Westinghouse ENGINEER

November 1966

Results of Mass-Transit Experiment Being Evaluated

A "live" operating experiment with Transit Expressway, an experimental mass-transit system, came to a close in September after some 100,000 people had ridden the system demonstration loop in South Park near Pittsburgh, Pennsylvania. Results obtained from the experiment are being evaluated by MPC Corporation, an independent research group staffed by Mellon Institute, the University of Pittsburgh, and Carnegie Institute of Technology.

The Transit Expressway concept is designed to provide commuters with service every two minutes around the clock, a smooth silent ride in pollution-free electric vehicles, an exclusive right-of-way where the rubber-tired vehicles can cruise at speeds of 50 miles an hour and more, a high standard of operating ease and safety through computer control, comfortable seating in air-conditioned comfort, and reasonable cost. Since preliminary running tests began in August 1965, the system's three vehicles have traveled nearly 30,000 miles over the 9340-foot track loop. Almost 14,000 fairgoers rode the system during the 1965 Allegheny County Fair, held annually in South Park over the Labor Day weekend, even though it was not quite complete at that time. During the 1966 fair, 42,000 fairgoers rode the completed system. In addition, 35,000 more visitors from almost every state in the nation and every continent in the world rode the system during other open hours or by special arrangement.

The demonstration was made to determine engineering and operating feasibility and the costs of frequent-service rapid-transit systems specifically designed for medium-density areas. It was sponsored by the Port Authority of Allegheny County with the financial assistance of the U.S. Department of Housing and Urban Development, Pennsylvania State Department of Commerce, the Board of Commissioners of Allegheny County, Westinghouse, and other private industries. Land for the project was donated by the Board of Commissioners of Allegheny County.

Westinghouse ENGINEER
November 1966, Volume 26, Number 6

162 Seeing Under the Sea with Sonar
J. T. Laing and A. Nelkin

169 Electric Power and Pure Water from Dual-Purpose Nuclear Plants
J. D. O'Toole and W. H. Stinson

175 Refuse Reclamation . . . A Solution to a Growing Urban Problem
L. G. Reimer

178 Factory Testing by Computer Simulation Reduces Drive-System Start-Up Costs
W. C. Carter, R. A. Montoro, and T. O. Curlee III

183 Coordinating Protective-Device Settings Gives Maximum Freedom from Electrical Outages
V. C. Cook

188 Technology in Progress
Drill Being Developed for Core-Sampling on Moon
Chemical Reactions in Gases Initiated by Laser Energy
F-111 Aircraft Power System Passes 5000-Hour Test
Process-Control Computer System Has Simplified Programming
Resonant-Gate Transistor Performs Tuning Functions
Integrated-Circuit "Breadboard" Can Serve Various Purposes
High-Intensity Ultrasonic Transducer for Continuous Processing of Liquids
Products for Industry

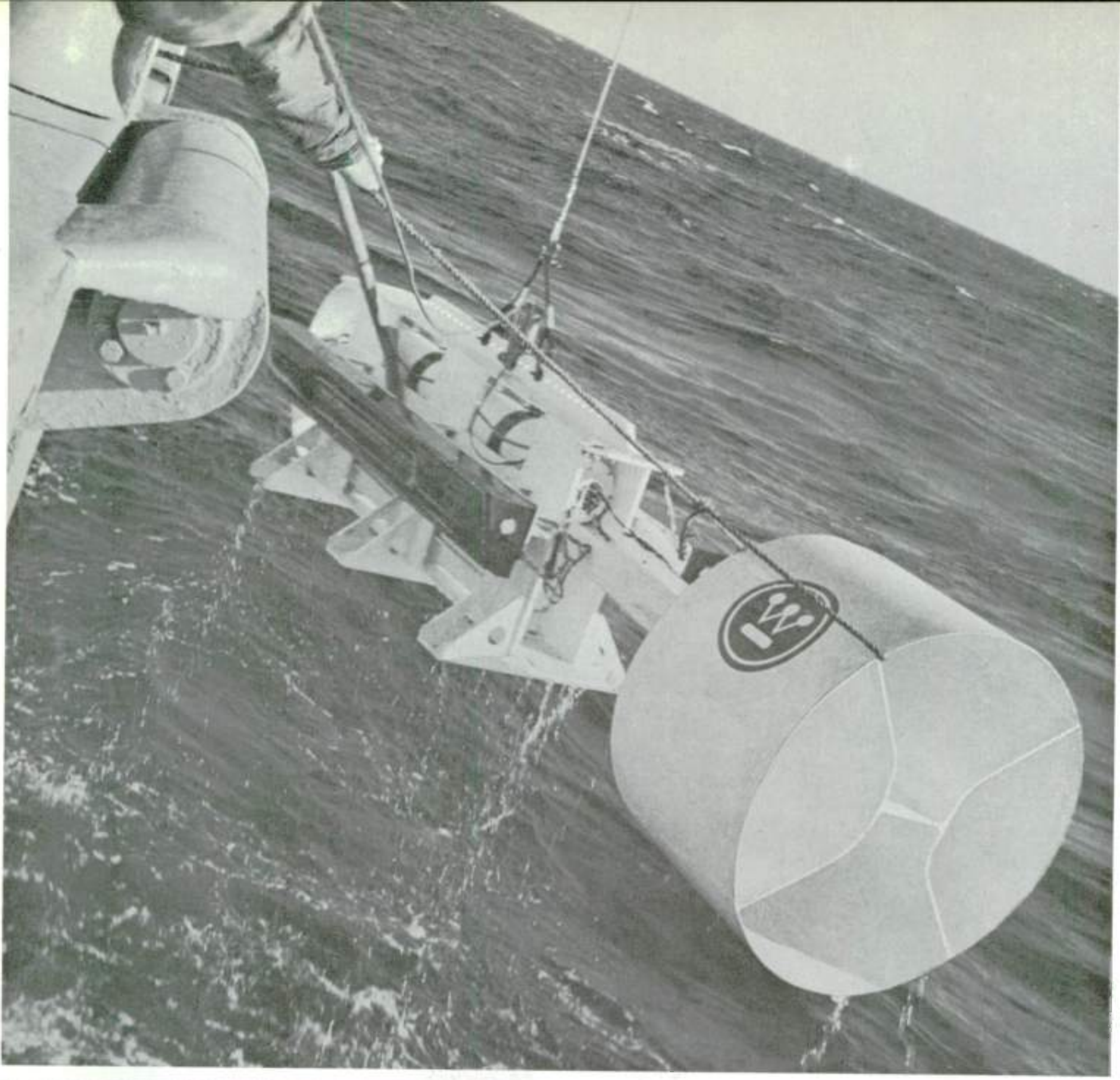
Subscriptions: United States and possessions, $2.50 per year; all other countries, $3.00 per year. Single copies, 50¢ each.

Mailing address: Westinghouse ENGINEER,
P. O. Box 2278, 3 Gateway Center,
Pittsburgh, Pennsylvania 15230.

Published bimonthly by the Westinghouse Electric Corporation, Pittsburgh, Pennsylvania. Printed in the United States by The Lakeside Press, Lancaster, Pennsylvania. Reproductions of the magazine by years are available on positive microfilm from University Microfilms, 313 North First Street, Ann Arbor, Michigan.

The following terms, which appear in this issue, are trademarks of the Westinghouse Electric Corporation and its subsidiaries:
Prodac; PowrMag.

Cover design: Side-looking sonar is the subject of this month's cover design by artist Tom Ruddy. As the sonar transmitter-receiver moves above the ocean bottom, sonar pulses are transmitted in a fan-shaped pattern from port and starboard transmitters. For the rest of the story, "Seeing Under the Sea With Sonar" begins on page 162.



Seeing Under the Sea with Sonar

J. T. Laing
A. Nelkin

A side-looking sonar system bridges the gap between conventional long-range low-resolution sonar and short-range high-resolution optical techniques.

An ocean-bottom scanning sonar system, which operates like a radar system but with the time base slowed down to accommodate the relatively slow speed of acoustic energy in water, is now providing detailed pictures of the ocean floor at depths ranging from less than 50 feet to 20,000 feet. The line-by-line picture that is produced is a pattern of highlights and shadows (Fig. 1), analogous to an optically viewed panorama illuminated by side lighting, with objects outlined in such a way as to permit their identification.

This precision side-looking sonar system has been tested and refined over a period of several years. The technique allows inspection of the sea floor and objects lying upon the floor, with resolutions available from about six inches up to several feet. With normal attention to system requirements and to the operational details, the system can protray the sea floor surface and objects on it in true relative size, shape, and orientation. The mapping rate for a single system is typically in the range of 0.1 to 1 square nautical mile per hour. With this resolution capability and area coverage rate, bottom-scanning sonar bridges the vision gap between optical techniques, which yield resolutions of about 0.1 inch at 50 feet maximum range, and precision echo sounders, which measure bottom depth in thousands of fathoms of water but provide no graphical detail. In addition to searching for objects on the bottom, other potential applications for side-looking sonar include bottom surveys for geological or biological purposes, mineral or petroleum prospecting, underwater cable surveys, and bottom navigation.

Sonar and Seawater

Acoustic energy is used almost universally for transmitting intelligence through water because seawater is virtually opaque to electromagnetic propagation (artificial lighting is effective only to about 50 feet). Thus, compressional wave propagation is the only presently known means for transmitting signals over appreciable distances under water.

The term "sonar," an acronym derived from the words *so*und *n*avigation *a*nd *r*anging, was applied originally only to those underwater equipments that transmitted an acoustic pulse and observed the echo return from an underwater reflector (such as the ocean bottom, sea mountain, fish, submarine, etc.). More recently, the term has been used to describe any system that uses underwater acoustic energy for observation.

Several phenomena reduce the effectiveness of acoustic energy as it is transmitted through water. Since sound diverges spherically, its intensity decreases inversely as the square of the distance over which it is propagated. Acoustic energy is also absorbed by water, an effect that reduces intensity exponentially with distance; this loss increases with increasing frequency.

The velocity of a sonic wave depends largely on the physical properties of the medium. Sound velocity in a liquid is

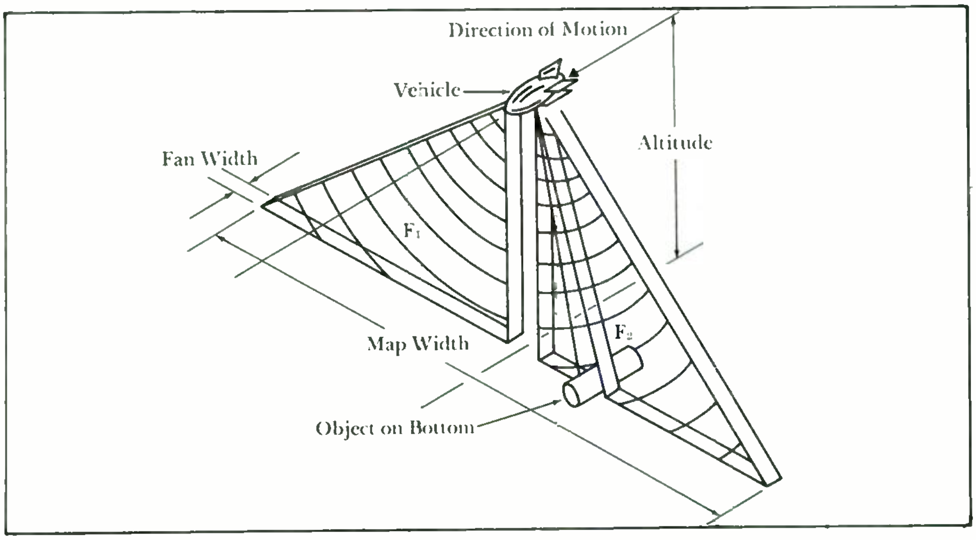
$$c=\sqrt{1/\beta\rho}$$

where β is the adiabatic compressibility factor and ρ is density. Thus, the speed of sound in seawater is a function of temperature, pressure, and salinity. For practical purposes, the speed of sound in seawater is about 5000 feet per second.

A sonic wave is a deformation of the sound-carrying medium, consisting of alternate compressions and rarefactions that travel through the medium. In modern sonar systems, this deformation is generally produced with electrostrictive transducers—blocks of material such as barium titanate that change dimension in an electric field. An alternating electric field is established by applying an ac voltage to conductive coatings on opposite sides of the block. The sonic energy generated can be increased by increasing the electrical power input driving the transducer up to the point where cavitation, or boiling, develops. Cavitation, which limits the ultimate acoustic energy that can be transmitted, occurs when the acoustic pressures generated exceed the hydrostatic pressure head above the

J. T. Laing is Manager of the Oceanographic Subdivision, Underseas Division, Westinghouse Defense and Space Center, Baltimore Maryland. A. Nelkin is Manager of Electroacoustics and Ocean Research Laboratory, Westinghouse Research Laboratories, Pittsburgh, Pennsylvania.

1–Underwater vehicle *(above)* of towed ocean bottom scanning system contains two transducer housings (port and starboard), an electronic unit assembly, batteries, and housing. The sonar system builds up a three-dimensional view *(below)*, line by line. The large "object" on the left is a chasm or ravine about 200 by 600 feet.



2–*(Right)* As the sonar transmitter-receiver moves over the ocean bottom, sonar pulses are transmitted in a fan-shaped pattern from port and starboard transmitters; the echo from each fan width is recorded as a line.

transducer and the instantaneous pressure approaches zero. Thus, acoustic transducers can be employed most effectively at great depths.

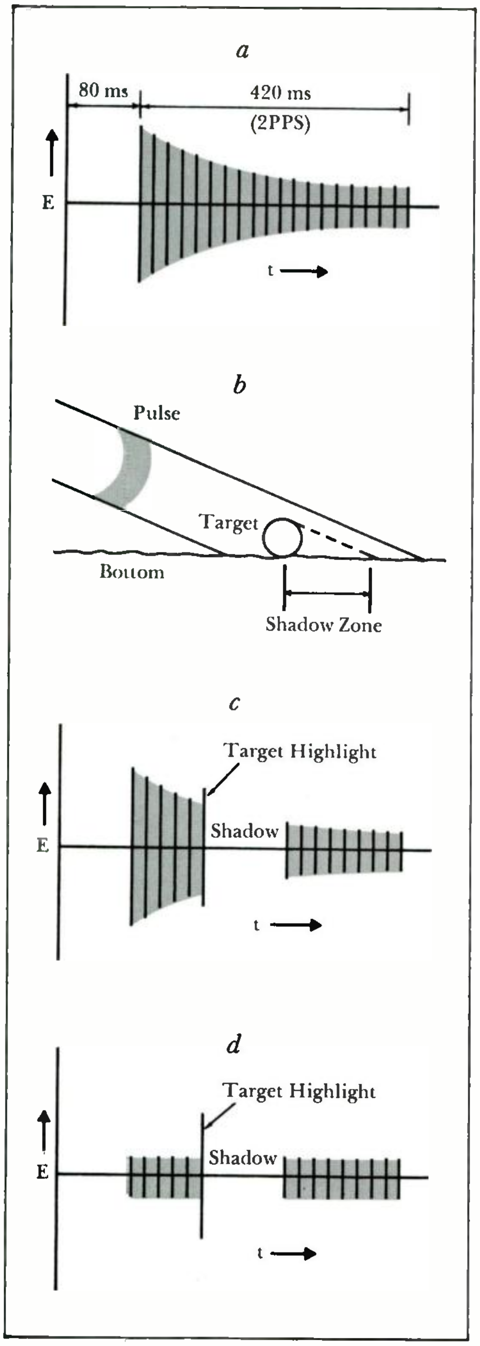
The reflection of an echo from a target is determined by the geometry, size, and reflecting properties of the reflector. The only way the sonar designer can affect the echo level is by changing the source level or the frequency.

Since the direction of arrival of the echo is generally of interest, it is necessary that the acoustic elements of the sonar system have highly directive radiating properties. This is of particular importance in mapping sonars, where the directivity is accomplished, in much the same manner as early mapping radars, by long-line arrays of transducer elements. The array has an overall length of several hundred wavelengths and a height of less than one wavelength. This unit has a straight as well as a focused array. The radiated waves from each individual element are phased so that they reinforce each other in the focus area, but are out of phase (and therefore weak) outside the focus areas. In the configuration used in the ocean bottom scanning sonar system, a narrow fan-shaped pattern is produced having a highly directive beam in the scanning direction, but a wide beam in the vertical plane to afford maximum lateral range coverage across the bottom.

Side-Looking Systems

The geometry of a side-looking sonar system is shown in Fig. 2. Transmitting transducers on both sides of the underwater vehicle transmit pulses of high-frequency acoustic energy downward and to either side, perpendicular to the direction of vehicle travel. The wave front proceeds through the water and strikes the bottom, "illuminating" a narrow strip with sound. Energy is backscattered from points along this bottom strip and returns to the receiving hydrophones as target echoes, delayed by the round-trip transit time to the particular scattering area.

The envelope of a typical bottom reverberation signal for a relatively smooth bottom with no target is shown in Fig. 3a. Targets or projections on the bottom (Fig. 3b) reflect energy more effectively, intensifying the return signal; the bottom areas behind these objects lie in an acoustic shadow and thus cause interruptions in the bottom reverberation signal (Fig. 3c). The length of the interruption depends on the size of the shadow cast by the target.



3–Envelopes of bottom reverberation demonstrate typical ocean bottom scanning: (*a*) reverberation pattern with no target; (*b*) shadow zone is formed by target on ocean bottom; (*c*) target produces a highlight and shadow in the reverberation pattern; (*d*) receiver amplifier gain is varied so that reverberation pattern appears to the recorder as a constant background signal except where target is detected.

In the receiver, amplifier gain is varied with time so that the typical no-target bottom reverberation pattern appears to the recorder as a constant background signal. Variations from this typical reverberation pattern, created by protruding objects and their shadows, produce lines of varying intensity (Fig. 3d). Thus, as the vehicle proceeds, adjacent strips of bottom are illuminated by each transmission pulse and a composite line picture of the bottom is produced.

A simplified block diagram of a dual-channel system is shown in Fig. 4. In a dual-channel system, separate port and starboard transmitter-receivers operate simultaneously at slightly different frequencies. Synchronizing pulses generated at the recorder trigger the transmitters via the switch-gate assembly. This causes each transmitter to generate short high-frequency pulses, which are converted to ultrasonic energy by the transmitter transducers. The receiving hydrophones pick up the echo signals, which are amplified and returned to the receivers. The display can be one or a combination of three types: (1) Wet-paper facsimile recorders, which provide both real-time readout and a permanent record; (2) direct-view storage tubes, which provide excellent real-time readout when a permanent record is not required; and (3) cathode-ray tube and film-recording combinations where instant viewing is not important but the highest quality records are desired. Of course, permanent records can also be provided by recording the video signals on magnetic tape for later playback of display.

Operating Parameters

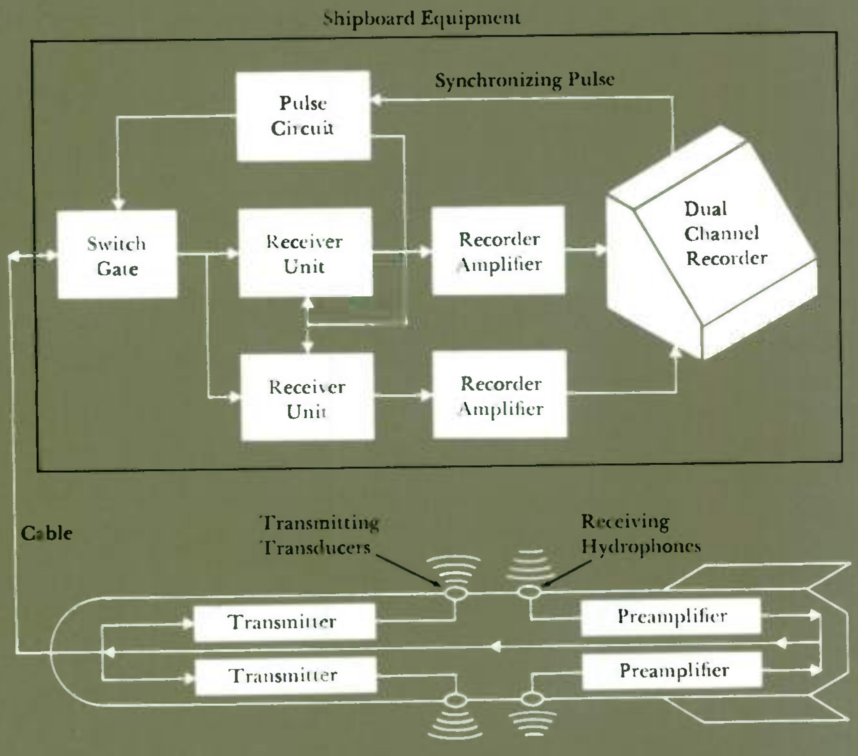
For ocean-bottom surveys or searches with scanning sonar to be practicable, two conditions must be satisfied: first, system resolution must be good enough to insure detection of the target or objects of interest; and second, mapping rate should be as high as possible to minimize operating costs. Since mapping rate is directly proportional to lateral range and advance rate, and resolution capability is inversely proportional to these variables, the system parameters chosen for a specific application must compromise the conflicting requirements of mapping rate and resolution capability.

