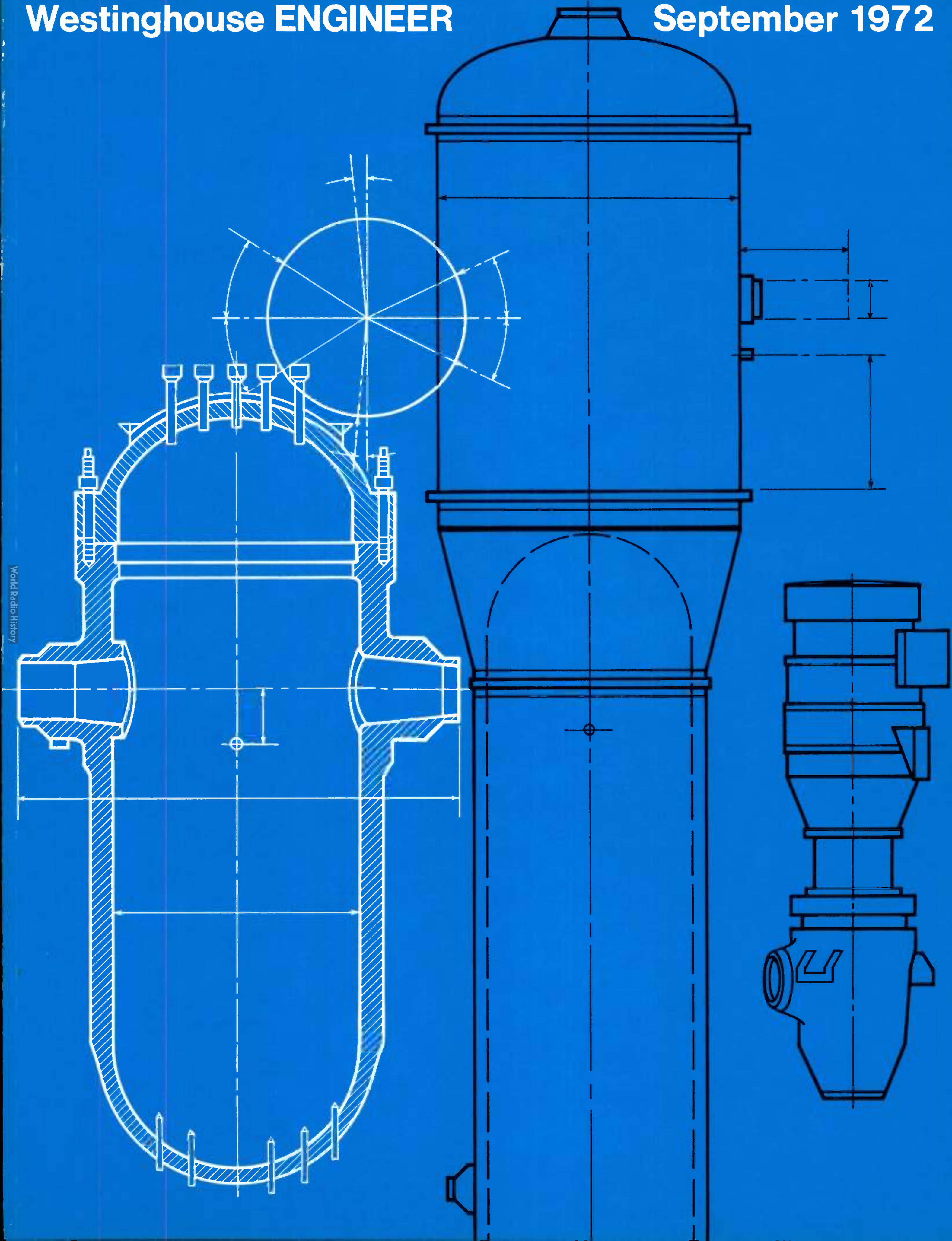
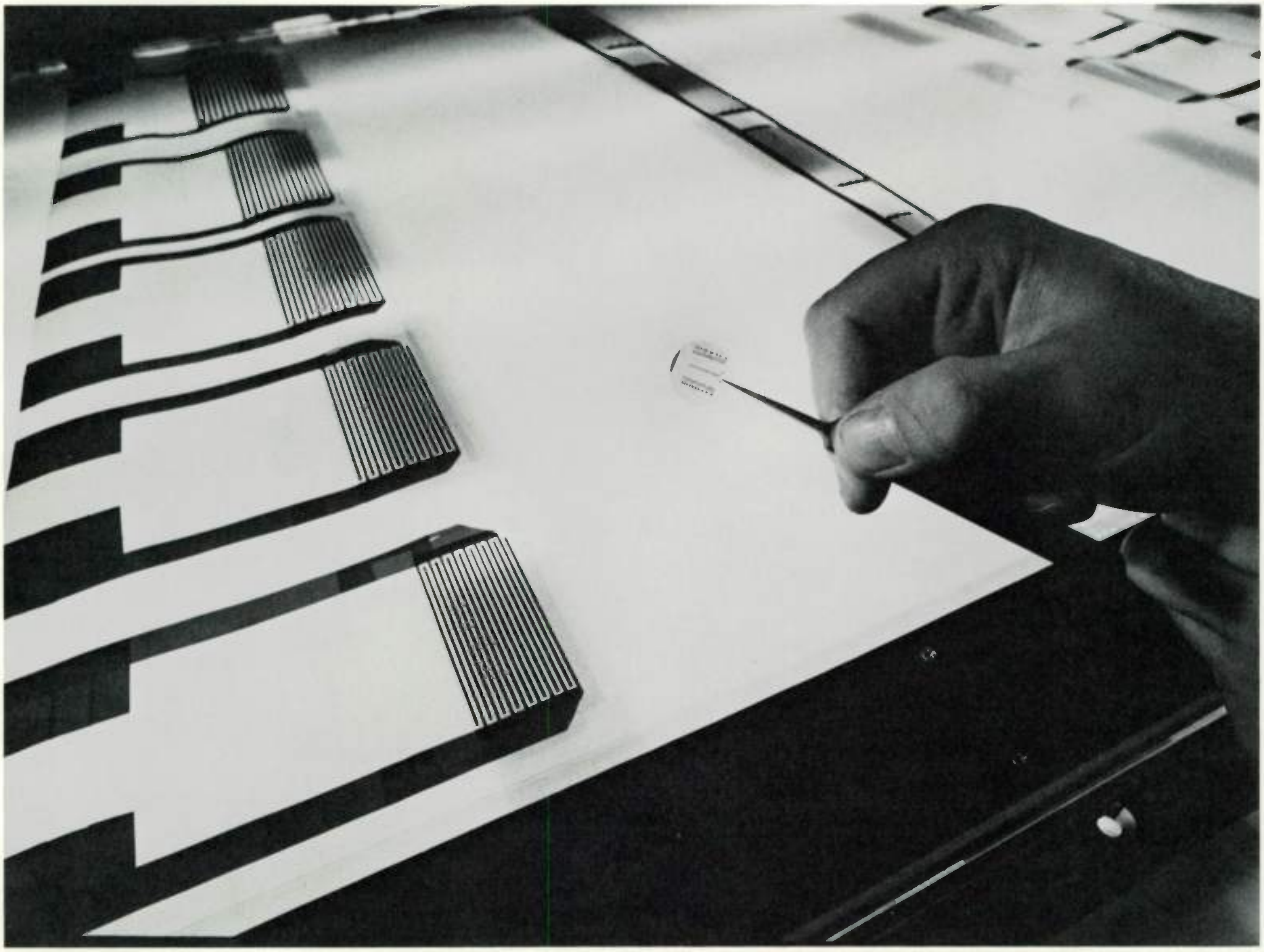
Westinghouse ENGINEER September 1972





