50) show a semianechoic chamber in which semi-free-field conditions are created by a lining of wedge-shaped sound-absorbing material on all sides except the hard reflecting floor. Sound power level values established by NEMA as authorized engineering information for T-frame motors are given in Table III. The values broadly represent noise levels of motors that are typical of today's construction. Actually, a given motor built by any manufacturer may not have peaks in all the bands, with the result that overall values are less than those shown in the table.

The main noise sources in motors are electromagnetic, mechanical, and windage noises. Their frequency compositions vary with internal design.

International Standards for Motor Noise

Interest in noise standards is worldwide, and the International Electrotechnical Commission has a working group finalizing a document on airborne noise limits for rotating electrical machinery. Proposed limits for sound power level in A-weighted dB (dBA) are given in Table IV, while Table V gives the proposed limits for sound pressure level at a distance of one meter from the surface. Both types of values are proposed because some countries use one and some the other. No values are established for each octave band.

Table IV. Proposed IEC Limits for Sound Power Level (dBA)

Speed Range n (r/min) →	$n < 960$		$960 < n < 1320$		$1320 < n < 1900$		$1900 < n < 2360$		$2360 < n < 3150$		$3150 < n < 3750$	
Type of Ventilation →	*DRPR*	*TEFC*	*DRPR*	*TEFC*	*DRPR*	*TEFC*	*DRPR*	*TEFC*	*DRPR*	*TEFC*	*DRPR*	*TEFC*
Electrical Power P (kW)												
$P < 1.1$	—	76	—	79	—	80	—	83	—	84	—	86
$1.1 < P < 2.2$	—	79	—	80	—	83	—	87	—	89	—	91
$2.2 < P < 5.5$	—	82	—	84	—	87	—	92	—	93	—	95
$5.5 < P < 11$	82	85	85	88	88	91	91	96	94	97	97	100
$11 < P < 22$	86	89	89	93	92	96	94	98	97	101	100	103
$22 < P < 37$	89	91	92	95	94	97	96	100	99	103	102	105
$37 < P < 55$	90	92	94	97	97	99	99	103	101	105	104	107
$55 < P < 110$	94	96	97	101	100	103	102	105	104	107	106	109
$110 < P < 220$	98	100	100	104	103	106	105	108	107	110	108	112
$220 < P < 400$	100	102	103	106	106	109	107	111	108	112	110	114

Table V. Proposed IEC Limits for Sound Pressure Level at One Meter from Machine Surface (dBA)

Speed Range n (r/min) →	$n < 960$		$960 < n < 1320$		$1320 < n < 1900$		$1900 < n < 2360$		$2360 < n < 3150$		$3150 < n < 3750$	
Type of Ventilation →	*DRPR*	*TEFC*	*DRPR*	*TEFC*	*DRPR*	*TEFC*	*DRPR*	*TEFC*	*DRPR*	*TEFC*	*DRPR*	*TEFC*
Electrical Power P (kW)												
$P < 1.1$	—	67	—	70	—	71	—	74	—	75	—	77
$1.1 < P < 2.2$	—	69	—	70	—	73	—	78	—	80	—	82
$2.2 < P < 5.5$	—	72	—	74	—	77	—	82	—	83	—	85
$5.5 < P < 11$	72	75	75	78	78	81	81	86	84	87	87	90
$11 < P < 22$	75	78	78	82	81.5	85.5	83.5	87.5	86.5	90.5	90	93
$22 < P < 37$	77.5	79.5	80.5	83.5	83	86	85.5	89.5	88.5	92.5	92	95
$37 < P < 55$	78.5	80.5	82.5	85.5	86	88	88	94	93	96	95.5	98.5
$55 < P < 110$	82	84	85	89	88.5	91.5	90.5	93.5	92.5	95.5	95	98
$110 < P < 220$	85	87	87	91	90.5	93.5	93	96	95	98	96	100
$220 < P < 400$	86	88	89	92	92.5	95.5	94	98	95	99	98	102

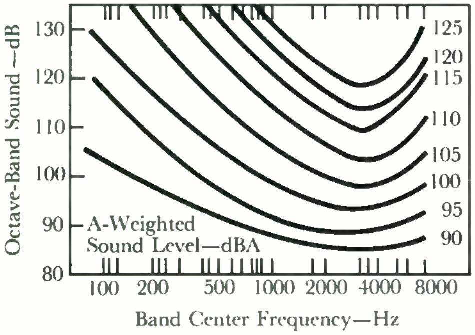
Tables IV and V are from *Draft Document on Noise Limits for Rotating Electrical Machines*, Technical Committee No. 2, Rotating Machinery, International Electrotechnical Commission.

Walsh-Healy Act

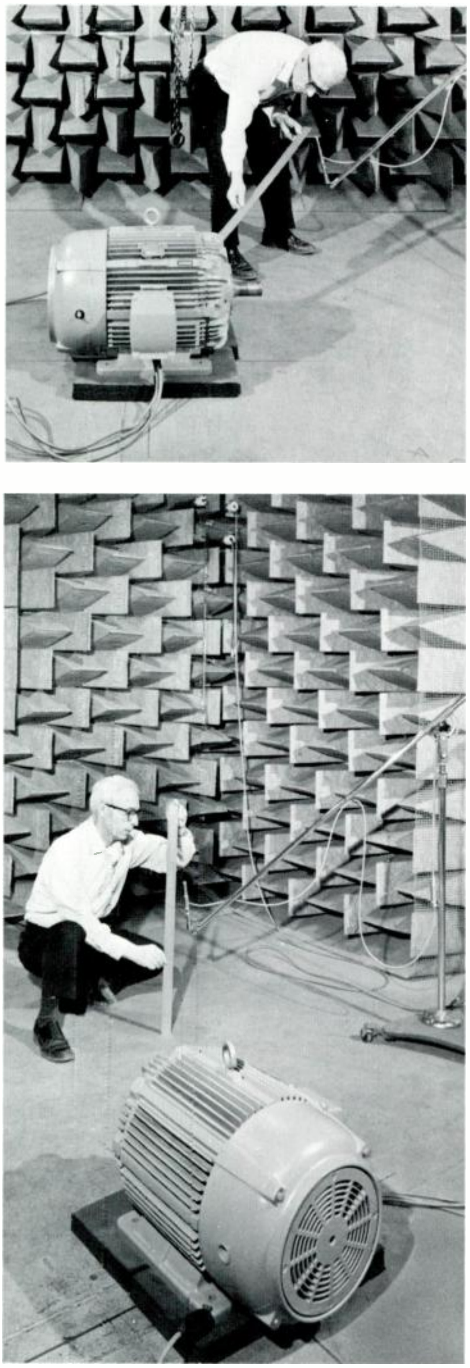
Of the many regulations in force to control noise levels, the provisions of the Walsh-Healy Act on occupational noise exposure have been most widely quoted and used. The A-weighted sound pressure levels permitted by it for daily exposure are shown in Table VI. When noise levels are determined by octave-band analysis of sound pressure level, Fig. 4 is used to determine the equivalent A-weighted sound level. The A-weighted sound level corresponding to the point of highest penetration into the octave-band sound level contours is taken as the A-weighted sound level. Then the period of exposure is determined from Table VI.

Table VI. Permissible Noise Exposures, Walsh-Healy Act

Duration per Day (hours)	*Sound Level (dBA)*
8	90
6	92
4	95
3	97
2	100
1½	102
1	105
½	110
¼ or less	115



4—The Walsh-Healy act provides this graph for users who can't apply Table VI directly because their data are in octave-band sound pressure rather than in A-weighted sound pressure. The user determines the A-weighted sound level corresponding to the highest point of penetration into the contours.



5—Tests are conducted in a controlled environment, in this example a semianechoic chamber. The chamber is lined with sound-absorbing wedges on all sides except the floor. The tester is locating a microphone with respect to the motor and the floor; it will transmit sound to measuring equipment outside the room.

There has been some misunderstanding about the use and application of this act; for example, some people have applied the limits directly to equipment. Actually, the limits given in the act refer to noise levels a human is exposed to at his work station. These levels depend on many factors such as the person's distance from the noise source, the number and types of sources in the vicinity, and their locations. Also, the numbers given in the table are sound pressure levels and not sound power levels. Typically, for a motor, the sound pressure level at 3 feet from the surface is about 10 dB less than the sound power level.

Conclusion

To summarize, noise is a complex subject but one in which concern for people's well-being has resulted in creation of industry standards and government regulations. The motor user as well as the motor manufacturer has a role to play in controlling noise exposure.

REFERENCE:

[1] *Test Procedure for Airborne Noise Measurements on Rotating Electrical Machinery*, IEEE No. 85, Feb. 1965.

Solid-State Rod Control System for Pressurized Water Reactors

F. T. Thompson

A solid-state rod control system has replaced a motor-driven cam-controlled contactor system for pressurized-water reactors. The first plant to use the new system was the Robert Emmett Ginna Plant of Rochester Gas and Electric Company, which began producing electricity for the Rochester, New York, area in December 1969.

A flexible, modular, highly reliable solid-state rod drive system for pressurized-water reactor plants has been proven by the trouble-free operation on the Robert Emmett Ginna PWR. Modular design permits the system to accommodate a wide range of plant sizes. It will be used on all nuclear plants that Westinghouse presently has under construction or on order.

Control-Rod Stepping Mechanism

As the demand for electrical power from a pressurized-water plant increases or decreases, the rate of heat generation in the nuclear reactor is adjusted by withdrawing control-rod assemblies if more power is needed, or inserting them if a decrease in power is desired. The Ginna reactor has 33 control-rod assemblies, each containing 16 absorber rods to control the rate of fission. Twenty-one full-length rod assemblies are used to control the rate of fission during normal operation; eight full-length rod assemblies are used for plant shutdown; and four part-length rod assemblies are used to control the neutron flux distribution within the reactor.

The system presently used to raise and lower the full-length control-rod assemblies incorporates a jack-type electromechanical mechanism within the reactor to withdraw or insert each assembly. Control rods are moved in steps of ⅝ inch, repeated as many times as necessary to move the rods to a position that produces the desired output from the reactor. Each jack mechanism (Fig. 1) includes three electromagnetic coils: one for gripping the rod to a movable member, one for lifting the movable member, and one for holding the rod in a stationary position. The coils are energized in a specific sequence. To raise (withdraw) a rod that is being held by the energized stationary coil, the following sequence is employed: the movable coil is energized, gripping the rod to the movable member; the stationary coil is de-energized; the lift coil is energized, raising the rod and the movable member; the stationary coil is energized, holding the rod in its new position; the movable coil is de-energized, releasing the rod from the movable member; and, finally, the lift coil is de-energized, permitting the movable member to fall to its original position. A similar sequence is followed for lowering the rod. In case of emergency, the reactor is shut down by de-energizing the stationary, movable, and lift coils so that rods fall by gravity to their fully inserted position.