Resolution in the fore and aft direction is limited by the width of the insonified strip (fan width). The vehicle advance in the pulse-to-pulse interval should be approximately the width of the fan so that map strips will be adjacent, and not overlap or skip bottom area between lines. Typically, fan width and advance rate are adjusted to yield many strips across the target. Advance rates from one to four knots are commonly used with beamwidths ranging from 0.1 to 0.3 degree. The patch of bottom area covered by the narrow beam and the pulse length should be small enough so that a target shadow cannot be filled in by simultaneous echo from the surrounding bottom.

Lateral resolution over most of the lateral range is approximately equal to the *linear ping length*, defined as $ct/2$ where c is the speed of sound in water and t is pulse length. However, at bottom ranges directly below the transducers (Fig. 5), the length of reflecting bottom area is much greater due to the unfavorable geometry, resulting in lower resolution. Thus, the best lateral resolution is obtained with low operating altitude and short ping lengths.

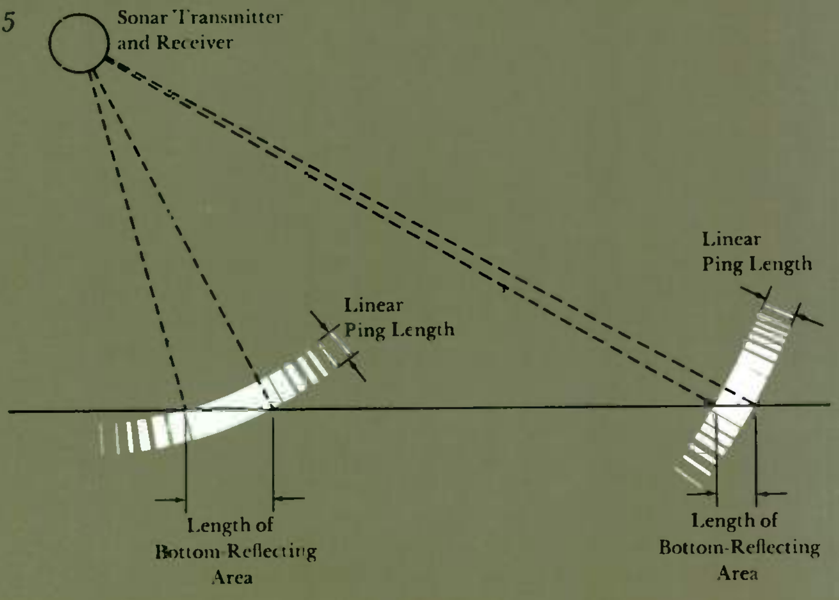
The maximum lateral range of the fan to each side of the vehicle, although set by the pulse repetition rate, is limited by the same parameters that limit resolution. Altitude, advance rate, and speed of sound in water will determine how much time is available for the echo return. Usually, for maximum utilization of the records, which experience has shown to require good balance between highlight and shadow definition, lateral range to

4



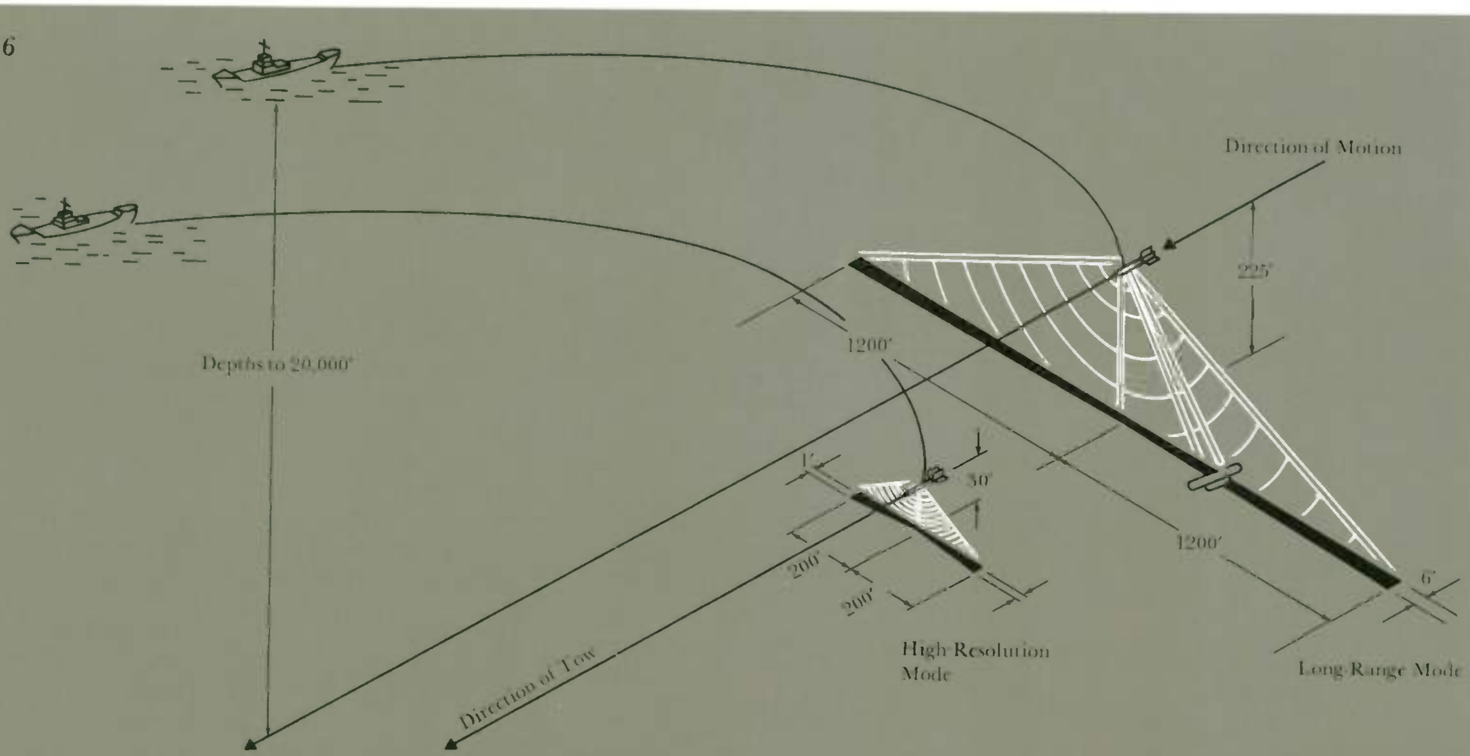
4–System operation is depicted by this simplified block diagram.

5

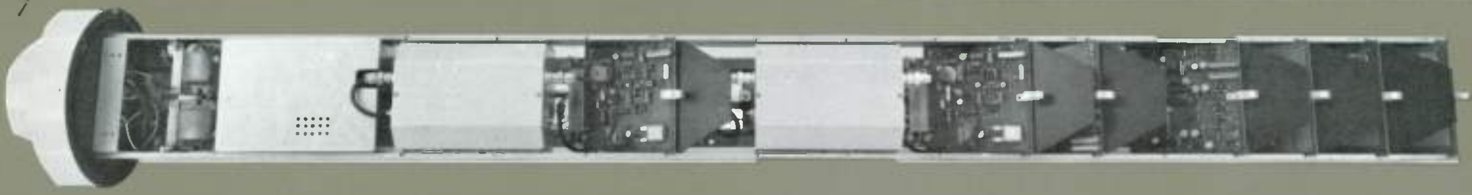


5–Except in areas directly under the vehicle, lateral resolution (length of bottom reflecting area) approximately equals linear ping length.

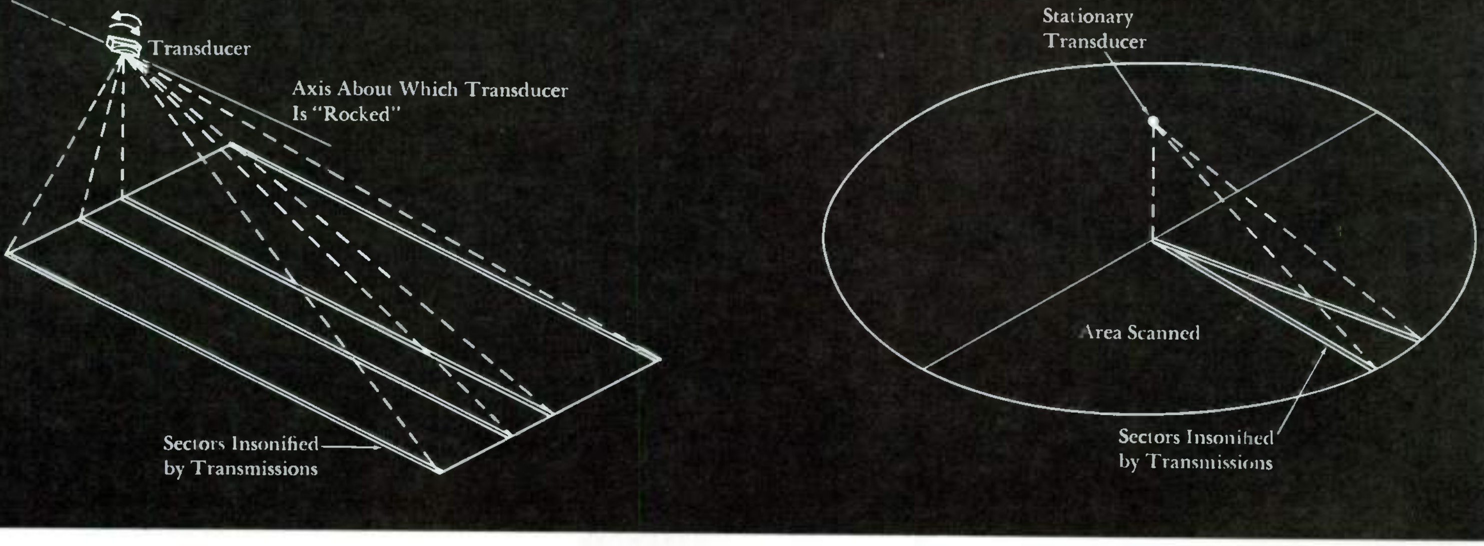
6


Direction of Motion
225'
1200'
Depths to 20,000'
1'
30'
200'
200'
1200'
6'
High Resolution Mode
Long-Range Mode
Direction of Tow

7



8a


Transducer
Axis About Which Transducer Is "Rocked"
Sectors Insonified by Transmissions
b
Stationary Transducer
Area Scanned
Sectors Insonified by Transmissions

one side is held to something less than 10 times altitude. Another limitation that holds lateral range to a similar value is the very low ratio of backscattered energy to incident energy that occurs at the shallow grazing angles at distances beyond 10 times altitude. Under such conditions, the system is power limited. And finally, multipath signals scattered from shorter range areas begin to arrive and fill in shadowed areas, resulting in loss of detail.

The net effect of these various considerations of resolution and range requirements can be summarized by a rule of thumb: average total mapping width will range between 300 and 1000 times system resolution. Westinghouse has built sonars for different applications within this range with effective resolutions from a few inches up to 80 inches.

Side-Looking Sonar Applications

As a class of equipment, ocean-bottom scanning sonar encompasses applications with widely varying range and resolution requirements, and they can be built for a variety of platform configurations. For surface ship applications, the platform is a towed sonar vehicle. For submersibles, the same basic components can be adapted to hull mounting. In a third variation, a mechanical scanning head provides bottom observation from a relatively fixed position, such as from a hovering submersible, deep cable-lowered probes, or a fixed ocean platform or buoy.

With minor modifications for different performance characteristics, a complete sonar system can be synthesized by selecting building blocks consisting of simple line transducers, solid-state transmitting-receiving circuits, and cathode-ray tube or recording-type visual displays. These components have already been designed and tested in the marine environment.

Hull-Mounted Configurations—Very high resolution side-looking sonars, where transducer beams are finely focused with limited depth of focus, are most practicable in submersible hull-mounted configurations because the altitude of the submersible (particularly at low altitude) can be most accurately controlled. The transducers are hung on the hull and the transmitter-preamplifier package can be either inside or outside the pressure hull. An external pressure-proof package was the choice for the Navy's bathyscaphe *Trieste II* (and in other space-limited submersibles, such as Westinghouse *Deepstar* vehicles), whereas for the Reynolds International deep-diving submersible *Aluminaut*, only the transducers were outside. The ocean-bottom scanning sonar built for the *Trieste* is typical of a high-resolution system for installation on a submersible where inside space is limited.

The systems built for the *Aluminaut* and the *Trieste* were bimodal systems in that by a flip of a switch, the system could be operated in a long-range search mode with an average patch resolution of 2½ by 4 feet, or in a short-range, high-resolution focused mode with an average patch resolution of one by one foot. The bimodal system operates at altitudes of either 225 or 20 feet, with corresponding bottom lateral ranges of approximately 2400 and 400 feet.

Both short- and long-range modes operate at 220 kc, and the port and starboard beams time-share the same transmitter, preamplifier, receiver, and recorder amplifier. This arrangement permits a minimum of hardware inside the pressure hull, and therefore the lowest possible power consumption and weight.

The inboard equipment, which is completely solid-state, consists of the receiver and associated timing circuits, recorder amplifier, recorder controls, port and starboard recorders, and power supplies. Separate port and starboard paper recorders were used to save space inside the hull. The recorders have high- and low-speed motor control to accommodate bimodal recording.

The external components of the system consist of an electronics assembly contained in a pressure housing and two transducer housings, one on either side of the vehicle. The outboard electronic equipment is contained in a cylindrical assembly formed by stacking circular circuit boards on threaded rods. The assembly contains the transmitter, transmitter pulser, transmitter lockout, and preamplifier. The pressure housing is about 53 inches long. When installed, the assembled housing is purged of air and filled with dry nitrogen to prevent moisture condensation inside the housing at low temperatures.

Each transducer housing contains two line transducers: a straight unfocused transducer for long-range operation and a curved focused transducer for short-range operation. The transducer housings are filled with oil so that inside pressure equalizes with the ambient pressure through a compliant membrane over the transducer faces.

Towed Configuration—In the ocean-bottom mapping system, a sonar vehicle is towed at approximately 225 feet above the ocean bottom at depths down to 20,000 feet (Fig. 6). The total lateral search range is about 2400 feet. A fore-aft acoustic beam width of 0.3 degree produces a resolution of 6 feet at 1200-foot range (one-half the total lateral search range), decreasing to 2.5 feet at minimum resolution. Separate port and starboard beams are operated at 150 and 160 kilocycles. In addition, a high-resolution mode of operation is provided in which a focused beam of the same frequency scans the bottom from an altitude of 30 feet. In this situation, the resolution is about one foot, and the path width is 400 feet.

The underwater vehicle (Fig. 1) contains an electronic unit assembly, a battery and housing, and two transducer housings (port and starboard), each containing a transmitting transducer and two receiving transducers, one focused and one unfocused. Each transducer consists of a line array of 19 barium titanate elements mounted in plastic holders. Each element is 3.6 inches long, and the total transducer array is 68 inches long. The piezoceramic element is backed by sound-

6–A bimodal system can be operated in a long-range mode for maximum mapping rate, or high-resolution mode for maximum target definition.

7–The underwater electronic assembly contains the sonar transmitter, transmitter pulser, and preamplifier.

8–When ocean-bottom scanning sonar is operated from a fixed transducer, focused transducers can be rocked (*a*) to scan the bottom in a rectangular pattern, or rotated (*b*) to scan the bottom in a circular pattern.

absorbing rubber, which absorbs the back radiation and helps equalize the pressure surrounding this element. For high ambient pressure operation up to 10,000 psi, the transducer housing is oil-filled and pressure-equalized.

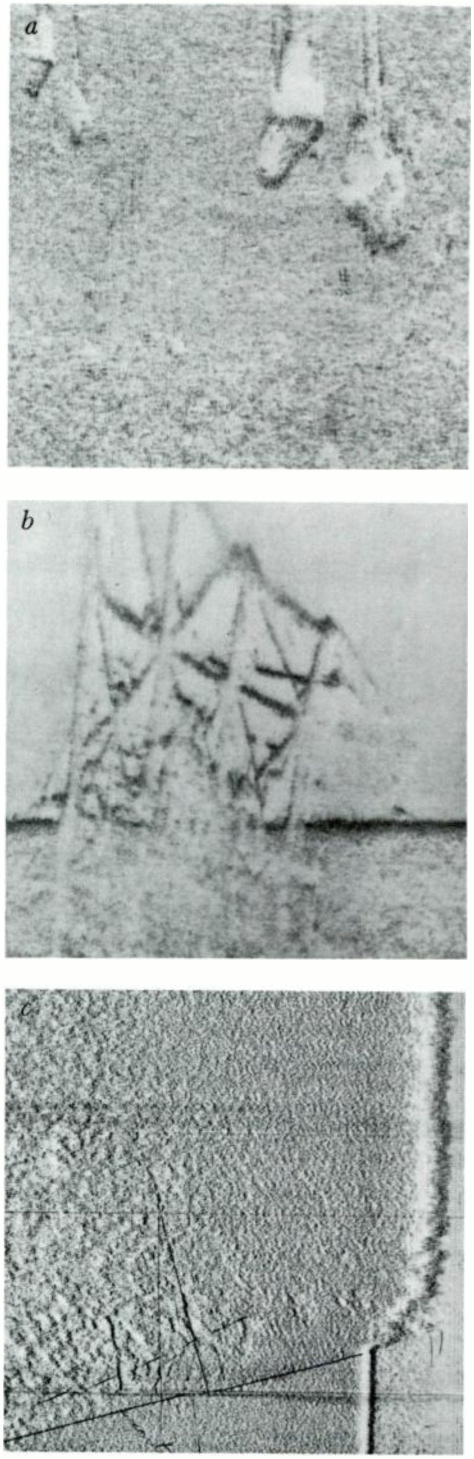
The underwater electronics package (Fig. 7) contains two transmitters and two preamplifiers. Power is supplied by three 12-volt, 60-ampere-hour automotive batteries in series. A conservative estimate of the battery discharge time is 30 hours. The circuitry is all solid state and is mounted in a cylindrical housing also designed to withstand 10,000-psi ambient pressure.

The towed vehicle is connected to the shipboard section by a combination electrical and towing cable, whose mechanical and electrical characteristics are suitable for the tow depths and speed. Cables of the double- or triple-layer, preformed spiral type are available for towing to 20,000 feet. Vehicle altitude is maintained within acceptable limits by winching in and out, and the electrical signals are conducted through slip-rings on the winch. All of the signals, both up and down the cable, are telemetered over a single two-conductor link, which is generally a coaxial cable in the core of the tow cable.

The shipboard system contains two complete receiver units (operating at 150 and 160 kc). Each unit contains a 6-kc bandwidth filter amplifier, a time-varied gain amplifier, and automatic gain-control circuitry.

The paper recorder (or other recording system) records the video information from the system, and initiates the synchronizing pulse of the system.

Mechanical Scanner—Ocean-bottom scanning sonar can also be operated from a fixed transducer location to provide an image of a bottom area. This technique was developed to overcome the limited capabilities of a towed configuration for making localized underwater observations, such as inspecting underwater installations, guidance of grappling operations, supervision of divers operating in murky water, sentry duty monitoring river mouths or harbors, or in any application where continuous observance of a limited bottom area is required.



9—Ocean-bottom scanning sonar views of (*a*) downed aircraft in Lake Michigan, (*b*) lost drilling rig, and (*c*) earthquake fault off the Alaskan coast.

Two scanning modes have been developed for focused transducers: (1) In a rocking mode, a curved-array transducer is rotated about a horizontal axis (Fig. 8a), causing the downward-directed beam to sweep the bottom in a rectangular pattern. (2) In a rotating mode, the transducers are rotated about a fixed vertical axis (Fig. 8b) so that the angular sectors of bottom examined with each transmission become sectors of a semicircular search area.