Thumbnail Sketch

The design etched in gold on the small quartz disk forms an acoustic surface wave channel selector, part of an experimental communications device that may be a forerunner of a solid-state television tuner. Signals enter the middle strip and are converted into ultrasonic waves on the surface of the disk. Each pair of "combs" at the sides can be used to tune in a single channel by converting a particular frequency back into electrical signals for amplification. The design is a miniature reproduction of the large pattern beneath it, reduced and transferred to the disk by a photographic process. Development work on the device is under way at the Westinghouse Research Laboratories.

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Front Cover: Included in the material contained in a Standard Information Package for a nuclear steam supply system is a complete set of outline drawings for the equipment supplied. Artist Tom Ruddy chose drawings of three major system components for this month's cover design. The Standard Information Package is described in the article that begins on the following page.

Standard Information Package Benefits Nuclear Plant Licensing and Construction

W. H. Arnold, Jr.
D. R. Grain

Standardization of nuclear steam supply design, with standard options available, has made it possible to issue firm design information literally within days of contract award.

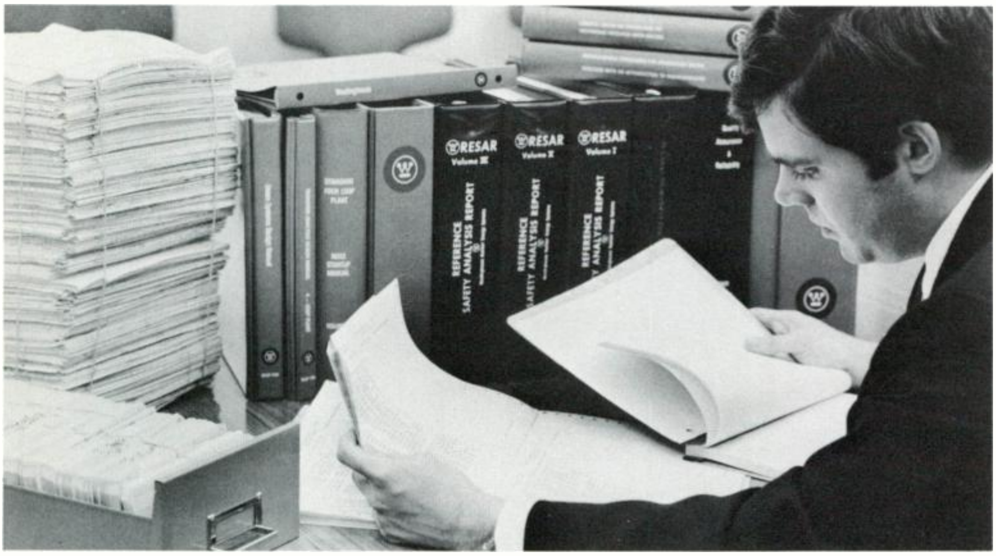
Standardization of the nuclear steam supply system (NSSS) has many advantages from the standpoint of hardware, but of even greater benefit in the initial phases of plant scheduling are the gains made possible in software—the early release of engineering information so essential to the utility for plant licensing and to the architect engineer for plant layout and construction scheduling.

Development of the Standard NSSS

The Westinghouse pressurized-water reactor has reached maturity through several generations of power plants, which span 12 operating plants built between 1957 and the present. The best features of the components and system design principles used in these projects, as determined through experience with the entire product cycle from design through construction, start-up, and operation, have been incorporated into the current standard NSSS.

Standardization does not mean that NSSS design is stagnant or inflexible to particular utility needs. To the contrary, changes will continue to be made in an evolutionary and controlled fashion based on information from operating plants and planned introduction of improved technology. But standardization does permit the establishment of a base-line design that can be used for every project. Particular utility needs can be met by tailoring that base-line design, and by inclusion of standard options.