The present jack-type mechanism is capable of operating at 72 steps per minute to provide a maximum rod speed of 45 inches per minute. This is a significant improvement over the previous mechanism, which had a step length of ⅜ inch and a rate of 60 steps per minute. The faster rod speed improves the capability of the plant to follow variations in electrical demand.

Since the new rod mechanism has a higher power requirement than the previous design, a redesign of the power supply for the electromagnetic coils was necessary. The current supplied to the coils of the previous mechanism was controlled by means of electrical contactors that connected the coils across a regulated dc voltage in the proper sequence. The sequence was generated by a motor-driven set of cams, rotated one revolution per step. This fixed-voltage, on-off switching arrangement was satisfactory for the lower-speed, lower-power mechanism, but it is not so well suited to the higher-power design. For example, coil resistance varies considerably as coil temperature varies over a range from 25 degrees C to the maximum operating temperature of 200 degrees C. The excess current over the required value would increase the operating temperature of the coil and shorten its life. Furthermore, the energy stored in the inductance of the coil must be dissipated in the contacts or suitable transient suppression devices. This dissipation can be a limiting design factor at higher stepping rates. And finally, a timing malfunction could cause excessive dissipation in the coils due to high-current excitation for an extended period.

Solid-State System

To avoid those problems inherent with a cam-controlled contactor system using fixed-voltage on-off switching, a new solid-state rod control system was developed. It is highly reliable and improves operating conditions to increase mechanism life.

A simplified diagram of the rod control power supply system is shown in Fig. 2. Three-phase ac power is supplied by two separate motor-generator sets, which are driven from two sources of ac power. The generators are synchronized to provide a single source of redundant three-phase 60-Hz power. The redundancy is needed to ensure a reliable continuous source of power to the mechanisms.

A separate controlled rectifier assembly is used for each subgroup of four lift coils, movable gripper coils, and stationary gripper coils. A simplified diagram of a rectifier circuit is shown in Fig. 3. The load, which consists of the mechanism coils, is highly inductive and results in a nearly constant current during a line-voltage cycle. Under steady-state conditions, the magnitude of the current is proportional to the average voltage applied by the controlled rectifiers. This voltage is controlled by adjusting the phase of the firing pulses applied to the gates of thyristors *Q1*, *Q2*, and *Q3*. The voltage applied to the load for three different firing angles is shown by the heavy dark curve; the resulting load current is also shown. The use of a three-phase ac voltage permits simple, reliable, natural commutation of current from one thyristor to another.

Problems that could result from power-source voltage variation, coil resistance tolerance, and a 1.7-to-1 variation of coil

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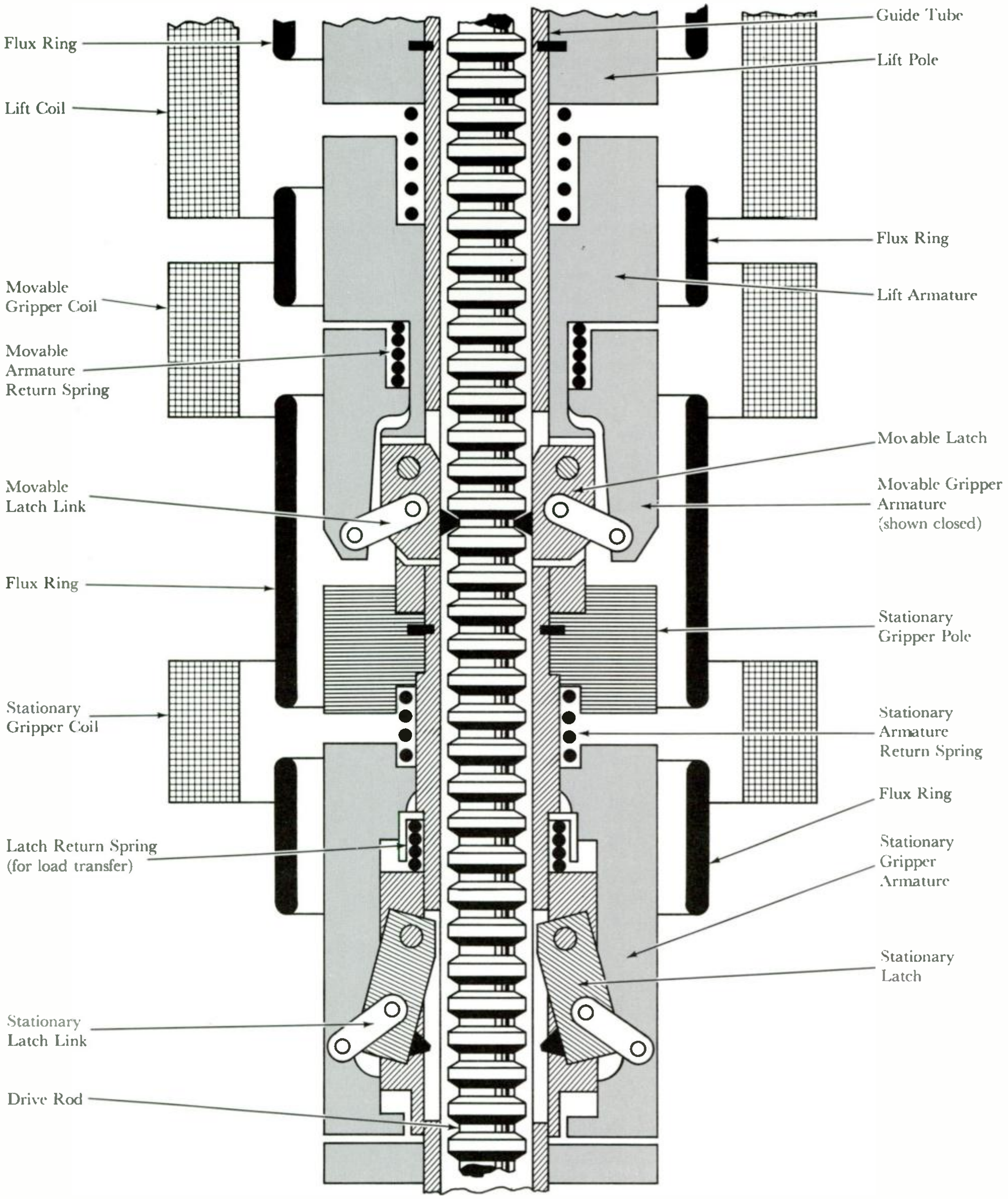
The author acknowledges the many contributions of André Wavre, who carried this development to a successful conclusion, and he thanks Dean Santis for his contributions to the logic unit.

1


Flux Ring
Lift Coil
Movable Gripper Coil
Movable Armature Return Spring
Movable Latch Link
Flux Ring
Stationary Gripper Coil
Latch Return Spring (for load transfer)
Stationary Latch Link
Drive Rod
Guide Tube
Lift Pole
Flux Ring
Lift Armature
Movable Latch
Movable Gripper Armature (shown closed)
Stationary Gripper Pole
Stationary Armature Return Spring
Flux Ring
Stationary Gripper Armature
Stationary Latch

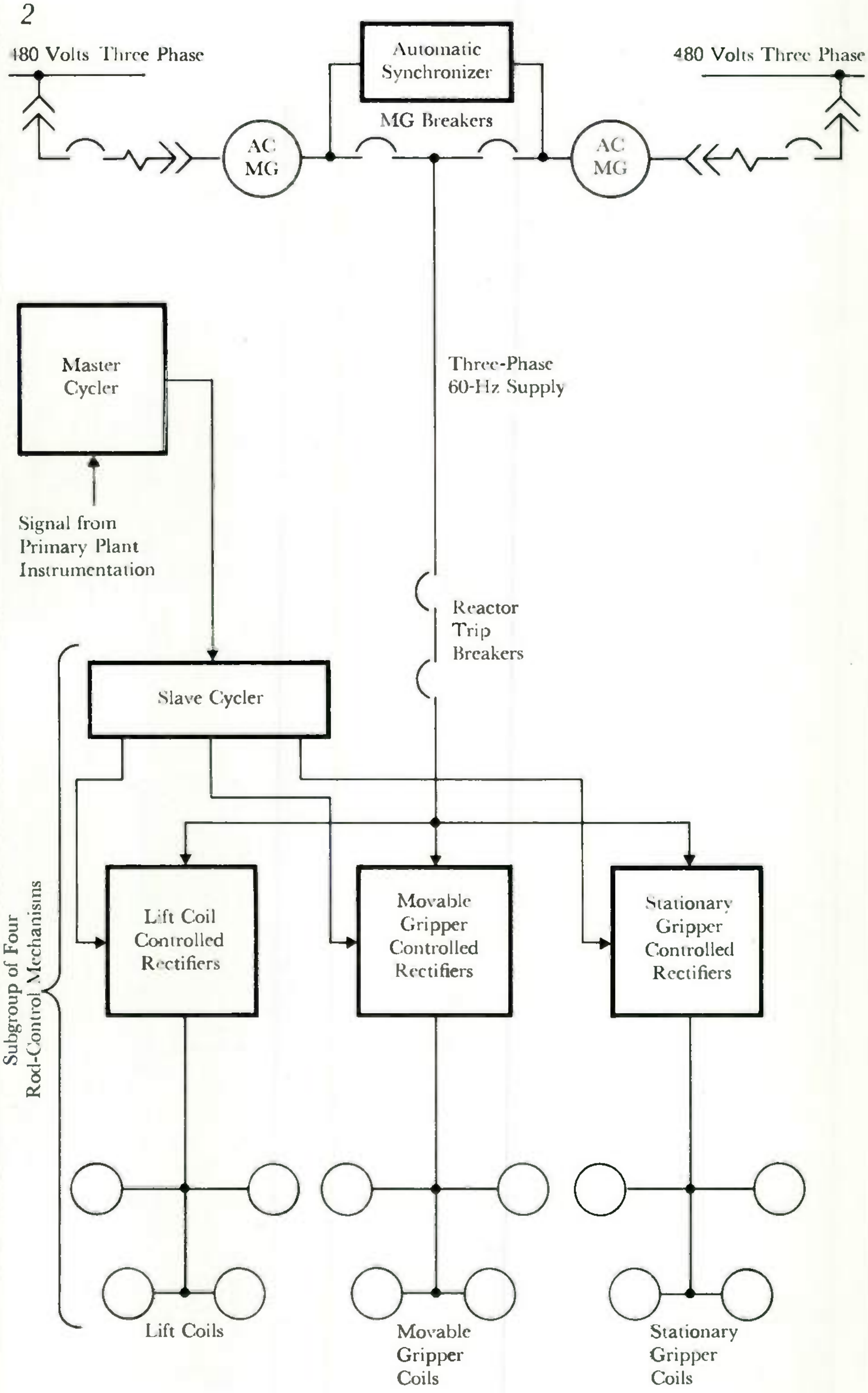
resistance with temperature are avoided by using a closed-loop system to regulate coil current. The load for a set of thyristors consists of four coils connected in parallel. A diode in series with each coil prevents current from circulating between the coils. A precision current-monitoring resistor is also connected in series with each coil as shown in Fig. 4. The largest of the four currents is compared with a current reference signal by the auctioneering current regulator, and the error signal is used to control the phase angle of the firing pulse generator. In this manner, coil current can be controlled at any desired value and is relatively independent of line voltage and coil resistance.

