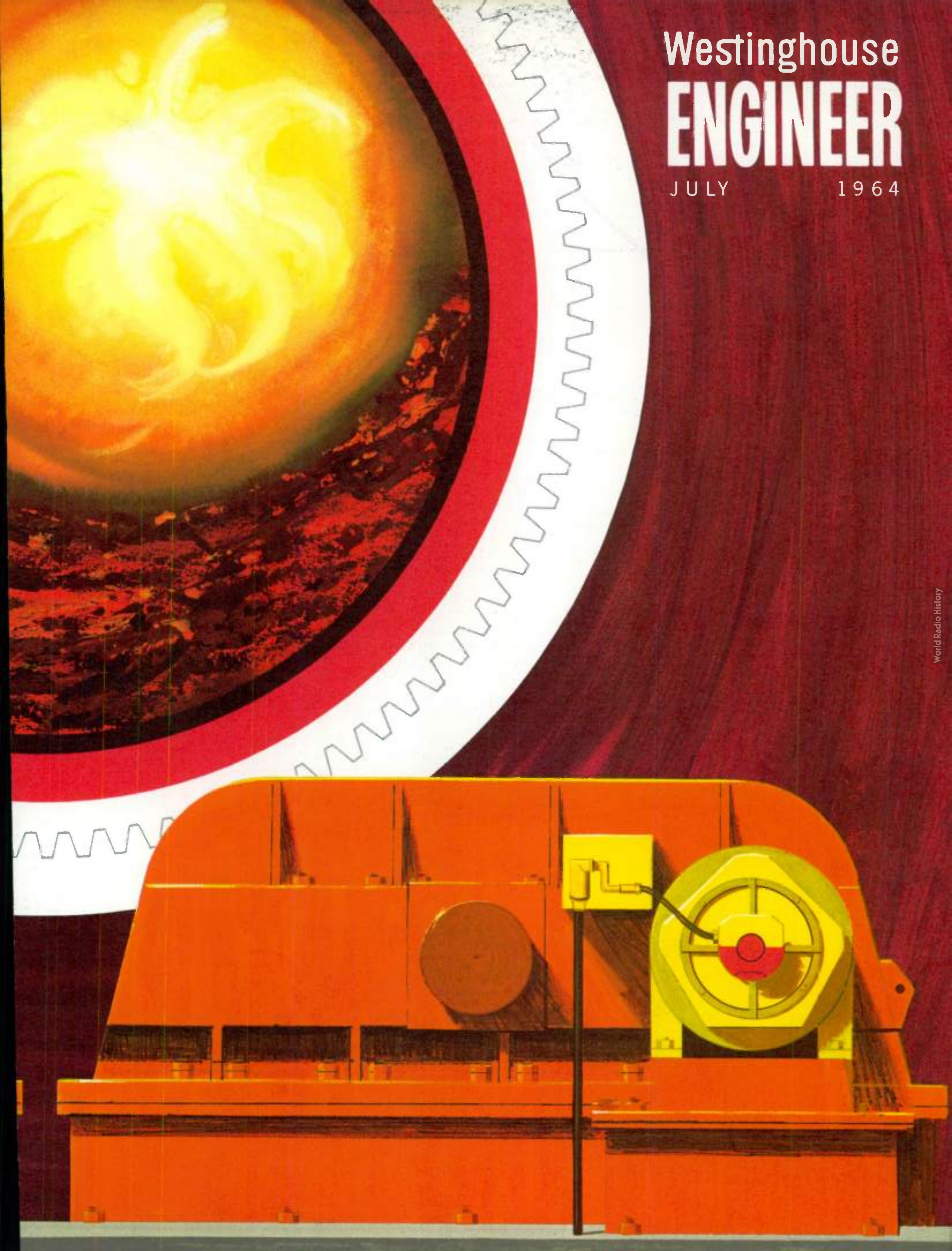
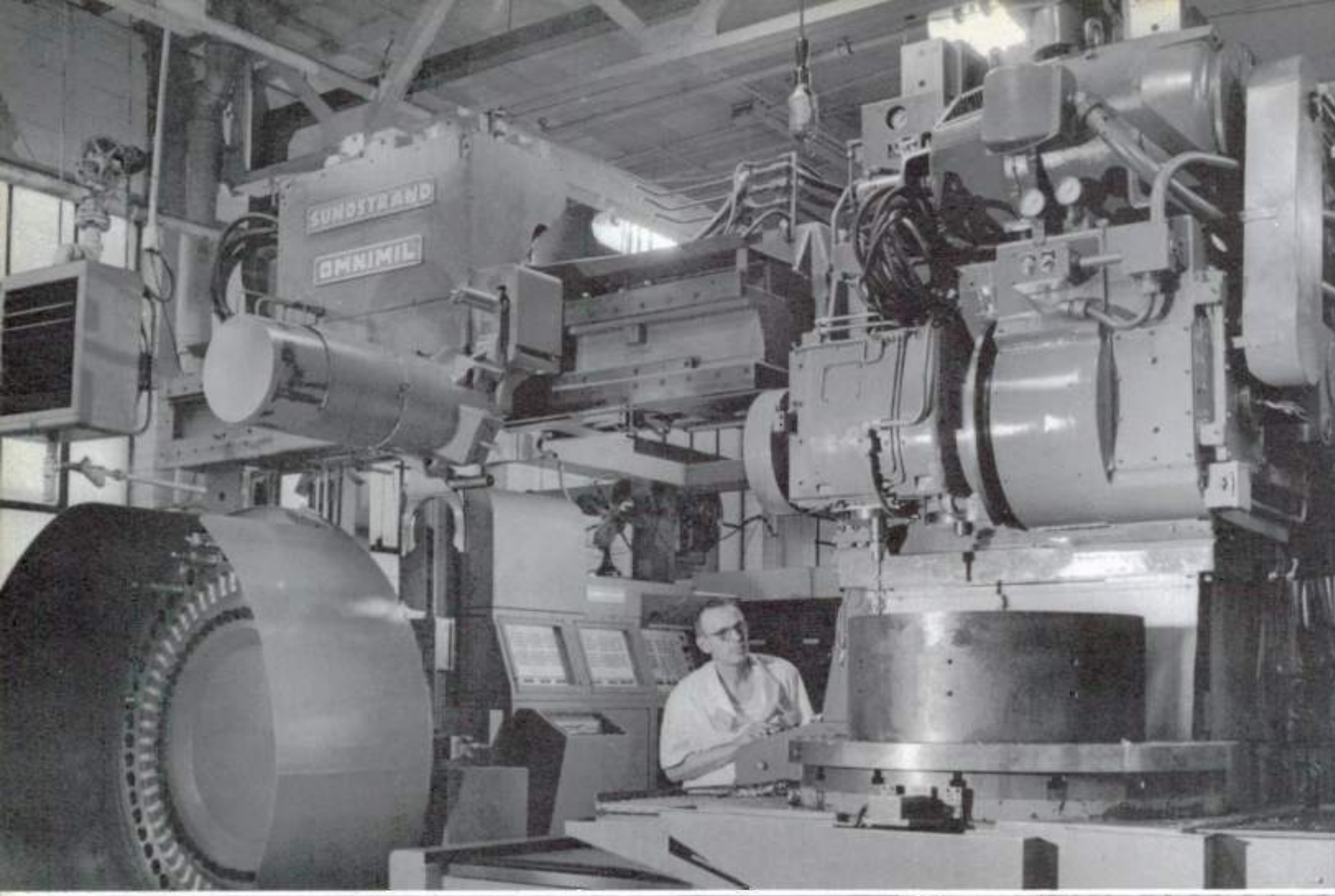
Westinghouse

ENGINEER

JULY 1964





Computer-assisted numerical control operates this five-axis milling, drilling, and boring machine and the four other machine tools in the machining section of the Westinghouse Homewood Division, Pittsburgh. The other tools are an engine lathe and turret lathe, both of which can perform full contouring, and a three-axis drill press and two-axis drill press that can do light milling in addition to drilling.

Because the machining section's primary products are renewal parts, production is characterized by many different products, small lot sizes, and frequent repeat orders. Numerical control was installed to reduce lead time and setup time, to eliminate or simplify the jigs and fixtures formerly required, to reduce scrap, to reduce the inventory of finished parts required, and to permit greater freedom in design changes.

The computer program includes a compiler that greatly reduces the amount of time otherwise required to produce tapes for complicated parts. For some parts, a tape can be produced by entering only material specifications, dimensions, and reference points into the computer; the compiler then determines the sequence of operations to be followed and supplies the additional information that the computer needs to calculate feeds and speeds.

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Prodac, Reactifier, Load-O-Matic, Thermalastic, Moduline.

Cover Design: A swirling inferno of flame converts raw materials to cement clinker in the huge rotary kiln of a cement plant. Thomas Ruddy of Town Studios, Pittsburgh, has chosen the kiln to represent the significant trend in the industry to use of larger production machinery operated by complex electrical drive and control equipment.

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Trends in Cement-Plant Power and Control

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Larger production machines, centralized and automatic control systems, and extensive instrumentation enable modern plants to produce a more consistent product at higher efficiency than before.

Portland-cement production in the United States reached an all time high in 1963 with 350 million barrels produced. Production will continue to increase because it is spurred on by ever-increasing construction of buildings and roads. New more efficient plants, and modernized existing plants, are meeting the need. These plants make better use of manpower, through the use of fewer and larger production machines and more automatic control, and thereby increase cement output at lower unit cost.

The manpower required per barrel of product is only half that required in 1957. (One barrel is equivalent to four 94-pound bags of cement.) A typical plant producing 2 000 000 barrels a year in 1957 had three raw mills, three kilns, and three finish mills; electrical energy consumption was about 25 kwhr per barrel of cement. Today, a modern plant of the same production capacity may have a single raw mill, a single kiln, and a single finish mill and require only 18 kwhr per barrel. Furthermore, quality has been improved as automation has made the production of cement more and more a science instead of an art.

Because the equipment required for automatic control is relatively independent of individual machine size, the trend to fewer larger machines encourages automation. The modern plant is also characterized by having centralized control to interlock departmental flow lines, by careful selection of raw materials mined in the quarry, and by heavily instrumented raw-material blending and kiln operation. Already, computers have been used in several plants to aid in raw-material selection, to control raw-mix blending automatically, and to anticipate kiln disturbances. All of these factors help in the continuous realization of capacity production of a more uniform product.

Power Distribution

Only a few modern plants generate their own electric power; those that do are located where an adequate electric-utility supply is not economically available. Most plants look solely to the electric utility for power.

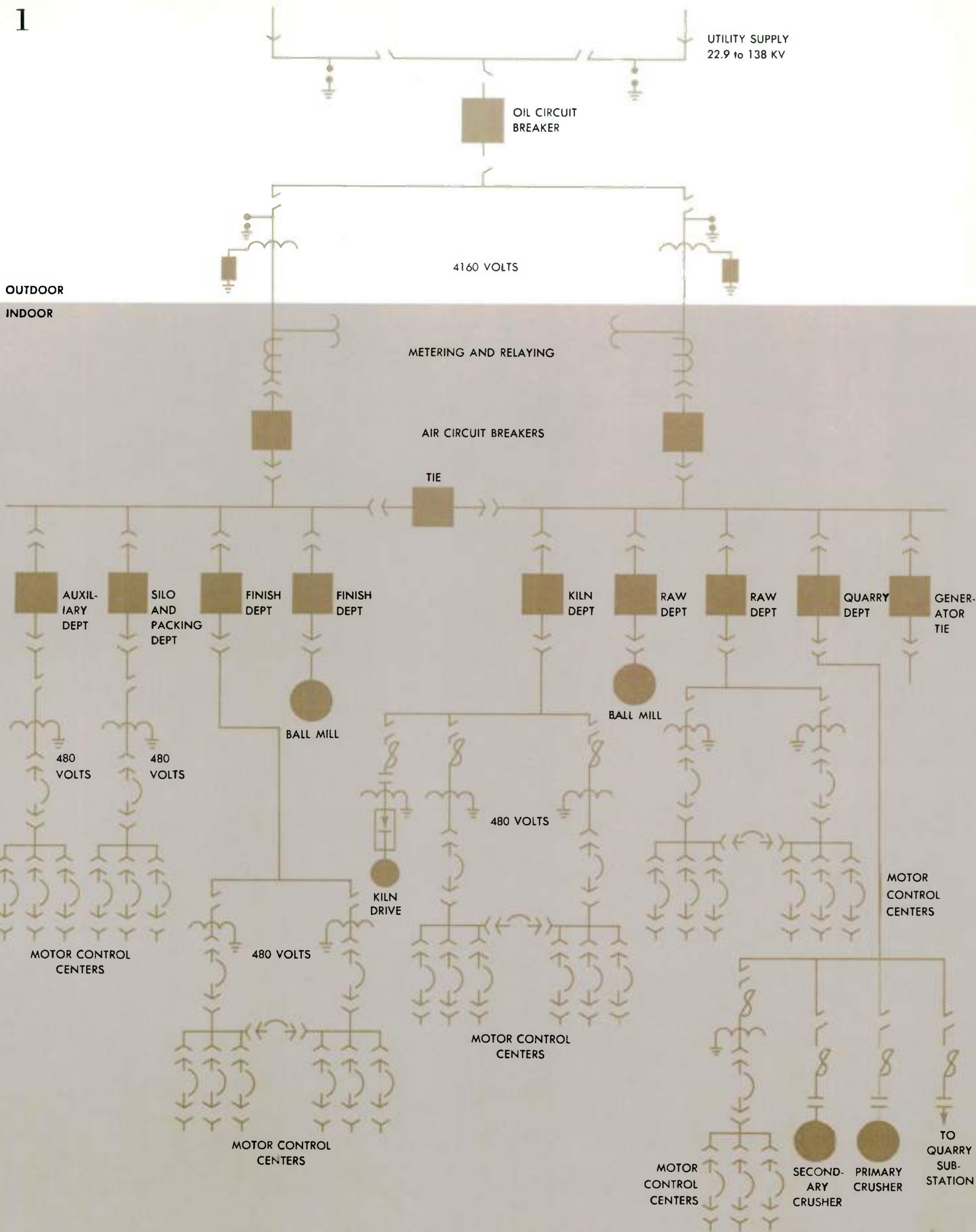
The distribution system for a modern plant is diagrammed in Fig. 1. Substation capacities for typical plants are: one million barrels per year, 6250 kva; two million barrels per year, 10 000 kva; three million barrels per year, 15 000 kva. Substations are no longer placed under a roof, because modern dust-collecting techniques help keep the plants clean. However, it is well to locate the substation on the windward side of a plant and use the next higher creepage level of insulation on exposed bushings. The use of enclosed terminal chambers instead of bushings for voltages under 15 kv reduces exposure to dust. Double-ended substations are used above 7500 kva to insure service continuity.

Plant distribution at 4160 volts provides a satisfactory flow of power with acceptable voltage regulation and losses, and this voltage is economical for supplying motor drives of 250 horsepower and above. Only the largest plants need a distribution voltage of 13 800 volts. Plant distribution systems are resistance grounded to limit ground fault damage and to minimize transient overvoltages. Development of the plant power system is usually radial; however, the selective radial system with an alternate source of power for use in event of cable faults is often used. Multiple cables with an excess of installed capacity make possible quick restoration of power after a cable fault.

Switchgear at the distribution voltage level is of the metal-clad drawout type and may be located either indoors or outdoors in switchgear integral shelters. When indoors, the switchgear is situated in clean pressurized rooms. The 480-volt power for the many motors under 250 horsepower is derived from power centers placed at load concentrations in clean pressurized rooms. The trend is toward increased use of ventilated dry-type power centers because they reduce support requirements, eliminate the hazards associated with liquid-filled transformers, and cost less. Power centers are kept to ratings of 1000 kva or less to limit short-circuit capacities to levels that allow use of economical circuit breakers and control centers.

Control centers for the 440-volt motors are located in the same rooms as the power centers. Control interlocking is usually effected by relays located either in the control centers or with the pilot devices in the plant's centralized control panel.

Portable equipment in the quarry distribution system is safety-grounded. To minimize frame-to-ground voltages during ground faults, the ground faults are limited to 25



TYPICAL POWER DISTRIBUTION SYSTEM for a cement plant. Metal-clad air circuit breakers supply each department at 4160 volts.

amperes by a neutral grounding resistor. An isolation transformer separates the quarry system from the plant power system to reduce short-circuit capacity and, at the same time, allow use of the high-resistance safety-grounded system. Ground wires are carried in the power cable from the quarry substation to portable quarry switchhouses, and they are continuously monitored for continuity. Type SHD portable cables, also with integral ground wires, carry power from the switchhouses to the shovels, draglines, drills, and other equipment.

Machine Drives

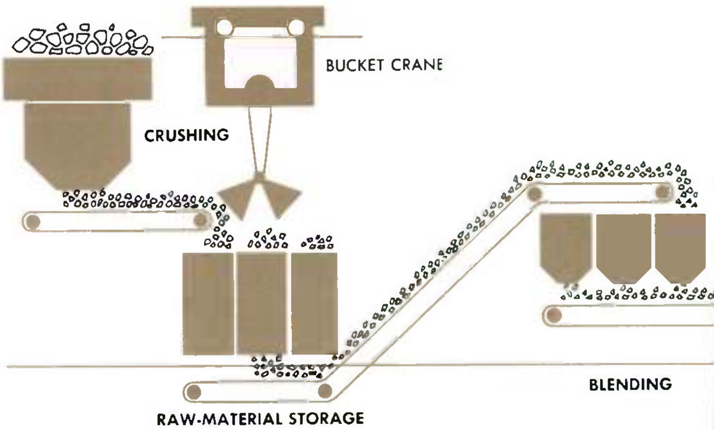
Ever-increasing size is the basic characteristic of cement-plant drives. For example, ball-mill drives of 4500 horsepower are in service and drives of 6600 horsepower are being considered. The use of fewer and larger drives makes reliability essential, since a single main-drive failure can shut down a whole plant. Consequently, static devices are increasingly used; their inherent reliability enhances service continuity. Another development is increasing use of highly regulated drives to maintain set speeds accurately and to help eliminate variables that may affect product uniformity.

Crushers—Limestone and shale are reduced from the as-quarried size to less than one inch in two stages of crushing. The primary crusher is usually a jaw, gyratory, or roll crusher; it is a hard-starting device, and it develops high peak loads during operation. A wound-rotor motor with 250 percent maximum torque is used to drive the primary crusher.

Secondary crushing is done by cone, hammermill, or impactor crushers. Hammermills and impactors are high-inertia machines requiring 20 to 30 seconds to accelerate. Their motors must have more than the normal amount of

MANUFACTURE OF PORTLAND CEMENT

The portland-cement process begins with the crushing of the rocky raw materials (mainly limestone and shale or clay). Crushing is usually done in two stages, with the second stage reducing the material to less than one-inch size. The raw materials are then stored in bins, from which they are conveyed to hoppers that supply blending feeders. They are released in the proportions required for the proper chemical combination and conveyed to a raw-grinding mill. Here the materials are ground fine, either dry (dry process) or mixed with water to form a slurry (wet process). The ground mixture is then fed into a long rotating kiln heated by burning fuel blown in with air. The kiln is inclined and, as the raw materials tumble down it, the intense heat generated by the burning fuel fuses the materials and chemically unites their elements into a new material called clinker. The clinker is cooled, gypsum is added to regulate setting time, and finally the mixture is ground to a fine powder. This powder is portland cement, the basic ingredient of such construction mixes as concrete, mortar, stucco, and plaster.



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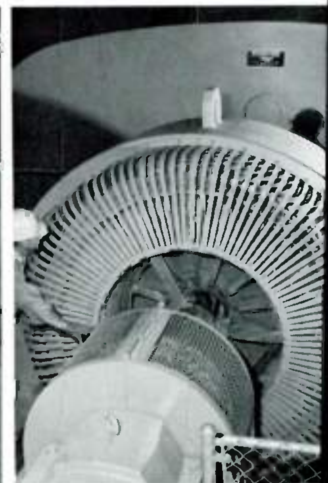


1) BLENDING-FEEDER DRIVES for raw-mill feed at Marquette Cement Company's Pittsburgh plant employ weighbelts to regulate the amounts of material fed. The drive motor is a totally enclosed nonventilated type for protection from dust.