New Jobs for Sonar

Low-altitude, side-looking sonar is now recognized as an important new instrument that can be useful for detailed observation of the ocean bottom and for high-resolution search of bottom areas. In addition to its first use in the search for the submarine *Thresher*, other applications have been the search for a downed aircraft in Lake Michigan (Fig. 9a), the surveying of a sunken drilling rig off the Gulf coast after a severe hurricane (Fig. 9b), and a survey off the Alaskan coast to detect bottom changes after the 1964 earthquake (Fig. 9c). More recently, the towed configuration was used in the search for the nuclear bomb off the Spanish coast.

One can envision a large number of oceanographic and marine engineering tasks for this new instrument. A partial list would include: searching the ocean floor at any depth for the recovery of specific objects of hardware—missile parts and instrument packages, or sunken ships and aircraft; bottom surveys, again in any water depth, for scientific studies—geological, biological, beach erosion, or acoustic propagation and reflection; bottom surveys for resource exploration—petroleum, ores, or food; precise navigation by exact knowledge of bottom topography; and bottom surveys for site selection—for fixed installations of instrument packages, observation stations, weapon ranges, or underwater cable routes. Both technical feasibility and suitable operational techniques for carrying out these various tasks have already been clearly demonstrated.

Electric Power and Pure Water from Dual-Purpose Nuclear Plants

J. D. O'Toole
W. H. Stinson

Filling two pressing national needs by one technical solution is a highly desirable approach. The nuclear dual purpose plant, which produces both electric power and pure water, is a current example.

The combination of nuclear electric-power generation and water-purification facilities in one plant requires lower investment and has lower operating costs than can be achieved by separation of these two processes. Thus, with increasing demands for electric power and a growing problem of adequate supplies of pure water, such a nuclear dual-purpose plant is an excellent solution to current problems in many areas of the world. Design and construction of the first large nuclear dual-purpose plants seem imminent.

Important considerations in evaluating nuclear dual-purpose plants are: the status of technology in nuclear steam supply systems; energy costs for such systems; possible turbine-generator configurations and their influence on cost of energy supplied to the water purification plant; the effect of reactor "stretch," i.e., the capability to increase reactor output during its lifetime; and the need for optimization in dual-purpose plants.

This discussion is confined to large nuclear power plants applied to water purification using the flash evaporator cycle, because this combination seems most suitable for present application; however, some of the fundamental concepts apply also to fossil-fuel plants, and to all distillation plants, whether converting seawater, brackish water, or other polluted water to pure water. The possibilities outlined here are based on existing, well-proven components and systems that are available today.

The basic elements of the nuclear power and water-purification plant are the nuclear heat source, the turbine-generator plant, and the water-purification plant.

The heat source is a nuclear steam supply system using a pressurized water reactor (PWR). In the future other reactors may be developed to the point where they will displace present types; however, for at least the next decade, light water reactors will have a distinct edge in reliability, proven performance, and cost.

The nuclear heat source supplies steam to a turbine-generator plant, where it is expanded through high-pressure and low-pressure turbine cylinders as it would be in a conventional steam power plant. However, before the steam is expanded to the usual condensing pressures, some or all of the flow is exhausted to the multistage flash evaporator water purification plant.[1]

The Nuclear Steam Supply System

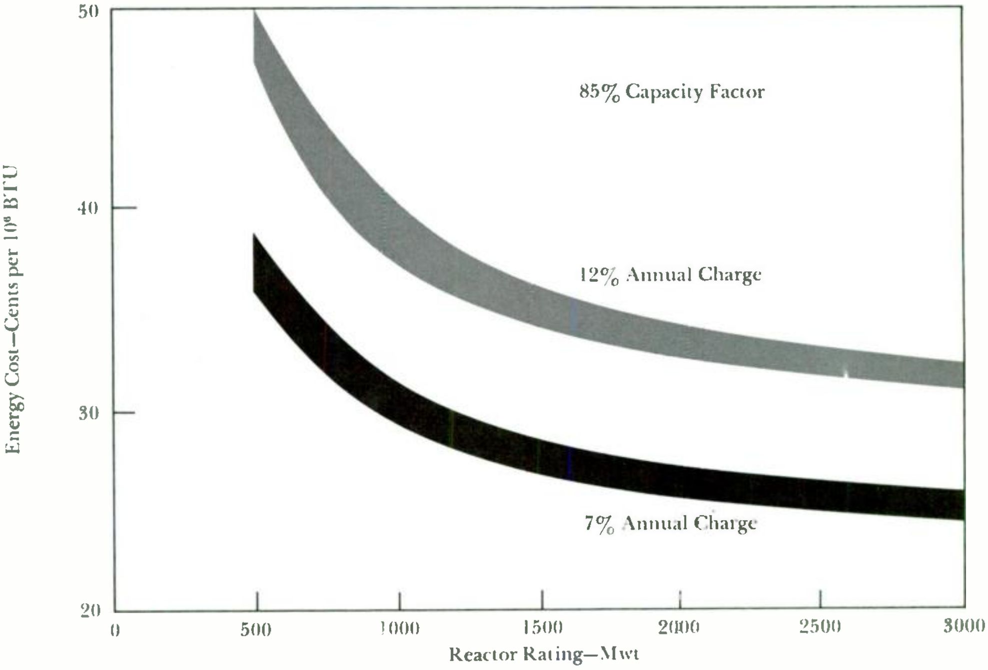
The increasing volume of commercial nuclear power business has allowed the principal components of the modern PWR to be developed in "modules," which insures that mass production economy is approached. Examples of modules used in different quantities for plants of different ratings are steam generators, reactor coolant pumps, control-rod drives, and fuel assemblies.

The number of modules required in typical applications of various PWR sizes is shown in the table below. All of these modular components are presently available and are in various stages of production for PWR power plants and, of course, would be equally applicable to dual-purpose plants.

Typical Numbers of Modular Components for PWR Plants

Reactor Rating Mwt	*Maximum Gross Mw Electric Output*	*Number of Components*			
		Steam Generators	*Coolant Pumps*	*Control Rod Drives*	*Fuel Assemblies*
700	240	1	1	21	69
1450	490	2	2	32	121
2200	750	3	3	45	157
2950	1000	4	4	65	193

1–Cost of Energy from a PWR Nuclear Steam Supply System



J. D. O'Toole was formerly Advisory Engineer, Advanced Reactors Division; W. H. Stinson is Advisory Engineer, Electric Utility Headquarters, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania.

Cost of Heat

The revenue requirements of "costs" associated with the nuclear steam supply system may be divided by the heat energy produced by that plant to express an equivalent "cost of energy." This cost of energy depends on the following variables: (1) capital investment; (2) annual fixed-charge rate; (3) fuel cost; (4) operation and maintenance costs; and (5) plant capacity factor.

Obviously no single curve of energy cost versus size would be completely applicable with so many factors to be considered. Therefore, typical ranges of energy costs versus size for two commonly used annual fixed charge rates, 7 percent and 12 percent, are shown in Fig. 1. These bands are based on a pressurized water reactor with an 85 percent plant capacity factor, private ownership of nuclear fuel, and typical site conditions, and they include capital, operation, maintenance and nuclear insurance costs.

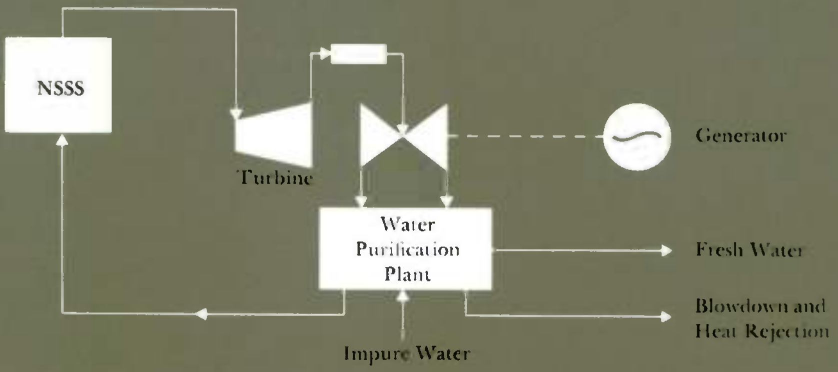
The significant feature of these energy cost characteristics is the downward trend with increasing reactor size. This has, of course, provided the impetus for most of the studies of large nuclear installations. For the production of electric power only, the capital, operation, and maintenance expenses of the selected turbine-generator plant must be added to arrive at an estimate of the total cost of the single product of such a plant. Where *two* products are involved a different approach must be used. One that also evaluates the energy flow from the turbine exhaust to the water desalting plant.

The Turbine-Generator Plant

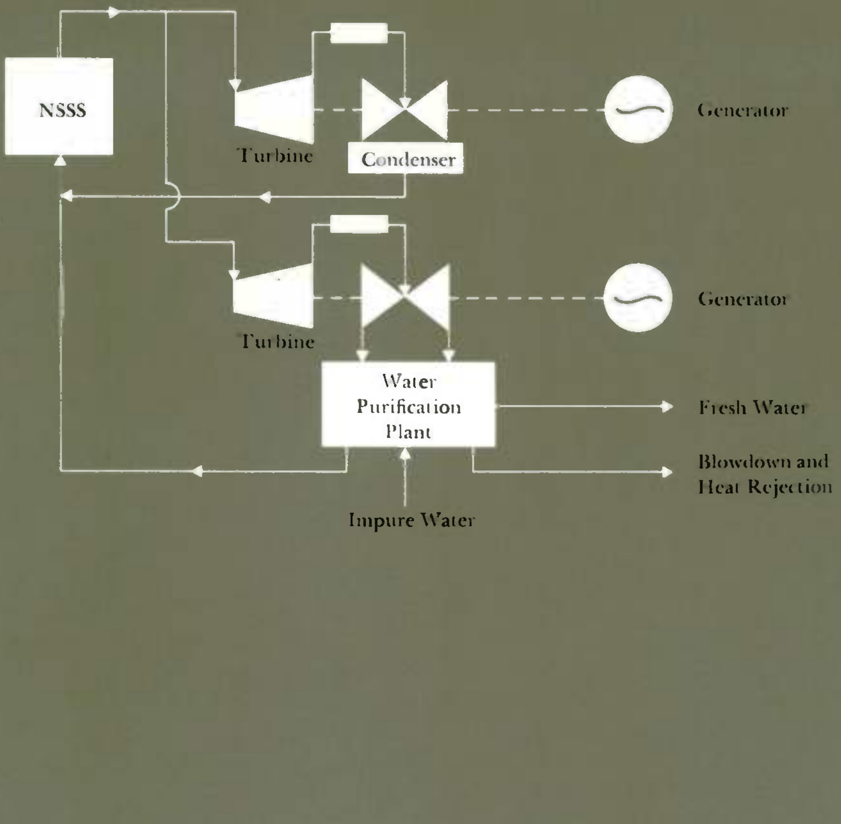
In the nuclear dual-purpose plant, where the turbine serves as a common element to both the nuclear power generation plant and the purification plant, various configurations are possible.

Most studies have been based on a back-pressure turbine exhausting its full steam flow directly to the water purification plant, except for that extracted for feed heating and auxiliaries (Fig. 2a). The basic approach is a good one. The overall plant meets all standards of reliability and often has the most eco-

2a—Back-Pressure Nuclear-Power Purification Cycle



2b—Multi-Shaft Nuclear-Power Purification Cycle



nomical water system and electric system. One limitation, however, is that for a given water-production capacity, the noncondensing turbine has a rather limited range of possible full-load electrical ratings. The quantity of exhaust steam is largely set by purification plant economics, and because kilowatt output follows steam flow closely, there is a limitation on the selection of electrical output as a function of water output.

The typical ranges of electrical output that match water production capacities are shown in Fig. 3. If the water system demand and the electrical system demand happen to fall within the range of these curves and are either continuous or occur at the same period of the year, this arrangement of a nuclear system, a noncondensing turbine, and a water purification plant in series is an attractive configuration and approaches the overall minimum levels of product cost.

With this arrangement, curves of costs of steam to the water-purification plant can be derived for any set of assumptions regarding fixed charge rates, equipment costs, fuel costs, and plant capacity factor. Westinghouse practice is to use a computer program to optimize the overall plant, including the water purification plant; however, a curve such as Fig. 4, which provides steam costs to the water plant, is useful for making close estimates of ultimate costs of water that may be expected from the dual-purpose plant. A number of assumptions must be made for any such curve to be valid. The two most important are the value of electrical energy and the plant capacity factor. Here the electrical energy is assumed to be valued at its cost of generation in a straight nuclear plant of the same net electrical output. The plant capacity factor was 85 percent. While different values might be used, the water purification plant capacity factor is usually assumed to be of this order or possibly higher, and, of course, the electrical and water plant capacity factors must correspond reasonably due to the steam cycle configuration.

The fixed charge rate applicable to the power plant facilities can be seen from Fig. 4 to have only a small effect on water plant steam costs for large plants, so these charges are of relatively little concern to the water utility company.

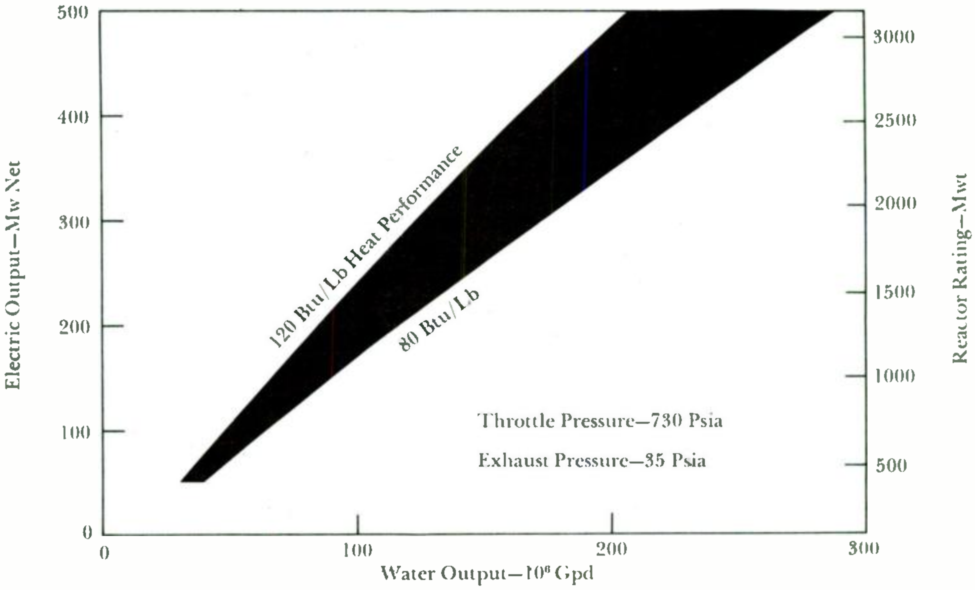
The basic steam costs for the back-pressure turbine cycle provided in the foregoing curves are of general application; however, water output and power output requirements may not both fall within the band indicated. In this case, cost penalties would be associated with installation of a dual-purpose plant that is electrically smaller or larger than the system requires. This would be reflected in added cost of steam to the water plant. For this reason, among others, the tendency is to consider addition of condensing generating capacity to supplement the back-pressure generation described above.

A common nuclear steam supply system could supply energy to two turbine shafts; i.e., to a condensing turbine-generator and a back-pressure turbine-generator unit in parallel (Fig. 2b). In this type of application, utility practices might be to credit the net station power output at a value of mills/kwh corresponding to cost of generation in a straight power plant of the same net rating and output.

This actual mills/kwh credit then would be smaller than that used to develop Fig. 4, where electrical plant rating was smaller; however, the incremental cost of most plant components would be lower than in the straight back-pressure cycle. Since these two factors tend to offset each other, the steam cost to the water plant given in Fig. 4 also will apply in a general way to the larger plants that produce more electric power than the basic single-shaft back-pressure turbine-generator plant.

The two-shaft arrangement of Fig. 2b is an excellent approach to large dual-purpose plants since the revenue requirements for the total of both products approach minimal values because of economics of size and inherent flexibility in loading and operation. The segregation of cost between the two products is a different matter and is not considered here, although it may have a bearing on selection of configuration. Such a plant can, in many cases, match very closely the capacity factor requirements dictated by the electrical system. The noncondensing turbine will supply the continuous steam demands of the water purification plant, and the electrical energy supplied by the condensing turbine will be reduced over the plant life to generally permit the total plant to be dispatched economically.

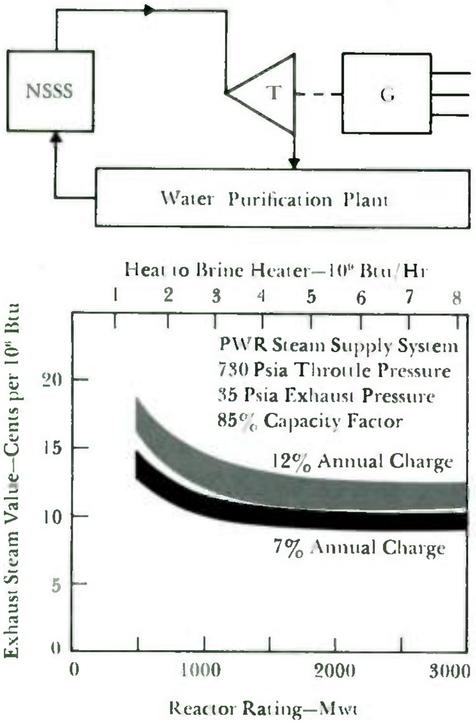
3—Power-Water Combinations with Full Back-Pressure Cycle



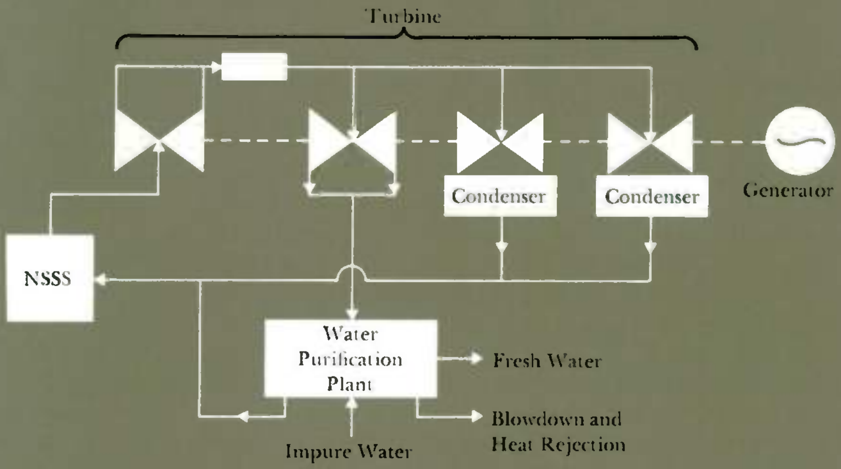
The same concept can also be used in a single-shaft design in which the noncondensing generation is combined with the condensing turbine. An arrangement that merits consideration in large plants is shown in Fig. 5a. Here all the steam from the nuclear system passes through the turbine inlet and high-pressure section. At the crossover, part of the flow continues to the low-pressure ends and condensers; the other part enters a separate cylinder and is exhausted at suitable pressure to the water purification plant. This single turbine-generator unit performs the function of the two-shaft arrangement and entails savings in both apparatus and structures. It can be designed so that at full load (or some other point) the thermal performance is at an optimum value because loads and steam flows will be matched for one load-point operation.

With constant water-purification-plant steam requirements, the electrical output of this turbine can be dispatched in accordance with normal utility practices.

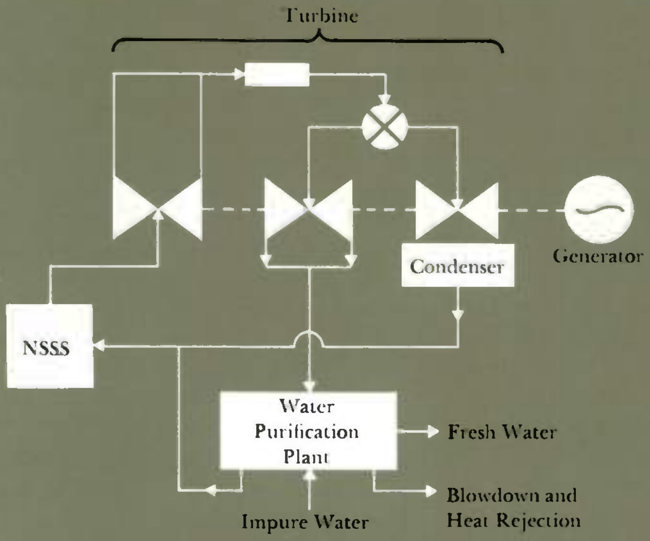
4—Cost of Heat from a Full Back-Pressure Cycle



5a—Single Turbine Nuclear-Power Purification Cycle



5b—Nuclear Power Purification Cycle with Emergency Spinning Reserve



Provision can be made for operation of the turbine-generator in event part or all of the water plant were out of service, affording an electric availability equal to a single-purpose power plant.