The ability to regulate current results in lower coil dissipation and therefore lower coil temperature and longer mechanism life. A comparison of the lift-coil current waveforms for the contactor and solid-state systems is given in Fig. 5. In both systems, current is permitted to increase with full-voltage forcing until a current level is reached which ensures that mechanical movement has taken place. The solid-state system then regulates the current at this value, independent of power supply voltage and coil temperature. In the contactor system, current rises to a higher value, determined by supply voltage and coil resistance.

After mechanical movement has been achieved, the magnetic air gap is reduced and less current is required to hold the lift coil in the raised position. The current is reduced as shown, which permits a reduction in dissipation and faster decay of current when mechanism release is desired. In the solid-state system, the power dissipation problem is solved by returning power to the m-g set when the current is suddenly reduced rather than being dissipated in an arc. Furthermore, only normal line voltage appears across the coils, which reduces voltage stress on the coils and connecting cables.

A separate current-regulating loop is provided for lift coils, movable gripper

2



1—Rod control drive mechanism.

2—Rod control power supply system.

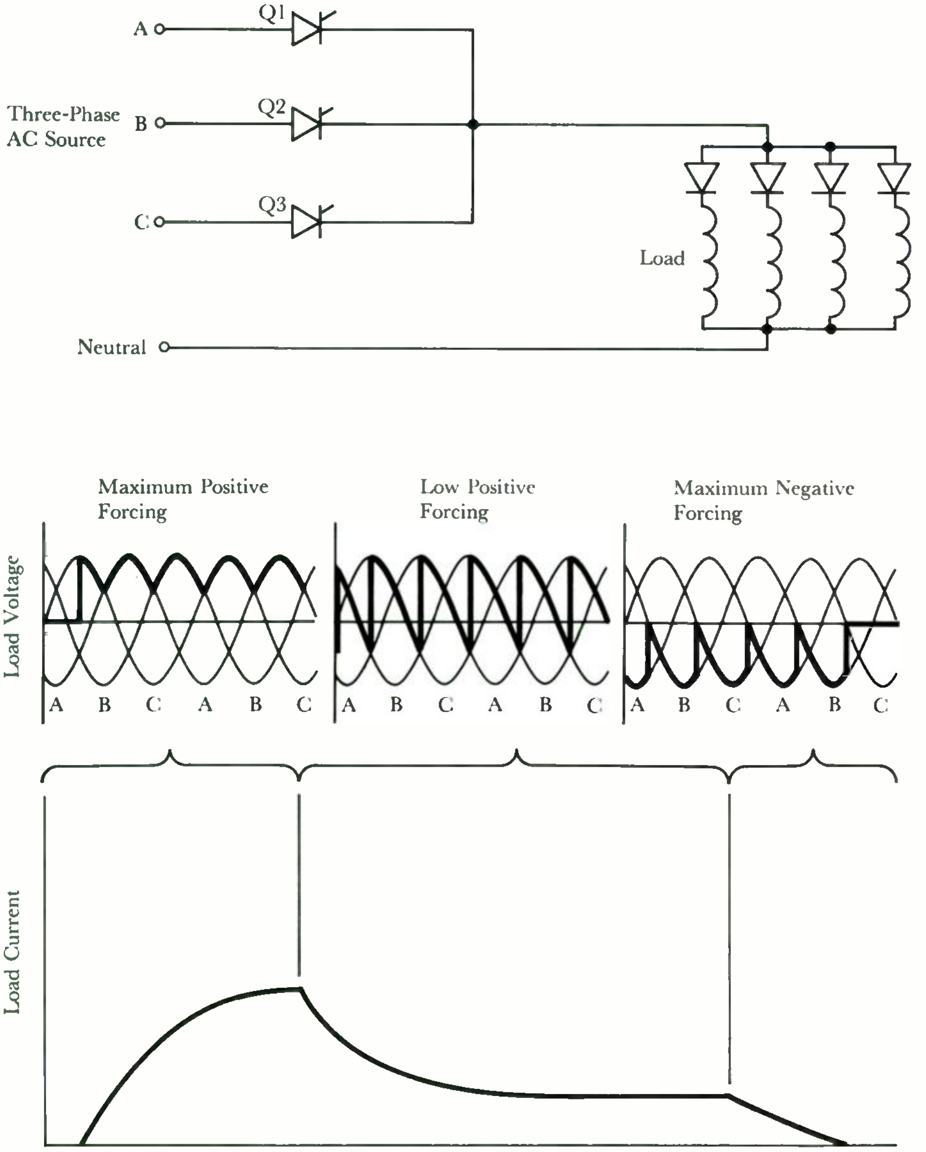
coils, and stationary gripper coils. The current values correspond to the reference command signals applied to the current regulators, as shown on the withdrawal and insertion sequences shown in Fig. 6. The 780-millisecond sequence corresponds to one mechanism step. The system remains at time zero until the master control calls for a mechanism step, and then a single sequence is initiated. The rate of rod movement depends on how often a sequence is initiated.

The mechanical slave cycler used in the contactor system has been replaced by the integrated-circuit solid-state slave cycler shown in Fig. 7. The input *go* pulse line is energized to initiate a cycle. This sets the pulse-control circuit and permits the 164-Hz square wave to drive a counter. Specific counts are recognized sequentially by the decoder and initiate full-current, reduced-current, or zero-current orders to the lift, movable-gripper, and stationary-gripper signal generators. A completion signal from the decoder signals the end of the 128-count sequence, resets the pulse control circuit, and holds the counter in the zero state. One slave cycler is required for each independently operated power supply.

Plant Organization

The maximum configuration plant contains four control banks of three groups per bank, and two shutdown banks of three groups per bank. If each group of each bank had to be moved independently at any instant, 18 power supplies would be required. Fortunately, this is not the case because shutdown rods are not operated at the same time as control rods. The shutdown rods are fully withdrawn during plant startup and remain there until plant shutdown is desired. Therefore, a multiplexing system permits rod power supplies to be shared between control banks and shutdown banks. Furthermore, the plant is organized so that the rods of banks *A* and *C* are never moved at the same time, which permits power supplies

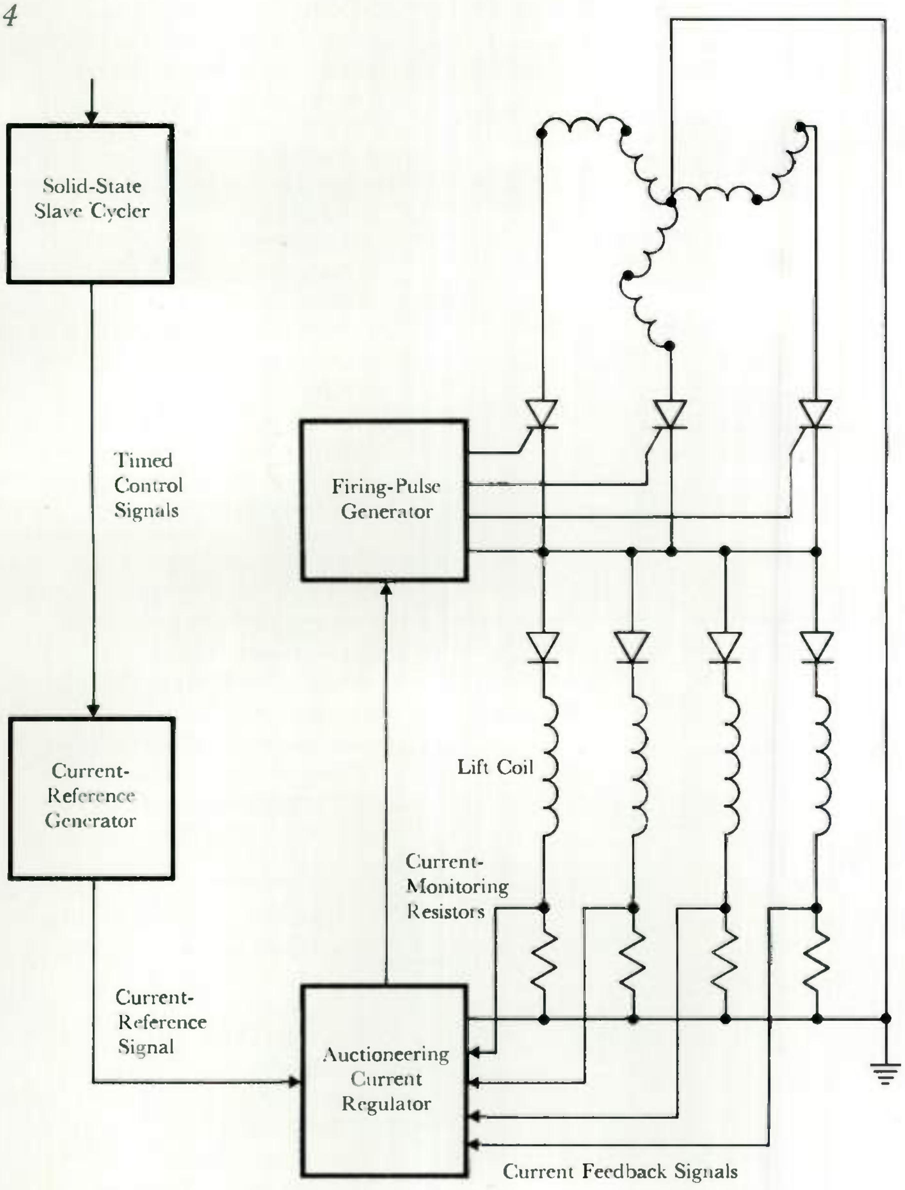
3

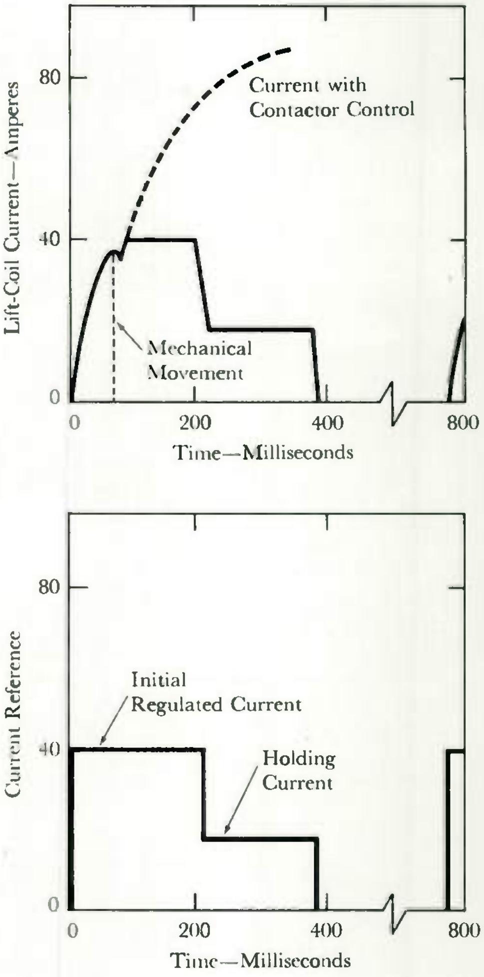


3—Phase-controlled thyristor operation.