2) THYRISTOR MOTOR CONTROLS for the feeder drives are grouped in cabinets and cooled by internal air circulation. One of the plant's double-ended dry-type 2000-kva power centers can be seen in the background.

3) THE 4400-HORSEPOWER DRIVE MOTOR for a large cement-plant ball mill is a synchronous induction type. It is started as a conventional wound-rotor motor to minimize inrush, and then it is run as a synchronous motor.

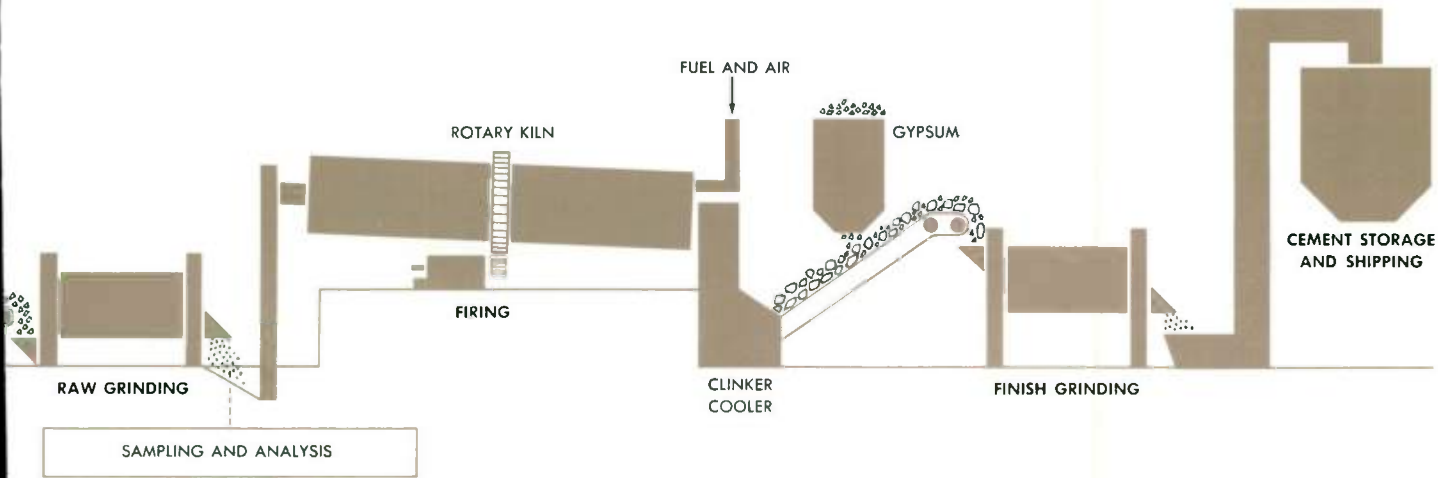
rotor heat-storage capacity. Because secondary crushers usually are uniformly loaded, motors developing normal torque are satisfactory.

Secondary-crusher feeder drives are often adjustable-speed drives that automatically change feeder speed in response to changes in the crusher load. This feature maintains maximum output without overloading the crusher and the drive.

Blending Feeders—One of the most critical steps in the cement-manufacturing process is the blending of the various raw materials. The operation is performed by a system of conveyors called blending feeders. A new drive recently developed for blending feeders is a thyristor adjustable-speed dc drive. This drive is more accurate and reliable than the earlier Ward Leonard type. It is applied in ratings from 3/4 to 5 horsepower, and it controls speed over a 48-to-1 range at constant torque.

The feeder-drive static speed regulators are accurate to 0.2 percent at a base speed of 2500 rpm and to 1.5 percent at one-twelfth base speed. The speed reference signal for each regulator can be adjusted by a 10-turn potentiometer to alter the speed of each feeder drive independently of the others over a 12-to-1 speed range by armature voltage control. A master reference 10-turn potentiometer can adjust all feeder drives in a group over a 4-to-1 speed range while maintaining the speed proportionality set by the individual reference potentiometers. An external master reference signal can be inserted to control the speed of all feeder drives over the 4-to-1 range and thus regulate total feed. Also, all potentiometers could be driven by a control computer.

Each feeder-drive regulator includes a transistorized operational amplifier that magnifies the error between the speed reference signal and the signal from a motor-mounted



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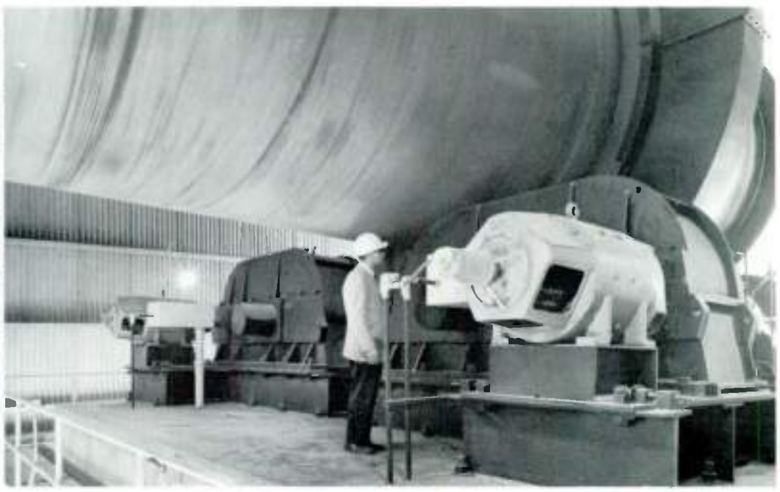

4) LARGE ROD AND BALL MILL used for raw grinding at the Marquette plant is driven by this 3000-horsepower synchronous motor. In the background is one of the plant's smaller ball mills for finish grinding.

5) KILN DRIVE at the Marquette plant is a twin-motor Reactifier type. The power, control, and protection equipment for the 500-horsepower dc drive is housed in metal-enclosed cubicles in a building directly under the kiln.

tachometer generator (Fig. 2). The magnified error signal is applied to the control winding of a gating amplifier. The gating amplifier, essentially a small magnetic amplifier, then produces output pulses that are position-modulated with respect to the ac supply voltage. The position-modulated pulses are applied to the control terminals of two thyristors (silicon controlled rectifiers) that are connected with two diodes in a full-wave bridge. The pulses cause the thyristors to conduct current with varying angles of phase delay during the forward half cycle of the supply voltage, and the conducted portion of the supply voltage wave provides the controlled voltage for the drive-motor armature.

The feeder drives are of modular construction and, for interchangeability, control panels are identical for drives of three horsepower and less. Each group of drives is housed in an enclosed cabinet, and each group has its own short-circuit protection, master reference, power supply, and internal circulating fan. Totally enclosed nonventilated motors complete a low-maintenance reliable drive package tailored to dusty cement plants.

Grinding Mills—The ball and rod mills that grind the crushed blended rock materials and the clinker to less than 200-mesh size are usually driven by synchronous motors, because these motors have high efficiency and the ability to correct power factor. The motors are full-voltage started where power systems are capable of supplying the approximately 600-percent inrush necessary to develop the 150-percent net shaft starting torque and the 120-percent net shaft pull-in torque required in this application. One ball-mill drive rated 4500 horsepower and 13 200 volts, full-voltage started, is in service. Since not many plant power systems can handle the inrush required by a motor of this size, other drive types are usually needed.

An example is a 4400-horsepower synchronous induction motor requiring only 200-percent inrush to develop ball-mill accelerating and synchronizing torques. It has been in service for a year and a half. The motor is a wound-rotor machine with three sliprings, an oversize air gap, and oversize windings on the cylindrical rotor. Air gap and windings are oversize because once the motor is up to speed as a conventional wound-rotor machine, it is synchronized and run as a synchronous motor; its dc field current is then twice the ac current expected in a conventional wound-rotor winding.

Secondary resistor control keeps this motor's acceleration torque increments to within 40 percent of rated torque to ease motor torque into the large expensive gear train and gently bring the mill up to speed. This smooth application of torque enhances gear life. A static synchronizing panel initiates the application of the dc field from a static regulated exciter at the proper phase and at one-percent slip to synchronize the motor smoothly. Drive power factor is continuously adjustable to 85 percent leading. The drive can operate continuously as a wound-rotor motor, without the dc field, if the excitation system malfunctions. The static devices, alternate wound-rotor motor operation, low torque increments, and smooth synchronization all enhance the reliability of this important cement-plant drive.

Kilns—The large rotary furnace called the kiln also has been increasing in size and horsepower requirements, and its drive is considered the most important in the plant. Kilns range up to 18 feet in diameter and 540 feet long.

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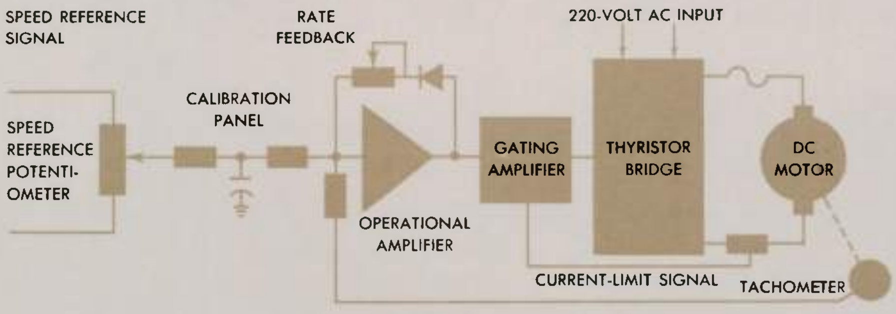
THYRISTOR REGULATOR for a blending feeder drive. An error signal is generated by comparison of a speed reference signal with a speed feedback signal, and this error signal regulates a thyristor full-wave bridge to control the voltage delivered to the motor armature. The speed reference signal can be supplied by an integral source, by an instrument controller, or by a control computer.



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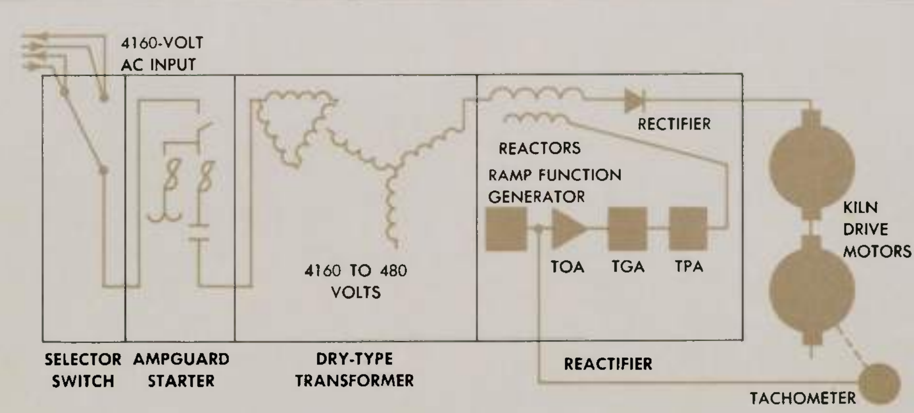
REACTIFIER KILN DRIVE is another recent application of all-static circuitry for reliability and ease of control. The speed error signal is amplified by a transistorized operational amplifier (TOA), a thyristor gating amplifier (TGA), and a thyristor power amplifier (TPA) to control self-saturating power reactors that adjust motor armature voltage. The drive motors are two identical shunt-wound machines with armatures connected electrically in series and mechanically through the kiln drive gears.



They operate over a speed range of 20 to 80 revolutions per hour at essentially constant torque, and a starting torque of 200 percent rated is required to start them.

The largest Reactifier dc drives built are driving cement kilns. A 500-horsepower twin-motor drive (two 250-horsepower motors) and two 600-horsepower twin-motor drives have recently been placed in service. These kiln drives have two stabilized shunt motors with their armatures connected in series to share load current (Fig. 3). The motors are separately excited and mechanically connected. Speed is controlled to 0.5-percent accuracy at base speed, including a 10-percent supply-voltage variation, load changes from 75 percent to full load, 20-degree-C ambient temperature change, and 24-hour drift. This drive is replacing the Ward Leonard kiln drive because of the reliability and ease of control afforded by its static control circuitry.

The drive control system has a static ramp function generator and current-limit override for stepless controlled acceleration to a preset speed. Provision is made for insertion of an external speed reference from a controlling instrument for speed control. Also included is provision for future computer control of kiln speed.

Power equipment consists of a high-voltage selector switch for an alternate feed, a high-voltage fused starter for drive switching, a ventilated dry-type transformer to transform 4160-volt power down to 480 volts, and a reactor and rectifier cubicle for the ac to dc conversion. Because power diodes are individually fused and applied with additional capacity, loss of a string in each phase does not shut down the drive. Balance reactors force current balance between each diode; therefore, the diodes need not be especially selected for parallel operation. Lights indicate diode failure. Only faults or dangerous overtemperatures in the transformer, diode, or reactor assemblies will shut down the kiln drive, and a signal warns the operator of slight overtemperatures due to overload. These protective features provide the continuity of kiln operation that is essential for profitable production of cement clinker.

Other Equipment—Overhead traveling bucket cranes are vital in plant operation because they handle practically all of the coal, limestone, gypsum, sand, and clinker used. The trend is to ac Load-O-Matic crane control, which employs saturable-reactor speed control on wound-rotor motors for all motions.

The many conveyors, elevators, pumps, compressors, and fans are driven by squirrel-cage motors. Dripproof enclosed induction motors are satisfactory for most drives in moderate dust conditions; an elastomer coating is given the windings for additional abrasion resistance. In extremely dusty locations, totally enclosed fan-cooled motors with rotating bearing seals are applied. Gears and gearmotors have special breathers and bearing seals. Large synchronous pedestal-bearing machines are usually of open construction, with a special silicone dispersion treatment given to the Thermalastic insulation to further protect against abrasive dust particles. The dc machines have commutator dust covers, and their speeds are kept to 1200 rpm or lower to minimize brush and commutator maintenance.

The power factor of a cement plant is close to unity because the synchronous ball-mill drives compensate for the power factor of the many induction motors. Cement-

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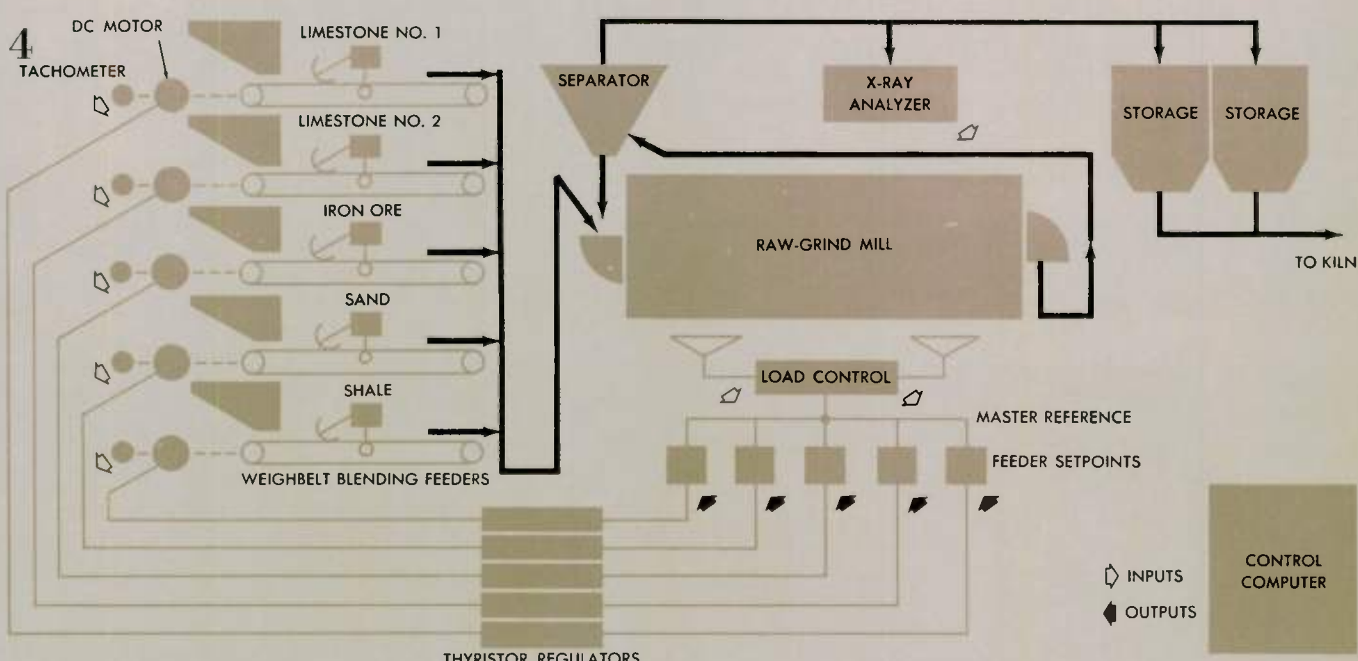

RAW-MATERIAL BLENDING could be regulated by a control computer to provide the proper chemical analysis of the kiln feed material. The computer adjusts the setpoints of the blending-feeder controls to adjust the proportion of each raw material fed into the grinding mill. A mill load-sensing device regulates the total feed to the mill.

TYPICAL CEMENT-PLANT DRIVES

Machines	Horsepower	Motor type	Control
Gyratory Crushers, Roll Crushers, Jaw Crushers	100 to 500	Wound Rotor	Magnetic Secondary
Cone Crushers	100 to 350	Squirrel-Cage NEMA B Special	Full Voltage
Hammermills, Impactor Crushers	600 to 1500	Squirrel-Cage NEMA B Special	Full-Voltage Reversing
Feeders	½ to 15	DC Stabilized Shunt	Thyristor-Controlled Adjustable Voltage
Ball Mills	1000 to 5000	Synchronous	Full Voltage
		Synchronous Induction	Magnetic Secondary
Kilns	250 to 1000	DC Stabilized Shunt	Static Adjustable-Voltage DC
		Squirrel Cage	Adjustable Frequency
Draft Fans	350 to 1250	Squirrel-Cage NEMA B Special	Full Voltage
		Synchronous	Eddy-Current Coupling
Bucket Cranes	50 to 300	Wound Rotor	Reactor
		Stabilized Shunt	Adjustable-Voltage DC
Cement Coolers	15 to 30	Stabilized Shunt	Thyristor-Controlled Adjustable Voltage
		Squirrel Cage	Eddy-Current Coupling
Conveyors	3 to 75	Squirrel Cage	Full Voltage
	100 to 300	Wound Rotor	Magnetic-Reactor Resistor
Elevators, Screws, Pumps, Drags, Air Separators, Belt Conveyors	10 to 300	Squirrel Cage	Full Voltage

plant loads, with the exception of the quarry and crushers, are steady: the average load approaches 75 percent of the connected horsepower.

Automatic Control

The trend to greater use of automatic control has been the most spectacular change in cement plants. All phases of the cement process are heavily instrumented, and they are controlled with set-point controllers that regulate such variables as temperatures, pressures, flows, and speeds. A number of plants have adopted static logic elements, instead of the many control relays commonly used, to interlock material flows. Both the magnetic-core and the transistorized types are used. Smaller space requirements, greater reliability, and lower cost (in the more complicated sequencing circuits) motivate the trend to static switching.

Important process variables are recorded. Instruments, closed-circuit television receivers, pushbuttons, annunciators, and interlocking relays are concentrated on a central control panel, enabling an operator to monitor and control the plant from a single location. This concentration of control at a single location also facilitates the next step—computer control.