Westinghouse evaluations of this arrangement consider the heat rate penalties involved and typical utility loading schedules in which the first years represent base load, and in later years dispatching for part load operation. The nature of the penalties involved for added plant energy costs, as compared to the two-shaft arrangement, is shown in Fig. 6.

Such a cycle as this must be evaluated for the particular situation involved, as must all plant concepts. Westinghouse studies covered plants in the range of 50 to 100 million gallons per day in conjunction with the largest current nuclear steam supply systems. In these studies, which considered plants experiencing levelized lifetime electrical capacity factors of 70 to 80 percent, the first cost savings of this arrangement appear to equal or exceed the increased annual operating costs.

Peaking and Spinning Reserve Capability

The question is sometimes raised as to the capability of various dual-purpose plant arrangements for peaking or spinning reserve duty on the electric system. For example, the back-pressure cycle of Fig. 2a would be adaptable to these concepts with an arrangement such as Fig. 5b, whereby a condensing end is added. Normal operation would be with steam flow through the throttle, crossover, and exhausting through the back-pressure element, with the condensing end maintained under vacuum with only a flow of cooling steam. Under emergency conditions, the main flow from the crossover would flow through the condensing ends to produce added electric output. Of course, in the rare instance where this emergency feature operates, the water plant could be shut down until restoration of normal electrical conditions.

On the basis of first cost and fuel economics, Westinghouse estimates indicate that in some cases this added electrical capacity could be obtained at cost equal to or better than other methods of obtaining system peaking and spinning reserve capability, including allocations for charges to electric power for lost water purification plant capacity during the periods.

The worth of this possible choice has to be evaluated for each situation, but studies have shown that spinning reserve of this type may have a value of $15 to $25 per kw depending upon system fuel costs, fixed charge rates, etc. Therefore, in the future such an arrangement may have economic merit.

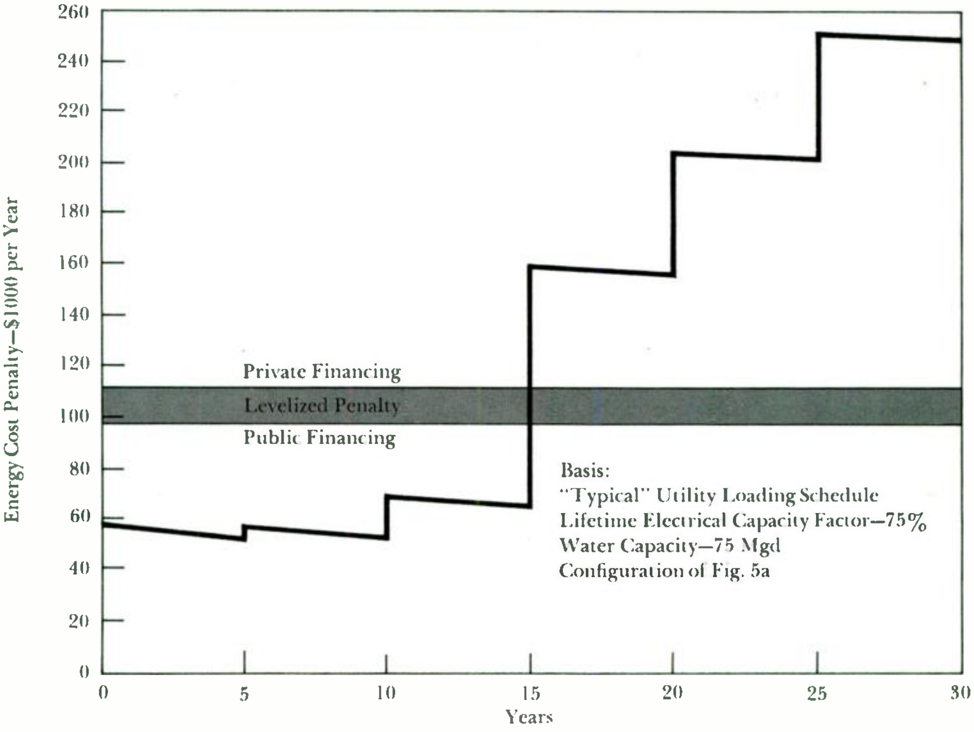
Reactor Plant "Stretch" and the Dual-Purpose Plant

Since the beginning of the electric-utility nuclear-power industry, the matching of the turbine-generator to the nuclear system supply steam has presented a rather unique problem to the plant designer. This has been due, in part, to the immaturity of the technology, and therefore to the uncertainty of the reactor output that would ultimately be achieved. The power output history of the first PWR plants has shown that the reactor inevitably achieves an output in excess of the installed turbine capability. The maturation of the industry has, of course, changed this situation to a degree; but even today, there still remains a significant potential for reactor output "stretch," which should be considered when turbine-generator, and water plant capacity are considered.

A typical PWR power capability characteristic curve is *A-B* on Fig. 7. Any point on curve *A-B* could be selected as the reactor plant 100 percent output point, and would define the steam pressure and reactor heat output for 100 percent reactor load. All points on curve *A-B* have constant design margins with respect to: (1) peak-to-average reactor heat flux; (2) peak-to-average reactor coolant enthalpy rise; (3) reactor coolant flow; (4) steam generator effective heat transfer area; and (5) steam generator overall heat transfer coefficient.

Experience has shown that actual peak-

6–Energy Cost Penalty—Single-Shaft Nuclear Purification Cycle



Basis:
"Typical" Utility Loading Schedule
Lifetime Electrical Capacity Factor—75%
Water Capacity—75 Mgd
Configuration of Fig. 5a

to-average performance of the reactor will be somewhat better than the design values; however, the extent to which this margin can reasonably be exploited must be determined by some reactor operating experience. Similarly, it has been demonstrated that at least some of the normal design margins in pumps and steam generators will be realized in greater plant output.

Curves *A′-B′* and *A″-B″* are displacements of curve *A-B* that represent the power capability characteristics of the same PWR when different degrees of output extrapolation have been achieved. Points *1*, *2* and *3* might be respectively, the initial, stretch, and maximum outputs of a power plant if a turbine-generator is installed that will accommodate the maximum reactor plant output as shown on Fig. 7. This approach to stretch in a single-product nuclear generating plant usually results in very desirable economics for the incremental electric power output. It also suggests that a similar approach for a two-product nuclear plant might offer some advantage. Further work should be done in this area to evaluate the engineering and economic implications.

The Problem of Plant Optimization

Everyone in the power generation business is familiar with the effort that goes into taking and evaluating bids for a new generation station. Each new project seems to be different from older plants in one respect or another. Questions must be resolved with regard to unit ratings, steam conditions, exhaust pressure, condenser size, number and types of feedwater heaters, type of fuel, type of boiler, cooling water source, etc.

All of these same options are considered when combining a power plant with water purification facilities; but to them must be added the steam pressure to the water purification plant; quantity of steam required; price of water purification plant versus the cost of steam; general cycle configuration; and, finally, the overall plant optimization to provide the most advantageous product ratio—quantity of electric power to quantity of pure water produced. Further complexities are involved when joint ownership of facilities is involved.

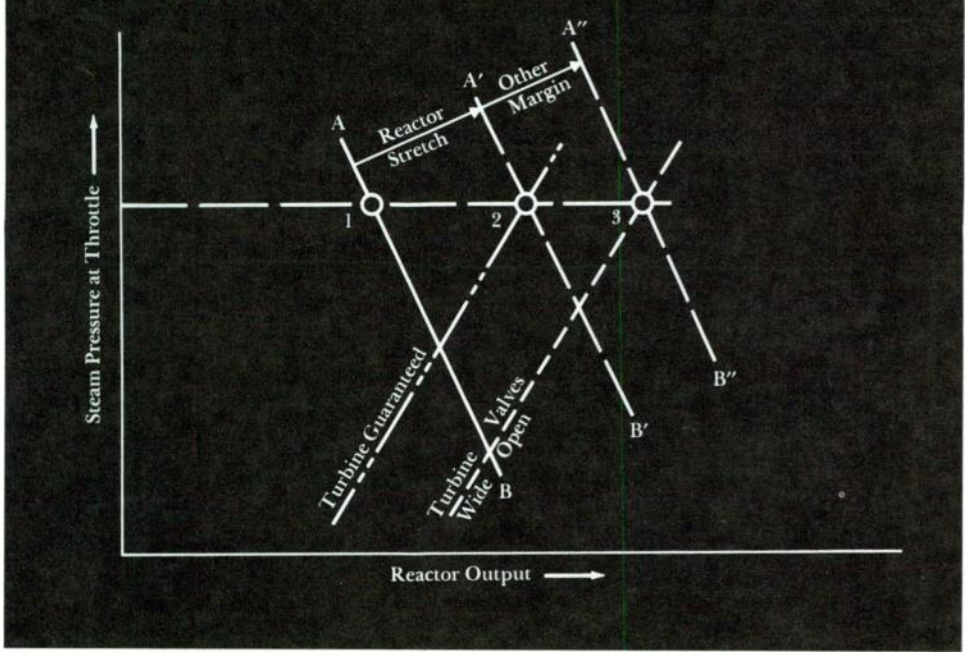
In undertaking a combination-plant project, one of the first steps that must be taken is to specify the economic ground rules. As one would suppose, this is more complex than for a single-purpose plant in most actual situations. First, there are two products instead of one, and costs must be distributed between them. However these complexities are resolved, the final answers must be in accord with the political and economic objectives of the enterprises involved in the project. The economic ground rules should reflect these objectives.

Once the basic ground rules are established, the possible plant design parameters can be reflected in functions of price, performance, and annual operation and maintenance expense of the steam source, power plant, and water purification plant. These functions can be written into computer programs that give complete "maps" of costs of products—both power and water—over all possible ranges of design and economic parameters.

Future Prospects

While there is no nuclear dual-purpose plant of practical significance either built or under construction, the future unquestionably holds promise for such plants. Probably, the first plants will use light water reactors, such as the PWR, in combination with turbine-generator units and flash evaporators in straightforward configurations. Subsequently, greater emphasis will be placed on plant flexibility and sophistication to meet the particular electric and water system needs, such as peaking, spinning reserve, etc. Because of their established technology and improving economics, light water reactors should remain principal energy sources for such plants for many years to come. Even after the advent of their most likely successor, the breeder, the need for plutonium may extend the economic life of PWR plants. Vast complexes utilizing both "burner" and "breeder" reactors have been envisioned, which will make more effective use of our nuclear fuel resources and provide lowest cost electric power and fresh water.

7–Typical PWR Power Capability Characteristic Curves



Westinghouse ENGINEER **November 1966**

Reference:

[1] Gaunt, R. E., et. al., "Pure Water Via Flash Evaporator," *Westinghouse ENGINEER*, November 1965.

Refuse Reclamation...A Solution to a Growing Urban Problem

L. G. Reimer

Efficient and nuisance-free disposal of city trash and garbage is provided by St. Petersburg's new refuse reclamation plant. Materials with salvage value are removed and sold, and the rest of the refuse is converted into a salable organic compost.

The ideal way to dispose of a city's trash and garbage, it has been said, is to convert it into useful and marketable forms by processes that are fast, inoffensive, silent, economical, and invisible. A close approach to that ideal is provided by the refuse reclamation plant opened recently in St. Petersburg, Florida. The plant, if not quite invisible, at least is housed in attractive modern buildings that look like a light industrial plant and blend in with their surroundings in a city park.

The disposal operation consists essentially of salvaging marketable items such as metal and rags and converting the rest of the refuse into a soil-conditioning compost. There is no incineration and therefore no smoke, and complete enclosure of the process excludes flies and rodents. The composting process takes only five days, is highly mechanized, and produces no offensive odors.

Because the plant is nuisance-free, it is located right in the city to minimize hauling costs. The sale of salvage and compost is another favorable factor in plant economics.

Why Reclamation?

Rising sanitation standards have made the traditional dumping and burning of refuse unacceptable. Consequently, two improvements have evolved: controlled dumping and burying with soil (sanitary landfill), and controlled burning of the combustible constituents in special incinerators.

Sanitary landfill permits disposal at low cost for relatively small communities, although careful planning and control are necessary to avoid flies, rodents, odors, water pollution, surface seepage, and uncontrolled scavenging. Larger communities like St. Petersburg cannot long rely on landfill because convenient sites are soon filled and more remote sites bring excessive hauling costs.

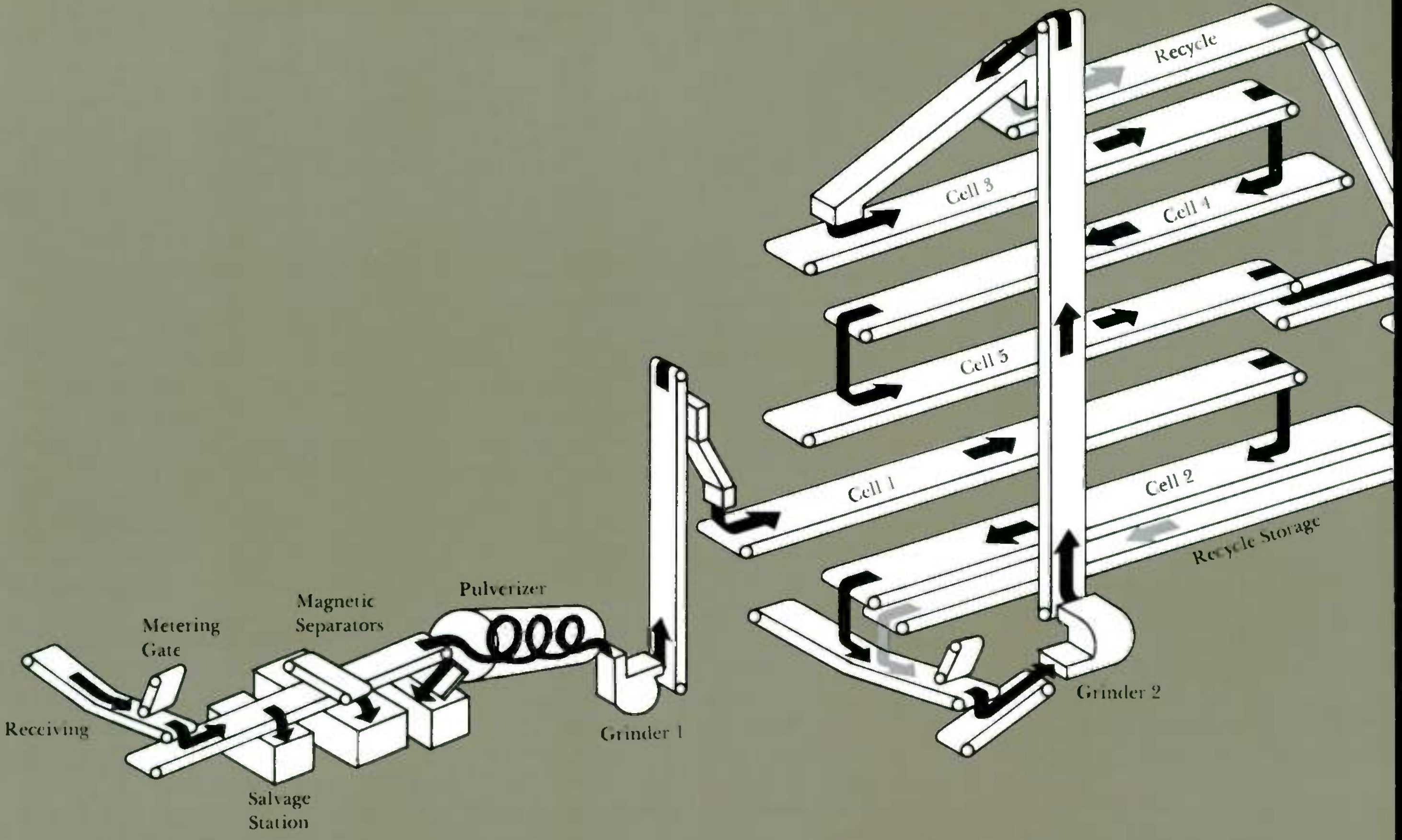
Incineration costs more and has to be justified by savings in hauling charges. Installations designed to minimize air pollution and ash residue are usually among the most expensive, but even in the more elaborate plants a residue of about 20 percent of incoming tonnage must be disposed of at suitable dumping sites. Moreover, there always remains some degree of odor, smoke, and air pollution with today's incinerators.

Modern reclamation plants are the most desirable means of disposal, especially where land values are high or pollution is a special concern. The plants can be made into attractive and nuisance-free installations and thus be permitted to locate centrally to bring hauling costs down to a minimum.

Processes for creating compost from waste material have been used before,

Refuse reclamation plant is located in a St. Petersburg park bounded by residential neighborhoods. Landscaping helps it blend into the park, and its nuisance-free operation makes it an inoffensive addition to the area.

L. G. Reimer is St. Petersburg plant project engineer in Material Handling Projects, Industrial Systems Division, Westinghouse Electric Corporation, Buffalo, New York.


Recycle
Cell 3
Cell 4
Cell 5
Cell 1
Cell 2
Recycle Storage
Pulverizer
Magnetic Separators
Metering Gate
Receiving
Salvage Station
Grinder 1
Grinder 2

but the International Disposal Corporation type of plant marks the first application of modern material-handling techniques to help keep operating costs low. Designs are under study for plants similar to the St. Petersburg plant but of larger capacity.

Plant Operation

After being weighed in, the city refuse trucks dump their loads in the enclosed receiving area (see diagram). Large items such as bed springs are removed, and such easily segregated wood products as tree limbs and crates are shredded to facilitate handling and decomposition.

A conveyor drops the refuse onto a picking belt, where about 10 percent of the incoming tonnage is removed for sale. Rags are picked off manually, while ferrous materials are removed automatically by magnetic separators.

The remaining material is thoroughly mixed and moistened in a pulverizer. This is an inclined rotating drum with its inside wall covered by many triangular plates attached in a spiral pattern. The pulverizer discharges into a special grinder developed to handle the wide variety of materials encountered. Grinding hastens the subsequent decomposition by exposing more surfaces for bacterial action. An elevator transfers the ground material to the digester, which consists of five cells and steel apron conveyors that move the refuse into and through each cell.

Each conveyor travels its length in about 12 hours and then remains stationary for about 12 hours, since the daily input capacity of the digester is designed for the amount of refuse the plant can process in one work day. Another grinder regrinds the partially decomposed material, as it passes from primary to secondary sections, to accelerate decomposition. Also, oversized material appearing at the end of the process is passed back through this grinder.

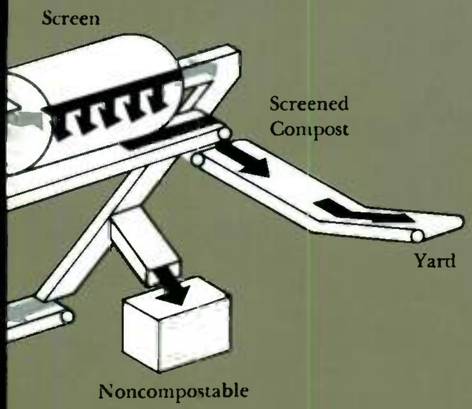
The digester conditions provide a favorable environment for the types of bacteria and fungi that cause rapid, sanitary, and odor-free breakdown of the refuse. These microorganisms also produce enough heat in their metabolic processes to kill all harmful organisms and weed seeds. The temperature is maintained by insulation on the outside walls and by the self-insulating qualities of the refuse inside.

After passing through a screen, the compost is carried out into the yard by a long conveyor (see photograph). From there, some of the compost is loaded directly into trucks for bulk sale. The rest is screened again to produce a material of fine grain structure, which is bagged for sale to home gardeners and nurserymen.

The final compost product has less than 20 percent of the volume and about 80 percent of the weight of the incoming refuse. As a source of humus for soil conditioning, it is like peat moss, cattle manure, and leaf mold in many respects but is of a consistent granular texture and so can be applied mechanically.

The new plant is owned and operated by International Disposal Corporation, Shawnee, Oklahoma; it was designed, engineered, and built by Westinghouse. It can process up to 105 tons of refuse (trash and garbage) a day, a capacity adequate for a surrounding area of 55,000 people out of the city's 210,000 population. Under a 20-year renewable contract with the city, International Disposal Corporation must dispose of 31,200 tons of refuse a year (100 tons daily during a six-day work week) in a nuisance-free manner. The city presently pays for the service at $3.24 per delivered ton, with allowance for variations in future labor and material costs.