Initial efforts toward PWR standardization concentrated on major system components such as the steam generator and reactor coolant pumps. Those efforts resulted in the modular or unit-building-block concept, introduced in the mid-1960's. That approach made possible significant engineering and fabrication cost reductions by use of standardized loop components—pumps, piping, and steam generators—to supply plants of widely different ratings. Today, reactor coolant pumps, steam generators, loop isolation valves (when required), and control-rod-drive mechanisms are identical for all sizes of nuclear plants (Table I). Reactor vessels and internals, pressurizers, and loop layouts are the same for all plants of the same size.



Typical Standard Information Package contains two basic categories of information: material that defines precise details of the nuclear steam supply system being supplied; and material that provides guidance and design criteria of a more general nature, applicable to any PWR plant.

The Need for Standardized Information

In the latter half of the 1960's, Westinghouse began building plants on a turnkey basis and, in so doing, gained experience with factors that affect total plant costs, such as the influence of the NSSS design on those total plant costs. Turnkey plant experience demonstrated that attention must be focused on the total plant, and that the schedule is strongly influenced by the availability of firm engineering information, not only for major components but also for the total NSSS requirements. Early release of that information by the NSSS vendor is vital to permit the architect engineer to begin accurate and timely layouts, to minimize licensing delays, and to reduce field-change operations that are caused by information gaps, misunderstandings, or changes. That flow of information must take place much earlier than the requirements for equipment delivery would dictate.

This urgent need for complete information lead to the concept of the Standard Information Package, a technique made possible by standardized NSSS designs. With this standard package, vital information such as equipment outline drawings is available practically upon receipt of authorization to proceed.

The Standard Information Package

The Standard Information Package defines the details of the current base-line or standard design. If necessary, changes can be made to reflect particular utility requirements, but they are always made as changes relative to the standard design. Differences between the current standard design and the NSSS finally sold will inevitably occur,

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and the definitive design of the standard plant makes it possible to alert the utility and architect engineer to areas of the package which do not reflect his particular plant.

The base information package defines the basic nuclear steam supply system. In addition to the base NSSS, a number of standard options are also offered—for example, boron recycle system,* spent fuel pit system, and component cooling water system. Those options make it possible to respond to the particular and different needs of each utility. Option modules of information are added to the base information package to describe those standard options that have been selected for a particular plant.

Subsequent to the first issue of the information package, design efforts are directed toward tailoring the package to meet the particular utility requirements and updating the total package to a "certified for construction" level. Thus, the Standard Information Package becomes a tool with which all parties work: utility, architect engineer, and NSSS vendor.

Initial efforts for standardizing the software package were directed to defining the standard NSSS design simply by means of a drawing list. From this starting point, the scope has been expanded to include the Reference Safety Analysis Report and some 15 formal manuals of engineering information. Those manuals not only describe the details of the standard design but also serve to pass along information on accumulated experience. With the information available in the Standard Information Package, the utility and architect engineer can quickly become familiar with the details of the plant and also take advantage of guidance given on such items as layouts, shielding, chemistry, materials, and quality assurance programs.

The Standard Information Package is divided into two basic categories of information: Type A documents define precise details of the plant (Table II); Type B documents provide general guidance information (Table III).

Type A Information

Since Type A information must provide detailed descriptions of the specific plant, this information must be updated to a "certified for construction" level subsequent to its initial issue. A brief review of the contents of the information packages (listed in Table II) will clarify their role in the Standard Information Package.

Reference Safety Analysis Report—RESAR is considered an integral part of the Standard NSSS concept and an essential ingredient to achieving the objective of reduced licensing time. RESAR, along with other information contained in the Standard Information Package, reflects the current standard design. RESAR Revision 2 has been submitted to the AEC; this is the so called "Modular RESAR."

RESAR comprises many separate reports, each of which describes a different aspect of the Standard NSSS. To provide RESAR with a built-in facility for change, all numerical and other specific parameters are contained in separate tabulations and referenced throughout the body of the report. Changes in parameters are made by replacing numerical tables rather than reediting text.