For example, applying a control computer for automatic blending of raw materials can relieve the plant chemist of a tedious and difficult job, especially when the kiln feed comprises more than four materials. Also, a more uniform mix results from a closely controlled raw-blend system. A generalized raw-material blending system controlled by a computer is diagrammed in Fig 4.

Five different raw materials are blended in this system to provide material of the chemical analysis required for kiln feed. Each weighbelt feeder has a gate control to maintain a constant weight per foot of belt loading. An adjustable-voltage thyristor regulator controls belt speed. With a constant weight per foot of belt maintained by the scale, the speed of the belt controls the amount of material fed. Therefore, a closely regulated feeder drive can maintain a constant feed to the process. A master control potentiometer driven by the output from a grinding-mill load-sensing device controls all feeder speeds simultaneously, thereby controlling total feed while maintaining the ratio of each material in the total feed.

When the raw mix has been ground to the required fineness, it is sampled and analyzed by an x-ray emission analyzer. Its actual composition is then compared with the desired analysis stored in the control computer. The computer calculates any changes in raw material required from the individual feeders. It then changes feeder-drive setpoints (by controlling stepping motors that drive the speed-control potentiometers) to correct the analysis.

Another part of the cement process undergoing close study is the kiln department. At present, an operator controls fuel, kiln speed, feed rate, and draft to correct for process changes. Kiln disturbances sometimes occur because the operator over- or under-corrects control variables in an attempt to compensate for changes in raw material or kiln temperature. Loss of production results, because the production rate is slowed to permit the operator to stabilize kiln operation before gradually bringing the kiln back to rated output. A control computer could improve kiln operation by remembering changes in process variables and anticipating the control action required to achieve rated production of a uniform product.

Conclusion

Cement-plant managers are constantly looking for new ideas—new means to improve uniformity of an acceptable product at a competitive cost. The most fertile area of improvement is in the use of reliable electrical equipment, closely monitored and controlled. Accurate transducers can sense process operation, data-logging can quickly and compactly record process changes, and decision-making devices can automatically correct for process disturbances.

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A New Concept for a Navigation Satellite System

E. S. Keats, Project Manager, Navigation and Surveying Systems, Westinghouse Defense and Space Center, Baltimore, Maryland.

A new navigational system that uses computerized control stations and satellite relays is proposed for world-wide navigation and traffic control for ocean-crossing ships and aircraft.

Today's advances in space and electronics technology have made possible a new kind of world-wide navigation and traffic-control system. Satellites orbiting the earth are the key to a navigation system that could direct traffic, locate distressed craft, and direct rescue vessels. Such a system would be invulnerable to weather and would enable ships and aircraft to cross oceans more safely, efficiently, and economically. This satellite navigation concept has resulted in a feasibility study by Westinghouse under contract to the National Aeronautics and Space Administration.

Need for a New Navigation System

During the past twenty years, more than two dozen ground-based radio navigation systems have been put into service in various locations around the world. A fundamental deficiency in all of these navigation systems is that they are inherently incapable of providing position information to anyone other than the ship or aircraft using the system. Air traffic-control agencies, air-sea rescue services, and operating companies are thus isolated from the craft after departure until and unless the navigator radios his calculated position. Despite many advances in communications equipment, timely position reports from ships or aircraft in mid-ocean are often difficult to receive. Ground-based radio navigational aids are ineffective far from shore; in bad weather, navigators are unable to use the stars to locate position; and a reported position is always vulnerable to human errors in calculation and transmission.

International air regulations require that aircraft inform the air traffic-control agency of their positions at specific intervals when communications can be established. Ships, however, are not required to radio position information to shore, and, because it is often difficult, do so less frequently.

The inadequacies of our present navigational systems are highlighted during emergencies or disasters, when ships and aircraft are in trouble or lost. Too much time is spent in just discovering that an emergency situation exists, finding the vessel or its survivors is difficult, and the problem of determining which rescue craft is near a disabled craft is frustrating.

Improved communications between ships and aircraft at sea and control centers ashore is a partial solution. This solution, however, would still require personnel on the ship or aircraft to take the initiative in calculating the craft's position. Position calculation can be a time-consuming task even for the most rapid system; failure to perform it regularly, and perhaps not at all, during an emergency situation would disable the system at times when it is needed most.

A far better and safer way to provide accurate navigation information is to remove the work of position calculation from the craft and perform these computations at established land bases. Accurate position information could then be transmitted automatically, quickly, and reliably to ships, to aircraft, and to traffic routing and safety agencies at periodic intervals. Such a system could also provide ships and aircraft with weather reports and forecasts, notices of unusual dangers, warnings to avoid collisions, and other information useful to insuring a safe passage. A system using satellites can provide these and many additional benefits that cannot be provided with present land-based navigational methods.

Elements of the System

The proposed navigation satellite system for world-wide continuous coverage consists of satellites, ground stations, and navigational equipment aboard ships and aircraft.

Satellites—Eight satellites orbiting 6000 miles in altitude can provide continuous coverage of the entire earth's surface (Fig. 1). Four satellites will be in an orbit at 55 degrees inclination, and the second four will be in an orbit at right angles to the first, also at 55 degrees inclination. The satellites serve essentially as line-of-sight relay stations for transmitting information between the control stations and the ships and aircraft. Line-of-sight transmission permits the use of the more plentiful higher frequencies.

The satellite contains two interferometers (Fig. 3) plus amplifying and data-transmission circuits. Other radio equipment communicates with the control station and relays data from the control station to ships and aircraft. All of the electronic equipment in the satellite will use

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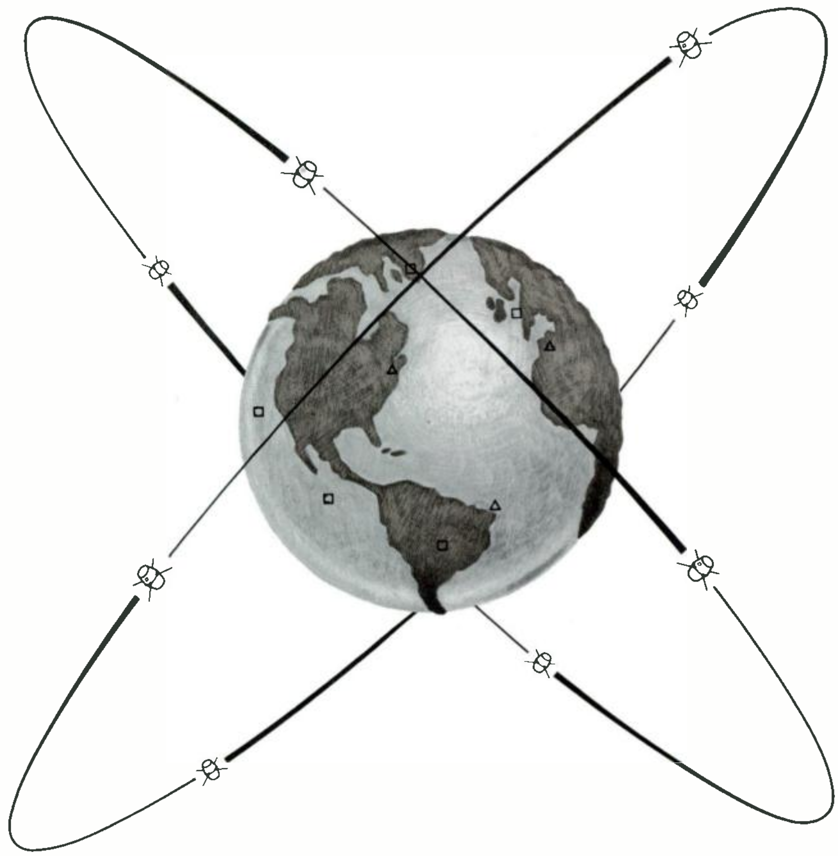

WORLD-WIDE COVERAGE is possible with eight satellites, six control stations, and eighteen reference stations.

redundant circuitry to provide maximum reliability and long life in orbit.

The proposed cylindrical satellite is 52 inches in diameter and 48 inches long, and it weighs 322 pounds. The satellite is covered with solar cells to provide power for electronic equipment. The force of gravity can be used to stabilize the satellite on an imaginary line to the center of the earth. This technique would keep the satellite antennas directed toward earth, thereby concentrating radio signal energy and gaining efficiency.

Control Stations—Six control stations, spaced equidistantly around the surface of the earth, are needed for world-wide coverage. Each control station is provided with a computer for calculating craft positions and providing traffic services. The control stations are the traffic overseers and keep the entire system going by controlling all operations among the various parts of the navigation satellite system. They monitor and track all satellites. As central control points, they provide information about ships and aircraft and relay information to ships and aircraft from outside agencies, such as Air Traffic Control, Air-Sea Rescue, and the Weather Bureau.

Control station equipment includes the electronic computers and associated radio transmitting, receiving, and measuring equipment. It can be built in modules so that stations can be expanded as directed traffic increases.

To communicate with the satellites, the stations will have tracking antennas similar to those presently used by NASA for receiving data from spacecraft. The control stations also contain the measurement portions of the distance- and angle-determining system, so that the satellites can serve primarily as relay stations.

Reference Stations—Eighteen reference stations, spaced symmetrically around the earth, are used to determine the location and attitude of the satellite in space. This use of reference stations simplifies satellite construction by permitting less rigid satellite antennas; also, the satellite will not need to carry its own calibration devices, and perturbations of the satellite's orbit will not affect the accuracy of the system.

Each reference station consists of a receiver, transmitter, and antenna, all of which operate automatically. This equipment can be located in existing buildings, such as universities or scientific installations, and can be maintained by personnel already there.

Navigation Equipment on Ships and Aircraft—The user ships and aircraft will carry inexpensive electronic navigation equipment that automatically generates, receives, repeats, and sends signals for position fixes, emergency reports, and other information. The receiving, transmitting, and display equipment required can be installed in the navigator's compartment in a 40-pound unit of about

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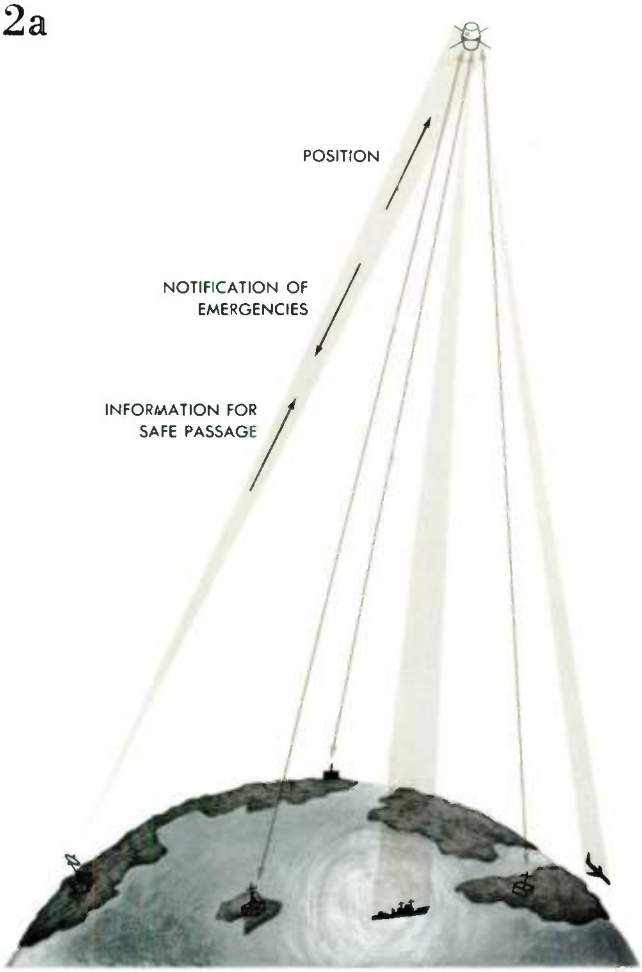

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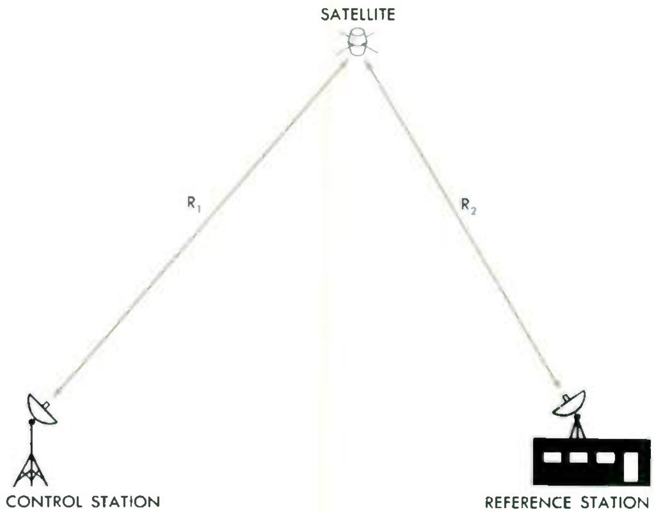

POSITION OF A SHIP OR AIRCRAFT can be determined by finding the exact position and attitude of a satellite and then finding the direction and distance of the target vessel from the satellite. Satellite location is found by measuring the range of the satellite from three reference stations of known location (a). The attitude of the satellite is found by measuring the direction (see Fig. 3) of four reference stations from the satellite. As shown in the sketch (b), distances are found from elapsed-time measurements of R_1 and (R_1 + R_2).

two cubic feet in volume. This equipment includes a conventional type of data section to receive and examine radio transmissions and accept only those messages that are addressed to it. Also included is a section to receive and transmit the radio pulses used in determining distance and direction from the satellite to the ship or aircraft. Each unit has a screen or paper printout to display information, and a frequency shifter to enable the ship or aircraft to report an emergency situation.

Ships and aircraft will each mount two small antennas, one to receive data and the other to receive and transmit the radio pulses that are used in the distance and direction measurement.

Navigation Satellite System Operation

The calculation of ship or aircraft position is made from two elements of information: The location and attitude of the navigation satellite in earth coordinates, and the distance and direction of the ship or aircraft from the satellite.

The *location* of the satellite in space is calculated from distances measured from three reference stations, whose locations are accurately known (Fig. 2). A distance-measuring pulse from the control station is repeated by the satellite, received and repeated by a designated reference station, and relayed back to the control station by the satellite. From the elapsed time intervals, the control station can determine the distance of the satellite from the control station, and the distance of the control station from a particular reference station via the satellite. Subtracting one from the other gives the distance from the satellite to the reference station. The motion of the satellite during the measurement process is taken into account by the computer. Each control station thus keeps a continuous position track of each satellite within its line of sight.

The *attitude* of the satellite can be determined from a measurement of the *direction* of several reference stations from the satellite. Direction is determined by the interferometer (Fig. 3), which operates in a manner somewhat similar to the way a person senses the direction of a sound source by listening with both ears. Immediately after sending the distance-measuring pulse, the reference station sends an angle pulse to the satellite. The satellite interferometer amplifies and frequency shifts the angle pulse and forwards this information to the control station, where the signal is analyzed and the direction of the reference station from the satellite determined. Angle measurements obtained from several reference stations permit a calculation of satellite orientation with respect to an established coordinate system on the earth.

The distance and direction of the ship or aircraft from the satellite is determined by an analogous process. The control station addresses a coded message via the satellite to the ship or aircraft to tell it that its position fix will be determined on the next transmission. The data section of the shipboard navigation equipment recognizes the alert and prepares to receive and transmit radio pulses for distance and direction measurement. The control station then initiates the pulse, via the satellite, and the shipboard transmitter replies with a distance and an angle pulse. The control station determines the distance and direction of the ship or aircraft from the satellite, and combines this information with the known position and attitude of the satellite to compute ship or aircraft position. The control station then radios the ship or aircraft its position via the satellite. The sequence takes only a fraction of a second, and is repeated every time a fix is made.

Entering and Leaving the System

A ship or aircraft enters the system by notifying the control station that it is ready to depart from a port or airfield. An automatically generated identifying code is sent via the satellite to the control station where the computer causes the ship or aircraft to start receiving the navigation satellite system service. The craft's position is immediately determined and reported so that the craft can check out the accuracy of its equipment by comparing the calculated position it receives with the known location of the port or airfield.

The ship or aircraft continues to receive position fixes on a regularly scheduled basis until it arrives at its destination. It then notifies the control station to remove it from the system. In this way, system facilities are not tied up by ships in port or aircraft on airfields.

The computer in the control station initiates action to determine the location of each ship every hour and jet aircraft every ten minutes. Supersonic aircraft might require a three-minute location interval. Ships and aircraft will receive fixes more often when approaching land or hazards, or whenever they request the additional service.

A System for the North Atlantic

During the course of the study, it became apparent that another, possibly more desirable, interim Navigation Satellite System could provide continuous coverage over a limited area at much less expense. For example, a system could be designed to cover the North Atlantic with only one control station, three reference stations, and one satellite at synchronous altitude stationed over the equator at about 33 degrees west longitude (Fig. 4). This system would operate the same as the world-wide system, and the same equipment would be required for the satellite, ships and aircraft, control station, and reference stations.

System Benefits

The navigation satellite system described has been designed to provide position information accurate to one nautical mile. Authorities recognize this accuracy as sufficient for operating ships and airplanes. This accuracy would permit traffic-control agencies and air-sea rescue services to pin-point the location of all ships and aircraft using the system.

A system that determines aircraft position and keeps air controllers continuously informed would be particularly

3 INTERFEROMETER TECHNIQUE FOR MEASURING ANGLES

a) The proposed navigation satellite contains two interferometers, which consist of phase-angle measuring antennas plus amplifying and data transmission circuits. The sets of antennas are at right angles to each other and are positioned parallel to the earth's surface. Each set consists of inner antennas, which give gross angle determinations, located three feet out on the arms. Outer antennas, which give accurate angle determination, are located on the same arms 50 feet from the satellite cylinder. The direction of a ship, aircraft, or reference station is determined by measuring the phase delay between the signals received by the pairs of antennas: $\phi = (2\pi D/\lambda)\sin\theta$, where D is the distance between antennas, λ is the wavelength of the incoming signal, θ is the geometric angle to the signal source, and ϕ is the phase delay angle. The limitation of the technique is the ability to measure ϕ. For a given error in ϕ, the error in θ is decreased as D is increased. When D is increased, however, there may be a number of possible values of θ for any value of ϕ. An inner pair of antennas with lesser accuracy is used to determine which value of θ to use. The satellite interferometer amplifies and frequency shifts the signals received by the interferometer antennas. It forwards this information to the control station, where phase measurement and angle determination is made.

b) The angle that is measured by a set of interferometer antennas describes the surface of a cone, with its apex at the interferometer and its axis coincident with the interferometer. Thus, two sets of interferometers at right angles to each other and parallel to the earth describe two cones; the cones intersect along two straight lines, one pointing toward the ship, aircraft, or reference station and the other away from the earth.

c) The distance (Fig. 2) and direction thus computed from the satellite to the ship or aircraft describes a volume of cylindrical shape whose diameter is the angular uncertainty and whose depth is range uncertainty. The projection of this volume on the surface of the earth gives latitude and longitude. Since the volume has approximately equal dimensions in all directions, its projection has the same size in all positions and the accuracy of the system is independent of the relative position of the ship or aircraft with respect to the satellite.