4—Current regulator system.

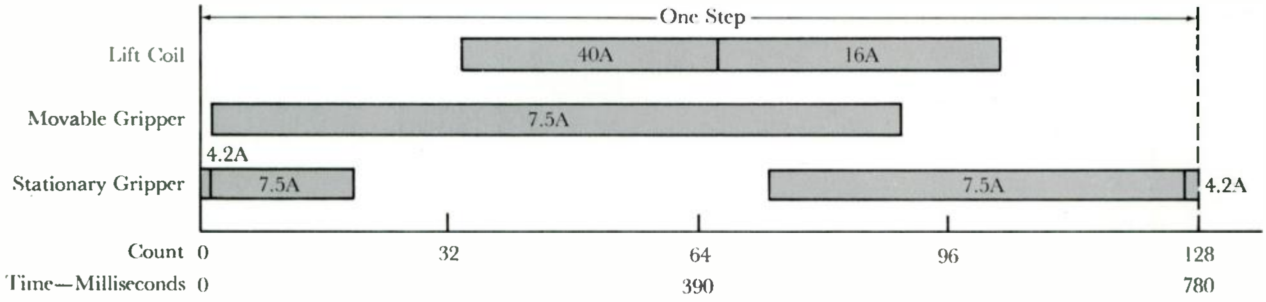
4



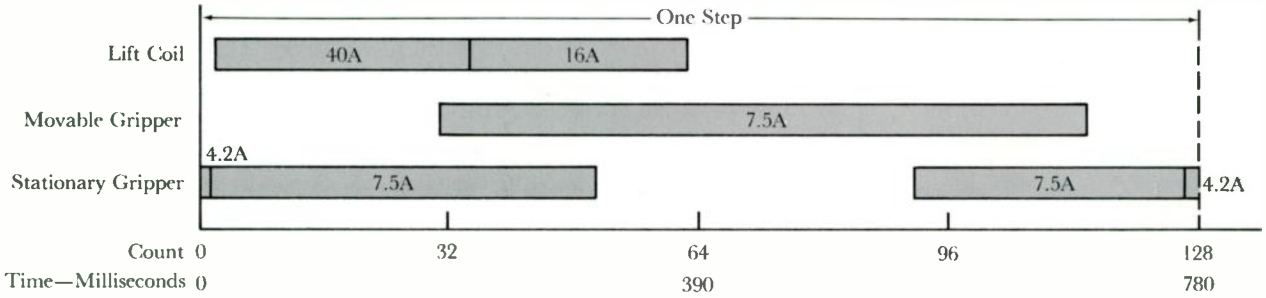


5—Lift coil current waveform and current reference signal.

6

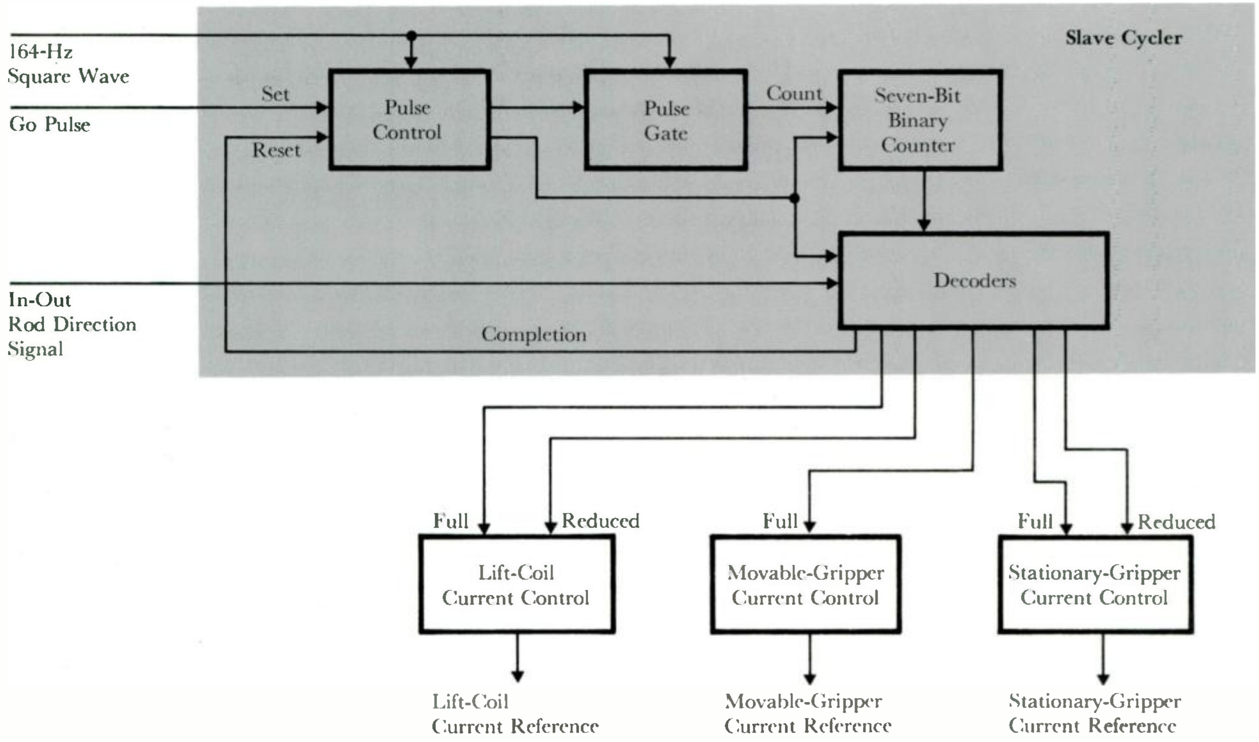


Withdrawal Sequence



Insertion Sequence

7



to be shared between these banks. Similarly, the rods of banks *B* and *D* are never moved simultaneously. As a result, the maximum four-bank configuration requires only six power supplies for the control and shutdown banks. These supplies are designated *1AC*, *2AC*, *3AC*, *1BD*, *2BD* and *3BD*. The *1AC* supply is shared by control bank *A* group 1, control bank *C* group 1, and by shutdown bank *A* group 1. Similarly, the designations *2AC* and *3AC* refer to groups 2 and 3 respectively of banks *A* and *C*. The *1BD* supply is shared by control bank *B* group 1, control bank *D* group 1, and shutdown bank *B* group 1. The *2BD* and *3BD* supplies control groups 2 and 3 of these banks.

The arrangement of banks, groups, and mechanisms for the Rochester Gas and Electric system is shown in Table 1. There are four control banks of two groups each and one shutdown bank of two groups. Each group consists of a number of mechanisms that are electrically paralleled to step simultaneously. The two groups in a bank are moved sequentially so that they are always within one step of each other. For example, at 6 steps per minute, the first group begins a step at time zero and completes it in 780 milliseconds. The second group starts its step at 5 seconds after time zero, also completing it in 780 milliseconds. At the maximum stepping rate of 72 steps per minute, the second group starts its step before the first group completes its step.

The control banks are overlapped to obtain a more uniform reactivity change per step. As shown in Fig. 8, the rods of control bank *A* are withdrawn until step *S1* is reached. From step *S1* to step *S2*, the rods of bank *B* move in synchronism with those of bank *A*. After step *S2*, the rods of bank *B* move alone until step *S3*, at which point they move in synchronism with those of bank *C*. Similarly, banks *C* and *D* overlap from step *S5* to step *S6*. The overlap set points, *S1* through *S6*, are preset by six digital thumbwheel switches located in the logic cabinet.

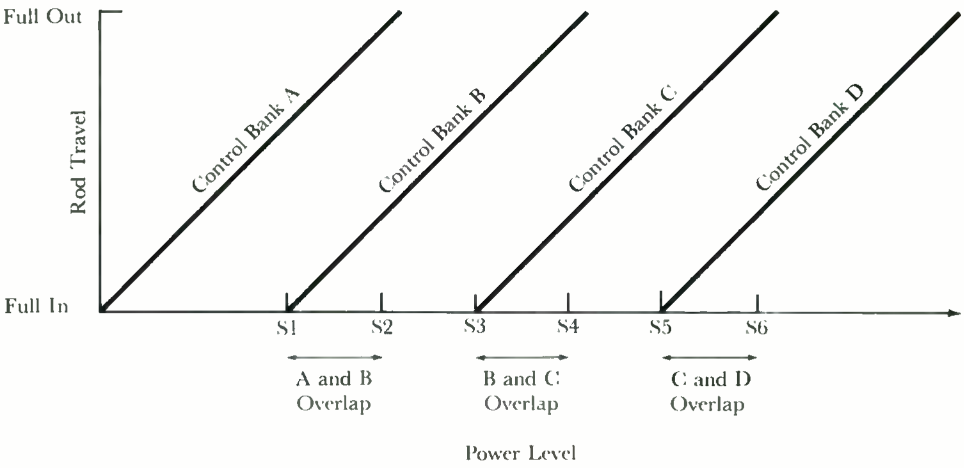
Overall System

The overall rod-control system for the Ginna plant is shown in Fig. 9. The mode of system operation is controlled by the *bank selector switch*, which may select the shutdown bank or any control bank for manual operation as controlled by the *in-out* lever at a selected stepping rate between 6 and 72 steps per minute. When the selector switch is placed in the automatic position, the *reactor control system* determines the *in-out* rod direction and stepping rate needed to achieve the desired average temperature of the reactor coolant. The *master cycler* selects which group within the selected bank or banks is to be moved and provides *go* pulses to the appropriate slave cyclers. The *slave cycler* upon receiving a *go* pulse initiates a single insertion or withdrawal sequence, depending upon the *in-out* direction signal. The *slave cycler* generates current order signals for the stationary-gripper, movable-gripper, and lift-coil supplies in its associated power cabinet.