Westinghouse ENGINEER **November 1966**



Diagram—**As trash and garbage enter the system, rags and ferrous metal are salvaged. The remaining material is broken down by grinding and by the action of microorganisms in the digester; it emerges five days later as a soil-conditioning compost. Any compost that is too course to pass through the screen openings is recycled.**

Photo—**Compost is conveyed from the digester building in background after controlled bacterial action there has converted ground refuse into compost. Some of the material is sold in bulk, and some is bagged.**

Reference:
Furlow, H. G. and Zollinger, H. A., "Reclamation of Refuse," *Westinghouse ENGINEER,* May 1964, pp.80-85.

Factory Testing by Computer Simulation Reduces Drive-System Start-Up Costs

W. C. Carter
R. A. Montoro
T. O. Curlee III

The components of an industrial dc-motor drive system seldom come together for a combination test before they are installed. Nevertheless, closed-loop operation of the regulator and logic circuits can be verified before installation. Computer simulation of the other system components does the trick.

As the complexity and capability of industrial dc-motor drive systems continue to increase, the drive manufacturer's problems in testing his product adequately yet economically become increasingly difficult. Today's closed-loop systems encompass such a wide variety of applications that the task of designing and applying adequate tests for their drives approaches that of designing the drives themselves. Moreover, the nature of these high-performance systems is such that it is almost impossible to guarantee an efficient field start-up *unless* the closed-loop operation of the drive equipment has been verified before installation.

Fortunately, the art of computer simulation has progressed to the point that it now offers a practical solution to many of the drive manufacturer's testing problems and also an effective method of checking drive performance. In computer simulation, all the controlled components of a drive system (including the process machinery) are simulated with an analog computer. The computer is connected to the drive's regulator and responds to the control of the regulator and the commands of the logic circuits as the actual components would respond.

Computer simulation provides a fast and safe method of finding equipment faults, such as wiring errors, that can best be corrected in the manufacturer's plant. Equally important, start-up time is reduced by the testing and adjusting done in the course of the computer test. This reduction in start-up time permits the user to get into profitable production sooner, and it reduces the amount of process material lost during start-up.

For the purpose of this discussion, a "drive system" is considered a combination of components designed to perform a particular function or some part of a particular process. Examples of such functions and processes include accurate positioning of the pinch rolls used in steel mills and removal of earth from an excavation site.

In general, a dc-motor drive system consists of five basic components: the process machinery that performs the ultimate task of the system, the drive motor (or motors) and gearing that furnish mechanical power to the process machinery, power conversion equipment that furnishes electric power to the drive motor, logic circuitry that determines the sequenced operations and functions of the system, and a multiloop regulator and its associated transducers that maintain constant control of the system. The regulator and logic circuitry are the *controlling* components of the system, and the power-converting apparatus, drive motor, and process machinery are the *controlled* components. Performance of a system must be judged on the basis of how well the controlled components are, in fact, controlled.

A "drive," then, is considered in this article to be that portion of a drive system that does not include the process machinery. Its function is to convert electrical energy into controlled mechanical power for the process.

A simple adjustable-voltage speed-regulated drive system is diagrammed in Fig. 1 as an example. Its drive accurately controls the speed of the process machine in accordance with the magnitude of a reference voltage applied to the regulator speed controller. The reference may come from another drive system so as to match the speeds of the two systems, or it may come from an independent source. In any case, when the system is functioning, the speed of the machine is proportional to the reference voltage. The system illustrated, having a solid-state field exciter and a generator, uses both static and rotating power converters. The regulator is a two-loop type having an inner current loop and an outer speed loop, which is the main control loop. Logic circuits determine the operating modes and functions of the system by manipulating the regulator signal director.

A unique combination of these drive-system components usually is required for every application: the drive must be more or less custom designed to fit the application, and rarely can two different users be supplied with the same equipment even if they are in the same industry. Moreover, a complete drive system is rarely if ever supplied by one manufacturer. The user receives his drive equipment from one supplier and his process machinery from one or more others. As will be seen later, it is these facts that make it such a difficult and complicated task to manufacture—and especially to test—drive equipment.

One of the easiest ways to test a drive is to test each of its components individually. Unfortunately, however, this type of test gives no information on how the system in which the drive is to be used will perform. In fact, about the only way that a drive manufacturer can be absolutely certain that his equipment will perform properly is to have the complete system in one location for a thorough closed-loop combination test. This, of course, is virtually impossible due to the absence of the process machinery. Moreover, other system components may not be available for a combination test because it is frequently an advantage to both the user and the manufacturer to ship the drive components that have shorter schedules as soon as they are individually tested. Since these components usually include the rotating power apparatus and heavy equipment, the user can pour foundations, set machinery in place, run conduit, and make many preliminary checkouts.

Although a complete system test cannot be performed, still a drive can often be combination tested. If its own rotating power apparatus is not available, a convenient and suitable test-floor motor (or m-g set and motor combination) can be substituted, and the drive can be loaded by means of a tool generator and resistive load. This has been considered the ultimate test that can be applied, but it is ex-

---

W. C. Carter and R. A. Montoro are engineers in General Industries Systems, Industrial Systems Division, Westinghouse Electric Corporation, Buffalo, New York. T. O. Curlee III is an engineer in the Systems Control Division, Westinghouse Electric Corporation, Buffalo, New York.

pensive and time consuming. It also requires that the drive components converge at a specific place at a specific time, which creates scheduling and shipping problems. And since the drive is not connected to the process machinery, the results of such a test vary with the type of system and application involved. Consequently, a combination test is only applied when it is believed necessary by the drive design engineer.

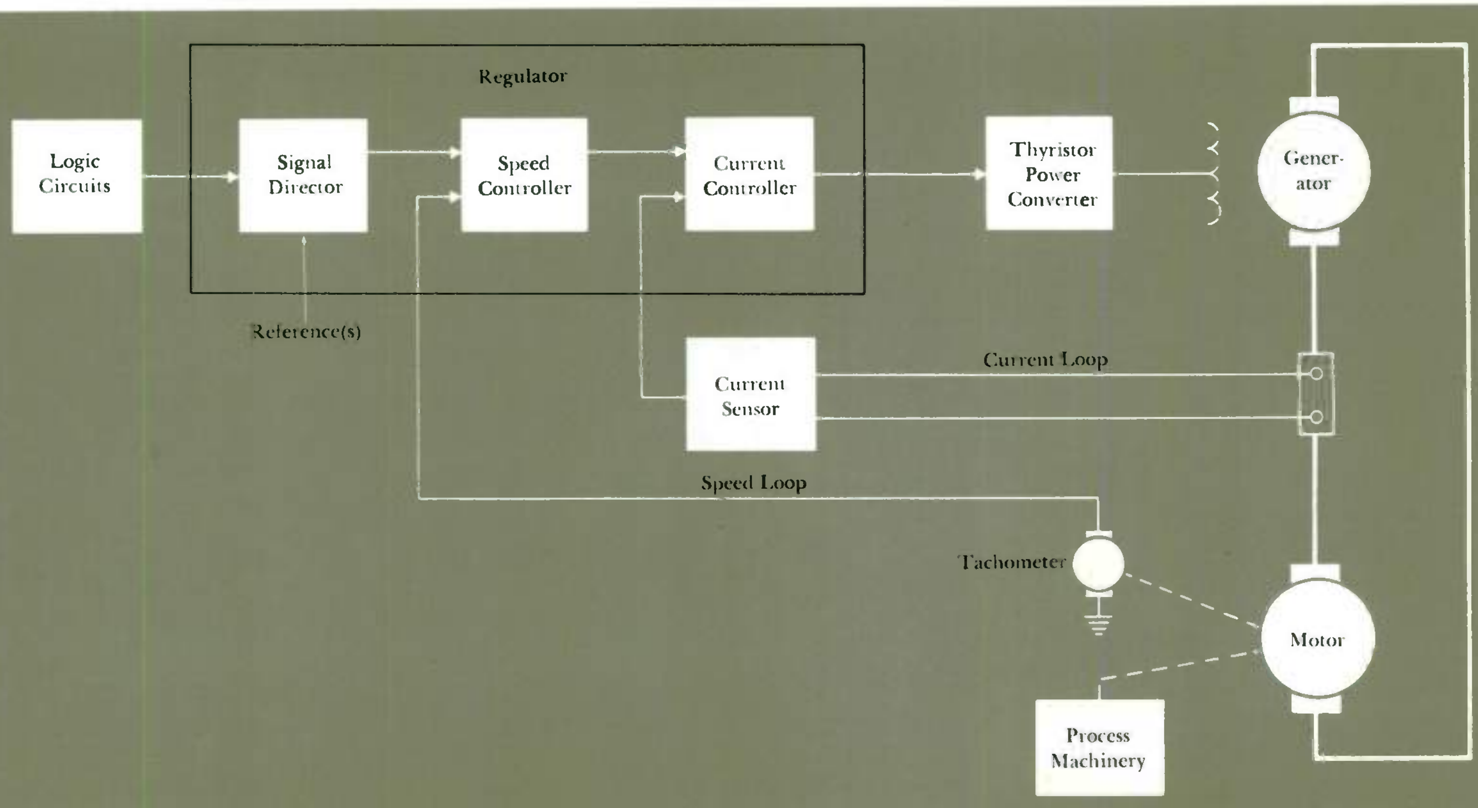
A practical and effective method by which drive-system performance *can* be determined is by testing the regulator and logic circuitry by computer simulation. All the controlled components of the system, including the process machinery, are simulated with an analog computer. The computer is connected to the regulator and responds to the commands of the logic circuits and the control of the regulator as the actual components would respond under field conditions. This type of test provides an accurate and valuable indication of overall system performance by allowing the closure of all regulating control loops.

Computer Simulation

The Systems Control Division began to test dc-motor drives by computer simulation about three years ago. The analog computers used include the Westinghouse DC Drive Test Console (a special type that will be described shortly) and several general-purpose types. The latter are extremely flexible in that almost any system can be simulated. They are composed of a number of operational amplifiers that are set up and interwired to form the analogs of the system components that are to be simulated. Since some components, dc motors for example, must be simulated every time a drive is tested, the analogs of these components are more or less permanently built up and stored. It is then only necessary to adjust the characteristics of the standard analogs and wire them in with the unique analogs to create the total analog.

No matter how sophisticated a system may be, the computer test applied to the drive can be made equally if not more sophisticated. But, since practical economics are involved, every effort is exerted to make the test as simple as is consistent with the results that must be obtained. A description of the analog to be set up on the computer is given to the test personnel, along with other test information. Results of the test are sent back to the drive design engineer for approval.

The cost of a computer test is determined mainly by the degree of accuracy with which a system is simulated. But, since the primary objective is to check regulator performance and *not* to simulate a system, it is desirable for practical

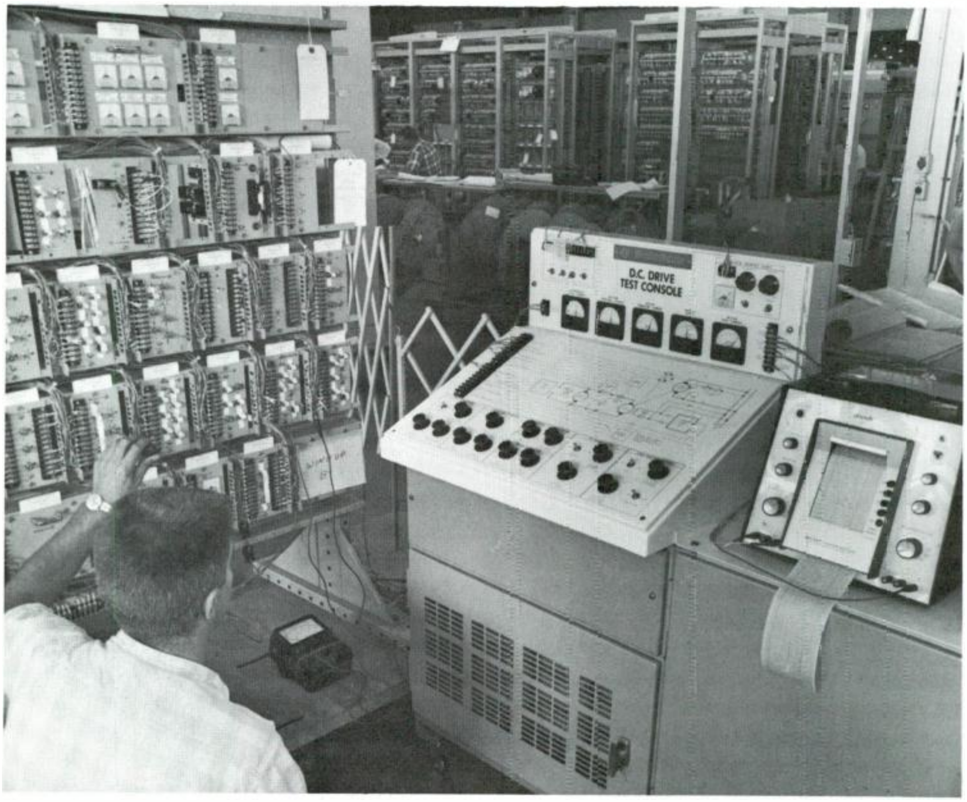


1–The speed-regulated drive system diagrammed here has a two-loop regulator, with speed of the process machinery determined by the incoming reference to the signal director. The regulator and logic circuits of such a system are readily tested and adjusted by simulating the rest of the system with an analog computer.

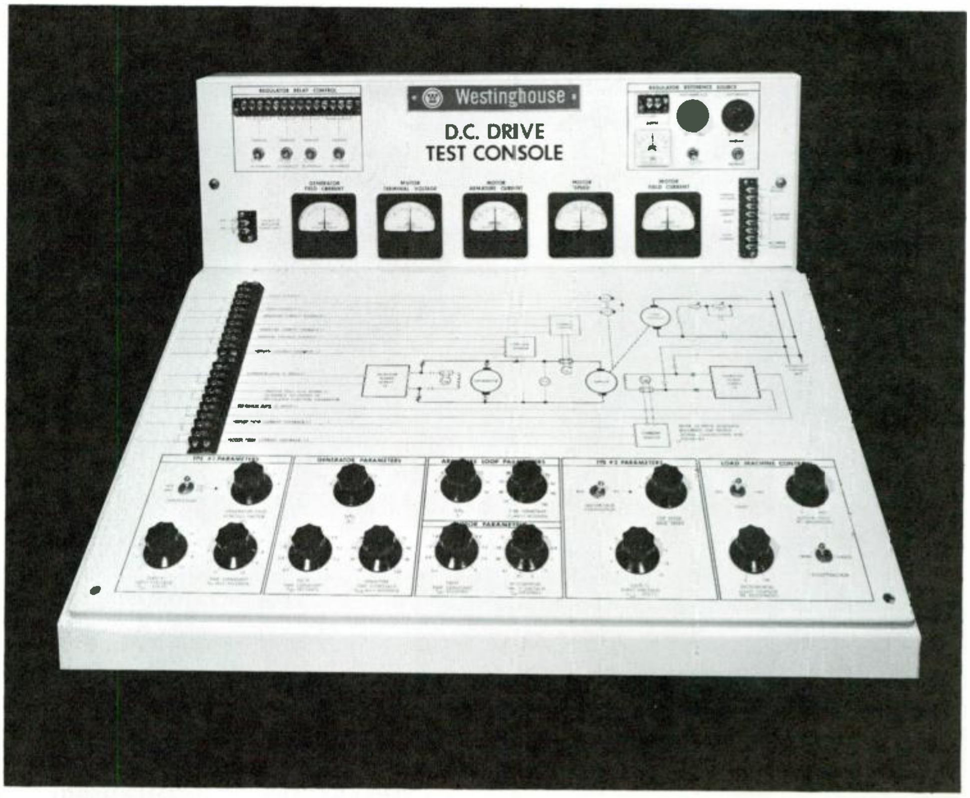
reasons (and frequently possible) to simplify the system analog without reducing the reliability or significance of the test results. The extent to which the analog can be simplified depends on the nature of the system involved; more specifically, it usually depends on how closely the drive is integrated into the user's process.

For example, if the drive's function is to control the speed of a machine that is stiffly coupled to its drive motor, the performance of the system can often be determined on the basis on how well the motor speed is controlled. It then may not be necessary to create the analog of the process machine except to represent its inertia. The characteristics of the system may be such that the drive's field performance can be virtually guaranteed if it performs well under the extreme conditions of simulated impact loading or an instantaneous change in control reference while connected to the simulated inertia load. On the other hand, it may be the function of the drive to regulate a variable not directly related to the drive, such as tension in a moving strip of steel in a rolling mill. Strip tension, the controlled variable, cannot be measured at the drive or within it but must be measured at the process machinery or the strip itself. Consequently, a thorough closed-loop test of this system would require that both the process machinery and the motion of the strip be simulated. Without computer simulation, however, the drive would be practically untestable from a systems standpoint.

Quite often, a system cannot be simulated exactly because of lack of sufficient



A drive regulator is wired to an analog computer for testing *(upper right)*. The computer in use here is the Westinghouse DC Drive Test Console, a unit designed specifically for drive testing. It simulates the other system components so that the regulator can be operated as though it were in the actual closed-loop system. Steady-state characteristics of the regulator are being adjusted so the drive will run at the proper speed in the field.



2–Control panel of the test console was designed so that a regulator can be connected for computer test as easily as the complete drive can be combination tested.

information about it. More often than not, process machinery is custom designed for a particular system and its characteristics may never be known or verified until after start-up. The information provided the drive design engineer may be based on machine design calculations and may or may not be accurate enough to allow an exact simulation. If not, the engineer must rely on his experience and estimate the machine characteristics. Since this makes the characteristics of one system component analog only approximate, it may not be practical to simulate the other components accurately.

Instead of estimating the characteristics of a system component, it may be more practical and effective to computer-test a drive by using a fictitious analog. This can be done because of the nature of the drive regulator. Although most systems are unique designs, their regulators are equipped with a variety of adjustments so that the unknown peculiarities of the system can be compensated for during start-up and the system performance optimized. The normal procedure is to calculate and make these adjustments before the drive is shipped so as to guarantee an initially stable system; it is also possible to calculate them on the basis of a fictitious system for the purpose of a computer test. A test applied in this manner results really in a check of the *theoretical* performance of the drive, but the nature of the system and the experience of the design engineer may warrant it. In other words, this type of test verifies that the drive hardware was built properly and that it performs as it was designed to perform.

The Westinghouse DC Drive Test Console, the latest addition to the family of test computers used, was designed specifically to simplify testing by simplifying the operation of the computer. It is a drive-system simulator rather than a general-purpose analog computer, and it can be applied to most of the drives produced by the Systems Control Division. It reduces the overall effort put into a test by removing the necessity for the drive design engineer to do the analog circuit design.

The main feature of the console is that its operation does not require a working knowledge of analog circuitry. Analogs of all the components shown on the console control panel (Fig. 2) are included in the internal circuitry of the console. To obtain the proper combination of these components, it is only necessary to manipulate the various rotary and toggle switches. Some of the switches control the circuits that interconnect the various analogs, while others adjust the characteristics or parameters of the simulated components. The parameters include gains and time delays of the power converters, time constants and armature resistance drops of the rotating apparatus, and speed range through which the drive motor must operate by field control. The switches that affect the characteristics of any particular component become ineffective whenever that component is switched out of the total analog.

Most of the information required to set up the console for a test can be obtained from the drive schematic diagrams. The parameters of the simulated components must still be supplied by the drive design engineer, but the console was designed so that these parameters could be used in their most readily available form with little or no calculation required. Since the components are shown pictorially on the control panel, the console is easily connected to the drive regulator. All connections are made with cables that connect to the vertical row of terminal blocks.

Once the console has been connected and the gains of all the control loops adjusted, the console meters are automatically calibrated. The calibration is in per-unit so it makes no difference whether the rating of the drive is 5 horsepower or 5000 horsepower. Moreover, this automatic calibration allows the steady-state performance of the drive to be checked or adjusted without the use of any other measuring instruments. The dynamic performance of the drive is checked by connecting an oscillograph to the console recorder outputs.

The exact procedure used to computer-test a drive depends on the nature of the system involved, but, in general, the test is conducted in one of two ways. One method involves *checking* the drive performance, and the second involves *adjusting* the performance. The first method, being shorter, is always preferred, but it can only be used if the drive design engineer has previously made the regulator adjustment calculations. Otherwise, the system may well go into an unstable condition when the computer is connected. If calculations have been made, the regulator is preadjusted and all the control loops to and from the computer are closed. If the performance falls within certain specified limits, the regulator adjustments are not altered other than to check that they have the desired effect on the performance.