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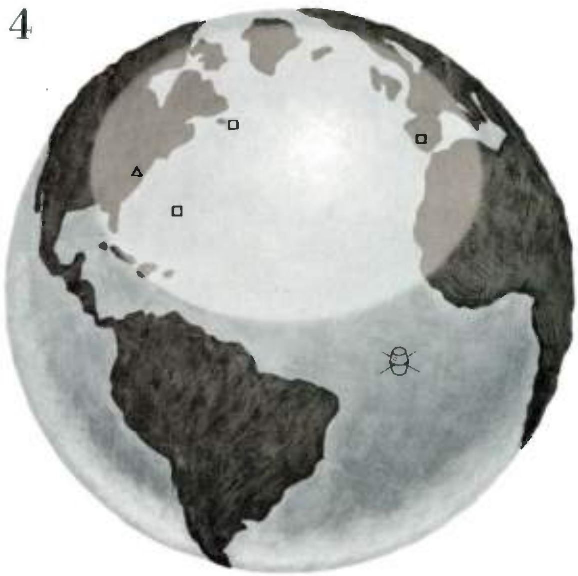
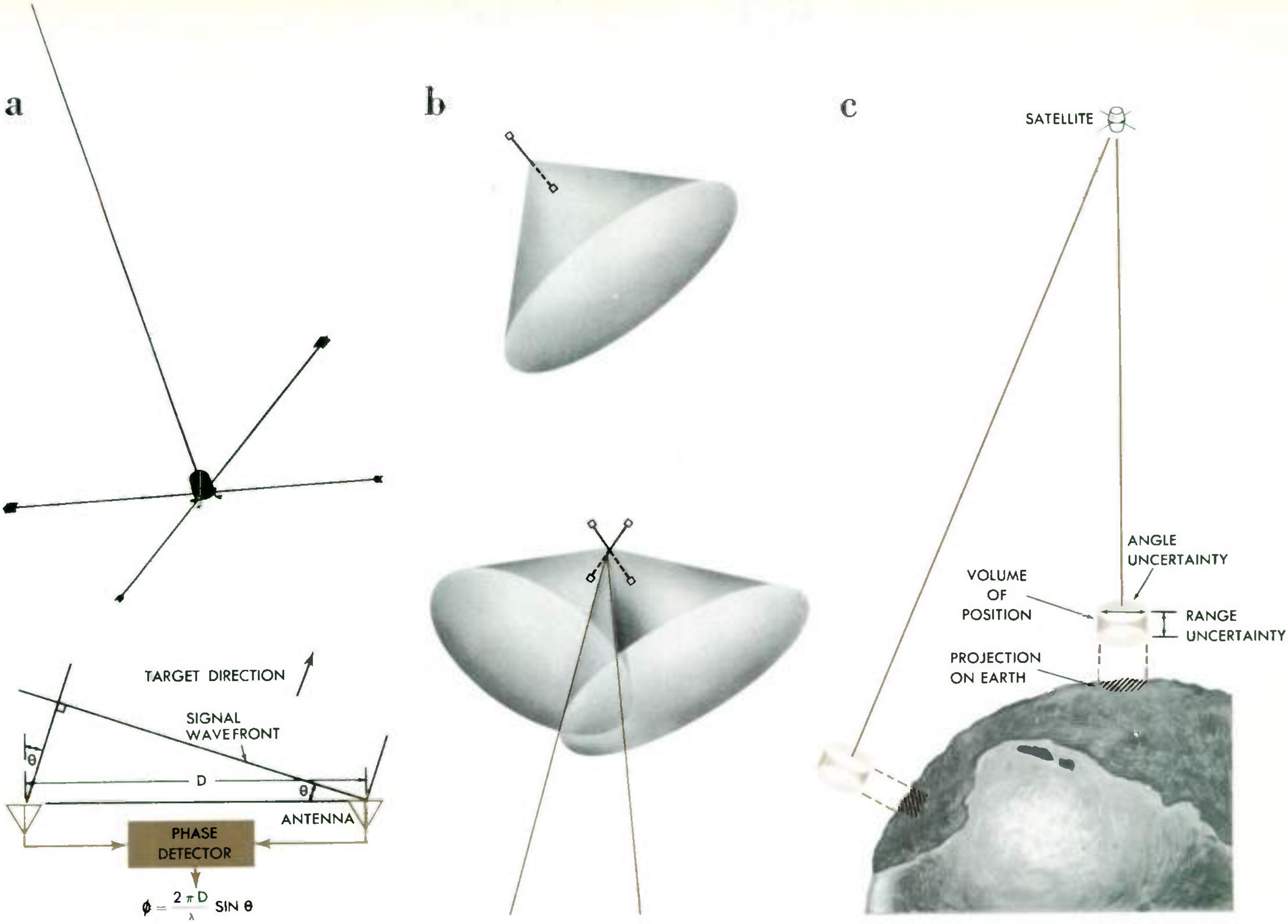


1 SATELLITE AT SYNCHRONOUS ALTITUDE
△ 1 CONTROL STATION
□ 3 REFERENCE STATIONS

NORTH ATLANTIC COVERAGE can be provided by a navigation system containing one satellite at synchronous altitude, one control station, and three reference stations.



valuable for air traffic control over the North Atlantic. Because wide spacing of aircraft is now required to avoid collisions, airspace is already limited and cannot be used efficiently. The increasing volume of international traffic and the coming generation of supersonic aircraft will produce an even more complex air traffic-control situation.

Even higher accuracy may be desired by special users such as Coast and Geodetic Survey vessels, marine surveyors, marine oil and mineral prospectors, and oceanographers. For these users, accuracies down to a fraction of a mile could be provided but would require more precise equipment aboard the vessels involved.

Weather measurements are presently made primarily from land-based stations because there are not enough ships capable of measuring the desired weather parameters and promptly communicating this information to the Weather Bureau. Supplementing these surface measurements, meteorological satellites measure certain weather characteristics that can be observed in space. Satellites could also relay weather information from ships, aircraft, and unattended buoys floating in the ocean but the data would be useless without knowledge of the time and precise location of the measurement. If the Navigation Satellite relayed the information, it could provide the precise location of measurements, even from drifting buoys, and send the information immediately and automatically to the Weather Bureau.

Possible Program

A navigational satellite system that provides world-wide navigation and traffic control service to ships and aircraft in any weather would be of international public benefit. This service would offer a practical use of outer space as a companion to the United States communication and meteorological satellite programs. Such a navigational satellite system could be developed, and the satellites placed in orbit, by the National Aeronautics and Space Administration. The system could be operated by one or more cooperating United States government agencies, or perhaps by an international body created for that purpose.

Existing sophistication in electronics and space technology would permit a demonstration of the essentials of the system on advanced technological satellites planned for launch over the next two years. Although the spaceborne equipment awaits development, the angle-measuring subsystem could be demonstrated now on a ground range.

The interim navigation satellite system for the North Atlantic consisting of one satellite orbiting over the equator at synchronous altitude could be developed in time to be ready for launch after the completion of the technological demonstrations. Elements of a world-wide navigation satellite system could be ready for launching by the late 1960's, and an operational system made available for use throughout the world by the early 1970's.

A New Approach to Distribution Transformer Design

Herbert W. Book, Project Supervisor, Distribution Transformer Division,
Westinghouse Electric Corporation, Sharon, Pennsylvania.

This unusual design may ultimately replace all dry-type and oil-filled distribution transformers. It may well be the most significant new concept in transformer design in several decades.

For years, transformer designers have studied means of improving the insulation of distribution transformers. The result has been a steady improvement in transformer design, both in paper and in oil insulation, which have always been significant elements of transformer design. Despite the improvements, however, insulation has remained the weakest element of the distribution transformer.

Now a new design concept has produced a dramatic change in distribution transformers. Fundamentally, this consists of using enameled foil for the transformer coils, and then imbedding these coils in a solid cast epoxy resin. Paper insulation is eliminated, and oil is used only as a coolant. The new design provides a unit that is smaller, lighter, more flexible, and in particular, more reliable. The results are so remarkable that within a few years the solid insulated units are expected to replace conventional oil-filled units, and many dry-type transformers as well.

General Characteristics of the New Transformer

For the first time, all-aluminum enameled-foil transformer coils are securely imbedded in an integrated resin structure (see photos at right). This gives them some unusual mechanical properties. The magnetic interaction that produces high forces on short circuit is easily withstood by these coils. The solid-insulation resin covering also gives the coil protection from environmental influences, such as dirt, dust, and moisture.

The cast-coil transformer provides the key for more reliable and efficient distribution systems. They can be applied anywhere that present oil-filled or dry-type transformers are used. For electric utilities, the new units can be applied underground or on the pole top. For industrial plants, the new units are light and easy to handle, and can be conveniently placed to feed portable tools, pumps, compressors, and machine tools. For commercial buildings and high-rise apartments, the cast-coil units can efficiently provide the required voltage to loads, such as electric appliances, ventilating fans, air conditioning, and lighting.

Cast-coil transformers have the same overload capacity as the present oil-filled units. However, they are flexible in rating. For example, if a cast-coil unit with a modest overload capacity is applied as a dry-type transformer, it has a 100 percent rating; as an oil-filled unit, its capacity is increased 40 percent; and as a water-cooled unit, its rating is increased 125 percent (see bar chart at right).

The aluminum enameled foil is first wound into rectangular coils on a low- and high-voltage winding machine. These winding machines also contain a press for attaching terminals to the foil ends.

The wound coils are assembled in the molds, then conveyed to a resin dispenser. Here, the epoxy resin impregnates the aluminum-foil windings. After this, the cast coils are put into curing ovens. The resin cures, forming solid insulation over the enameled-foil coils.

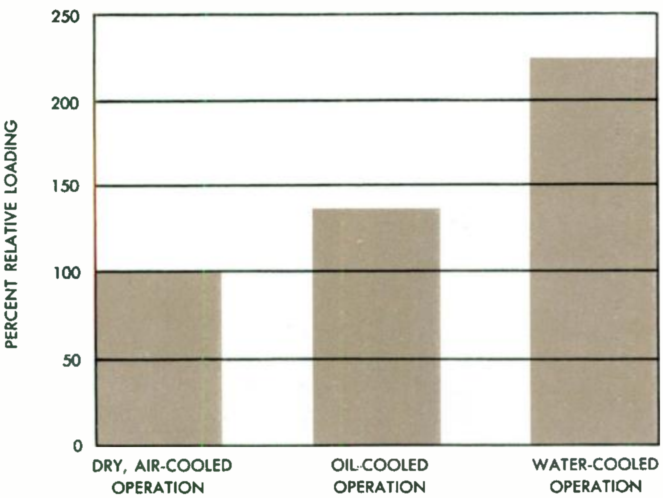
Some Advantages of the New Design

This construction has several significant advantages:

1. The paper insulation is eliminated. There is no cellulose to deteriorate and to absorb moisture, thus the life of the cast-coil units is increased, compared with present oil-filled transformers.

2. The cast-coil units have greater load flexibility than conventional distribution transformers. Their capacity can be more than doubled by merely adding to a dry-type unit a low-cost container and filling it with water. For oil cooling, the quality of the oil used is no longer a problem.

A COMPLETED 25-KVA, 7200-VOLT UNIT (top photo) is placed in its tank. In the bottom photo, the author is holding a 10-kva solid insulation unit. Limited quantities of 10, 15, 25, 50, 100, and 167 kva units are now being produced.



EFFECT OF COOLING OF CAST COIL DISTRIBUTION TRANSFORMERS, based on equivalent maximum winding temperature and using dry operation as a base.

In fact, "scrap" oil from conventional units can be used.

3. The coil is electrically and mechanically protected by solid insulation. No coil bracing is needed and there is no coil movement even under severe short-circuit conditions. Actually, the cast-coil transformer has virtually unlimited short-circuit strength. Gases (air), liquids, and solids have, roughly, relative intrinsic electric strengths of 1, 10, and 100. Solids are, therefore, the most desirable insulating material.

4. The new units are lighter and easier to handle. They can be installed indoors or outdoors—there are no underwriters' restrictions, no fire problems, and no toxic gases. Elimination of potential hazards makes the new units especially desirable for installation in hospitals, hotels, theaters, schools, factories, and other locations where large groups of people are present. Moreover, first costs will be lower for many applications.

Evolution of the New Design

The distribution transformer, reduced to its fundamentals, consists of a magnetic core of electrical steel, primary and secondary coils of copper or aluminum, and an appropriate system for insulating the coils for the application voltages. Auxiliary cooling, such as oil, is often required. The oil serves two purposes: as a coolant for coils, and as a vital part of the coil insulating system. A sealed tank retains and protects the high-quality oils used. Therefore, bushings are needed to bring the coil connections through the tank.

Great strides have been made in coil development as more knowledge of impulse distribution and insulation aging was obtained. To grade electrical stresses, new winding configurations were created. Insulation processing and additives extended the life of many types of transformers.

In spite of these improvements, the coil still remained the same coil of copper wire or strap insulated with oil-impregnated paper or cellulose in some modified form. Not surprisingly, the insulation system required for the coils has not improved as rapidly as other transformer components, such as the core.

The story behind the new solid-insulation transformer involves the use of computers to pave the way to new transformer design concepts, and the development of materials and methods to make these concepts practical.

Computer Guides Present Development—In 1958, a computer was employed to examine and analyze thousands of transformer designs and design influences. As a result, four basic insulation "space factor" weaknesses were uncovered:

1. The inefficient use of space resulting from the use of round or semiround conductors in a coil of overall rectangular construction.

2. The inefficient use of layer insulation between layers of coil turns (selection of insulation for the layer end having maximum electrical stress results in nonuniform stress at all other points along the layer).

3. The use of cellulose in sheet form resulted in insulation systems highly susceptible to failure in "creep" along the surfaces of the sheet, which can become contaminated in service.

4. The dual purpose of the oil, as paper impregnant and coolant, resulted in a compromise between the ideal cooling fluid and the refined, ultrapure oil needed for its insulation qualities.

Introduction of Strip Conductors—In 1956, when Westinghouse introduced low-voltage, strip-copper windings, it was clear that the conductor shape of the future was rectangular strip, or even thinner foil. Simultaneously, the time-worn concept of many turns per coil layer and few layers was replaced with one turn of strip or foil-per-layer. This eliminated the need for layer insulation in any form and produced a coil consisting of interleaved-turn insulation only. The additional benefits of improved coil short-circuit strength and better impulse voltage distribution added luster to the strip or foil conductor concept. Selected transformer types were converted in part, or entirely, to the strip-foil concept, using first copper and then aluminum to overcome the first two of the four basic weaknesses. But the major insulation creep problem and the oil problem remained. Its solution rested in the elimination of impregnated sheet cellulose as the basic insulation medium.

Since paper interleaving used with the strip-foil conductors could be replaced with enamel as the insulator, Westinghouse, with interested primary metals producers, cooperated to develop ways to produce a coated foil and strip having high dielectric strengths for transformer conductors.

However, major insulation and oil still remained a problem. Previously, some success could be claimed in the

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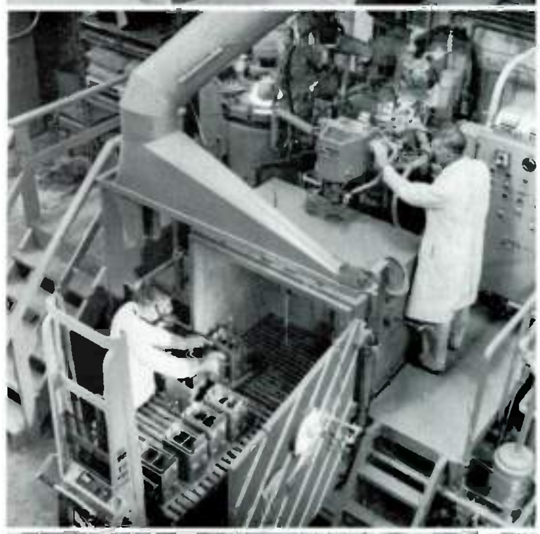

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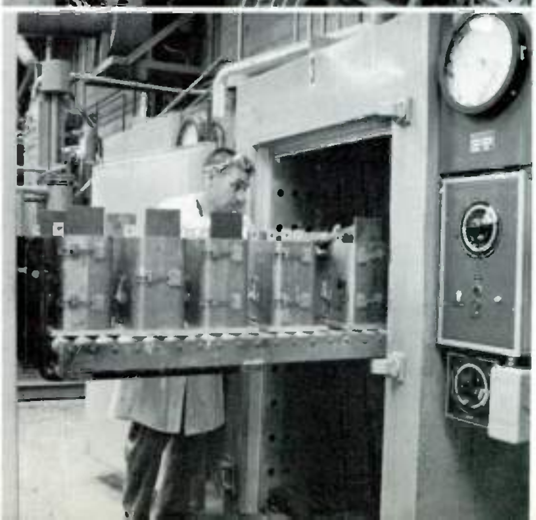
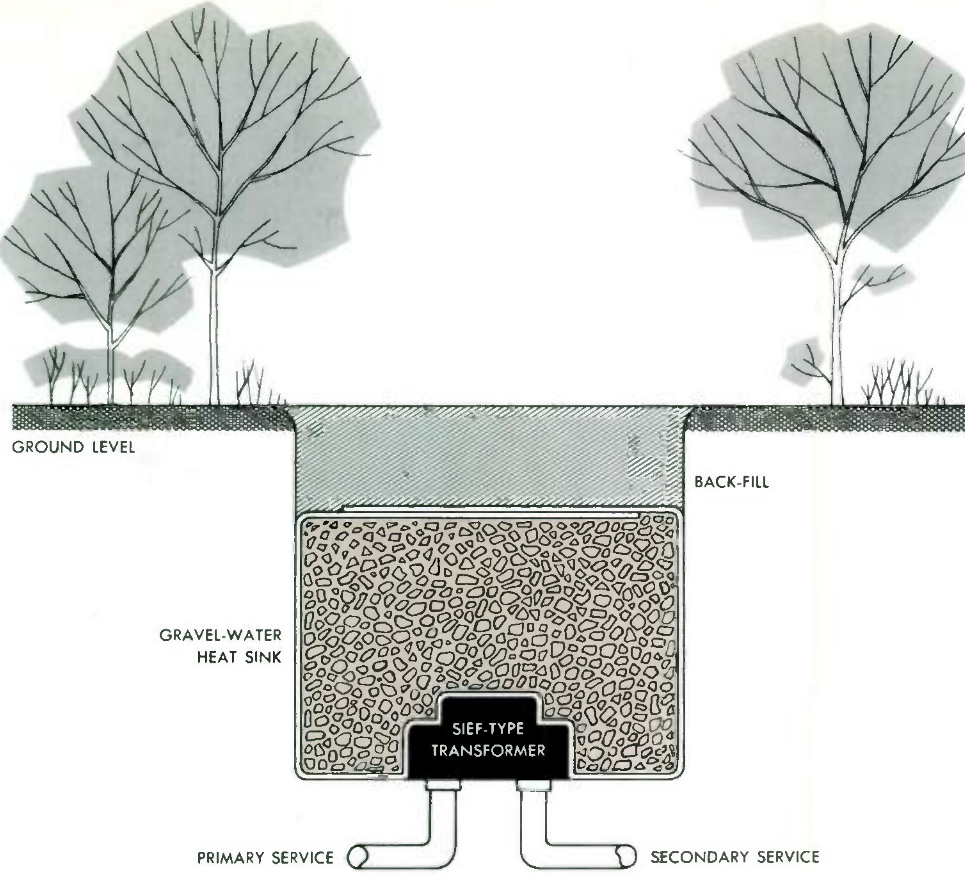


1, 2) LOW VOLTAGE (1) AND HIGH VOLTAGE (2) WINDING MACHINES. These machines not only wind the all aluminum enameled-foil coils, but also attach the terminals to the foil ends.
3) ALUMINUM-FOIL WINDINGS ARE CAST into the epoxy resin in this dispenser.
4) CAST COILS ARE THEN PUT IN CURING OVENS, where the resin hardens, forming the major coil insulation.



USE OF LOW COST HEAT SINK permits normal loading of cast-coil transformers for underground service.

use of epoxy casting as a transformer insulating medium, but no one had solved the many difficulties accompanying its application.

The difficulty was in obtaining casting integrity throughout the coil cross-section. A number of compromises were attempted, including post-impregnation of the coil structure with oil. The only solution to getting totally impregnated, corona-free, epoxy-cast coils appeared to be in "overdesign."