RESAR is reviewed by the AEC independent of specific site or utility considerations, and prior to the utility's submission of a formal construction permit application for a specific plant. The utility may include RESAR in total or in part by reference in the Safety Analysis Report for a particular plant. The advantage of this approach is that the AEC staff, once having reviewed the reference, will not have to review the document in the same depth for succeeding submissions. Only a completely identical report incorporated by reference can provide this kind of rapid approval. Mere repeating of paragraphs is not good enough; if the reference is different, the AEC reviews the total information.

Changes and deviations from RESAR by a particular applicant are incorporated in the form of supplements so that only the supplements require a second review. By such means RESAR can be used even in those cases where the particular project has deviations from the current standard design. Although the recent publication of the AEC's revised guide for preparation of Safety Analysis Reports will necessitate preparation of a RESAR Revision 3 to meet the new format, the basic concept will remain unchanged.

Fluid Systems Design Manual—This document contains both specific details of the plant and general guidance information and design criteria. System descriptions, flow diagrams, and parameter lists enable the utility and architect engineer to become quickly familiar with the details of the plant systems. Layout guidelines, safety criteria, functional requirements, and design criteria for interfacing systems provide reasonable assurance that costly misunderstandings can be avoided with a minimum flow of time-consuming correspondence.

Control and Electrical Systems Package—This standard information package consists of 30 discrete sets of design information. Each set covers a functional area such as nuclear instrumentation, rod control, and NSSS interconnection diagrams. This was the first standardized information package to be produced. From experience

Table I—Range of Plant Levels Obtainable with Standard Major Components

	Station Output (MWe) *630*	 *955*	 *1160*
Number of Loops	2	3	4
NSSS Power (MWt)	1882	2785	3425
Steam Pressure (psia)	920	964	1000
Hot Leg I. D. (inches)	29	29	29
Cold Leg I. D. (inches)	27.5	27.5	27.5
Reactor Coolant Pump Type	93A	93A	93A
Motor Horsepower	7000	7000	7000
Steam Generator Model	D	D	D

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*H. J. von Hollen and W. A. Webb, "New PWR Nuclear Power Plant Systems Reduce Radioactive Releases," *Westinghouse ENGINEER*, Sept. 1971, pp 130-4.

it had been found that total control and electrical systems information could save thousands of engineering man-hours in the huge task of cable selection and routing. In common with other documents in the Standard Information Package, the scope of this module is aimed at reducing misunderstandings and permitting possible conflicting requirements to be identified and resolved during the early stages of plant design.

Control and Protection Functional Requirements—This document provides information complementary to the functional elementary diagrams included in the control and electrical package. Some 20 subsystems are described. For each system the elementary diagrams are referenced together with the detailed system requirements, such as control board requirements, interlocks, system characteristics, setpoints, and test facilities. In addition, the associated equipment requirements for each system are also clearly defined and the appropriate regulatory design requirements referenced. The document describes the total reactor control and protection system requirements rather than limiting the description to just those items in the vendor's scope. This total coverage provides assurance that possible conflicting requirements and/or misunderstandings can be highlighted early in the design.

Standard Equipment Data Package—This manual is the principal source of information concerning the mechanical equipment to be provided. In addition to providing an equipment specification and drawing list, the document also contains, where appropriate, items such as data sheets, component installation information, typical performance curves, and spare parts lists.

Table II—Summary of Type A Material Supplied with Standard Information Package

Item	*Contents*
Reference Safety Analysis Report (RESAR)	Vendor licensing submittal that describes the standard design. This document is referred to in the applicant's own Plant Safety Analysis Report. (RESAR is also on file at the AEC.)
Fluid Systems Design Manual	In-depth description of the NSSS fluid systems together with design criteria and recommendations concerning balance of plant requirements: system flow diagrams; system descriptions; parameter lists; layout guidelines; interface requirements; safety classifications; and the functional requirements and design criteria for systems not in the NSSS vendor's scope.
Control and Electrical Systems	An index plus 30 sets of control and electrical design information. Over 600 drawings and a number of lists describe essentially all control and electrical equipment furnished by the NSSS vendor.
Control and Protection Functional Requirements	Describes the functional requirements for the NSSS reactor control and protection system. Provides information complementary to the diagrams included in the control and electrical systems package.
Standard Equipment Data Package	Prime source of information concerning the mechanical equipment to be provided. In addition to providing equipment specifications and drawing lists, the document also contains, where appropriate, items such as data sheets, performance curves, motor data sheets, etc.
Equipment Outline and Assembly Drawings	A complete set of the outline and assembly drawings referred to in the standard equipment data package.
Drawing List	A listing of all drawings to be provided in the NSSS vendor's scope of supply.