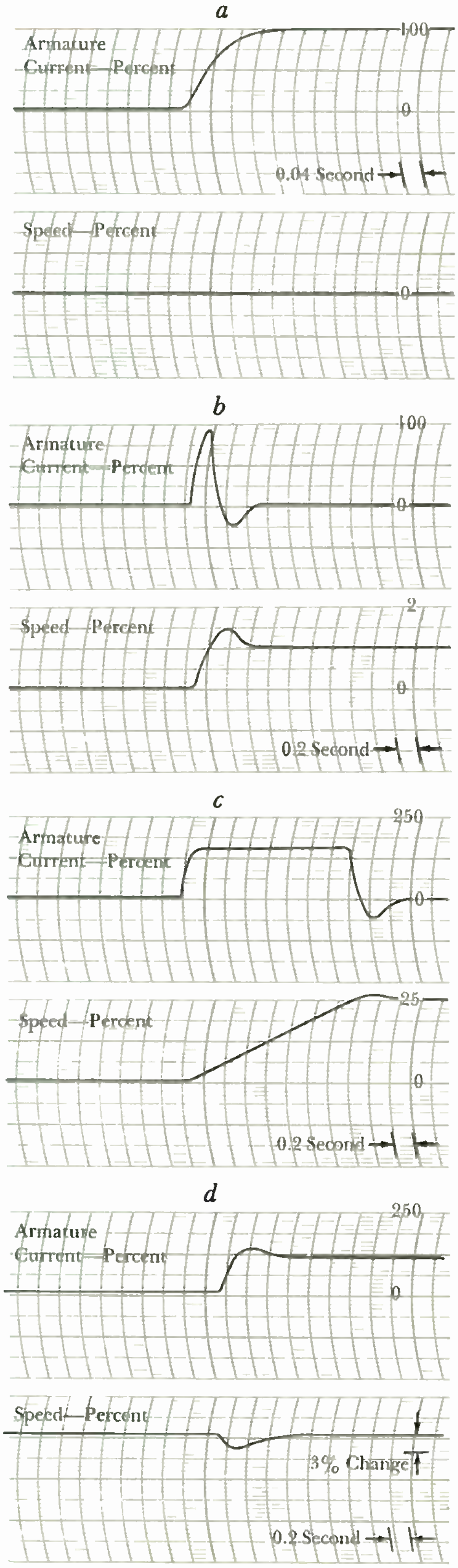
If the system is unstable when the computer is connected, or if it is not possible to preadjust the regulator, the performance of the system must be adjusted by a loop-by-loop process similar to that used to optimize a system during field start-up. All control loops are isolated from one another, and the dynamic response of each loop is adjusted independently. If the response of any particular loop is unstable or too fast or too slow, the appropriate adjustments are made to rectify the condition. In a two-loop system such as that shown in Fig. 1, the inner control loop (current loop) *is part of* the outer (speed) loop. The only way the response of the two can be adjusted independently is to adjust the current loop first with the speed loop disconnected and then adjust the speed loop after it has been reconnected to the current loop. The performance of the system can be considered optimum when the response of the main control loop is optimum.

The performance of a system similar to that shown in Fig. 1, when simulated with the DC Drive Test Console, is shown in Fig. 3. Fig. 3a shows the essentially optimized current loop response (armature current response to a step reference), with the speed loop disconnected and the drive motor in a simulated locked-rotor condition.

Dynamic response of the speed loop to a step reference, after it had been closed around the current loop and optimized, is shown in Fig. 3b. The reference called for a steady-state speed of only one percent of top speed; if a reference of greater magnitude had been applied, the drive motor would have accelerated under current limit (a protective feature of the current loop), and it would have been impossible to check the dynamic performance of the loop. A step reference is used to check response as a matter of convenience because the theoretical response to a step reference is easiest to calculate. It is generally not possible to define mathematically the reference to which the drive will be required to respond after it is installed, but, under normal operating conditions, the controlled variable follows its reference.

Speed of the drive motor as it accelerates to 25-percent speed in response to a 25-percent speed reference is shown in Fig. 3c. The drive immediately goes into current limit, which has been set at 150 percent of rated value. The armature current drops to zero when the motor reaches proper speed, because an inertia load requires no torque under steady-state conditions.

Speed response of the drive under simulated impact loading is shown in Fig. 3d. Recovery time (time required for the drive to return to its proper speed) for a 100-percent load is approximately 0.8 second. This value was considered reasonable for the drive that was being tested, but recovery time is a function of the mechanical time constant of the system and varies from drive to drive.



3–(*a*) Armature current of a simulated motor reaches rated value in approximately 0.15 second in response to a step reference to the drive regulator current loop. Motor speed remains at zero due to simulated locked-rotor condition of the motor. (*b*) Simulated motor accelerates in response to a step reference to the speed loop. The design of the regulator is such that speed is expected to overshoot when responding to a step reference, but under normal operating conditions little or none should occur. Positive current (torque) accelerates the motor, and negative current decelerates it back to proper speed. (*c*) Simulated motor accelerates to 25 percent of top speed under current limit. Constant torque causes it to come up to speed linearly. (*d*) Simulated impact load slows motor momentarily. The drive does not reach current limit, so additional torque is available to accelerate it back to proper speed.

When the performance of a drive has been adjusted so that it is similar to that shown in Fig. 3, the logic circuits are checked to verify that the sequenced operations occur in the proper order and that the drive functions in all its operating modes. With this done, the computer test has been essentially completed.

Conclusion

Drive testing by computer simulation provides a practical and safe method of uncovering those system problems and deficiencies that can be corrected most efficiently and effectively in the manufacturing plant. Wiring errors and omissions, for example, are easily discovered during the closed-loop test that the computer provides. An undiscovered error such as an open or shorted armature current feedback loop could conceivably damage thousands of dollars worth of power apparatus in the field, but in a computer test it merely results in a nonoperational drive.

Computer testing also can result in a shorter start-up period, which is extremely important because it permits the user to get into profitable production that much sooner. Since the drive regulator can be at least partially adjusted before installation, the adjusting operation can sometimes be eliminated from the start-up procedure altogether. Computer testing can also reduce the amount of process material normally lost during a complex start-up. In the paper industry, for instance, a trial-and-error start-up is accompanied by delays while "broke" (damaged paper) is removed from the floor and machinery. While computer simulation would not guarantee a push-button start-up, it could allow the start-up engineer to perform more efficiently and reduce the amount of broke.

It has not been the intention to imply that testing by computer simulation is a panacea for drive-system problems. It is definitely no substitute for competent design and application engineering, nor does it replace the start-up engineer. It is, however, an effective tool that helps the drive manufacturer supply users with advanced and dependable equipment.

Coordinating Protective-Device Settings Gives Maximum Freedom from Electrical Outages

V. C. Cook

Protective devices for electrical distribution systems, such as circuit breakers, protective relays, and fuses, can provide adequate protection and isolate trouble properly only if they are set to operate at the proper current values. A system study determines those values.

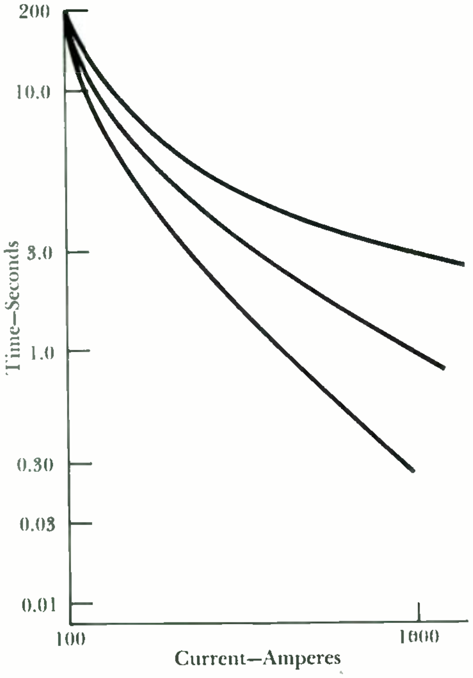
Protective devices in electrical distribution systems generally are properly coordinated when the systems are designed and built, but that is no guarantee that they remain coordinated. System changes and additions can, and frequently do, change the protection requirements, leaving some of the protective devices unable to properly interrupt the available fault currents. Consequently, periodic study of protective-device settings is as important in preventing power outages as is periodic maintenance of the distribution system.

This periodic study becomes more important as industrial plants and commercial buildings come to rely more and more on continuous electric power. In many industrial processes, even a momentary loss of power can cause serious loss in production and in wasted materials. Other facilities that depend on uninterrupted power are hospitals, military installations, communications systems, and computer facilities. Only through a system coordination study can the relay and breaker settings and fuse ratings be selected that will provide maximum protection for the equipment and also trip selectively during fault conditions.

The proper current values at which protective devices interrupt power can be determined by carefully considering the ratings of the protected equipment and the relationships of the various protective devices in the distribution system. In other words, the device settings must be chosen in such a manner that the devices will be properly coordinated and will operate sequentially in a predetermined pattern. The desired sequence is that the device nearest the trouble spot trips first and isolates the troubled section from the balance of the system. The adjacent protective device toward the power source should serve as backup protection, remaining closed unless the first device fails to clear the faulted section within a specified time.

Relays and circuit breakers are available with various current pickup and time-delay adjustments. Determination of the proper settings may involve considerable computation and study, and the wide range of time-current characteristic curves available complicates selection of the proper settings.

In general, the time-current characteristic curves of relays, breakers, and fuses follow an inverse pattern to permit relatively long operating time at low values of current and increasingly faster operating time at higher values. Time-current curves for three different devices set at the same minimum operating point are illustrated in Fig. 1. At 100 amperes, all three devices operate in approximately 200 seconds; however, at 1000 amperes, the operating time varies between about 0.3 second and 3.0 seconds. Thus, any one of the devices may provide the desired overload protection at 100 amperes, but, at 1000 amperes fault current, only one device may be selective with the adjacent device. Adjacent devices that are properly selective at low values of current, for example, may be mismatched at higher values (Fig. 2a). Two devices that are properly coordinated at all values of fault current are illustrated in Fig. 2b.



1—Time-current characteristics of three different protective devices differ, even though all are set for the same minimum operating point. Consequently, some of the devices may not give the desired protection at the higher fault-current values. (The curves, and those in Figs. 2 and 3 also, are plotted on logarithmic scales to show the wide range of time and current that is covered.)

To determine the best combination of settings and fuse ratings, fault currents in the system have to be calculated, and the tripping characteristics of the protective devices under the fault conditions have to be examined.

System Study

The general procedure used by the Electric Service Division in making a coordination study and selecting the correct settings is as follows:

1) Collect the necessary data—
   - Single-line diagram;
   - Nameplate data of equipment;
   - Impedance data of equipment;
   - System operating conditions (tie breakers open or closed, large-motor starting sequence);
   - Short-circuit capacity of power sources.

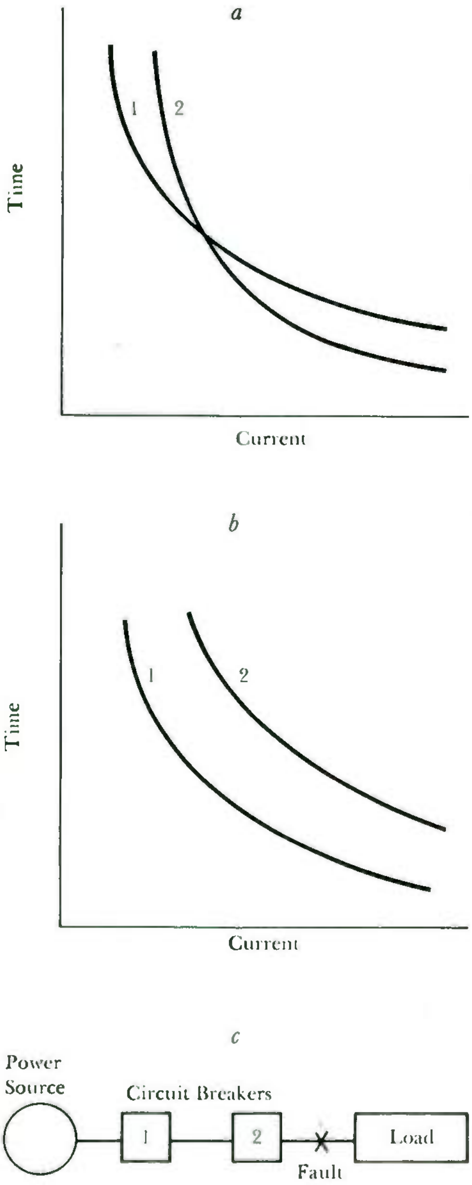
2) Calculate fault currents—
   - Select convenient kva and kv base values;
   - Calculate equivalent impedance values;
   - Make impedance diagram;
   - Calculate fault currents on major buses.

3) Select preliminary settings on the basis of—
   - Overload protection;
   - Calculated maximum and minimum fault currents;
   - Desired coordinating interval between protecting device and backup device;
   - Service continuity requirements.

4) Check preliminary settings—
   - Plot curves on common voltage base, using lowest voltage as the base value and

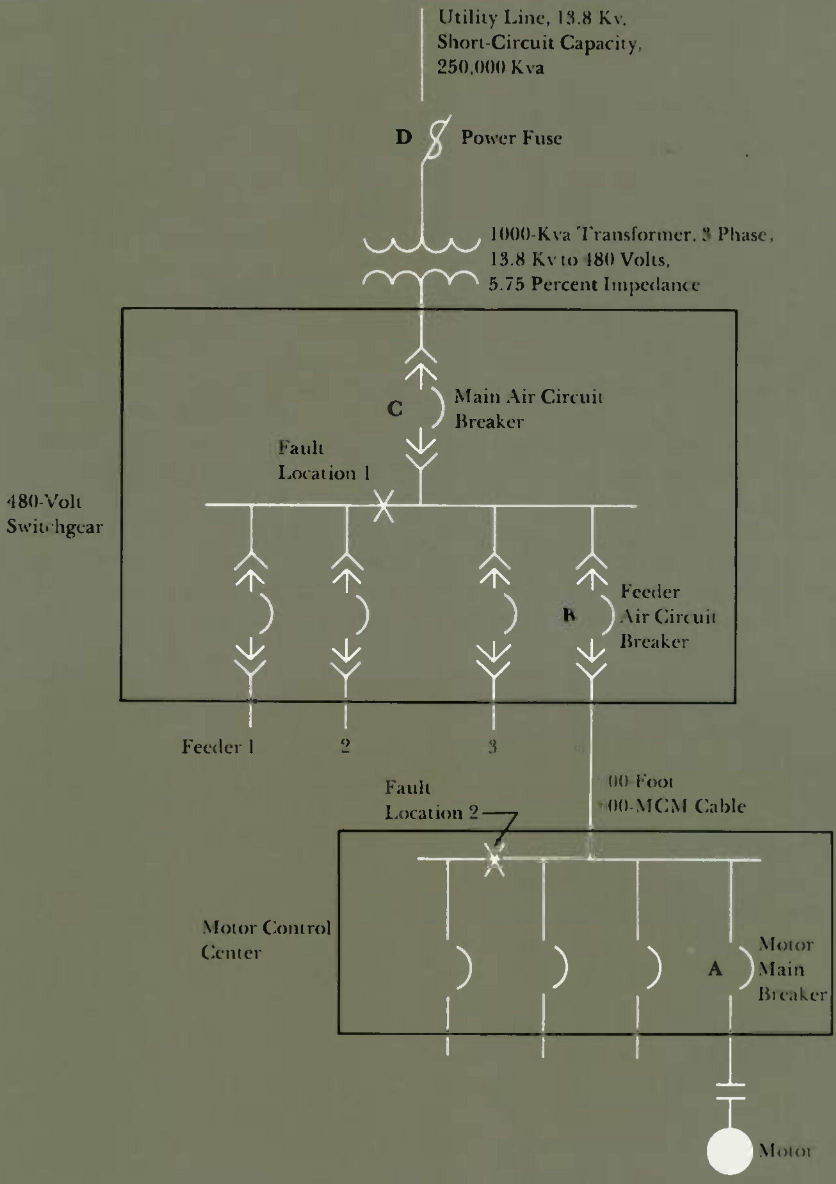
---

V. C. Cook is Kansas City/Denver Electric Service Manager, Westinghouse Electric Service Division, Kansas City, Missouri.



2–*(a)* Two protective devices, even though properly coordinated at low current values, may be mismatched at higher values. *(b)* Properly coordinated devices maintain the desired relationship at all values of fault current. *(c)* Device *1* would be located nearest the fault, and device *2* would remain closed and serve as backup protection for *1*.

3–*(Right)* Simplified distribution system is the basis of the accompanying example of how the proper coordinated settings for protective devices are determined.



plotting the curve of the device nearest the fault first;

Allow coordination time interval;

Plot curve for succeeding devices.

5) Check curve plot for overlap of adjacent devices.

6) Revise preliminary settings, if necessary, to prevent overlap.

7) Check final settings for—

Selective operation at maximum fault current;

Selective operation at minimum fault current;

Compatibility with short-time ratings of transformers and cables;

Check instantaneous settings for compatibility with inrush currents of transformers and large motors.

These steps are illustrated by the following example, which is based on the system diagrammed in Fig. 3. Since the magnitude of the fault current on a particular bus in the system depends on the total impedance between the power source and the point of the fault, the impedance of each component must be calculated and the impedances combined in series or parallel as the case may be. To combine the impedances conveniently, the actual impedance value of each device can be converted to an equivalent value referred to a common kva and kv base value. The fault current value depends also on the short-circuit capacity of the power source, so an equivalent impedance value of the power source is included in the impedance calculations.

The actual prefault voltage should be used in determining the fault current; however, to simplify this example, the prefault voltage is assumed to be the system rated voltage. Impedances and fault currents are calculated at right.

The next step is to choose the preliminary settings of the protective devices. The choice of setting depends on the rating of the equipment to be protected and the allowable coordination interval between adjacent devices.

The fuse for the transformer 13.8-kv primary is selected in accordance with manufacturers' fuse application tables, which specify a rating of approximately 250 percent of the transformer full-load current. Full-load current is 42 amperes,

Calculating Impedances and Fault Currents

Base values are first selected as 100,000 kva and 13.8 kv. Utility system equivalent impedance is then calculated:

From Fig. 3, utility short-circuit capacity is 250,000 kva.

$$\begin{array}{l}\textit{Per-unit impedance}\\ \textit{on 100,000-kva base}\end{array} = \frac{\textit{Base kva}}{\textit{Utility short-circuit kva}} = \frac{100{,}000}{250{,}000} = 0.4.$$

Transformer equivalent impedance is calculated:

$$\begin{array}{l}\textit{Transformer}\\ \textit{per-unit impedance}\\ \textit{on 100,000-kva base}\end{array} = \frac{\textit{Nameplate percent impedance}}{100} \times \frac{\textit{Base kva}}{\textit{Nameplate kva}}$$

$$= \frac{5.75}{100} \times \frac{100{,}000}{1000} = 5.75.$$

The 480-volt cable equivalent impedance is calculated:

From tables, approximate positive-sequence impedance of 500-MCM cable is 0.005 ohm per 100 feet.