Then the unique possibility was considered of uniting the enameled-foil and the solid-epoxy cast insulation system. This combination solved many problems. Solid-cast resin supplied the enameled foil with a major insulation and also mechanical protection. In addition, the inability of the solid-resin system to thoroughly impregnate dense winding structures was circumvented because of the unique nature of the foil-strip winding. Having only turns (and turn insulation), but no layer insulation with its accompanying points of stress concentration, this type of winding eliminated the need for complete winding impregnation. In this method of construction, the voltages between turns in the windings are so low that corona is no problem.

Present Status and the Future

High-voltage, dry-type, cast-coil units are already being produced for high-rise apartment service. A limited number are now in 15-kv service providing full-impulse levels on safe, lightweight transformers. Production of controlled quantities is under way, substituting the cast-coil units for the copper-paper type in liquid-cooled, pole-type transformers. Limited quantities of 10-, 15-, 25-, 50-, 100- and 167-kva ratings are being produced. These are the forerunners of other ratings and types to come. Sufficient initial production of solid-insulation enameled-foil coils is planned to provide industry with the broadest possible application experience.

Trial installations of water-cooled units and others designed for direct burial, without derating, are under observation. Results, thus far, indicate that the cast-coil unit for underground distribution in directly buried installations will be made commercially available soon (see illustration above).

An entirely new industry is developing to produce enameled foil for the new transformer, and, at Westinghouse, major changes in manufacturing facilities for producing the units are under way to supply the electric utility and industrial markets.

Within a few years, a large portion of the Westinghouse distribution transformer manufacturing will be converted to cast-coil construction. This conversion will provide new equipment and new facilities to manufacture solid-insulated units since they will eventually replace present oil-cooled units. In fact, these new transformers will be found in both liquid-cooled and dry-type units; eventually they will be applied in commercial, industrial, and utility applications in all voltages and all kva ratings.

Superconducting Generators for Superconducting Magnets

Superconducting magnets are becoming valuable research instruments because they produce extremely intense magnetic fields with relatively small and uncomplicated equipment. However, the large perpetual currents that circulate in them have had to be introduced from outside the magnet vessel (which contains liquid helium at −452 degrees F). The current is led in by thick cables that are not superconducting.

To provide a simpler method of energizing the magnets, a small high-current superconducting generator has been developed at the Westinghouse Research Laboratories. It is placed inside the Dewar vessel in the same liquid helium that cools the magnet. Because the generator itself is made of superconducting materials, it produces large currents with nearly 100-percent efficiency. In one version, the device has no moving parts.

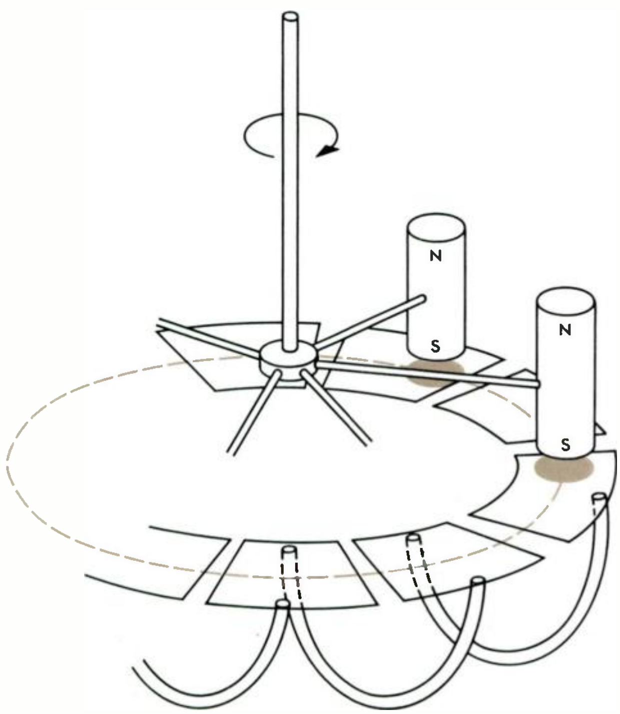
The heart of the generator is a series of flat plates of superconducting metal, usually lead or niobium, arranged in a circle and connected electrically by superconducting wire. (See illustration.) In the type illustrated, several small superconducting magnets rotate close to and parallel with the superconducting plates. These exciting magnets turn at about 100 rpm, in a typical generator, and in a circle about four inches in diameter. The device produces more than 800 amperes.

Like all electric generators, the superconducting model produces electricity by cutting magnetic lines of force with electrical conductors. The way in which this is done, though, is far different from the conventional methods. The superconducting generator takes advantage of two unique properties of superconductors: rather than taking up magnetic lines of force, as metals ordinarily do, a superconductor strongly repels a magnetic field; but when the magnetic field is strong enough, the superconductor instantly loses this and all other superconducting behavior. Therefore, the exciting magnets in the superconducting generator have two functions. They create the magnetic field required by the electric generator, and they make "holes" of normal-behaving metal through the superconducting plates as they sweep past.

In operation, the magnetic field of the exciting magnets is rejected by the superconducting plates except at these holes, where the magnetic lines of force pass through easily. As the magnets turn, the holes move with them, dragging the lines of force along. The lines are swept past a superconducting wire, setting up an electric current in it. In this way, the requirement of cutting a magnetic field with an electrical conductor is fulfilled.

The amount of current derived from the generator depends on such factors as the number of superconducting plates, the strength of the field from the exciting magnets, and the speed with which the magnets are rotated. The generators have been used to bring superconducting magnets up to strengths as high as 40 000 gauss.

In another version of the generator, the turning magnets are replaced with three fixed electromagnets energized by alternating current. The alternating current creates a rotating magnetic field, as it does in conventional ac motors. This construction gives a superconducting dc generator with no moving parts.



SUPERCONDUCTING GENERATOR (left) consists essentially of exciting magnets and plates of superconducting metal connected by wires. In this version of the generator, the magnets are rotated mechanically by a shaft.

LARGE NEW BLAST FURNACE (right) is one of the first with completely programmed charging. The Prodac control system also supervises other operations of the furnace and performs data logging. Its central control area includes the equipment that initiates, monitors, and records furnace operations to improve furnace productivity and help produce a more consistent pig iron.

Blast Furnace Charged by Automatic Controller

A digital programming control that initiates, monitors, and records the charging program of a large new blast furnace is enabling the operators to improve furnace productivity. More accurate and reliable measurement of the charging materials, positive repeat of charging cycles, and increased speed and efficiency of charging add up to greater productivity per unit input of time, labor, and material. The control also helps produce pig iron that more consistently comes within the desired analysis specifications. The furnace, affectionately named Amanda, is rated at 3340 tons per day production.

This Prodac prescheduled digital programming system at Armco Steel Corporation's Ashland, Kentucky, works is one of the first to be given complete supervision of the charging of a blast furnace. The system programs and controls the weighing and charging of all stock-house materials—scrap, water, ore, limestone, coke, and miscellaneous material. Feeding of all materials into their respective weigh hoppers, emptying into the skip hoist, and control of the skips, furnace bells, distributor ring, equalizer valve, and stock-line recorders are all initiated and monitored automatically. For versatility, extra skips of any raw material can be added to the furnace without changing the preset charging program.

To set up a charging program, the operator sets the quantity-selector counters for each material, selects the proper bins from which to feed, and sets initiating instructions for furnace bell operations at the proper point in the charging sequence. Then the control system takes over. When a skip load of coke, for example, is called for, the skip, upon entering the loading pit, signals the coke weigh hopper to open its gate and fill the skip. When the *empty* signal is received from the weigh hopper, the gate is closed and the skip started to the top of the furnace. Simultaneously, the coke screen, collecting conveyer, and feeders start. The filling coke is weighed and, when the proper amount has been fed into the emptied weigh hopper, the screen, conveyers, and feeders are stopped and the bin gates closed.

The Prodac programming system also controls the mechanisms at the furnace top that admit and distribute raw materials. When the skip reaches the top, it is counted as it discharges its load through the distributor and onto the small bell. The sequence of dumping from the small to the large bell and into the furnace follows a preset program. In all of the charging steps, a monitoring section prevents such errors as sending skip loads to the furnace when the large bell is too full to receive them.

A data-logging system with a 24-hour clock records the day, hour, and minute for each operation on punched tape, and an automatic typewriter reads the tape to print out the data. For totalizing of the recorded data, the tape is processed through statistical equipment.

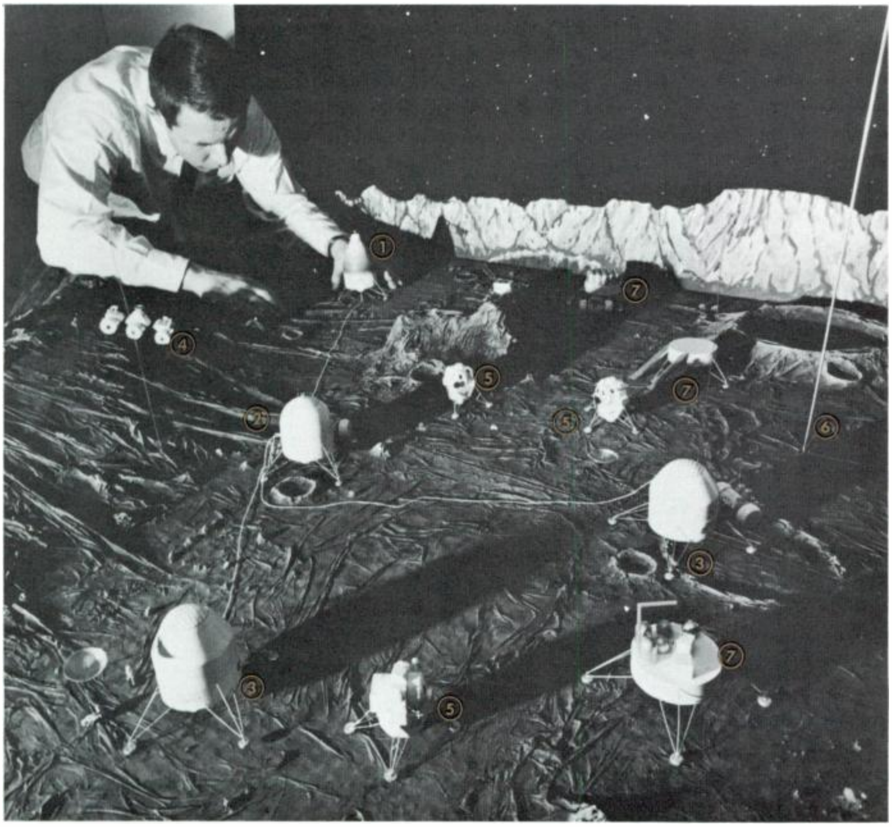
Test sequencing of all counters, shift registers, and static circuitry can be performed, including test print-out of the sequence as preset on the selector-switch and patch-board panels. This feature simplifies testing and maintenance because it permits checking the program and the data-logging system without operating any of the equipment.

More than 300 static control modules based on silicon diodes, transistors, and magnetic amplifiers take the place of many of the conventional starting relays, contactors, and limit switches. The static devices enhance reliability because there are no springs to break, contacts to wear and burn, screws to vibrate loose, and operating settings to be readjusted.

A LUNAR BASE CONCEPT is illustrated by these models of a portion of the moon's surface and of the equipment required for a manned exploration mission. The scale of the models is 1 foot=100 feet. They were made by the Westinghouse Defense and Space Center, Systems Operations, on the basis of various studies performed by Westinghouse groups. The transport vehicle assumed for all of the payloads is the Saturn V, which would carry about 25 000 pounds of unmanned payload.

The *nuclear power supply* (1) would produce about 100 kilowatts of electric power from a turbine-generator powered by a nuclear reactor. The entire plant is contained in a single Saturn-V payload section, which measures about 20 feet in diameter by 30 feet in height. It provides power for work, life support, fuel and oxygen regeneration, and operation of communication equipment. A *regeneration unit* (2) recreates the chemical fuels of secondary power supplies. For example, water produced by the fuel cells of the roving vehicle is broken down by electrolysis into oxygen and hydrogen, which are then liquefied and stored cryogenically.

Personnel shelters (3) accommodate six men, or twelve in an emergency. They have complete life-support systems and use either power from the nuclear supply or from a back-up fuel-cell supply in the shelter. Each has a parabolic antenna for video and data transmission and communication with the earth; a tall mast on each supports VHF antennas for communication with men outside the shelters and with the two-man *lunar roving vehicle* (4) when in line-of-sight range. *Lunar excursion modules* (5) are vehicles in which men arrive on the moon and return to a lunar orbit; in lunar orbit, the modules rendezvous with an Apollo-class spacecraft for the return to earth. A 500-foot mast supports the *ground-wave propagation antenna* (6) used for over-the-horizon communication. Small two-wheel resupply trailers would transport materials, equipment, and food between units of the base. *Landing vehicles* (7) would bring the roving vehicle, resupply trailers, and resupply payloads.



NEW LITERATURE

Industrial and Power Tubes Technical Guide presents detailed application information and technical specifications for industrial and special-purpose tubes. A direct-interchangeability list is also included. Price, $.75. Order from Westinghouse Electronic Tube Division, P.O. Box 284, Elmira, N.Y.

High-Voltage Silicon Rectifier Handbook is a 229-page book for design engineers. It includes information on high-voltage silicon rectifier characteristics, applications, and design considerations. (A high-voltage application is defined as one in which the recurrent peak voltage is 3000 volts or more.) One entire section covers design criteria for selecting rectifiers, and another discusses specific applications. Other sections deal with corona, reliability, terminology, high-voltage assembly ratings, and device specifications.

Price, $2.00. Order from Westinghouse Semiconductor Division distributors or from Printing Division, Westinghouse Electric Corporation, Box 398, Trafford, Pennsylvania 15085.

Chesapeake Bay Bridge-Tunnel Gives Motorists Clear Sailing

Motorists using the new Chesapeake Bay Bridge-Tunnel may blink twice when the bright roadway lights seem to disappear into the water and suddenly reappear a mile away (see photograph). The disappearing act is the result of two tunnels that dip under the bay to provide ship channels to and from the Atlantic Ocean.

The 17.6-mile system, which was opened this spring, was built at a cost of $140 000 000 to connect Virginia's eastern shore with the Norfolk area. It reduces the crossing of the bay from a 1½-hour ferry ride (not counting waiting) to a ½-hour drive. From north to south, the system consists of a two-lane roadway that stretches across two bridges, dips into a tunnel, crosses a trestle, dips into another tunnel, and finally crosses another trestle to the mainland (see map).

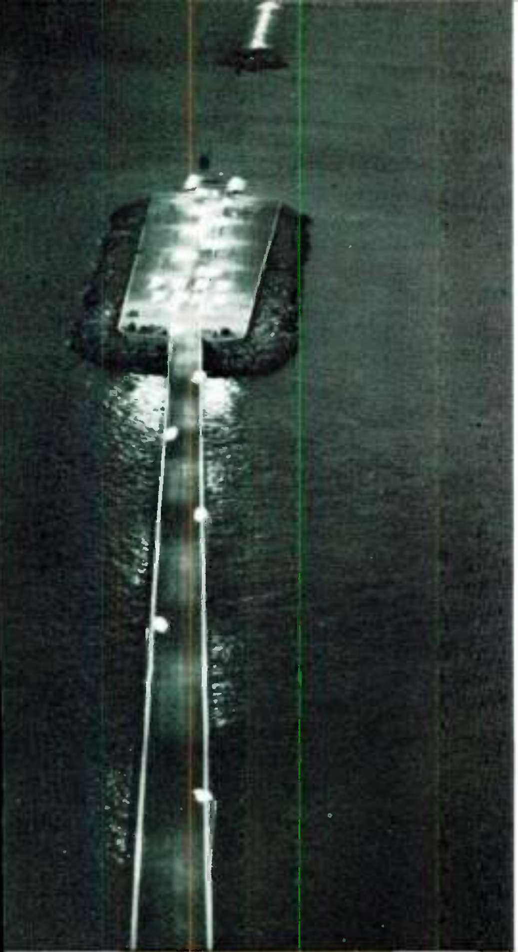
At night and during bad weather, 380 mercury-vapor lamps light the way along the 15 miles of bridges and trestles. Day and night, 3788 fluorescent lamps light the two mile-long tunnels that lie as much as 98 feet below the ocean's surface. Fresh air is supplied to the tunnels by 24 fans.

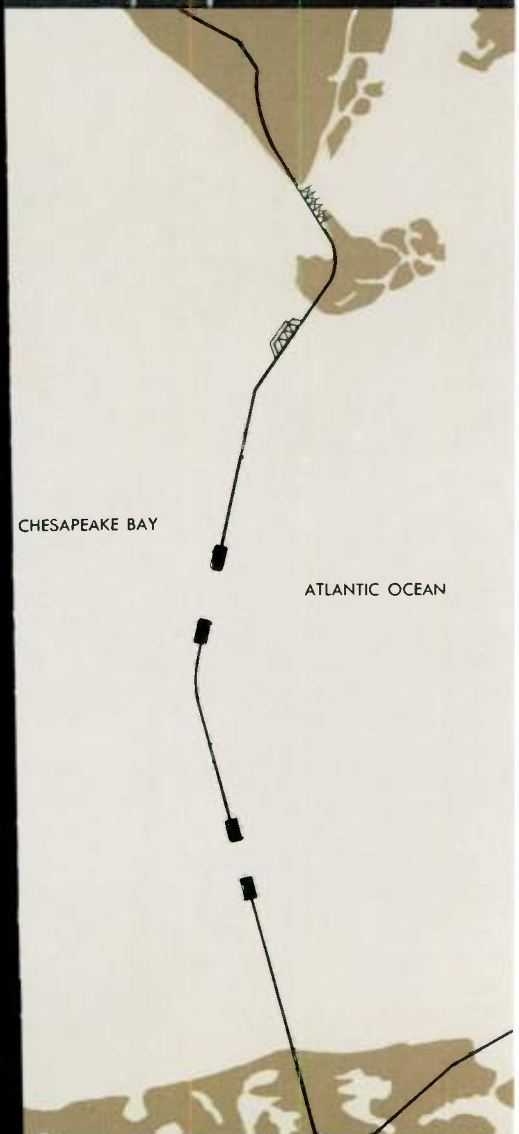
Power for the tunnel ventilation equipment, lighting, pumps, and other needs comes from substations in the ventilation buildings. These buildings are located on each of the four eight-acre man-made islands where the tunnels connect with the trestles. Diesel generators will take over in the event of power failure.

The substations receive their power from a mainland power station. This station's two 13.8-kilovolt feeders also distribute power to 11 lighting power centers attached to the sides of the trestles. These are made of aluminum and stainless steel to resist corrosion.

The Westinghouse lighting and power equipment was installed by E. C. Ernst, Inc., electrical contractor to the Chesapeake Bay Bridge and Tunnel Commission.

CHESAPEAKE BAY BRIDGE-TUNNEL crosses 17.6 miles of water at the lower end of the bay, with two mile-long tunnels providing clear channels for shipping. Mercury-vapor lamps light the bridges and trestles of the system.