The *bank overlap* unit automatically selects which control bank is to be stepped

Table 1. Bank and Group Organization

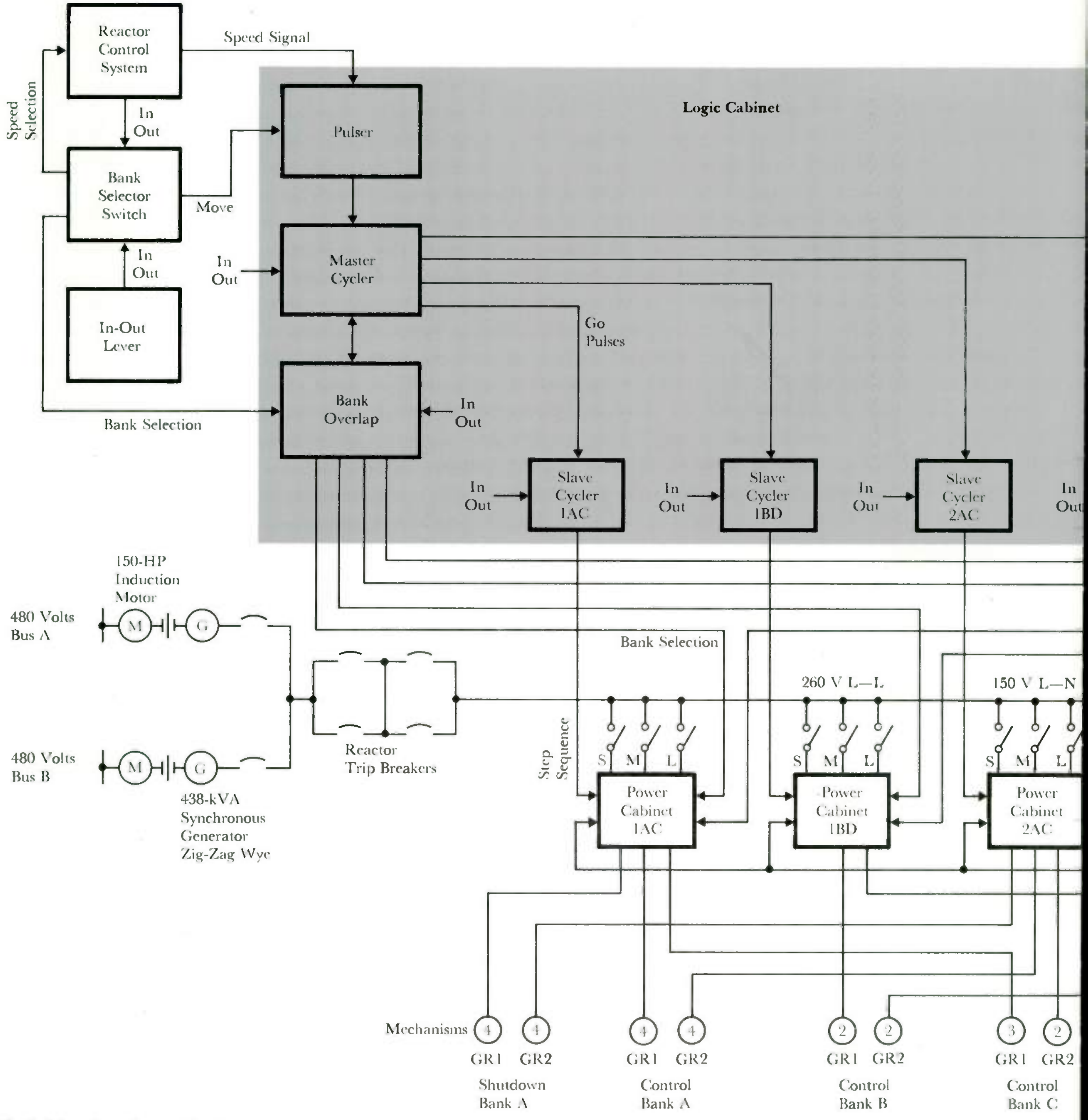
Bank	*Group*	*Power Cabinet*	*Number of Mechanisms per Group*
Shutdown Bank A	1	1AC	4
Shutdown Bank A	2	2AC	4
Control Bank A	1	1AC	4
Control Bank A	2	2AC	4
Control Bank B	1	1BD	2
Control Bank B	2	2BD	2
Control Bank C	1	1AC	3
Control Bank C	2	2AC	2
Control Bank D	1	1BD	2
Control Bank D	2	2BD	2
Part-Length Rod Bank		(separate control system)	4
Total Mechanisms			33



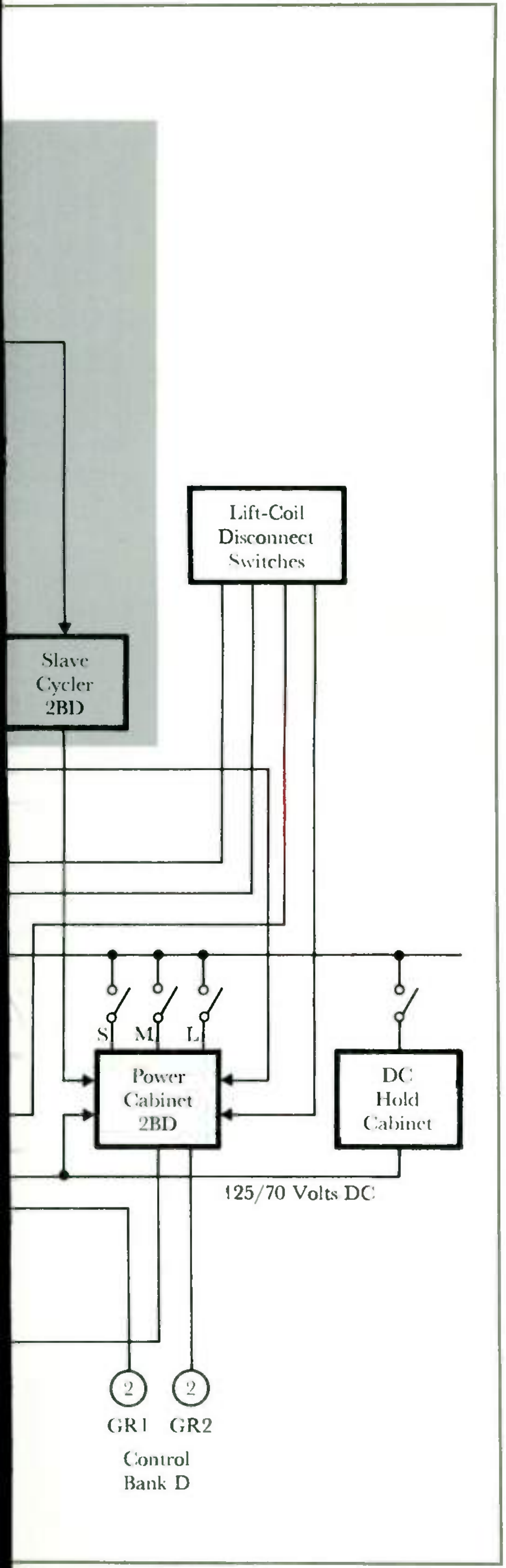
6—Slave cycler sequences.

7—Slave cycler and current reference generators.

8—*(Right)* Control bank movement.



9—Full-length rod control system.



and overlaps the banks in accordance with a predetermined pattern. The bank selection signal from the bank overlap unit controls which bank a given power supply cycles. Only one of the banks connected to a given supply may be moved at a time.

A failure in the power cabinet may require the replacement of a fuse, circuit card, or other component. A dc hold supply is connected through three switches in each power cabinet to energize any one of the three groups of stationary gripper coils. This avoids the possibility of dropping a rod during maintenance. Lift coil disconnect switches are also provided to permit moving individual mechanisms to achieve rod alignment.

Failure Detectors

A unique feature of the solid-state rod drive system is its ability to automatically detect and localize equipment failures. The voltage corresponding to a maximum current order is sensed in each current regulating system. If the maximum current order exists for longer than a specific length of time, a condition which could overheat the mechanism coil, an *urgent alarm* signal is actuated in the control room and a light on the offending power cabinet is energized to indicate the source of the trouble.

A failure of one of the phases of the phase controlled thyristor regulators is detected by a ripple detector which recognizes the excessive ac ripple caused by this type of fault. This fault causes an *urgent alarm* signal and the energizing of a different light on the offending power cabinet.

The failure of the current regulation system is indicated by a demand for full-positive or full-negative forcing for an excessive period of time. This failure causes an *urgent alarm* and an appropriate indication at the offending power cabinet.

A logic error detector senses if the stationary-gripper and movable-gripper current orders are zero at the same time. This condition would drop a rod assembly, so it causes an *urgent alarm* and results in a holding current order being supplied to all grippers, thereby preventing rod dropping. The disconnecting of any circuit board is detected and also results in an *urgent alarm*.

Redundant dc power supplies are provided to ensure reliable operation of the system. In case of a failure of one of a redundant pair of supplies, a *non-urgent alarm* is given that indicates the need to service the defective supply.

Conclusion

The solid-state rod control system provides regulated current to the rod mechanisms, thereby enhancing mechanism life and performance. Power dissipation in the mechanisms and the equipment is minimized because inductively stored energy is returned to the ac power source. System down-time is minimized through conservative design and the use of automatic failure detection to localize and identify equipment failures, thereby facilitating rapid servicing.

Technology in Progress

Mine Rescue and Survival System Being Evaluated

Although underground coal mining has the most stringent safety regulations of any of the mining industries, it is still the most hazardous. Ripping coal from a subterranean workplace can churn up coal dust and also release methane gas, both of which form explosive mixtures with air. Cave-ins and fire often follow an explosion, and both can also occur without an explosion. For those reasons, a program has been launched by the U.S. Interior Department's Bureau of Mines to turn a conceptual study of coal-mine rescue and survival systems into hardware. The program is being carried out and tested by the Special Systems Division, Westinghouse Defense and Space Center.