Length of cable is 300 feet.

$$\textit{Total impedance} = 0.005 \times 3 = 0.015 \textit{ ohm.}$$

$$\begin{array}{l}\textit{Per-unit impedance}\\ \textit{on 100,000 kva base}\end{array} = \textit{Impedance in ohms} \times \frac{\textit{Base kva}}{\textit{Rated } kv^2 \times 1000} = \frac{0.015 \times 100{,}000}{(0.480)^2 \times 1000} = 6.5.$$

Total equivalent impedance to fault location *1* is

$$\begin{array}{r} 0.4\\ \underline{5.75}\\ 6.15 \end{array} \text{ per unit.}$$

Total equivalent impedance to fault location *2* is

$$\begin{array}{r} 0.4\\ 5.75\\ \underline{6.5}\\ 12.65 \end{array} \text{ per unit.}$$

Fault current at fault location *1* is calculated:

$$\begin{array}{l}\textit{Symmetrical RMS}\\ \textit{three-phase fault}\\ \textit{current}\end{array} = \frac{\textit{Base kva}}{\textit{Total per-unit impedance to fault} \times \sqrt{3} \times kv}$$

$$= \frac{100{,}000}{6.15 \times \sqrt{3} \times 0.480} = 19{,}600 \textit{ amperes.}$$

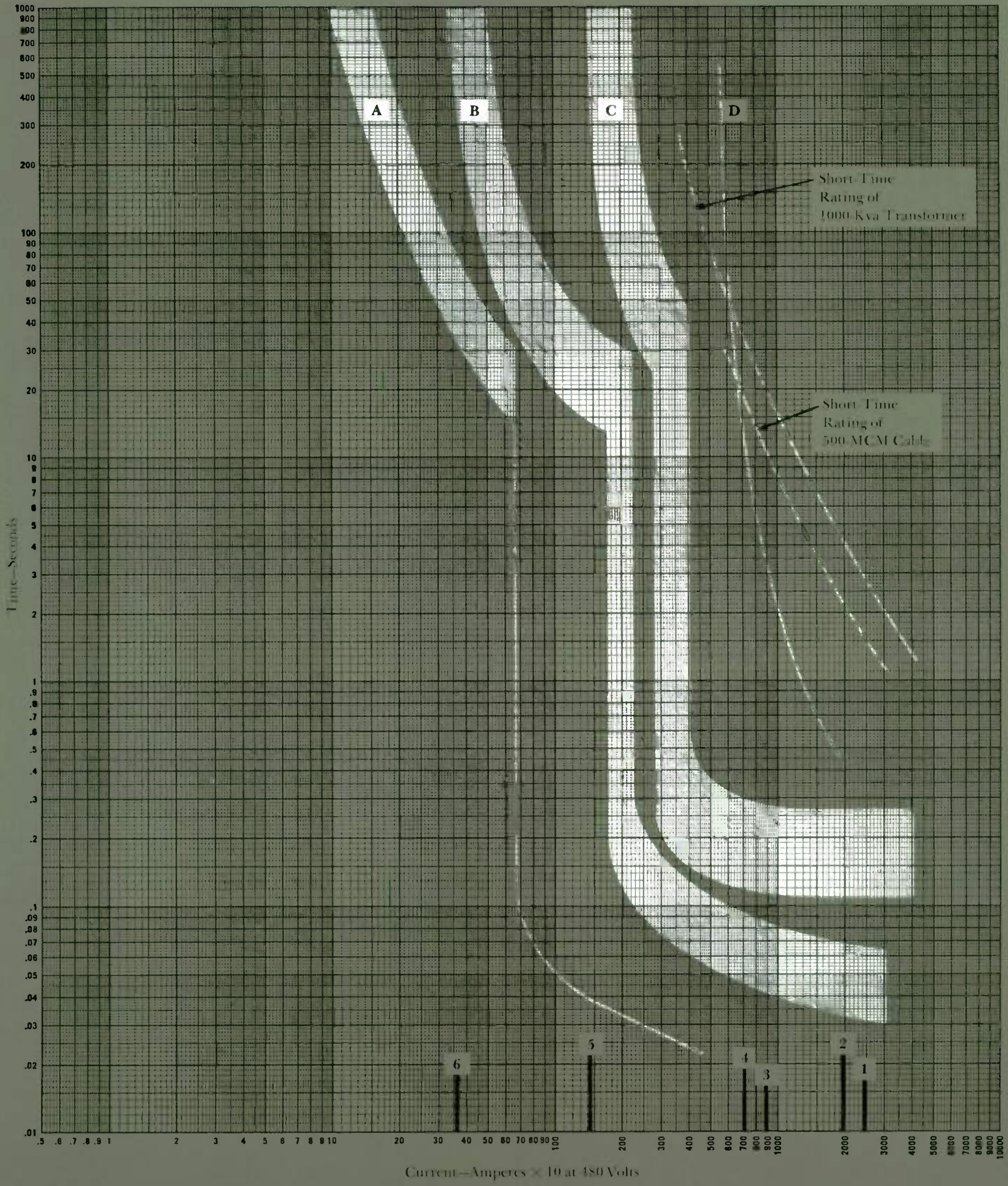
The calculated value of symmetrical fault current is used to determine the required interrupting rating of a protective device. However, the maximum value of short-circuit current that is possible may exceed the symmetrical value. This maximum fault current, called the asymmetrical value, depends on the ratio of the reactance to the resistance (X/R) in the system. Since this ratio is often difficult to determine, multiplying factors can be used to approximate the asymmetrical fault current. A commonly used multiplier for low-voltage systems is 1.25.

$$\textit{Asymmetrical fault current at fault 1} = \textit{Multiplying factor} \times \textit{Symmetrical fault current}$$
$$= 1.25 \times 19{,}600 = 24{,}500 \textit{ amperes.}$$

Fault current at fault location *2* is calculated:

$$\textit{Symmetrical RMS fault current} = \frac{100{,}000}{12.65 \times \sqrt{3} \times 0.480} = 9523 \textit{ amperes.}$$

$$\textit{Asymmetrical fault current} = 1.25 \times 9523 = 11{,}900 \textit{ amperes.}$$


A
B
C
D
Short-Time Rating of 1000 Kva Transformer
Short-Time Rating of 500 MCM Cable
1
2
3
4
5
6
Time—Seconds
Current—Amperes × 10 at 480 Volts
.01
.02
.03
.04
.05
.06
.07
.08
.09
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
2
3
4
5
6
7
8
9
10
20
30
40
50
60
70
80
90
100
200
300
400
500
600
700
800
900
1000
.5
.6
.7
.8
.9
1
2
3
4
5
6
7
8
9
10
20
30
40
50
60
70
80
90
100
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000

4—Device tripping curves based on preliminary settings are drawn to see if the settings are properly coordinated. Characteristics of low-voltage breakers are shown as tripping bands, and those for relays and fuses are single-line curves.

A. Molded-Case Thermal-Magnetic
Breaker, 10,000-Ampere
Interrupting Capacity.
Continuous Rating: 90 Amperes.
Instantaneous Setting: 750
Percent Trip Setting.

B. Low-Voltage Air Circuit
Breaker, 25,000-Ampere Interrupting
Capacity.
Rating: 400 Amperes.
Long Delay: 100 Percent Pickup,
20-Second Delay.
Short Delay: 750 Percent Pickup,
14-Cycle Delay.

C. Low-Voltage Air Circuit Breaker,
50,000-Ampere Interrupting Capacity.
Rating: 1600 Amperes.
Long Delay: 120 Percent Pickup,
25-Second Delay.
Short Delay: 250 Percent Pickup,
14-Cycle Delay.

D. Standard Speed Power Fuse,
300,000-Kva Interrupting Capacity.
Rating: 100E.
Minimum-Melting-Time Curve.

1. Asymmetrical Fault Current,
Fault Location *1*: 2[illegible],500 Amperes.
2. Symmetrical Fault Current,
Fault Location *1*: 19,600 Amperes.
3. Asymmetrical Fault Current,
Fault Location *2*: 9523 Amperes.
4. Symmetrical Fault Current,
Fault Location *2*: 1[illegible],900 Amperes.
5. Transformer Inrush Current.
6. Motor Inrush Current.

so a 100-ampere fuse should be satisfactory.

The transformer-secondary main breaker rating is based on application data that allows a breaker continuous current rating of approximately 125 percent to 133 percent of the transformer-secondary rated current. Transformer-secondary full-load current is 1200 amperes, so the main breaker setting is selected as 1600 amperes.

For the feeder breaker (low-voltage switchgear), the pickup setting is chosen on the basis of the 500-MCM cable current-carrying capacity and the connected load on the motor control center. The long-delay setting is chosen as 400 amperes.

The motor breaker rating is based on full-load current of the motor—63 amperes. Application data for this particular 50-horsepower motor allows a breaker trip rating of 150 percent of full-load current, so a trip rating of 90 amperes is chosen. The remaining breakers in the control center are smaller, so it is not necessary to plot additional curves.

After selecting the preliminary settings, trip curves are plotted on a common voltage base (Fig. 4). The curve plot is then inspected for curve overlap to determine possible miscoordination of the protective devices. It is also marked with the calculated fault current values and inrush values to determine if selectivity is maintained for all conditions. The short-time loading curve of the transformer and the short-time heating limits of the low-voltage cable may also be marked to be sure the limits are not exceeded.

The curve plot is then examined for mismatch of the devices for faults on the various buses. For a fault at location *2*, for example, circuit breaker *B* will trip and allow breaker *C* to remain closed and supply power to feeders *1*, *2*, and *3*. The time-current curves of the devices as plotted show that the conditions for good coordination are satisfied. There is no crossover or overlapping of the curves, and the adequate margin between curves indicates that proper selectivity is maintained.

This relatively simple example illustrates how time-consuming it could be to make all the required calculations and logic decisions manually. Fortunately, the digital computer can be used to great advantage in this field, since protective-device coordination studies require routine calculations and logic decisions based on comparison of known data. The time-current characteristic curve data and other system data collected by the Electric Service Division field engineer are programmed and fed into the computer, which then calculates the fault currents and device settings. The engineer completes the coordination study by setting the devices at the calculated values and making field calibration tests on the relays and breaker trip units. Computer processing has considerably reduced the time required to make a system study and has improved the accuracy of the results.

Conclusion

Protective devices in distribution systems do not necessarily stay coordinated, because changes and additions to the system affect the settings required. The addition of a larger transformer or substation, for example, immediately increases the available fault currents and may require that settings be changed to maintain protection and system coordination. A periodic study of the protective-device settings can be as important as periodic planned maintenance in eliminating unexpected power outages.

The frequency of these studies may vary considerably; however, if a system has not been checked during the past ten years, it is doubtful that the settings are coordinated and that all of the devices in the system could properly interrupt available fault currents. The money spent in making a study may be a fraction of the cost involved in an unexpected power outage from false tripping of a vital feeder breaker.

Drill Being Developed for Core-Sampling on Moon

One of the things men will want to learn when they finally stand on the moon is just what kind of rock or green cheese it is made of. They could pick up rocks from the surface, but those might not reveal much about the moon's structure because they could be meteorite fragments or surface material altered by impact. Consequently, lunar explorers in missions after the first Apollo flights will want a core drill for cutting subsurface samples.

Such a drill has been built. It is one of two types being evaluated by the NASA Marshall Space Flight Center for possible use in lunar exploration missions.

The drill is a rotary type designed to enable an astronaut on the moon to pull five-foot core samples, two inches in diameter, to the surface from depths of more than 100 feet. The astronaut pulls up on the outer drill casing after every five-foot drilling operation, causing an inside wedge-shaped ring at the bit to tighten. The tightening action breaks off the core sample, and the inside barrel containing the core is then hoisted up on a wire. This operating method permits the drill and outer casing to remain in the hole, saving drilling time and preventing possible cave-ins.

The lunar drill could be attached to a vehicle or to a shelter. It will weigh 36 lunar pounds—about 200 earth pounds—and stand about eight feet tall. An electric motor will turn the drill at 1000 rpm. The drill and its supporting members are made of a lightweight alloy of aluminum and beryllium.

In the core drills commonly used on earth, tons of water are flushed down the drill hole to cool the bit and remove the cuttings. Since it is impractical to transport that much water to the moon for drilling, the development engineers provided a closed-cycle system that needs but one pound of cooling water. The water is flushed down internal passages, turns to steam at the cutting area, rises through other internal passages to the surface, and is condensed and recycled.

The cuttings, which contain most of the heat generated in drilling, are quickly removed by a "snowplow" arrangement of the diamond tips on the bit face. These tips push the cuttings into the path of auger flights on the outside of the drill, and the drill's rotation carries them to the surface. The development engineers have demonstrated that a hollow-core diamond drill will cut basalt—a hard mineral—without the use of water for flushing, and they have also successfully operated a diamond drill in vacuum.

Chemical Reactions in Gases Initiated by Laser Energy

Powerful light pulses from a laser have been found to produce chemical reactions in a variety of gases. Although the temperatures created by the laser are hot enough to break the gas atoms into ions, the chemical changes that the atoms undergo are typical of high-temperature chemical reactions rather than those induced by ionizing radiation.

The high-temperature reactions that have been achieved include transformation of methane primarily into hydrogen and acetylene, and of carbon dioxide into carbon monoxide and oxygen. Both reactions are typical of those produced by electric arcs and other high-temperature sources. In the laser experiments, they occurred with from 10 to 20 percent energy efficiency.

The laser used was a Q-switched ruby type, a laser that puts out energy concentrated into short pulses of extremely high power. Average power delivered by the laser was almost 200 million watts in pulses of 30 billionths of a second.

F-111 Aircraft Power System Passes 5000-Hour Test

A 5000-hour reliability demonstration test, probably the longest continuous test ever conducted on an aircraft electric power system, was completed recently on the power system used in the U.S. Air Force and U.S. Navy F-111 aircraft. The test, which supports excellent field operating results being achieved by the equipment, was five times as long as the normal qualification life test and more than twice the length of previous reliability demonstrations.

The object of the test was to prove that the system would meet the specification mean time between failures (MTBF) of 500 hours at the 90-percent confidence level; what it demonstrated was a 943-hour MTBF for the system and a 1282-hour MTBF for both the generator set and the constant-speed drive that provides a constant 8000-rpm generator speed. MTBF is worked out statistically from the test duration, number of equipment failures in the test, and desired confidence level. A 943-hour MTBF at the 90-percent confidence level, for example, means there is a 90-percent probability that the MTBF is actually 943 hours or longer.

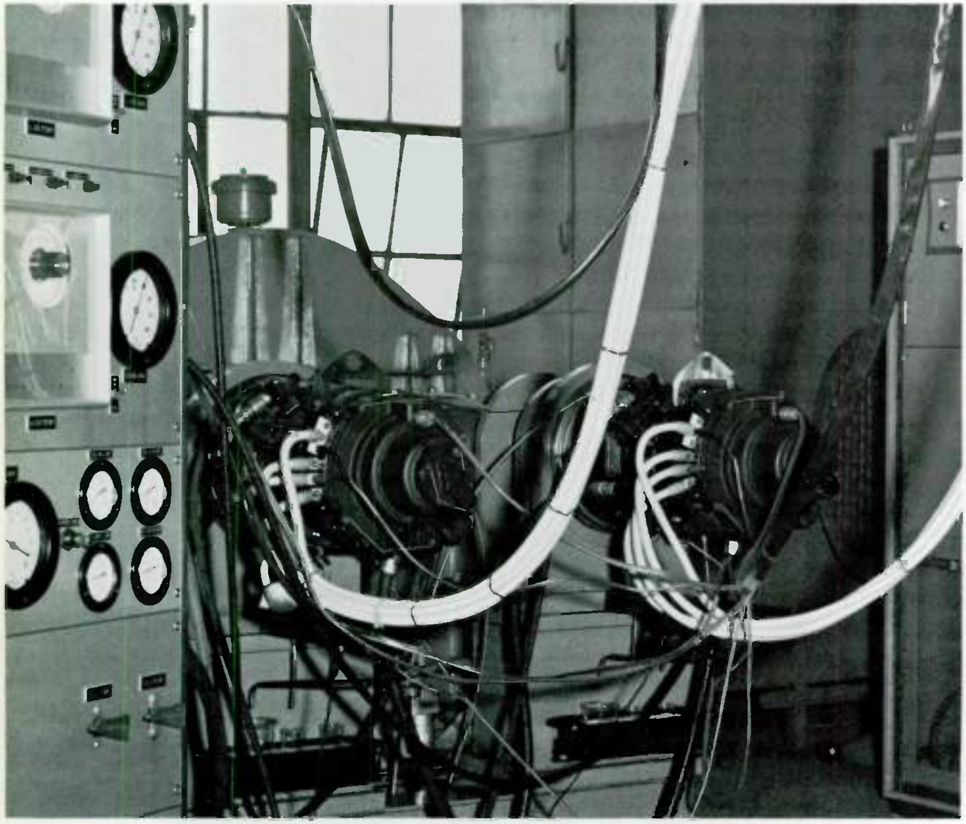
The test was conducted on a complete aircraft complement of equipment—two channels, each consisting of a constant-speed drive and an oil-cooled generator set. A generator set includes the 62.5-kva brushless ac generator, a generator control unit, and a current transformer. Generator loads, drive speeds, and oil temperatures were controlled to approximate normal aircraft operation.

Routine maintenance operations were performed during the test, as they would be in aircraft operation, and the generators and drives were overhauled at 1000-hour intervals. (One generator and drive, however, were run 1419 hours to determine the effect of extending the time between overhauls; no recordable degradation in operation occurred.) Generators and drives were found in good condition at overhaul, which consisted of replacement of bearings, rotating oil seals, and o-rings. Generator seal wear, for example, was so slight that oil leakage averaged less than 0.6 cc per hour over the duration of the test. (The specification maximum was 10 cc per hour.)

One generator and one constant-speed drive failed during the 5000-hour test. The generator failure occurred after 1651 operating hours and was attributed to a random workmanship defect; generator design has been modified to reduce the probability of a similar failure even further. The drive failure, which occurred after 551 hours, was categorized as an inspection error.

Comparison with the test of an earlier oil-cooled electric power system, conducted in 1960 and 1961, illustrates the progress that has been made since then. MTBF for that system was calculated at 650 hours instead of the 943 hours now demonstrated for the F-111 system; maximum oil leakage was specified as 450 cc per hour instead of 10; and time between overhauls was 500 hours instead of 1000. Moreover, that system weighed 96 pounds and developed 40 kva, while the F-111 system weighs only 85.1 pounds and develops 62.5 kva.

Top photo courtesy General Dynamics.



High-performance jet aircraft, the F-111, has two ac electric power generating systems. The system recently passed a 5000-hour reliability demonstration test that set a mean time between failures of 1415 hours at the 90-percent confidence level. Test setup included two generating systems mounted on a drive stand, recording equipment, and control devices. Running cycle was eight hours on and one hour off, with only the "on" time counted in accumulating the 5000 total test hours. Generators were operated 1000 hours before overhaul, except for one that was run 1419 hours to evaluate extended operation. It performed well throughout the run and was in good condition when disassembled for inspection.

Process-Control Computer System Has Simplified Programming

A new intermediate-size process-control computer system, designed to simplify programming by use of the universal FORTRAN language, is the first real-time on-line control system to offer the convenience of FORTRAN programming. Called the Prodac 250, it fills the gap between the smaller Prodac 50 and the larger Prodac 500 series.

Integrated circuitry gives the computer system a memory speed of one microsecond. Its speed and size fit it especially for steel production facilities, electric utility power plants, economic dispatch systems, automatic warehousing, production control, direct digital control of petrochemical processes, and automatic production and testing in repetitive manufacture.

The Prodac 250 employs the PROGEN system of software, a system that enables the user to devote his entire attention to his control approach, instrumentation, and the overall operation of the process rather than getting bogged down in computer details. PROGEN was developed by Westinghouse in 1964 for its own program engineers to eliminate the tedious, time-consuming, and expensive task of writing control programs in machine language—the coded language that is the only thing computers understand. With the PROGEN philosophy now extended into the software system of the new Prodac 250, the engineer who knows the process best can control it through familiar FORTRAN IV statements; machine instructions are automatically generated by the compiler and are ready for the computer. The PROGEN system includes a complete set of program management routines that recognize the real-time world of industrial process control. It can also incorporate prepackaged programs to perform some of the more common control functions.

Resonant-Gate Transistor Performs Tuning Functions

Integrated-circuit technology has made possible a revolutionary reduction in the size of electronic circuitry because such functions as energy conversion, detection, and amplification—previously accomplished with assemblies of electronic components—can now be synthesized into a single tiny crystal of semiconductor material. The technique not only conserves space and reduces power requirements but, even more important in many applications, it greatly increases reliability by radically reducing the number of devices and the number of wire connections in a system.

Remarkable though they are, however, integrated circuits have resisted attempts to build a high-quality tuning mechanism into them. Yet tuning—the selection of a narrow band of frequencies and the rejection of all others—is a basic requirement of radio receivers and transmitters and many other electronic systems. The common inductor-capacitor tuning network accomplishes this function in conventional circuitry, but it is not at all compatible in size with the tiny integrated circuits. Nor is it compatible with the objective of the integrated-circuit approach, which is to develop simple structures that accomplish complete functions.

A new experimental type of transistor overcomes this drawback with a device so small that 500 of them can be fabricated on a slice of silicon the size of a 25-cent piece (see photograph). It is, thus, compatible in size and fabrication method with integrated circuits.

The device substitutes the equivalent mechanical resonance of a vibrating metal "whisker" (which in turn controls the electrical resonance of the transistor's output) for the natural electrical resonance of an inductor-capacitor network. Its resonant frequency is set simply by the dimensions of the vibrating whisker. Because a mechanical resonator is used as the gate or control electrode of the field-effect transistor, the new device is called a resonant-gate transistor.