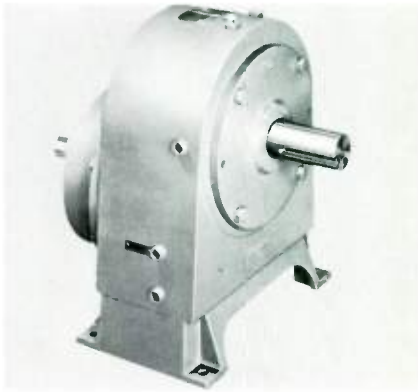


PRODUCTS FOR INDUSTRY

HALL GENERATORS are semiconductor devices that multiply magnetic field and device current linearly to produce an output voltage. They can be used as gauss meters, ammeters, wattmeters, function generators, choppers, and position indicators, and they are made in a wide range of voltage ratings and types. *Westinghouse Semiconductor Division, Youngwood, Pa.*

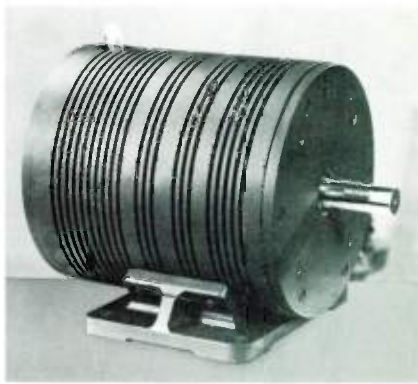
LIGHT-DUTY AC MAGNETIC CRANE-CONTROL SYSTEM, designated Class 13-660 crane control, is available in ratings to 125 horsepower for 600-volt 60-cycle wound-rotor induction motors. The NEMA Class 11 reversing controls meet requirements of crane hoists equipped with mechanical load brakes for all light-duty applications. They also can be applied for bridge and trolley motions for light intermittent-duty cranes. *Westinghouse Low-Voltage Distribution Equipment Division, 1844 Ardmore Blvd., Pittsburgh, Pa. 15221.*

MODULINE SPEED REDUCERS are single-, double-, and triple-reduction units for horizontal or vertical mounting. Ratings are from 1 to 571 horsepower, and speed ratios range from 1.25-to-1 to 238.4-to-1. Parts are standard and interchangeable. A built-in backstop can be included to prevent reverse rotation. *Westinghouse Motor and Gearing Division, Buffalo, N. Y. 14205.*



SILICON-RECTIFIER DC WELDING POWER SOURCE is engineered for heavy-duty operations where space is at a premium. The WSH-650 is rated at 650 amperes, 40 load volts, and 60-percent duty cycle. It can be used single or stacked two or three high. Dimensions are 28 inches high, 26 inches wide, and 42 inches deep. *Westinghouse Westing-Arc Division, Buffalo, N. Y. 14240.*

DUAL-FREQUENCY COMPACT MOTORS in a range of speeds and ratings are designed for aerospace and ground-support applications. The motors operate on 60-cycle or 400-cycle power, eliminating the need to stock more than one motor for a specific support application. An automatic frequency selector eliminates the possibility of trying to operate the motor at the wrong frequency. *Westinghouse Aerospace Electrical Division, Lima, Ohio.*



Verifying the Installation of Products (VIP)

Robert L. Finch, Manager, Facilities Planning, Portable Appliance Division, Westinghouse Electric Corporation, Mansfield, Ohio.

The interval between the time a product is shipped from the manufacturer and the time when it is operating in the user's plant is ordinarily unproductive and often costly. The product is shipped, unpacked, and installed, but until it is operating, it is not performing a useful function.

A new technique—called Verification of Installation of Products, or VIP—is now turning this interval into a highly useful and profitable period. Basically, this technique involves studying the installation of the product by industrial engineering methods and using the information gained to improve the product design, manufacturing methods, packaging methods, instructions, and the other elements involved in installation. Results achieved so far include reduction in the cost of the product, development of simpler and quicker installation and test procedures, improved reliability, and lower installation costs.

The term "installation," as used in the VIP program, is defined broadly to include material handling, unpacking, checkout, performance tests, and clean-up as well as the actual installation. The industrial engineering methods applied are similar to those that have long been used in the factory to improve manufacturing methods. Essentially, the VIP technique consists of taking a special form of motion picture of actual installations, studying the filmed results and associated information systematically and thoroughly, generating new ideas, and incorporating the new ideas into the product design, into the installation procedures, or into both.

How a Study is Conducted

A VIP study should be conducted as soon as possible in the product life cycle. Ideally, it should be a regular and normal part of the product verification procedures of all products. This insures maximum benefits to the customer at the earliest possible time.

The first step is to familiarize the customer with the technique, so that he can explain the program when enlisting the cooperation of his employes. A key fact here is that the VIP study is intended to achieve product improvement through design improvements; it is *not* essentially a work-measurement technique.

A special photographic technique called *memomotion* is used to film the operations. The normal speed (sound speed) of a motion-picture camera is 1440 frames per minute; in the memomotion method, a speed of 100 frames per minute is sufficient for most installations. This slower filming speed has several advantages. It records an ample amount of information about the installation on a relatively small amount of film. More important, the resultant film can be projected at the normal speed of 1440 frames per minute to show even a relatively long installation period in a short time.

All the operations required to completely install the product are recorded on film. The analyst also records the sequence of operations of the installation and notes any comments, criticisms, or suggestions that may be made about the product. The film is then edited to place all operations in proper sequence. The time required to do each operation is determined by counting the number of frames of film used during the operation.

With this data (operations and time required), the customer's costs of installation can be shown on an operational basis for detailed evaluation. Each operation in the study is carefully questioned in an orderly manner similar to the questioning of manufacturing operations. Areas that are emphasized are the purpose of the operation, design of the part, tolerances and specifications, installation tools, materials, material handling, and packaging.

A working committee composed of marketing, engineering, and manufacturing personnel then reviews the film and the detailed analysis prepared by the analyst. As the committee members review each operation, they ask specific questions such as these: Are products that are assembled in the plant disassembled at installation? Are all product finishes correct, considering installation problems? Are the specified installation tolerances too tight or too loose? Can more assembly be done in the plant? Can the packaging be improved? Can packaging materials be eliminated? Can total material handling be simplified? Can the product design be changed to simplify installation? Can a better method of installation be developed? Are the instructions adequate? Who should do the installation? Are the tools adequate? Can new tools be provided to simplify installation? Should the product be combined with another product?

The improvement ideas that emerge from the analysis are docketed, each to be acted on by the responsible member of the committee. Target dates are set for completion of the docket, and the committee meets regularly to follow up on the progress and final disposition of all dockets.

After implementation of the committee's ideas to improve the product's installation costs, a new installation incorporating the improvements is studied. This verifies the progress made and provides a graphic demonstration for future use when new materials and techniques may warrant another redesign of the product.

Case History: A Fluorescent Light Fixture

Taking the Study—At the job site, the industrial engineer and lighting sales engineer explained the purpose of the study to the contractor, asked about the method he would use to install the fixtures, and asked him to ignore the camera and have his men work as they normally would. The industrial engineer prepared an operation sequence sheet from the information he had received from the workers. The camera was then set up, and the photographing started. About 1100 feet of film was taken at 100 frames per minute, representing 7 hours and 20 seconds of actual installation. (Only 30 minutes is required to view the entire installation film.) The installation study required three working days.

Preparing the Study Data—The industrial engineer reviewed and edited the film so the operations would appear in proper sequence. Then he made a complete analysis of the film, starting by deriving time values for each operation by frame-counting the film. Each operation was questioned systematically to determine whether it could be eliminated, combined with another operation, reduced, or changed in some manner to reduce installation costs. The improvement ideas generated by the industrial engineer were listed for each operation.

Analyzing the Study—The film and analysis were reviewed with the working committee, which was composed of the supervisor of industrial engineering, sales manager, engineering manager, product manager, advertising manager, and two members of the design engineering group. The industrial engineer's ideas, supplemented with other suggestions from the committee, were recorded. The ideas were docketed and given to the responsible committee member for action. Target dates for completion of the dockets were set and a progress report was scheduled.

The analysis revealed that the following design changes were necessary:

1) *New design of door frame to keep shielding from dropping out.* In many of the doors the plastic shielding and metal tie rods had been jarred loose from the frame during shipment or in the normal handling required to assemble the door to the troffer. To replace the shielding, it was necessary to loosen screws in the frame, insert the shielding, and tighten the screws. This required from three to five minutes and was necessary on about 25 percent of the doors. A simple redesign of the door kept the shielding and tie rods from jarring loose.

2) *Modification of side runner to facilitate installation in grid-type ceiling.* The assembly of the troffer into the recess of the grid-type ceiling was impeded by four tabs on the ceiling runners. Many troffers had to be forced and pried into position with a screwdriver. A recess was designed into the troffer to clear the tabs, thereby eliminating the binding.

3) *Provisions to ship units completely wired and assembled on disposable pallets.* Troffers had been shipped in individual cartons. The door frames had been packed four to a carton and the lamps 24 to a carton. All of these items had to be unpacked and two wire-ways and a center plate disassembled from the troffer.

The films showed that the installer had to retrace his steps five times to complete the installation. He had to position the troffer, put in the lamps, and assemble the door. This sequence was improved by prewiring with an individual connecting cable and by assembling the lamps and door to the troffer at the plant. A disposable pallet to hold 21 units was designed. These design changes eliminated the troffer and door cartons and also reduced the installation time.

Follow-Up—To measure success, an industrial engineer filmed the installation of the redesigned product with the memomotion technique. The film was developed, edited, and analyzed by the industrial engineer. Time values for the new operations were derived by counting frames.

A cost comparison between the two methods of installation showed that the installation time per fixture was reduced from 27 to 5 minutes and the contractor's overall cost per fixture was reduced by 6 percent. The contractor received other benefits in improved reliability due to the improved installation methods and design changes. For example, prewiring reduced the number of service calls. Moreover, contractors installing this lighting fixture now have available a concise film showing the installation procedure. With it, they will be able to schedule workload and manpower requirements better.

The Present and the Future

VIP studies have been completed on many Westinghouse products, ranging from portable appliances to gas turbines. The results are dramatic. Examples include a 50-percent installation cost reduction for x-ray equipment, a 30-percent cost reduction for underground distribution transformers, and a 50-percent cost reduction for electric baseboard heaters.

Although the technique was developed to study installation, it can be extended to other areas. The most important area of development work presently is in the servicing of products. A program using a systematic analysis technique is being piloted, and results indicate that this type of program will insure development of more reliable products.

Another area being considered is the effect of environmental conditions on products. This includes a study of how products are actually used and the discovery of new products to meet customer demands.

Conclusions

The VIP program has proved its worth wherever it has been applied. While at first glance the technique seems most useful where installation time is relatively short, this is not the case; it has been equally valuable in studying installations that require weeks or even months. Moreover, the complexity of the product is not a limiting factor.

Among the advantages of the program are lower product costs, lower installed costs of a product, improved product designs, better product reliability, new product ideas, and the availability of a film that can be used for training and job estimation.

Lightweight Compact Generators Employ Aerospace Principles

By taking advantage of weight-saving techniques developed for aerospace electric generators, engineers have developed a practical 600-kva land-based generator weighing only about 900 pounds. This is a weight-to-power ratio of 1.5 to 1, compared with ratios of as much as 12 to 1 for the 60-cycle industrial type of generator.

The compact generator was developed mainly in response to the modern need for mobility in military power generation equipment. It also has nonmilitary applications where a power unit has to be moved repeatedly, as in oil fields, off-shore drilling platforms, emergency power supplies, and power packages for underdeveloped areas. Electric vehicle propulsion is another possible application.

The machine is a brushless ac unit operating at 400 cps and 6000 rpm; this relatively high frequency is the main factor in its light weight as compared with a 60-cycle industrial machine. Additional weight is saved by taking advantage of insulation materials and construction techniques that permit the unit to run hotter and faster than conventional generators. In effect, the electrical, magnetic, and insulating materials are worked harder.

Possibilities for design improvement brought out by development testing of this machine show that still further improvement of the weight-to-power ratio of high-

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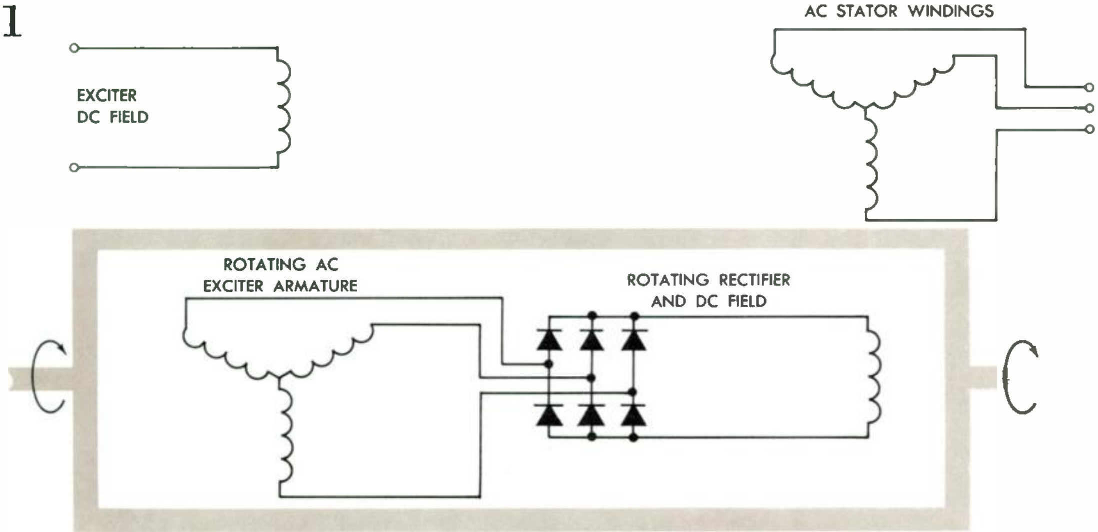

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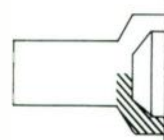
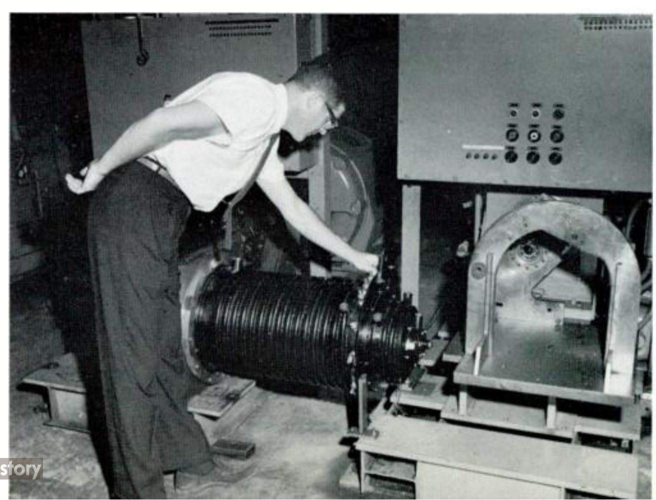


BRUSHLESS AC GENERATOR has an ac exciter armature, rectifier, and dc field in its rotor. Excitation current in the stationary exciter dc field generates ac power in the rotating ac exciter armature. The power is rectified to supply the rotating dc field, and this field generates ac power in the stator windings.

WEIGHT-TO-POWER RATIO OF 1.5 POUNDS PER KVA has been achieved in this 600-kva brushless ac generator developed for portable power supply. Generators supplying still more power per pound will be designed as a result of development tests with this machine.



power lightweight generators is possible. Engineers at the Westinghouse Aerospace Electrical Division expect to achieve a ratio of one pound or less per kva in future generator designs.

The compact generators are driven by a gas turbine with a step-down gearbox or by a diesel engine with a step-up gearbox. Full-load line current of the 600-kva 400-cycle machine is 728 amperes, and voltage is 275 to 475 volts.

The generator is a brushless type (Fig. 1). This design eliminates sliding electrical contacts and the attendant maintenance requirements, and it minimizes radio-frequency noise generation. It also provides most of the excitation power from an integral exciter on the shaft and thereby reduces the power required from the regulator. The generator is a conventional salient-pole machine with continuous damper windings to permit unbalanced loads with minimum voltage unbalance.

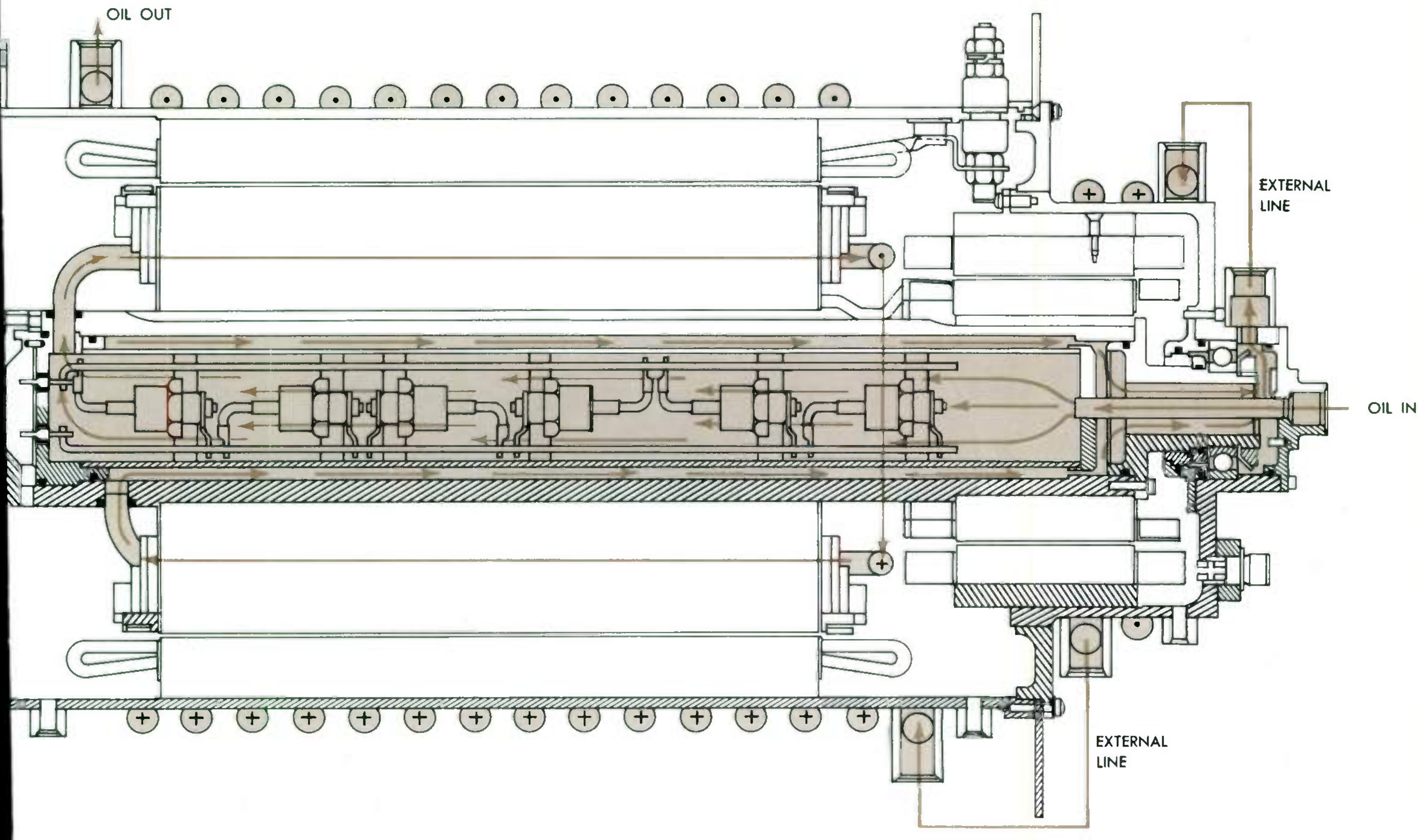
Present generators of this type are liquid cooled. Similar generators could be air cooled, but with some increase in size and weight.

The unit illustrated is cooled by circulating light oil through rotor and stator cooling circuits, which are connected in series (Fig. 2). The oil enters the shaft at the end opposite the drive end and cools the rotating rectifier assembly, rotating field, and exciter armature. It also cools and lubricates the bearing. The oil then passes through helical loops over the exciter stator and main ac stator before returning to the drive or to a heat exchanger.

The rotor field is cooled by conduction of heat from the copper conductors through the insulation to copper fins, which are spaced between conductors and attached directly to oil tubes in all of the rotor slots. Stator conductor cooling is by conduction of heat through the insulation, the stator iron, and the frame into externally wrapped cooling tubes. The coolant oil heat exchanger must remove up to 4260 Btu, or 75 kilowatts, per minute at an oil flow of 15 gallons per minute and an inlet oil temperature of 260 degrees F.