The rescue and survival system has three basic objectives: to enable miners who have survived a disastrous explosion to survive the equal dangers that immediately follow, including carbon monoxide poisoning, smoke inhalation, suffocation, roof falls, and additional explosions; to enable miners to receive and send emergency communications regarding their locations, available escape routes, nearby dangers, and rescue advice; and to provide an escape shaft if operating shafts or tunnels cannot be safely used. To meet those objectives, the system includes improved personal breathing apparatus, survival shelters, rescue communicating and locating equipment, and rescue drills. Rescue components are designed to be transported quickly by trucks or by cargo aircraft and helicopters.

Personal breathing apparatus is needed because a fire or explosion may leave insufficient breathable air. Present law requires that each miner have an emergency breathing device called a self-rescuer. However, the self-rescuer only filters out poisonous carbon monoxide: it depends on oxygen remaining in the mine atmosphere.

The breathing apparatus included in the new rescue and survival system is like closed-circuit scuba diving equipment: it provides a supply of oxygen and also filters out carbon dioxide after each breath to enable its user to rebreathe unused oxygen. Chlorate candles provide the oxygen. The unit is about the size of a cigar box when stowed in its carrying case, and it weighs 7 pounds.

Two types of survival shelter have been designed. One is a 15-man portable shelter to provide a place of refuge near the mine face as work advances. The other is a large centrally located permanent chamber that could accommodate 50 men for two weeks.

The portable shelter's arched walls are made of ribbed steel. The permanent shelter would be a 75-foot tunnel in rock with reinforced-concrete blast walls at each end; an 8-inch pipeline to the surface would provide a channel for fresh air, communications, and additional supplies.

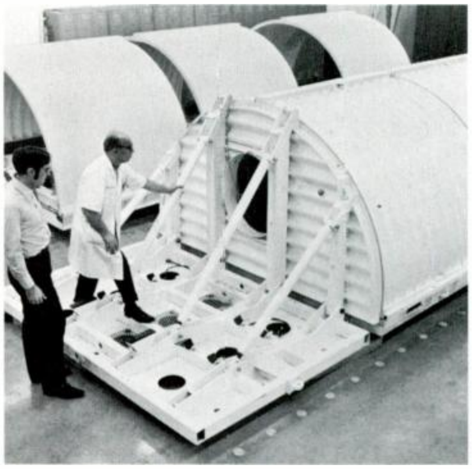
The emergency communications equipment consists of two systems, one for through-the-earth radio transmission of voice or beacon messages and the other enabling rescuers to detect seismic vibrations made by a trapped miner thumping with a pick, sledge, or timber.

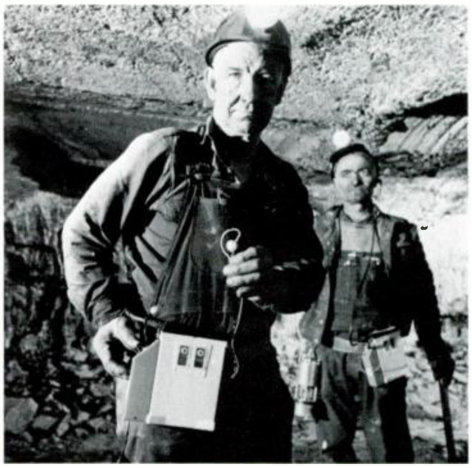
Ordinary radio waves cannot travel through earth, but very low frequency waves can, so they are used in the radio system. Each miner would have a miniature receiver attached to his headlamp battery case. In an emergency, the miner would turn on the receiver and listen for instructions. When he reached one of the shelters, he would find there a more powerful receiver and a pushbutton beacon transmitter.

The transmitter sends signals rather than voice to conserve its two-week battery power supply. It has six buttons for sending signals meaning "yes," "no," "unknown," "repeat," "good," and "bad," and it also has a key to answer questions by number of pulsed responses.

The seismic communications system employs a number of geophones on the surface to pick up the tiny earth tremors made by a signaling miner. The information is fed into a small computer that locates the signal's place of origin.

Two drills have been designed and built for rescuing miners when they can't come out through the mine shaft. (See photograph on back cover.) One would

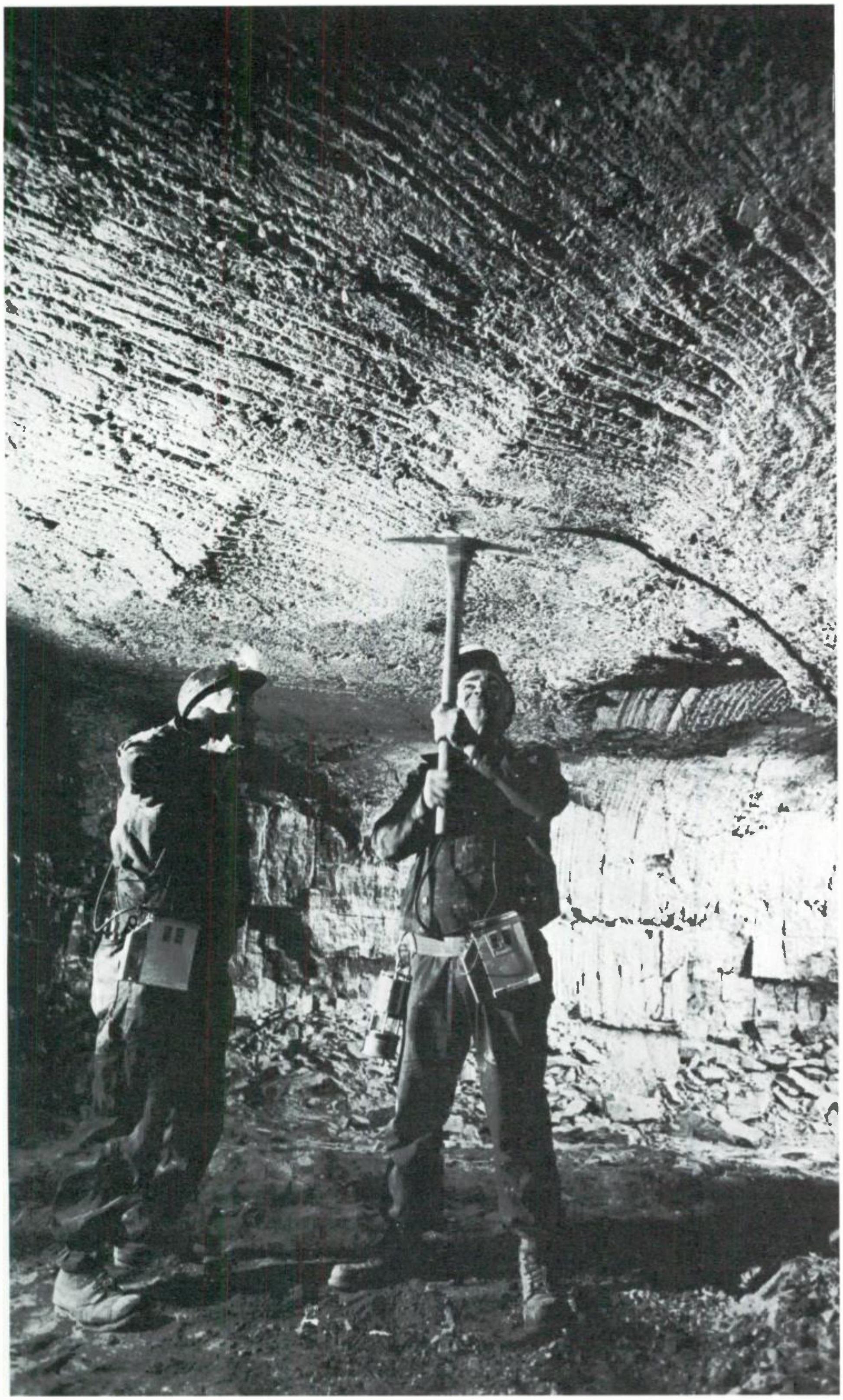




Top—**Portable shelter is part of the survival equipment. Its six modules would be stored close to the working face of the mine and assembled if needed. Supplies would be stored under the floor.**

Bottom—**Radio receiver, attached to the side of each miner's headlamp battery case, has an ear-plug speaker. Voice transmission from the surface over very low frequency waves would penetrate the earth to give the man emergency instructions.**

Right—**Seismic communication system enables miners to signal their locations. They thump on the mine wall or ceiling, and geophones on the surface pick up the vibrations.**



rapidly bore a hole 9 inches in diameter to the trapped men to supply fresh air, food, medical supplies, and wire communications. Then the other would drill a 28½-inch hole for pulling the miners out in a personnel capsule.

The smaller drill can bore as fast as 100 feet an hour; the larger operates up to 17 feet an hour. Both were designed and developed by Rowan Drilling Company, Houston, Texas.

Automatic Meter-Reading Tests Employ Telephone Lines

In field tests of an automatic meter-reading system, the Westinghouse Meter Division has successfully read electric, gas, and water meters of selected residences in Holmdel, New Jersey, from its development laboratory in Raleigh, North Carolina. Overall performance data showed accuracy to be better than that of manual reading. The cooperating companies were Jersey Central Power and Light Company, New Jersey Natural Gas Company, New Jersey Bell Telephone Company, and Monmouth Consolidated Water Company.

System operation was controlled by a decoder terminal in the laboratory. The terminal initiated a reading by transmitting the last four digits of the phone number of a particular home to the Holmdel central office, which had a data communication terminal furnished by American Telephone and Telegraph Company. The central office also had a special meter-reading access circuit that sent a signal to a meter-reading data set located at the residence without ringing the customer's phone. The data set, in turn, signaled the Westinghouse multiple encoder to transmit the three meter readings plus the identification code for that particular encoder. Data was returned through the access circuit to the data communication terminal, which then transferred the readings to the decoder for display. Allotted time for data transmission was 2 seconds, after which the meter-reading data set blocked transmission from the encoder and restored the phone line for normal service.

Eighteen homes were equipped. Readings were taken twice each working day between 8 a.m. and 4 p.m., amounting to 3064 calls over the duration of the tests. Since each call consisted of three meter readings, there was a total of 9192 readings. Only five percent of the calls could not be completed at the time they were made because of line access failures or line busy signals.

Thermal Discharge Plumes Mapped in Three Dimensions

Thermal measurements of electric utility plants' discharged plumes of heated condenser water, to see if the plumes comply with local regulations, are now being made rapidly, accurately, and in three dimensions. A plume is mapped by crisscrossing the area of water in a power boat, dragging two chains equipped at intervals with thermistors. The thermistors transmit water temperature information to the boat, where the data is recorded on strip charts; shore stations keep track of the boat's location as readings are made. About four hours are needed to determine a plume's width, length, depth, and temperature distribution.