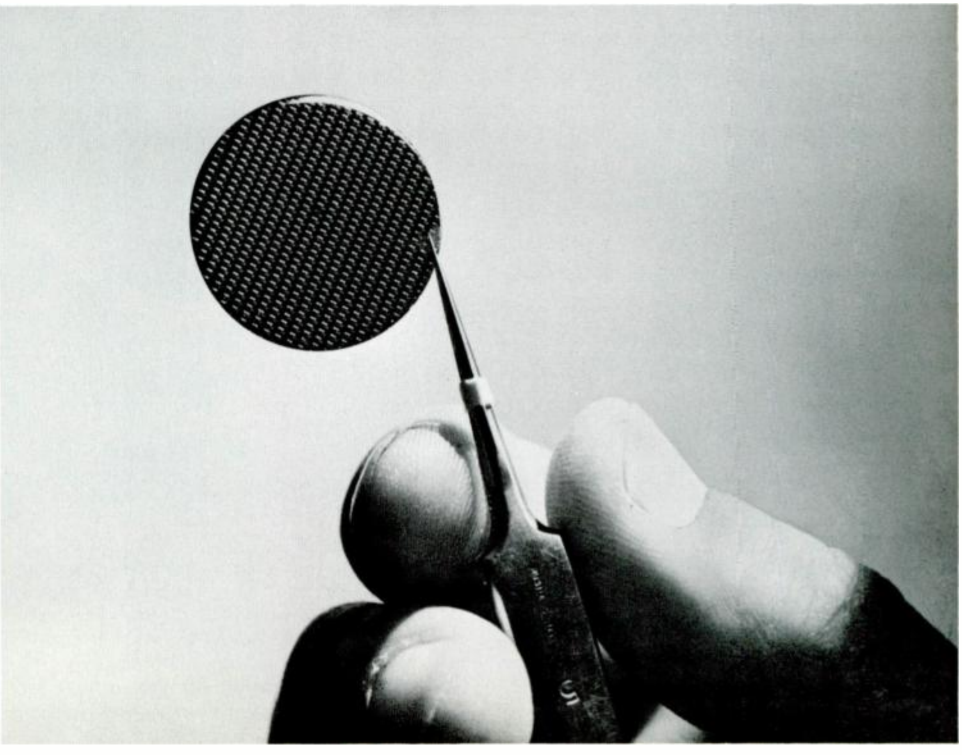
The metal resonator is cantilevered parallel to and about 0.0002 inch above the surface of the transistor, and insulated from the silicon-crystal substrate by an oxide layer. A dc polarizing voltage is applied between the cantilever and the grounded substrate. When an input signal is applied to an input force plate on the oxide layer, electrostatic force is developed between the plate and the cantilever. The polarizing voltage is kept large in comparison with the input signal voltage to insure that the cantilever is made to move appreciably only when the signal frequency equals the mechanical resonant frequency of the cantilever.

The electric field between the cantilever and the silicon substrate affects the channel conductivity between the source and drain regions of the transistor diffused into the silicon. Since this field is constant except when the cantilever moves, there can be no signal output from the transistor except near the resonant frequency of the cantilever. Thus, the device selects a desired narrow band of frequencies from the electrical oscillations arriving at the input.

A resonator 0.040 inch long has a resonant frequency of about 3000 cps. Transistors capable of tuning to a million cps appear feasible with present technology.

Transistors with two resonators also have been demonstrated. Their chief

Resonant-gate transistors, 500 at a time, are fabricated on a slice of silicon. A vibrating element in each transistor enables it to select a desired narrow range of frequencies from its input, thereby making it useful as a tuning device. Its small size makes it compatible with integrated circuits.



advantage is that the two resonators interact with each other and increase the ability of the device to discriminate against unwanted frequencies.

Potential uses for the device are seen in frequency filtering, tuning for IF amplifiers, and tone generation. Development of the transistor was supported in part by the Electronics Technology Division, Avionics Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Dayton, Ohio.

Integrated-Circuit "Breadboard" Can Serve Various Purposes

A new do-it-yourself integrated circuit, unlike other integrated circuits, leaves the last step in the manufacturing process for the user to perform. With a minimum amount of equipment, he can link the active areas of the tiny electronic unit in various circuit combinations to suit his special needs. The unit is intended for organizations that have electronics capability but don't have their own facilities for producing integrated circuits. Like other integrated circuits, it is almost microscopic yet performs the same electronic functions as many conventional components hundreds of times larger.

This integrated-circuit "breadboard" is expected to fill a significant void in circuit technology by making it possible for applied research laboratories and smaller companies to carry out research and development with integrated circuits without having to invest in a complete manufacturing facility. The only equipment required is a wire bonding machine, equipped with a microscope, for connecting gold bonds between various areas of the silicon chip. The chip contains 8 transistors, 44 resistors, and 5 diodes.

High-Intensity Ultrasonic Transducer for Continuous Processing of Liquids

A cylinderical ultrasonic transducer has been developed for use in processing liquids with high-intensity ultrasonic energy. Because of the shape of the transducer, it can be inserted in a piping system to treat liquid continuously as it flows through the system in chemical, pharmaceutical, and other processing or research-and-development applications. Process effects that are possible include emulsification, polymer alternations, particle dispersion, reaction rate and yield improvement, hydrogenation, hydration, nitration, and oxidation.

Because the entire inner wall of the cylinder is the energy-radiating surface, the power intensity developed can be much higher than that developed in conventional ultrasonic devices such as cleaning units. Power intensity can range up to 100 watts per square inch, contrasted with the 10 watts typical of cleaning units.

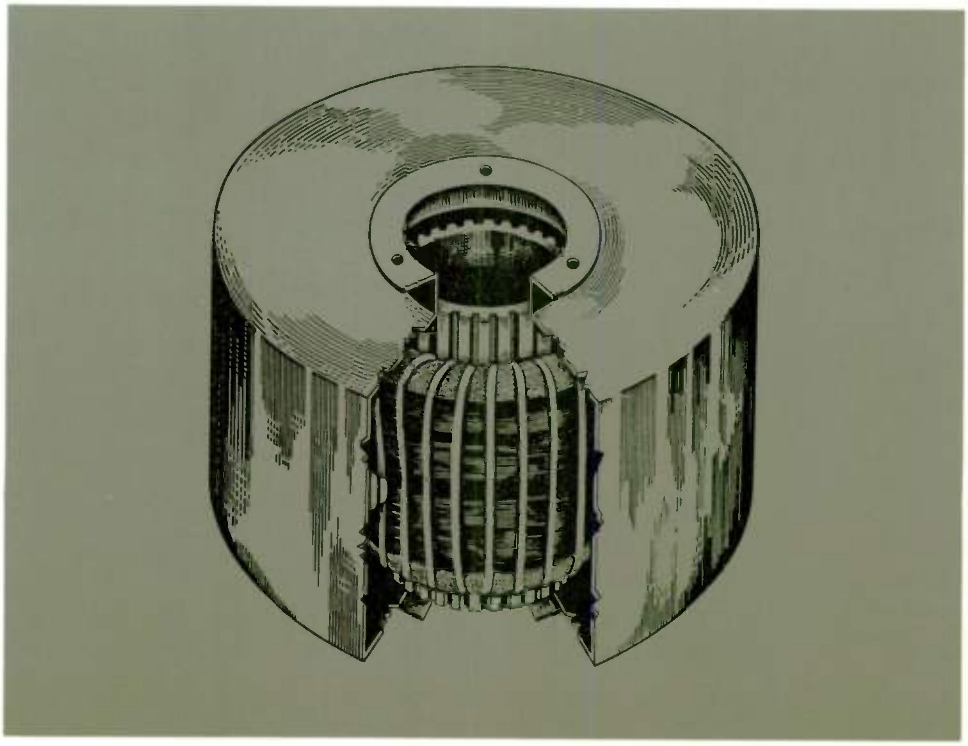
The focussing action of the cylindrical transducer, and the short transmission distance, permit effective treating of even highly viscous liquids. The units are especially effective for what might be called "micromixing"—such effects as breaking up suspended particles or causing adjacent molecules to interact or separate when they normally would not. They are not intended for gross stirring or mixing action.

Treatment time is varied as desired by controlling flow rates through series or parallel arrangements of the transducers. Batch treatment also is possible by using one or more transducers as batch containers. With a cap sealing the end of a batch container, liquid can be processed at pressures up to 250 psig.

The transducer has magnetostrictive ring laminations bonded to the outside of the stainless-steel cylinder that forms the process chamber. Direct and alternating currents in a toroidal winding establish the magnetic fields that produce radial vibration of the cylinder. The transducer is water-cooled and is driven by a one-kilowatt solid-state ultrasonic generator.

Cylinder length in the initial unit is 5½ inches and internal diameter 2½ inches. Resonant frequency is 16 kc, and power input ranges up to 2500 watts.

New high-intensity ultrasonic transducer is made in cylindrical form so it can be inserted in a piping system for continuous processing.



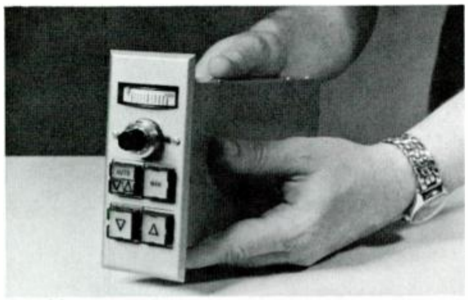
Products for Industry

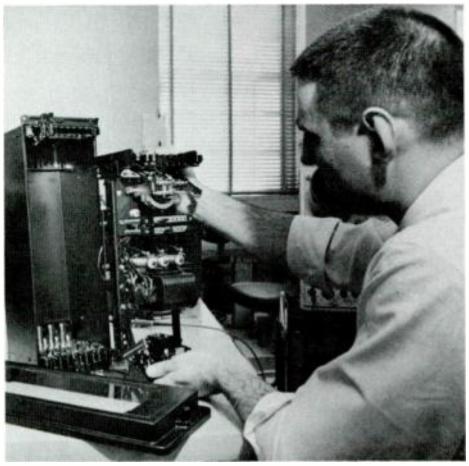
Meter measures cavitation activity in ultrasonic cleaning tanks to determine cleaning power in the liquid. It can be used in solutions at temperatures up to 220 degrees F. Meter is used by lowering its base into the liquid, turning a switch on, and reading the dial. It is based on principle that polarized electrodes are depolarized by ultrasonic cavitation. *Westinghouse Industrial Equipment Division, 2519 Wilkens Avenue, Baltimore, Maryland 21203.*

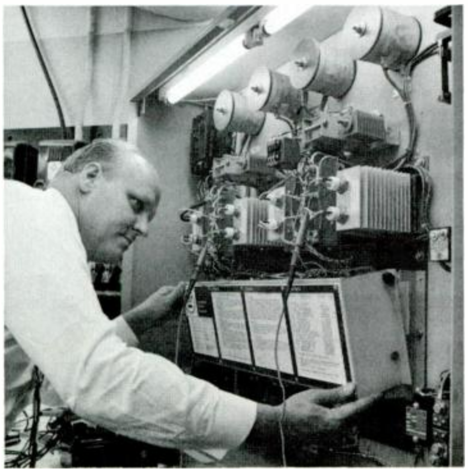
PowrMag Model 102 control station provides manual and automatic modes of operation with optional set-point and bias adjustments. It is for use with Hagan Model 101 electric actuators and automatic-balance electropneumatic positioning systems. Lighted pushbuttons indicate whether system is under manual or automatic control. During manual control, other buttons light up to signify what corrective action is required. Smooth transition is made from automatic to manual mode and vice versa without operator first having to balance system. Transfer between modes also can be accomplished by computer direction, external contacts, or as result of component failures. *Hagan Controls Corporation, a division of Westinghouse Electric Corporation, 250 Mt. Lebanon Boulevard, P.O. Box 11606, Pittsburgh, Pennsylvania 15228.*

High-speed pilot-wire relay affords complete phase and ground protection for two- and three-terminal transmission lines. HCB-1 relay is sensitive to negative-sequence component of line current in addition to positive- and zero-sequence components, greatly improving phase-to-phase sensitivity. Complete installation for a two-terminal line consists of two relays, two insulating transformers, and an interconnected pilot-wire circuit. For a three-terminal line, three relays, three insulating transformers, and a wye-connected pilot-wire circuit with branches of equal series resistance are required. Simultaneous tripping of relay at each terminal is obtained in about 20 milliseconds. Four sets of taps allow settings over wide range. *Westinghouse Relay-Instrument Division, Plane and Orange Streets, Newark, New Jersey 07101.*


Cavitation Meter


PowrMag Control Station


High-Speed Pilot-Wire Relay


Thyristor AC Crane Control

Thyristor ac crane control provides all-static reversing control for hoist drives as well as solid-state control for bridge and trolley movements. Both 500-Line controls are for use with polyphase wound-rotor crane drive motors. Reliable and efficient control with better performance characteristics than were possible before are provided by application of thyristors with gate control specifically designed for ac power circuits, eliminating need for saturable reactors. Equipment also is smaller and lighter, is easier to install, and requires less maintenance. The line is now available in ratings up to 125 hp and will shortly have 250-hp capability. *Westinghouse Systems Control Division, Box 225, Buffalo, New York 14240.*

Axiflex adjustable-vane axial fans for industrial and commercial air-handling systems feature speedy adjustment of vane pitch for balancing, expanding, or contracting an air-handling system, for making seasonal changes, and for compensating for unknown factors and errors in application. A single adjusting screw at the root of each vane is loosened. The vane is then positioned and the screw retightened. Fan diameters range from 18 to 106 inches, and volume of air handled ranges up to 450,000 cfm. *Westinghouse Air Conditioning – Sturtevant Divisions, Hyde Park, Boston, Massachusetts 02136.*

UTT load tap changer replaces URT tap changer for transformer ratings 15 kv, 1000 amperes, 10,000-kva regulation. Simplification and standardization make for greater reliability, longer life, and lower cost without sacrifice of performance. For example, all three phases are driven directly by a single shaft, decreasing the number of gearing mechanisms from three to one. Connections between transformer and tap-changer compartment are made through a cast-resin insulating panel with molded connectors. *Westinghouse Power Transformer Division, Cowan Road and 23rd Street, Muncie, Indiana 47305.*

About the Authors

Joseph T. Laing and **Arthur Nelkin** have worked as a team on the development of the ocean-bottom sonar system. Nelkin, at the Westinghouse Research Laboratories, has done the developmental research on the project, and Laing, at the Underseas Division, has supervised the implementation of this research into the working system described in this issue.

Laing obtained his BSEE from Bucknell University in 1946, followed by an MSEE from Carnegie Institute of Technology in 1948. He came to Westinghouse on the graduate student course and was first assigned to the Research Laboratories to develop homing systems for torpedoes. He moved to the Ordnance Division to follow this same line of work, and eventually he broadened his field to include a wide variety of oceanographic and mine countermeasure systems.

Shortly after the scope of the Ordnance Division was enlarged and it was made the Underseas Division in 1963, Laing was selected to attend the Harvard Graduate Business School's Program for Management Development. In mid-1964, he became Manager of the Oceanographic Subdivision, with responsibility for the manned submersible program, oceanographic instrumentation systems, and the recently organized Underseas Development Laboratory at San Diego, California.

Nelkin, graduated from Carnegie Institute of Technology with a BS in Physics in 1940. He went to work for the Bureau of Ordnance and designed antimagnetic installations for ships and demagnetizing stations for Navy yards. In 1944, Nelkin joined the Electronics Division of Westinghouse to design electronic circuitry for dynamic balancers. He left Westinghouse in 1945 to enter the service, where he supervised electrical test work at the Naval Ordnance Laboratory.

Nelkin returned to Westinghouse in 1946, this time to the Research Laboratories. His technological contributions here have included automatic frequency controls for radar and sonar, a torpedo-homing system, and other acoustical devices. Nelkin has headed the Electroacoustics Department since 1952, and has recently expanded the department to include the "newest and longest" arm of the Research Laboratories, the Ocean Research Laboratory at San Diego.

Under Nelkin's guidance, the Electroacoustics Department has produced such advances as the first transistorized torpedo-homing system, flow meters and surface wave scanners for Polaris submarines, the side-looking sonar used in the search for the USS Thresher, an acoustic elevator door control, and many other electroacoustic projects.

Nelkin has had three summer leaves of absence from the Laboratories to work with the National Academy of Science on defense study programs.

Two engineers who combine extensive experience in both nuclear and steam station components and systems joined to write this issue's article on dual-purpose plants.

John D. O'Toole had 14 years experience in a wide variety of nuclear plant design, engineering, and test positions before he joined Westinghouse in 1962. These encompassed both naval and electric utility nuclear designs. While with Westinghouse he worked on preliminary nuclear plant designs for electric utility application, and in 1964 became a manager in that activity. In early 1966, he moved into the area of evaluation of advanced reactor plant concepts, a position that required recommendation of programs aimed at developing the required technology to bring these concepts to commercial reality. O'Toole is a graduate of Stevens Institute of Technology, where he earned his ME degree in 1949.

William H. Stinson spent most of his first ten years with Westinghouse as a design engineer, a supervisory engineer, and a section manager in Small Steam Turbine Engineering, where he was responsible for generator and mechanical drive turbine negotiations and product engineering. He is now an advisory engineer in Electric Utility Headquarters Marketing, where his activities include studies and evaluations of advanced projects and concepts for power generation. Stinson is a graduate of Mississippi State University, where he earned his BS in Mechanical Engineering in 1942.

L. G. Reimer brings an extensive background of experience in plant design, construction, operation, and maintenance to his present post in the Industrial Systems Division. He was an Electric Service Division field service engineer in Baltimore from 1947 to 1965, supervising such projects as the rewinding of large rotating apparatus, the construction of an aluminum coil annealing furnace, the installation of steel processing lines, and the field testing and evaluation of insulation in large high-voltage machines. He also coordinated various steel-mill rolling and process-line projects.

Reimer graduated from Lehigh University in 1944 with a BSEE degree. He served in the U.S. Army Corps of Engineers from 1944 until 1946, and then joined Westinghouse on the graduate student course. As a Project Engineer in Materials Handling Projects, Industrial Systems Division, he is now responsible for refuse-reclamation plants such as the one he describes in this issue.

W. C. Carter won a Westinghouse scholarship to Carnegie Institute of Technology and received his BSEE there in 1956. Since then, he has completed the course work for an MSEE at the University of Pittsburgh.

Carter joined Westinghouse on the graduate student course in 1957 and was assigned to Industry Engineering, a predecessor of the Industrial Systems Division. He works at the design, application, and start-up of industrial drive and control systems, mainly those for the pulp and paper industry. This is his third article in the *Westinghouse ENGINEER.*

R. A. Montoro earned his BSEE at the University of Buffalo in 1951, and he has since taken graduate work there. He joined Westinghouse in 1951 in the General Control Division. In 1953 he moved to the Packaged Drives Group, and in 1963 to Quality Control Test Facilities. He joined General Industries Systems, Industrial Systems Division, in 1965, and there he works on the application of drives to industrial systems. Montoro has been awarded three patents, and he lives in a house that he designed and built himself.

T. O. Curlee III graduated from Clemson University with a BSEE degree in 1964. He joined Westinghouse on the graduate student course and, after student-course assignments with the Motor and Gearing Division and the Electric Utility Headquarters Department, went to the Systems Control Division. He is a design engineer there in the Industry Control Product Development Group.

Curlee designed the Westinghouse DC Drive Test Console used in the drive testing described in this issue, and he also contributed to the design of the M-4 (high-power) and M-5 (medium-power) thyristor power supplies for industrial drive applications. This is Curlee's first appearance in the *Westinghouse ENGINEER*, but as an undergraduate his articles appeared in the Clemson *Slipstick*.

V. C. Cook attended Peru State Teachers College and Doane College in Nebraska and then completed his education at Indiana Institute of Technology, graduating in 1948 with a BSEE. He joined Westinghouse in the Consulting and Application Department at Los Angeles and then transferred to the Electric Service Department there in 1951. His responsibilities included supervising the installation and erection of transformers, circuit breakers, substation equipment, large test-stand drives, cement-plant equipment, and other electrical devices.

Cook was named Los Angeles Electric Service Supervisor in 1964, and this year he became Kansas-City/Denver Electric Service Manager. He served as a communications officer in the U.S. Navy in World War II, and he is an IEEE member.

Workmen assemble the rotor and stator of a 9000-horsepower drive motor that will power a new wind tunnel for Lockheed-Georgia Company at Marietta, Georgia. This wind tunnel will be used to test design models of aircraft, including vertical take-off and landing (VTOL) airplanes. The development complex will be the world's largest privately owned facility of its type.