Conductor wire for all windings is insulated with an aromatic-polymer enamel that retains high dielectric and mechanical strength at elevated temperature, is not affected by petroleum-base oils, has excellent scrape resistance, and has a high coefficient of thermal conductivity. The last factor lowers operating temperature and makes for efficient use of electromagnetic volume. All windings are impregnated with an insulating varnish that has excellent bond strength at high temperature and is immune to chemical and solvent attack.

Westinghouse ENGINEER July 1964



GENERATOR IS LIQUID COOLED to help minimize its size and weight. In a typical unit, the cooling oil flows into the shaft and first cools the rotating rectifier assembly, rotating field, and exciter armature. It then cools and lubricates the bearing opposite the drive end and passes through helical tubing around the generator housing to cool the stator components. The unit has no bearing at the drive end because it is coupled directly to the drive gearbox.

Methods of Economic Comparisons

*P. H. Jeynes**
Public Service Electric and Gas Company, Newark, New Jersey.
C. J. Baldwin, Manager, Advanced Development, Electric Utility Engineering, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania.

The revenue requirements approach differs from many other methods of making economic comparisons. The fundamental advantage of the revenue requirements method is its consideration of minimum acceptable return on investors' committed capital. This minimum acceptable return must be separated from actual return if the comparison is to be compatible with the true financial objectives of a company.

The financial purpose of a corporation is to find opportunities for profitable investment of capital funds. The corporation's objectives regarding return on its capital investment are twofold: (1) minimize percentage return to new investors who supply incremental capital, and (2) maximize return to existing stockholders. To accomplish these objectives, a company must select the most desirable new projects. The desirability of a project is determined by relative economy, capital budget limitations, and other considerations not necessarily reducible to dollar amounts. But in every case, economic comparison is the first step in determining the most desirable alternative for profitable investment. And the key to economic comparison is the revenue requirements approach.

The basis for identifying economic choice by revenue requirements analysis is illustrated by the diagram of intent for the investor-owned company (Fig. 1 of reference 2). The project that maximizes profit incentive will best accomplish the company's financial objectives. Profit incentive is maximized by minimizing revenue requirements, the hypothetical revenues that must be obtained to cover all expenses incurred, including minimum acceptable return and expenses associated with this minimum acceptable return. The revenue requirements approach is based on the premise that minimum acceptable return (the dividends and interest paid on invested capital that is barely good enough to satisfy investors) can be estimated from market opinion of the company's securities (Fig. 6 in reference 1).

Because the revenue requirements analysis starts with minimum acceptable return and taxes on that return only, the method is quite different from many other methods of economic comparison. However, it is the only method that can consistently identify the economic choice and the alternative that best accomplishes the company's primary financial objectives. The advantages of the revenue requirements approach will be demonstrated by comparing it with some of the other popular techniques in use, such as the rate-of-return method and the discounted-cash-flow method. This comparison will also illustrate how these other methods can give misleading results unless they are restated to conform to the revenue requirements discipline. Thus, the case will be made for using the revenue requirements approach in the first place.

Cash Flow

An understanding of the flow of cash in a corporation is basic to all methods of economic comparison. The revenue requirement for minimum acceptable return represents an outward flow of cash, in the same direction as payments of such obligations as wages, raw materials, and taxes. These other cost obligations when added to depreciation and minimum requirement for return determine the total *cost* of doing business. To make it worthwhile to stay in business, revenues must produce a margin above this total cost.

On the other hand, most of the other methods of eco-

EDITOR'S NOTE:
This article is the third in the series on engineering economics by P. H. Jeynes and C. J. Baldwin. Frequent references are made to concepts discussed in the previous articles:
[1]"Financial Concepts for Economic Studies," P. H. Jeynes, C. J. Baldwin. *Westinghouse ENGINEER*, Jan. 1964, pp. 8-14.
[2]"Financial Mathematics for Economic Studies," P. H. Jeynes, C. J. Baldwin. *Westinghouse ENGINEER*, March 1964, pp. 41-47.

**Until his recent retirement, Mr. Jeynes was Engineering Economist with Public Service.*

nomic comparison are based on an analysis of cash flow starting with cash receipts, or revenues from sales. This treatment of cash flow traces the disposition of total revenues in a manner resembling an engineer's heat balance diagram, as shown in Fig. 1. Thus, it is sometimes referred to as an analysis of income behavior.

The total revenues from sales enter the left of the chart in a band proportional to dollars per year. If there are taxes on gross sales, these taxes are tapped off before the funds are put to any use by the company. The next deduction is for operation and maintenance expenses, taxes other than income tax, and other miscellaneous expenses. Subtracting the tax deductible items such as interest and tax depreciation leaves taxable income. The tax on taxable income is the next tap off the cash-flow stream. The remainder is the cash available for capital recovery costs (return and depreciation) at point A.

Book depreciation is not paid out to others but is retained in a depreciation reserve and reinvested in the business. For this reason, it is shown tapped off in an upward direction. The residual cash flow is *gross income*, expressed as a percentage of investors' committed capital, or net plant ($P-R$), where P is the gross plant and R is the reinvested depreciation reserve. After interest on debt is deducted, *net income* remains. To represent total earnings, credits for the use of the reinvested reserve (iR) come back into the cash-flow stream to produce its final value iP, the return on gross plant. If a company is doing well, the return on gross plant determined in this way is greater than the minimum acceptable return. In other words, i percent is greater than the minimum acceptable percentage return derived from market opinion.

The cash-flow analysis differs from the revenue requirements analysis in two major respects:

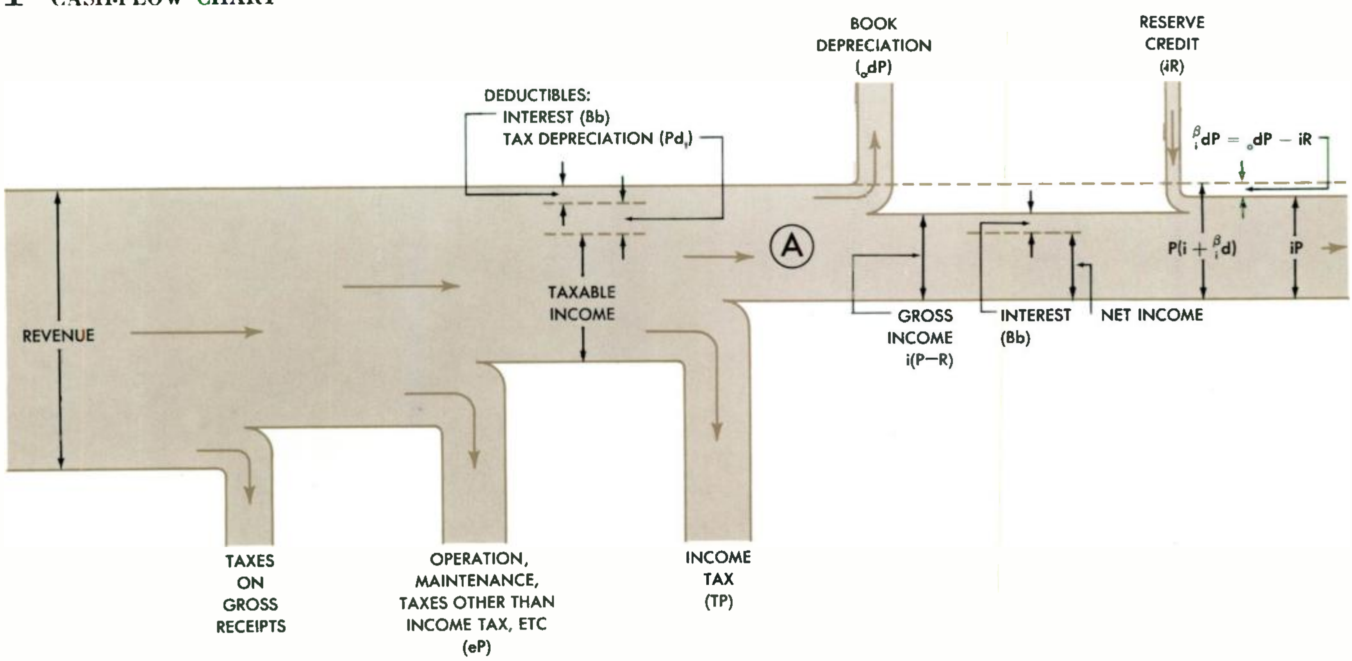
1) A cash-flow analysis starts with revenues and subtracts expense to end up with income, whereas revenue requirements analysis starts with minimum acceptable return and adds expenses to obtain cash outflow.

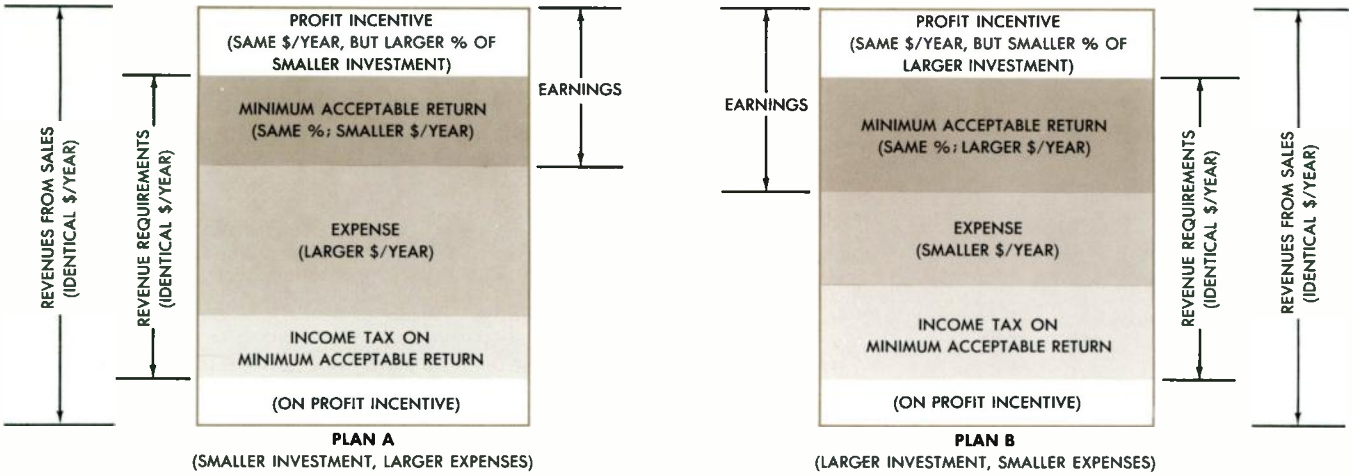
2) Cash-flow analysis determines the cash residual actual earnings. In other words, i percent represents actual earnings, and this figure is used to determine income taxes and the reverse-flow credit (iR) for use of depreciation reserves. The revenue requirement analysis uses an i representing only minimum acceptable return. Income taxes are calculated on this minimum return only, and minimum acceptable return i is used to get the reverse-flow credit (iR) for the use of depreciation reserves.

Security analysts assign a rather special meaning to the term *cash flow*. Instead of gauging a company's financial performance by looking at its reported income, they look at the residual cash available for earnings plus depreciation. They subtract from revenues all expenses except depreciation, and the remainder is the cash flow for capital recovery, which is called *the cash flow*. This treatment eliminates inconsistencies between companies in reporting earnings, arising from differences in the bookkeeping treatment of depreciation.

The cash-flow approach has suggested several methods for engineering economy studies, all of which, unlike the revenue requirements approach, start with an initial estimate of actual revenues. Thus, they are really profitability studies rather than methods of economic comparison. The cash-flow methods are the (1) rate-of-return method, (2) pay-off period method, and (3) the discounted-cash-flow method. Outside of the public utility industry, the great majority of economic decisions are reached by using one or more of these methods. The most important objection to these methods is that they use the indicator of *percent* return on the *incremental* capital investment, whereas a correct indicator of economy or profitability should be the

1 CASH-FLOW CHART





Plan A and Plan B have identical profit incentive (in dollars per year) out of identical revenues from identical sales. Therefore they are equally profitable; there is no choice between them. But earnings of Plan A are a larger percent of the smaller investment. Plan A appears to be superior; actually it is not.

dollars earned in excess of the minimum acceptable return on the investor's pool of capital. Some detailed discussion and numerical examples will illustrate the correctness of the latter approach.

Rate-of-Return Method

The popular rate-of-return method starts with an estimate of revenues, subtracts expenses to determine earnings, and then divides these earnings by the capital investment to reveal percentage return. The proposal promising the larger percentage return is presumed to be the economic choice, or the most profitable venture.*

Although this approach may seem logical, its fallacy is illustrated in Fig. 2. Consider two proposals, plan *A* and plan *B*, which are in fact equally economic and equally profitable. Revenue requirements are identical; hence there is no choice between them according to the exact definition of intent.[2] Plan *B* calls for a larger capital investment than plan *A*, and therefore has larger revenue requirements for return and income taxes. But the larger revenue requirements for return and income taxes are exactly offset by the smaller revenue requirements for other expenses (depreciation, operation, and maintenance), so that both plans show the same profit incentive for the same revenues. However, a rate-of-return solution could conclude that plan *A* is superior because the total earnings of plan *A* divided by the smaller capital investment could give a higher percentage return than a similar calculation for plan *B*. Therefore, the rate-of-return method will agree with the revenue requirements approach only if actual revenues happen to equal revenue requirements (that is, if the profit incentive is zero), or if the capital investments of competing proposals happen to be identical. Neither situation is apt to occur. Thus, if actual revenues are higher than revenue requirements, the rate-of-return method overstates the superiority of the plan with lower capital investment; if actual revenues are less than revenue requirements, the wrong choice is possible. The discrepancy lies in the attempt of the rate-of-return method to maximize percentage return on incremental investment instead of dollar return to the preproject investors.

**A common alternative is to divide the difference in expenses for competing proposals by the difference in respective capital investments.*

Pay-Off Period Method

The pay-off period technique, like the other cash-flow approaches, starts with an estimate of future revenues. All annual costs except depreciation* are subtracted to find the remainder available to recover (pay off) the initial investment. (This same approach can be applied to the difference in annual cost and difference in initial investment.) The procedure somewhat resembles the rate-of-return method, where all annual costs except percent return are deducted from revenues to find the amount left for return *on* investment; in the payoff period method, all annual costs except depreciation are deducted to find the amount left for return *of* the investment.

If the amount left for return of the investment is enough to pay off the investment in a reasonable period, the project is designated acceptable; otherwise it is rejected. A period of three to five years, and rarely as much as ten years, is the usual estimate of a reasonable period.

There is nothing wrong with the idea that a plan which pays off first is preferred, providing all other things are equal. In fact, this is what is accomplished by selecting the alternative with minimum revenue requirement. But the fault of the pay-off period method is the neglect of (1) the reinvested reserve (iR) component of capital recovery costs, (2) the effects of retirement dispersion, and (3) the fact that actual service life, not the arbitrary pay-off period, influences the depreciation cost per year. As a result, unless the economic choice is superior by an overwhelming margin, the least economic choice is almost always selected.

**Or less often, all annual costs except depreciation and return.*

3 REVENUE REQUIREMENTS SOLUTION

	Plan X (Investment $1,000,000)	Plan Y (Investment $1,500,000)
Acceptable Return at 6%	$ 60,000	$ 90,000
Depreciation at 2.72%	27,200	40,800
Income Tax (=Gross Income)*	37,200	55,800
Operation and Maintenance Expense	162,200	100,000
Annual Revenue Requirements	$286,600	$286,600

*$T=(0.5/1-0.5)\ (0.06+0.0272-0.05)\ (1-0)=0.0372$ (in per unit of investment.)

The Discounted-Cash-Flow Method

A technique formerly used for the economic comparison of alternatives was the test-year method. In this approach, hypothetical financial statements were set up for the competing proposals for one test year, and the proposal with the best statement won. Usually the year used was the first year after the proposed adoption. Industry has generally appreciated that such one-shot analyses are apt to be quite misleading since the buyer of new equipment commits himself for the lifetime of his facilities; hence the test-year method is now rarely used.

The discounted-cash-flow method, which is an extension of the test-year method, recognizes the need for analysis year by year over the lifetime of the equipment. It starts with an estimate of sales, either year by year or in terms of levelized lifetime revenue. All expenses except return and depreciation are subtracted, and here the first difficulty is encountered. As in all cash-flow procedures, the exact amount of income tax to subtract from total revenues is unknown because the amount of tax depends upon an unknown income. Cut-and-try calculations are usually used. Annual cash flow (cash available for capital recovery costs, return plus depreciation) is then reduced to a percentage of capital investment. It equals an annuity at some interest rate of *i* percent, to be determined, which will recover the capital investment over the service life of the facilities. Tables giving values of the annuity at different interest rates can be used to find the rate *i* percent at which the earnings have been discounted.

The method has some obvious shortcomings, such as its awkward treatment of income tax and its failure to recognize retirement dispersion in the annuity calculation. But the fundamental difficulty lies in its use of actual return as a discount rate and consequent failure to identify dollar earnings for preproject investors.*

**The Profitability Index Method of Ruel makes this same fundamental mistake. It is the discounted-cash-flow method with a graphical method for interpolating between the discrete return percentages in the annuity tables.*

A modified discounted-cash-flow method using the correct minimum acceptable return has been used by some public utilities for many years. It is difficult to apply to complicated problems, but will give the same answer as the revenue requirements analysis if properly used.

Economy versus Profitability

Financially healthy enterprises expect average earnings to be in excess of a *cut-off rate* that exceeds the minimum acceptable return by some margin determined by the risk of the project. Even for zero-risk projects, if such can be imagined, some margin must exist to justify the effort. Therefore, companies search for ventures that promise to do better than minimum acceptable return and avoid those that promise less. To always be sure of maximum profit for preproject owners, the criteria used to evaluate proposed ventures should work when applied to proposals that are marginal (no benefit and no harm to preproject investors), above average (extra earnings benefits for preproject owners), and subpar (inadequate earnings to provide even minimum acceptable return).

The revenue requirements technique correctly identifies the economic choice between proposals whether they are marginal, above average, or subpar. It does this by determining whether, out of *any* actual revenues obtainable, the extra earnings for preproject investors are maximized after minimum acceptable return is earned on the entire pool of capital. Future revenues do not have to be estimated to identify the economic choice, since the revenue requirements include only the minimum acceptable return and income taxes on that return only.

The minimum revenue requirements criterion of economy also identifies the most *profitable* alternative if the proposals under investigation do not in themselves produce differences in revenues. This is the case, for example, in the selection of the size or heat rate of a generating unit to be purchased, in selecting fossil-fuel or nuclear-fuel generation, or in evaluating transformer losses. None of these alternatives directly affect total sales to customers. On the other hand, some alternatives do affect sales, as for example, the promotion of electric heating.

For evaluation of this type of proposal, profitability studies are necessary to estimate probable earnings. The studies must start with an estimate of revenues, and the difference in revenues from differences in salable outputs must be recognized.

Economic studies can omit costs common to competing proposals since they do not affect the difference between proposals, nor the economic choice. On the other hand, profitability studies must include all costs if they are to determine the amount of probable earnings. Earnings obtained in profitability studies are reviewed as to their acceptability, and proposals are classified as desirable when the earnings are higher than the minimum acceptable return. The inaccuracies in the cash-flow methods of analysis become apparent in the complete profitability approach that will be demonstrated.

Plan X versus Plan Y

Suppose a decision is to be made between two proposals, Plan X and Plan Y. The company's minimum acceptable rate of return is estimated to be 6 percent. For simplicity, income taxes are estimated to be 50 percent of taxable income. This results in gross income and income taxes being equal. This assumes no debt and straight-line depreciation for books and taxes. Depreciation is taken to be a 6 percent annuity based on a 20-year service life with zero net salvage and no retirement dispersion. These simplifying assumptions do not affect the illustration of the principles involved in the various methods of comparison. The two proposals are as follows:

	Plan X	Plan Y
Capital investment	$1,000,000	$1,500,000
Annual expense, operation, and maintenance	$ 162,200	$ 100,000

The methods for determining the various components of revenue requirements have been described in the previous articles. The levelized annual revenue requirement for depreciation is the annuity that will recover the investment in 20 years at 6 percent ($_i d \times$ *Capital Investment*). The federal income tax is:

$$T=\frac{t}{1-t}\,(i+{}_i d-{}_o d)\,(1-\frac{Bb}{i})\times \textit{Capital Investment}$$

where $_o d$ is the straight-line book depreciation used for tax purposes, and other symbols are as defined in reference 2.