The most common alternate method of mapping is infrared photography from an airplane, in which warmer water shows up lighter than the surrounding cooler water. Such airborne photography costs more and produces only a map of the plume's width, length, and surface temperatures.

The new method is performed by the Westinghouse Environmental Systems Department, which also investigates chemical, biological, and physical effects of the discharge of heated water.

Mass Spectrograph Used with Radioactive Samples

Radioactive materials are being analyzed for the first time with a spark-source mass spectrograph, a powerful tool for qualitative and quantitative analysis. The instrument was modified for use on radioactive samples at the Mass and Emission Spectrographic Laboratory, WADCO Corporation, Richland, Washington. (WADCO is a Westinghouse subsidiary responsible for development and construction of the Fast Flux Test Facility part of the U. S. Atomic Energy Commission's Liquid Metal Fast Breeder Reactor Program.)

The spark-source mass spectrograph combines features of more conventional emission spectroscopy (which measures the characteristic light emitted by each chemical element when excited in an electrical arc or spark) and mass spectroscopy (which sorts atoms according to their mass). The sample to be analyzed is used as an electrode that is sparked as in emission spectroscopy. However, the ions evolved from the spark (rather than the light) are passed through the machine, where they are deflected in a magnetic field and collected on a photographic plate. The heaviest ions are deflected least, and each chemical element is uniquely identified by the position of its characteristic line on the plate. Concentrations are determined by the intensities of the lines. Measurements of impurities at the parts-per-million level are routine, and some can be determined at levels as low as one part in a billion.

Left—A sample is inserted into the spark-source mass spectrograph modified for analysis of radioactive materials.

Modification of the WADCO facility for radioactive operation involved construction of a glove box for safe containment of radioactive materials around the sample port, modification of the controls for operation with protective gloves, and installation of a separate glove-box facility for preparing the electrodes under controlled ultraclean conditions.

The first "hot" samples analyzed were uranium-233. The instrument also will be used to analyze plutonium fuel materials, which will power the Fast Test Reactor and must meet extremely rigorous purity specifications.

Airborne Radar Modified for "Look-Down" Ability

An Air Force AN/APQ-120 airborne radar system has been modified to enable it to "look down" to detect low-flying aircraft. The objective of the program is to develop and demonstrate ability to detect and track low-flying targets masked by ground clutter. A by-product of the development is that the radar system is also able to detect ground moving targets by use of pulse doppler techniques. The test aircraft is an F4E Phantom.

The look-down modification could be made on any type of pulse radar system, such as the more than 2000 radar systems supplied for the F4 aircraft. It entails improvements in the transmitter, the moving-target indication and tracking circuitry, and the clutter computing and tracking circuitry.

The system is being tested by the Air Force Armament Development and Test

Right—Radar system is shown extended from the nose of an F4E aircraft on its slide rails. The connected unit at the right contains the "look-down" modification circuitry and test instrumentation; it is carried in the aircraft's ammunition and instrumentation storage compartment for flight tests but, in a final design, the modification could be incorporated into the aircraft's normal electronics space.

Center at Eglin Air Force Base. The modification was done for the Air Force Aeronautical Systems Division by the Westinghouse Aerospace and Electronic Systems Division under a feasibility demonstration contract.

Ship's Speed Measured with Acoustic Signals

A new acoustic system devised to measure and record a ship's speed does so more accurately than do presently used logs, and it maintains its accuracy even during rapid maneuvering.

The system operates on the principle of an acoustic flow meter.* In such a meter, acoustic signals in a fluid are slowed or accelerated by motion of the fluid, depending on the relative directions of fluid flow and signals. In the simplest version, two acoustic transducers in the fluid face each other across a known distance in a known direction. Both simultaneously transmit, and then each switches to a receiving mode to pick up the signal transmitted by the other probe. The times for transmission and reception are compared for the two probes, and that information is used by electronic circuitry to compute the velocity of the fluid.

Called the Aculog (for "acoustic ship's log"), the new system senses relative movement between the water and the ship's hull and presents it as ship speed. It has three acoustic transducers to enable it to measure the speed of the ship's sidewise movement as well as headway and sternway. The transducers are on stainless steel probes mounted outside the hull.

An early version of the Aculog has been tested for the past two years to prove the feasibility of the technique. The system was developed by the Westinghouse Ocean Research and Engineering Center.

Instrument Monitors Oxygen Content of Flowing Sodium

An improved instrument for continuously monitoring the oxygen content of flowing sodium employs a solid-electrolyte electrochemical cell with a gas reference electrode and a flowing liquid sodium electrode. Voltage output of the cell provides a measure of the oxygen content of the sodium being monitored.

Two of the instruments were recently supplied by the Westinghouse Nuclear Instrumentation and Control Department to the Advanced Reactors Division. Since oxygen is the most important impurity in reactor coolant sodium, it is desirable that its concentration be monitored accurately by an on-line instrument. The new meter is sensitive to oxygen concentrations below 0.1 part per million and it responds in less than a second.

The liquid-metal oxygen meter incorporates an improved yttria-doped thoria tube as a solid electrode capable of conducting oxygen ions. A gas (air) reference electrode inside the tube is coupled to the electrolyte by means of a porous platinum coating. In both stability and insensitivity to temperature changes, use of a gas electrode is a major improvement over the metal/metal-oxide references used previously in oxygen monitoring systems. The meter can operate continuously for long periods of time in liquid-sodium loops at power-plant temperatures (about 900 degrees F).

At the Advanced Reactors Division, two carbon equilibrium loops and a loop

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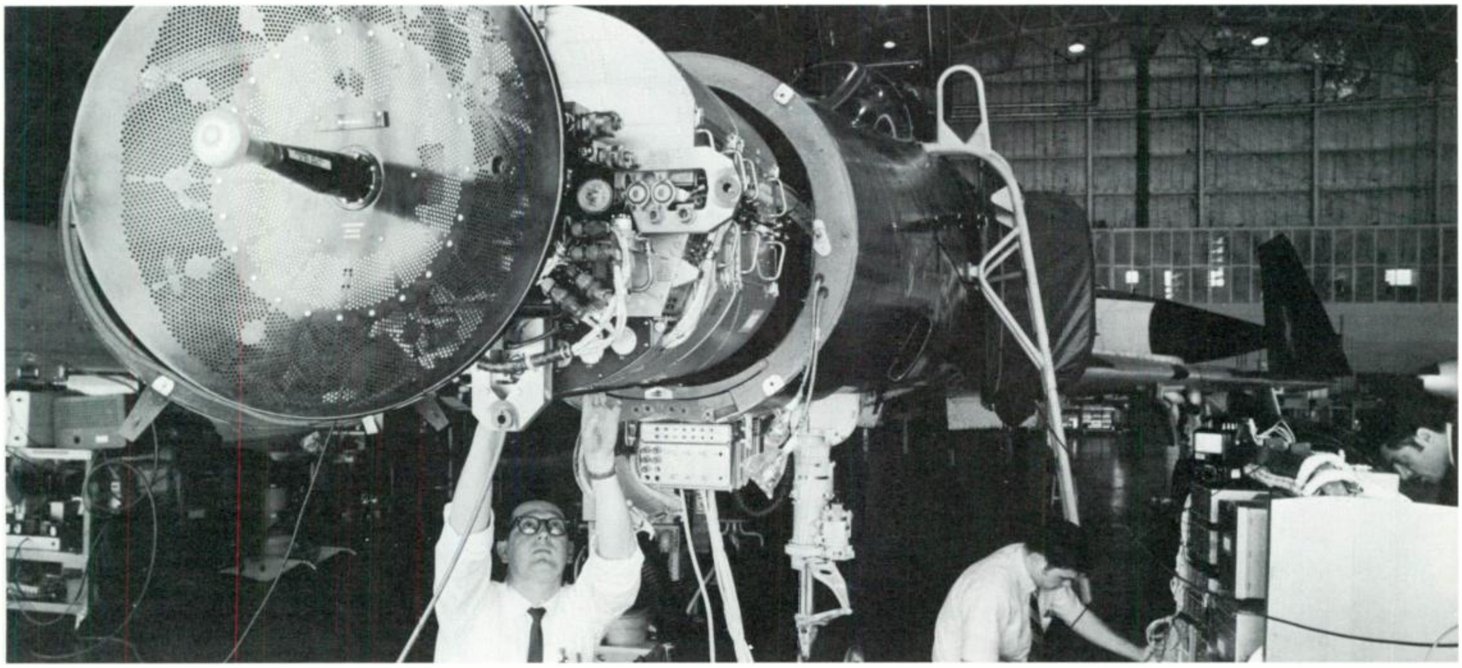
*C. R. Hastings, "LE Flowmeter–A New Device for Measuring Liquid Flow Rates," *Westinghouse ENGINEER*, Nov. 1968, pp. 183-6.



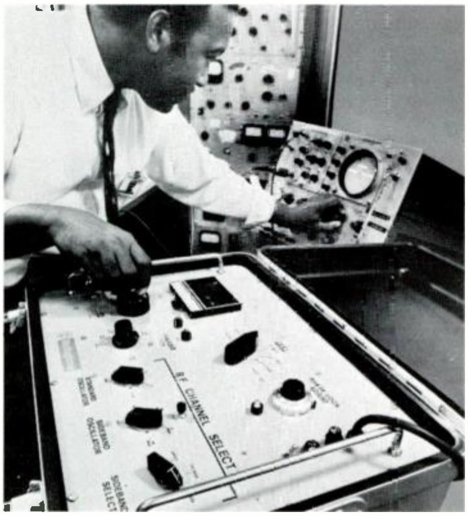
for fission-product studies contain the sodium for which oxygen monitoring is needed during long-term tests under sodium flow conditions. Additional oxygen meters are on order for installation in facilities related to development of liquid-metal fast breeder reactors.