The revenue requirements for Plans *X* and *Y* are summarized in Fig. 3. Since total revenue requirements are equal, there is no choice between the two proposals from a financial standpoint; they are equally economic and equally profitable (or unprofitable). Since the anticipated revenues are the same for either plan, the *financial equality* of the two proposals is not affected by revenues.

Now suppose the same two plans are analyzed with cash-flow techniques. Since cash-flow approaches must start with an exact estimate of the revenues, three analyses will be illustrated: (1) for revenues that are marginal (just equal to the revenue requirements); (2) for above-average revenues (greater than revenue requirements); and (3) for subpar revenues (below revenue requirements). Because of the similarity of the rate-of-return and the payoff-period methods, only the rate-of-return solution

4 RATE OF RETURN SOLUTION

Revenues $286,600 Per Year (Just Equal to Revenue Requirements of Figure 3)

	Plan X (Investment $1,000,000)		Plan Y (Investment $1,500,000)	
Revenues		$286,600		$286,600
Less Expenses:				
Depreciation at 2.72%	$ 27,200		$ 40,800	
Income Tax (=Gross Income)*	37,200		55,800	
Operation and Maintenance	162,200		100,000	
Total Expense		226,600		196,600
Earnings, by Difference		$ 60,000		$ 90,000
Percentage Return		60,000/1,000,000=6%		90,000/1,500,000=6%

Revenues $366,600 Per Year (More Than Revenue Requirements of Figure 3)

	Plan X		Plan Y	
Revenues		$366,600		$366,600
Less Expenses:				
Depreciation at 2.72%	$ 27,200		$ 40,800	
Income Tax (=Gross Income)*	77,200		95,800	
Operation and Maintenance (As Before)	162,200		100,000	
Total Expenses		266,600		236,600
Earnings, by Difference		$100,000		$130,000
Percentage Return		100,000/1,000,000=10.0%		130,000/1,500,000=8.67%

Revenues $246,600 Per Year (Less Than Revenue Requirements of Figure 3)

	Plan X		Plan Y	
Revenues		$246,600		$246,600
Less Expenses:				
Depreciation at 2.72%	$ 27,200		$ 40,800	
Income Tax (=Gross Income)*	17,200		35,800	
Operation and Maintenance (As Before)	162,200		100,000	
Total Expenses		206,600		176,600
Earnings, by Difference		$ 40,000		$ 70,000
Percentage Return		40,000/1,000,000=4.00%		70,000/1,500,000=4.67%

**Ordinarily taxes are computed by cut and try because of the complications of retirement dispersion, liberalized depreciation, and investment credits. Here, they can be computed by solving two simultaneous equations relating return, taxes, depreciation, expenses, revenues, and investment.*

6 RECONCILIATION OF RATE-OF-RETURN SOLUTIONS WITH REVENUE REQUIREMENTS

Above-Average Projects

	Plan X (Investment $1,000,000)	Plan Y (Investment $1,500,000)
Total Earnings, Rate-of-Return Solution	$100,000	$130,000
Less Minimum Acceptable Earnings at 6%	60,000	90,000
Profit Incentive for Preproject Owners. *Both plans are equally profitable.*	$ 40,000	$ 40,000

Subpar Projects

	Plan X	Plan Y
Total Earnings, Rate-of-Return Solution	$ 40,000	$ 70,000
Less Minimum Acceptable Earnings at 6%	60,000	90,000
Profit Incentive Deficit for Preproject Owners. *Both plans are equally unprofitable.*	$(20,000)	$(20,000)

5 DISCOUNTED CASH FLOW SOLUTION

Revenues $286,600 Per Year (Just Equal to Revenue Requirements of Figure 3)

	Plan X (Investment $1,000,000)	Plan Y (Investment $1,500,000)
Revenues	$286,600	$286,600
Less Taxes, Operation, Maintenance (Fig. 4)	199,400	155,800
Annual *Cash Flow*	$ 87,200	$130,800
Present Worth of a 20-Year Annuity (From Interest Tables of Ref. 2)	at 6%=11.4699	at 6%=11.4699
Present Worth of *Cash Flow*	87,200×11.4699 =$1,000,000	130,800×11.4699 =$1,500,000
Hence, apparent rate of return is:	6%	6%

Revenues $366,600 Per Year (More Than Revenue Requirements of Figure 3)

	Plan X	Plan Y
Revenues	$366,600	$366,600
Less Operation, Maintenance (Fig. 4)	162,200	100,000
Cash Flow Plus Taxes	$204,400	$266,600
Less Taxes (=Gross Income)	at 7.72%=77,200	at 6.39%=95,800
Annual *Cash Flow*	$127,200	$170,800
Present Worth of a 20-Year Annuity, From Interest Tables	at 11.20%=7.86	at 9.55%=8.78
Present Worth of *Cash Flow*	$127,200×7.86 =$1,000,000	$170,800×8.78 =$1,500,000
Hence, apparent rate of return is:	11.20%	9.55%

Revenues $246,600 Per Year (Less Than Revenue Requirements of Figure 3)

	Plan X	Plan Y
Revenues	$246,600	$246,600
Less Operation, Maintenance (Fig. 4)	162,200	100,000
Cash Flow Plus Taxes	$ 84,400	$146,600
Less Taxes (=Gross Income)	at 1.72%=17,200	at 2.39%=35,800
Annual *Cash Flow*	$ 67,200	$110,800
Present Worth of a 20-Year Annuity, From Interest Tables	at 3.00%=14.88	at 4.04%=13.54
Present Worth of *Cash Flow*	$67,200×14.88 =$1,000,000	$110,800×13.54 =$1,500,000
Hence, apparent rate of return is:	3.00%	4.04%

Note: The discounted-cash-flow technique allows for depreciation as though the apparent rate of return were the minimum acceptable return, which accounts for the discrepancy in apparent earnings as compared with the rate-of-return solution.

7 RECONCILIATION OF DISCOUNTED-CASH-FLOW SOLUTIONS WITH REVENUE REQUIREMENTS

Above-Average Projects

	Plan X (Investment $1,000,000)	Plan Y (Investment $1,500,000)
Annual Cash Flow	$127,200	$170,800
Less Depreciation at 2.72%	27,200	40,800
Total Earnings	$100,000	$130,000
Less Minimum Acceptable Earnings at 6%	60,000	90,000
Profit Incentive for Preproject Owners. *Both plans are equally profitable.*	$ 40,000	$ 40,000

Subpar Projects

	Plan X	Plan Y
Annual Cash Flow	$ 67,200	$110,800
Less Depreciation at 2.72%	27,200	40,800
Total Earnings	$ 40,000	$ 70,000
Less Minimum Acceptable Earnings at 6%	60,000	90,000
Profit Incentive Deficit for Preproject Owners. *Both plans are equally unprofitable.*	$(20,000)	$(20,000)

is shown in Fig. 4; the discounted-cash-flow solution is shown in Fig. 5. Both examples demonstrate that unless revenues are exactly equal to revenue requirements, the results will be misleading. When revenues are greater than revenue requirements, both cash-flow solutions favor the plan with the lower capital investment (Plan *X*); when revenues are less than revenue requirements, both plans favor the plan with the higher capital investment (Plan *Y*).

The problem with both cash-flow techniques is that they fail to take into account the minimum acceptable return that must be earned on the capital investment. The rate-of-return method can be reconciled with revenue requirements if minimum acceptable return on capital investment is removed from total earnings (Fig. 6); the profit incentive for preproject owners is now correctly stated, and both plans are shown to be either equally profitable, or equally unprofitable.

The discounted-cash-flow method goes astray by using actual return as a discount rate. The misleading solutions can be reconciled by calculating profit incentive to pre-project owners, as shown in Fig. 7.

The Annual Cost Dilemma

The annual cost method is another approach to economic analysis that has its foundations in fuzzy definitions of intent. Annual costs are estimated for each competing proposal over its lifetime, and the proposal with the lowest annual costs is selected as the economic choice. One error lies in the inclusion of a cut-off rate of return or an average return instead of the minimum acceptable return. Then, when proposals involve expenditures differing in time, future annual costs are discounted to their present value at the cut-off rate or at the average return on investment, and the proposal with the smallest present worth is presumed to be the economic choice.

Annual cost itself is a misnomer because the components of annual cost usually are (1) average return on investment, (2) depreciation, (3) taxes, and (4) operation and maintenance expenses. Actually, item (1), return on investment, is the exact opposite of cost since it represents the

8 REVENUE REQUIREMENTS OF COMPETING TRANSFORMERS

	Plan A		Plan B	
Capital Investment	$2,000		$2,400	
Revenue Requirements:	Percent	Dollars	Percent	Dollars
Return	6.00	$120.00	6.00	$144.00
Depreciation	1.74	34.80	1.74	41.76
Taxes	4.35	87.00	4.35	104.40
Operation and Maintenance	6.00	120.00	6.00	144.00
Losses	7.50	150.00	4.17	100.00
	25.59	$511.80	22.26	$534.16

Plan A is the economic choice by $22.36 per year.

earnings enjoyed by the owners of the business. An efficiently run business would have greater annual costs if it had a higher return. Thus, how can minimizing annual cost ever be a sure criterion of identifying the economic choice?

Attention is called again to the important difference between minimum acceptable return (a component of the revenue requirements), the average return, and the cut-off return (the last two usually used in annual cost analyses). Ignoring this difference and the financial objectives of a corporation, as set forth at the beginning of this article, can result in curious self-contradictions like the annual cost dilemma.

Minimizing annual costs alone, without regard to the revenue requirements situation, can result in incorrect decisions to purchase equipment in advance of need, to lease instead of own property, to buy increased insurance because of mysterious tax credits believed to reduce its net cost, or to pursue other courses of action that are sometimes economically unsound. The surest way to reduce annual costs is to reduce total earnings—but reducing total earnings is surely not a corporate financial goal.

The Capitalized-Cost Method

A method of analysis frequently confused with the revenue requirements approach is the capitalized-cost method. This method is usually applied where competing proposals have the same function, capacity, and date of installation, and where the only difference of importance is in their annual costs. A good example is the comparison of two transformers, one having greater investment cost but smaller losses.

If capital costs can be converted into annual costs by applying a carrying-charge percentage, then obviously, annual costs can be converted to a capital cost equivalent by dividing annual costs by the carrying-charge percentage. This process is known as *capitalizing* annual costs. However, the method can be misapplied, and when it is, wrong decisions result. The major difficulty is the determination of the appropriate carrying-charge percentage to apply in the capitalizing calculation. A simple demonstration will show that the percentage ordinarily used, the fixed-charge rate for the equipment in question, is not ordinarily the proper figure.

Consider two transformers: Transformer *A* costs $2000 and has losses that cost $150 per year; transformer *B* costs $2400 but has losses costing only $100 per year. Operation and maintenance expense is six percent of the investment, and the two units have equal life, capacity, and percentage taxes. Does the savings in losses of $50 per year justify the greater investment of $400 for transformer *B*?

An annual revenue requirements analysis demonstrates that transformer *A* is the economic choice by $22.36 per year, as shown in Fig. 8. Thus, the extra investment of $400 is not justified.

However, if the savings in losses of $50 is capitalized at the *fixed charge rate* of 12.09 percent (return, depreciation, and taxes) and credit given to transformer *B* capital cost for the capitalized value of the reduced losses, the credit is $50/0.1209=$413.56. Transformer *B* would be incorrectly chosen since its evaluated cost would be ($2400−$413.56)=$1986.44.

If the savings in losses is evaluated at the *carrying charge rate*, 18.09 percent (return, depreciation, taxes, operation, and maintenance), the correct answer is obtained because the revenue requirements calculation has been duplicated. However, suppose the operation and maintenance had been the same for the two units in dollars per year, not in percent. Then the percentage carrying charge would be different for the two units, and confusion as to the appropriate percentage for capitalizing would again result. Of course, selection of the right percentage will give the right answer, but the revenue requirements calculation must be kept in mind to select the correct percentage. Thus, the revenue requirements calculation might as well be made in the first place.

Economy versus Desirability

The revenue requirements method of analysis will always identify the economic choice of competing alternatives, even though the economic choice may not be the most desirable project for capital investment. The most desirable project also depends upon capital budget limitations and an evaluation of factors not reducible to dollar amounts. Complete and correct analyses will separate the determination of economy from these other evaluations. The evaluation of economy, as provided by the revenue requirements approach, is always a necessary first step. It identifies the project that is most economical and most profitable. If another project is chosen, as sometimes it may be because of capital budget considerations or irreducibles, such a decision must be made with due recognition of the extra costs involved.

ABOUT THE AUTHORS

A. C. Lordi divides his time about equally between the engineering of cement-plant and mine electrical power systems and equipment. He joined Westinghouse in the industry engineering department in 1954, after four years in electromechanical development engineering with Babcock and Wilcox Company. He has served on the mining-industry and cement-industry committees of the IEEE and is a past chairman of the former.

Lordi served in the Army Air Forces from 1944 to 1946. He started at Geneva College after leaving the service but switched to Pennsylvania State University and earned his BSEE in 1950. He received an MSEE at the University of Pittsburgh in 1958 and completed a program in marketing and business there in 1962. He is a registered professional engineer with a number of articles and disclosures to his credit.

Paul H. Jeynes and **Clarence J. Baldwin** are coauthoring the third article of a series on engineering economics in this issue. Jeynes, with Public Service Electric and Gas Company of New Jersey, and Baldwin, with Westinghouse, have worked together in this field since 1958 when the two companies began developing simulation techniques for studying utility system expansion.

Jeynes graduated from Sheffield Scientific School in 1918 with a PhB degree, and from Yale Graduate School in 1920 with an ME degree. He started with Public Service as a cadet engineer in 1920. He has held assignments in both the engineering and accounting departments and was involved in many phases of engineering economics. His work led to his appointment to the position of engineering economist for the company in 1957, the position he held until his retirement in September 1963.

Baldwin joined Westinghouse in 1952 after obtaining his BSEE and MSEE degrees from the University of Texas. He was awarded the B. G. Lamme scholarship in 1956 and obtained a professional EE degree at MIT.

Baldwin has had a number of assignments in the Electric Utility Engineering Department. He is presently manager of the Advanced Development Section, where he is responsible for investigations in power system generation, transmission, and distribution.

Baldwin was chosen for Eta Kappa Nu's Outstanding Young Electrical Engineer Award for 1961. A key factor to his selection was his work in developing power-system simulation techniques.

Robert L. Finch earned his BS in industrial engineering at Virginia Polytechnic Institute in 1950. He joined Westinghouse at the electronics division in Baltimore, and was assigned to the industrial engineering department.

In 1953, Finch moved to the x-ray division to become supervisor of cost reduction and methods improvement. He was brought to the headquarters manufacturing controls department in 1956 to work on a number of programs, including the engineered budgets standards program, the manual methods improvement program, the measured daywork program, and the VIP program that he describes in this issue.

Finch transferred to the Mansfield portable appliance division in 1963 to become manager of facilities planning, his present assignment.

The article on satellite navigation in this issue is the second by **E. S. Keats** on that subject. The first one, "Ship Navigation with Satellites," appeared in the January 1963 issue.

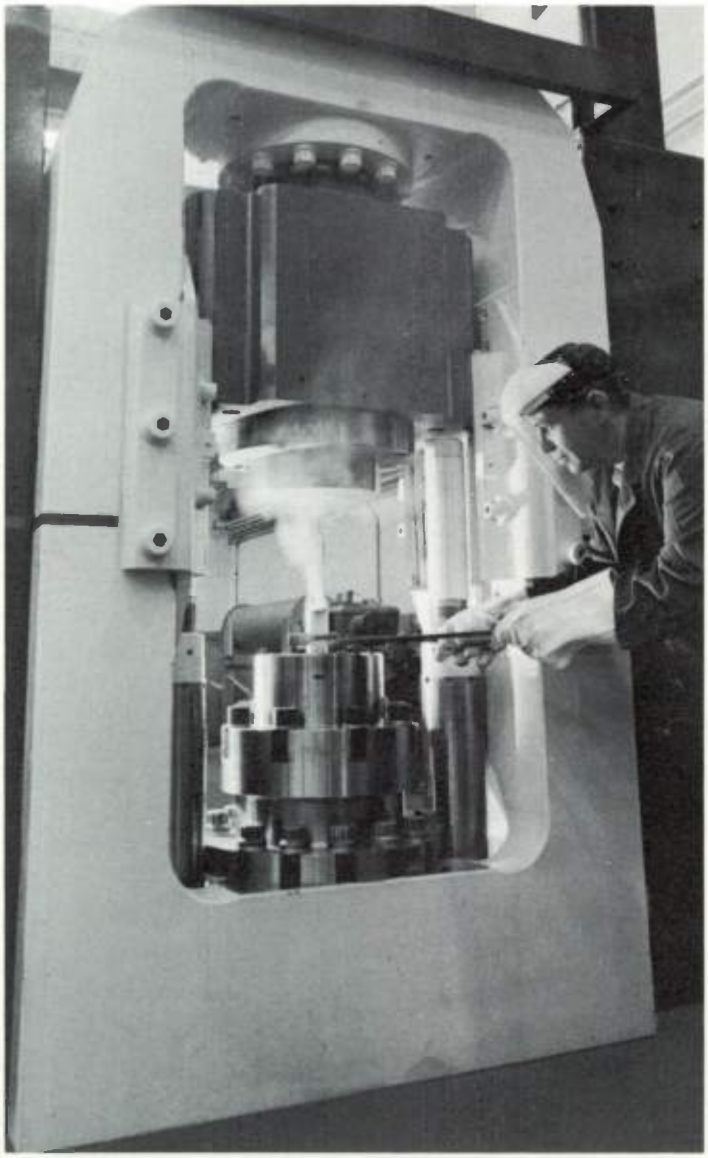
Keats is a 1935 graduate of the U.S. Naval Academy, and he earned an MS from Massachusetts Institute of Technology in 1948. He served as a U.S. Navy officer and aviator until 1958, when he retired from the Navy with the rank of rear admiral. He joined the Westinghouse Defense and Space Center, Baltimore, Maryland, shortly thereafter.

Keats was project manager for the Westinghouse portion of the Navy navigation satellite program. He is now project manager for Navigation and Surveying Systems, with responsibility for a NASA study contract on a navigation satellite system and for a U.S. Army Corps of Engineers contract to demonstrate precise position determination on shore with satellites. Besides writing systems articles, Keats writes on project management and recently conducted a series of seminars on improving the effectiveness of project management.

Herbert W. Book is the project supervisor in charge of the development of the solid cast distribution transformer, a new concept that he describes in this issue.

Book earned his BS in EE at Penn State in 1950 and joined Westinghouse on the Graduate Student Course. In 1951 he was assigned to the Distribution Transformer Department, his first assignment being in the standard development section. In 1958 he became a member of the long range major development group, and in 1963 was made a project supervisor, his present position.

Book's major fields of interest are insulation systems and equipment operating economics. He has been involved in many design changes in distribution transformers, including the zero impedance transformer (discussed in the September 1963 issue).



A new facility for refractory metal and alloy development and processing at the Astronuclear Laboratory will enable the space laboratory to produce any refractory metal from the raw material stage through processing, heat treatment, and fabrication. Typical of the many specialized pieces of equipment is this high energy rate forming press. A white-hot molybdenum billet is being placed on the platen for forging. The press uses the energy stored in compressed gas to drive a metal forming ram at high speed and with great force.