Products for Industry

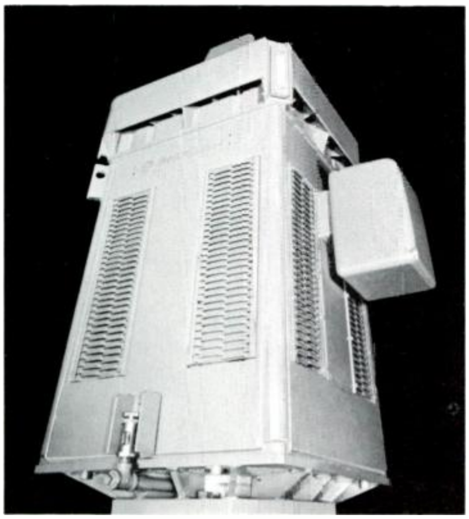
Arc welder for tungsten-inert-gas (TIG) welding has a solid-state control with built-in thermal compensation that eliminates time-consuming current adjustments during warm-up. The TWS-300 is an ac/dc saturable-reactor welder rated at 300 amperes. It can be adjusted for welding aluminum, magnesium, titanium, brass, copper, mild and stainless steels, alloy steels, and other metals, in sheets or thin, medium, or heavy plate. Though designed for TIG welding, it also performs well on most other welding processes. The control includes a thermistor that compensates for the effect of temperature changes on output current during warm-up. Voltage compensation reduces the effect of line voltage variations. *Westinghouse Welding Department, Box 300, Sykesville, Maryland 21784.*

Microwave signal tester provides extreme accuracy and resolution over a wide range of power levels. Called the Wave Analyzer for Noise and Deviation (WAND), the tester is built for evaluation of total performance of ground or airborne, commercial or military, microwave transmission systems in the frequency range of 9 to 10 gigahertz. It is connected to the final radio-frequency transmitter output of a microwave system to measure FM noise, index of modulation, and frequency deviation by means of a heterodyne receiver that translates the spectrum under test to an intermediate frequency, which is compared against a reference phase-locked i-f source. *Westinghouse Electronic Systems Support Division, Box 153, Baltimore, Maryland 21203.*

Arc Welder



Microwave Signal Tester



Vertical Pump Motor

Vertical pump motor is a Life-Line D large ac motor designed specifically for pump applications. The line includes Westinghouse frame sizes 5000, 5800, and 6800 (the three sizes immediately above NEMA frame sizes), with horsepower ratings from 300 to 2000. Thrust bearings available are angular-contact, spherical rolling, or tilting-pad Kingsbury type. Motor life is enhanced by use of an insulation system based on Thermalastic epoxy. The motor is available in solid- or hollow-shaft design in enclosures of weather protected Type I with or without air intake filters, weather protected Type II, and totally enclosed fan-cooled types. *Westinghouse Large AC and DC Motor Division, 4454 Genesee Street, Box 225, Buffalo, New York 14240.*

Dry-type transformers (Type ASL-R) are 25 percent lower in weight and smaller in base dimensions than previous ventilated dry-type units, reducing first cost, installation cost, and floor-space requirement. They can be handled with a forklift or crane. The transformers are available in ratings of 750 kVA and below, with high-voltage ratings 8.7 through 15 kV and low-voltage ratings 600 volts and below. Doryl varnish is used on the windings. Physical arrangements accommodate all standard types of transformer installation. *Westinghouse Power Transformer Division, 469 Sharpsville Avenue, Sharon, Pennsylvania 16146.*

Hollow-cathode line source improves ability to detect mercury by atomic absorption spectroscopy. Designated WL-22847A, the new source provides superior operating stability with low noise, making it possible to establish the presence of mercury down to the level of 10^{-10} gram with standard spectroscopy equipment. Applications include use in analytical laboratories where material compositions must be routinely determined and in pollution investigation and control laboratories. The device has extensive shielding to cut leakage, optimized gas pressure, and improved interior structure to discourage arcing to mercury condensed lower down in the cooler portions of the tube. It is warranted for 5 ampere-hours of operation. *Westinghouse Electronic Tube Division, P.O. Box 284, Elmira, New York 14902.*

About the Authors

A. W. Davis graduated from the University of Glasgow with a B.Sc. in Mechanical Engineering in 1933 and obtained his D.Sc. from the same university in 1957. While attending the university, he also worked for the Fairfield Shipbuilding & Engineering Co., Ltd. In 1953, he was appointed Deputy Managing Director of that firm, responsible for all aspects of machinery design, manufacture, and installation for steamships and motor ships of all types, and with responsibilities connected with the ship-building side of the Company.

In 1963, Davis became Vice Chairman and Engineering Director of the new company of Fairfield-Rowan, engaged in the same activities. (Fairfield-Rowan was formed by amalgamation of Fairfield with the marine engineers David Rowan and Company.)

Davis came with Westinghouse in 1966 to serve as a consultant to both the Westinghouse Marine Division and the Westinghouse International Company. He is presently Manager of the Marine Mechanical Department, responsible for the engineering and manufacture of all marine mechanical products at the Sunnyvale plant. He is also responsible for development of future designs.

R. J. Spreadbury received his formal education in England and began his career there. He graduated from Twickenham Technical College in 1955 with a Higher National Certificate plus endorsements in Electrical Engineering. In 1956 he added a further endorsement in Control Systems from the Farnborough (Royal Aircraft Establishment) Technical College.

Spreadbury spent 13 years with the British Army's Royal Electrical and Mechanical Engineers (REME). He worked on pure and applied servo theory, electronic control systems, and analog computers, a career that included 6 years lecturing at the Army School of Electronics and at the REME Training Center in Singapore. He then worked five years as a design engineer for Associated Electrical Industries in Manchester on inverters, converters, servo amplifiers, and radar instrumentation, becoming Inverter Engineering Section Manager of the company's Industrial Electronics Department at Leicester.

Spreadbury came to Westinghouse in 1968 to work at the Research Laboratories on parametrically energized magnetic devices. He has also been involved in feasibility studies for ac drive systems, thyristor chopper circuit analyses, and voltage transient investigations for various rapid-transit systems. He is currently a Senior Design Engineer in the Communications, Control, and Power Electronics Research Department. He is a member of IEE and IEEE.

P. K. Shenoy graduated with a BE degree in mechanical engineering from the PSG College of Technology, Coimbatore, India, in 1960. He worked on atomic reactor control systems in the Atomic Energy Establishment at Bombay before coming to the United States in 1966 to attend the University of Rochester. He joined the Westinghouse Medium AC Motor and Gearing Division in 1967 and, the following year, received his MS degree in mechanical engineering.

At Westinghouse, Shenoy has worked in the Research and Development Engineering section on development of induction motors, control of the insulating varnish treatment for motor windings, computer programming, and investigations of motor noise and vibration. He represents Westinghouse on the NEMA committee responsible for suggested noise standards for the motor industry.

F. T. Thompson obtained his BSEE from Rensselaer Polytechnic Institute, and his MS and Ph.D in Electrical Engineering from the University of Pittsburgh.

Dr. Thompson is presently responsible for research in the areas of magnetic and mechanical devices, electromechanical systems, biosciences and medical systems, system simulation and control, acoustics, urban systems, and computer and instrumentation research.

Dr. Thompson's 18 years of experience have been principally in computer and control systems and circuitry. He has contributed to the development of high-definition television circuitry, video disc recording, digital computers, drum memories, teaching machines, electric utility control systems and circuitry, speed controllers, telemetering equipment, analog-to-digital converters, analog-multiplexing circuitry, and high-speed digital logic systems. He has been issued 24 U.S. patents.

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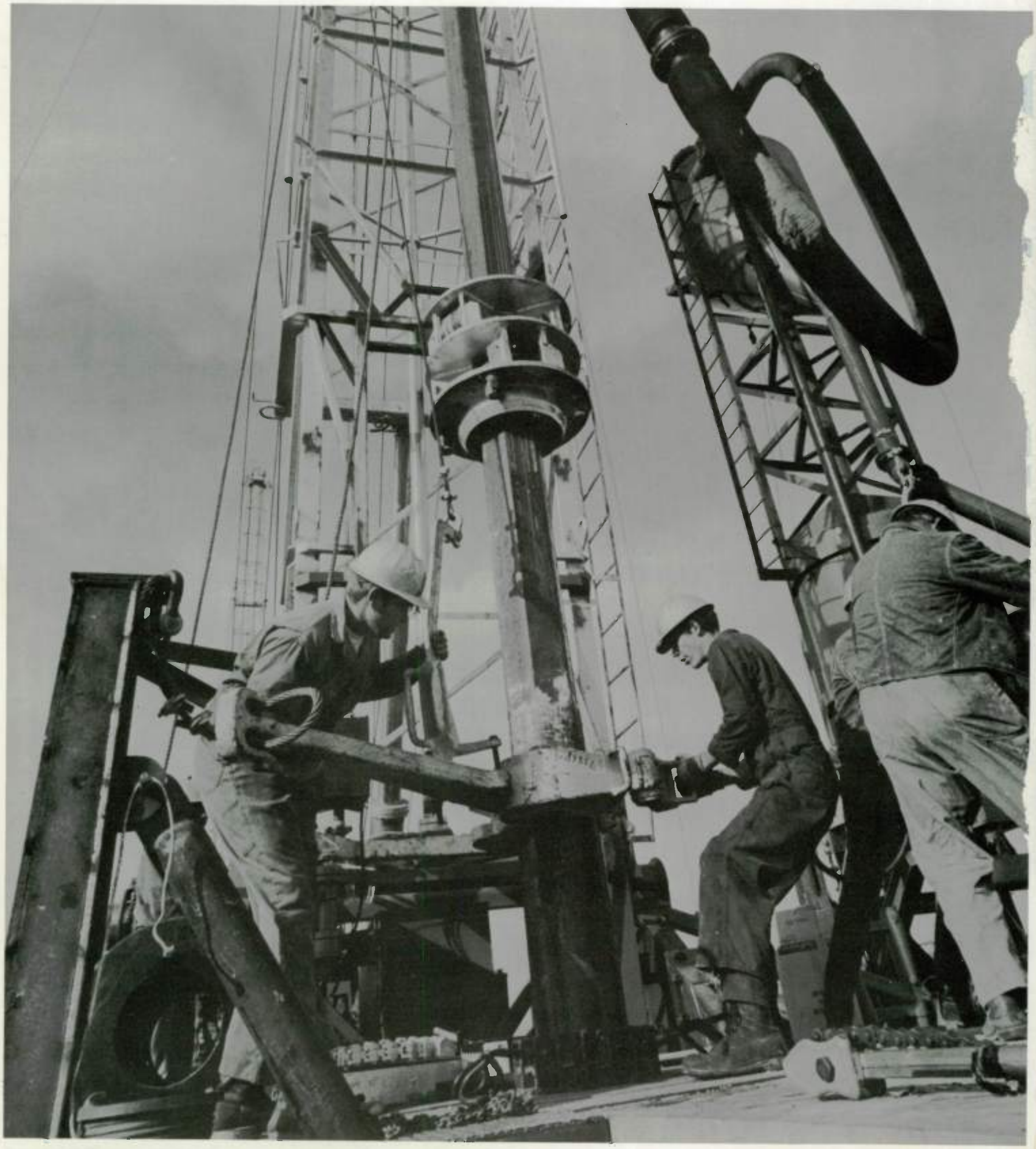

Powerful drills are part of a mine rescue and survival system. (See page 60.)