Equipment Outline and Assembly Drawings—This package contains a complete set of outline and assembly drawings referenced in the Standard Equipment Data Package.

A basic objective in the development of the above information packages is the ability to maintain flexibility to meet as far as practical siting factors and particular customer needs. Efforts continue to be directed toward improving that flexibility so that the first issue of the total Standard Information Package can be more closely tailored to the particular utility needs. Options are handled in different ways depending upon the specific plant under consideration. For example, in the Fluid System Design Manual, a system description and a flow diagram can be readily added to the base document. In the case of the Control and Electrical Systems package, however, such additions become impractical because so many drawings and lists can be affected by the addition of one system. Here, the opposite approach is taken, and the scope of the Control and Electrical Systems Package covers the basic nuclear steam supply system plus all the standard options. Each customer receives the total package whether or not all the items are in the scope of supply for his particular contract.

Type B Information

As summarized in Table III, the Type B category includes both guidance and design criteria information. Several of those documents change with plant rating and/or number of loops—for example, the Radiation Analysis Design Manual, mass and energy release data for containment design, and ventilation system design criteria. Changes to these documents are rarely necessary to meet particular utility requirements.

Keeping Standards Current

With the standardization concept, it is in the best interests of all concerned to maintain the Standard. However, the NSSS design must be kept abreast of the latest safety criteria, design codes, and technological improvements. Justified changes are made, but only after careful review. Once a design change has been approved, a procedure is set in motion to ensure that the necessary changes are made to all appropriate documents in a controlled and orderly manner.

In the case of new models the concept of the Standard Information Package is again used. This philosophy not only ensures organizational continuity, it also ensures that the new model builds on and uses as many well-proven components and systems from the previous Standard as possible.

Table III—Summary of Type B Material Supplied with Standard Information Package

Item	*Contents*
Quality Assurance and Reliability	Describes the quality assurance and reliability program and establishes control over the operations involved with design, fabrication, and construction of equipment for the nuclear power plants. All departments whose work contributes to the quality or reliability of equipment or services supplied by the vendor are affected by this program.
Steam Systems Design Manual	Provides NSSS design criteria for the secondary system. This includes the entire power generation cycle (turbine, condensers, feedwater heaters, pumps, etc.) plus all auxiliary systems such as the circulating water system, service water system, steam dump system, air ejector system, and plant air system.
Radiation Analysis Design Manual	Provides radiation source information for immediate use in the design of plant systems and shielding. Also included is a general description of radiation shielding associated with a PWR plant and a description of the design basis and parameters for shielding.
Chemistry Criteria and Specifications	Contains normal operation and design-basis accident criteria and specifications concerning water chemistry, chemicals, demineralizer resins, and plant materials selection.
Chemical Analysis Procedures	Contains recommendations regarding sampling schedules and techniques, and analytical chemistry procedures.
Radiochemical Procedures	Contains information regarding radiochemistry fundamentals, sample collection, instrument calibration, and radiochemical analysis procedures.
Ventilation System Design Criteria	Summarizes the NSSS design criteria for the reactor containment and auxiliary building ventilation system.
Material and Process Specifications	Contains recommended procedures for assembly and installation of the NSSS components.
Refueling Equipment and Layout	Contains fuel handling building layout recommendations and associated balance of plant items such as crane capacities, underwater lighting, and equipment storage. The associated drawings are included in the equipment outline and assembly drawing package.
Mass and Energy Release Data	Gives data necessary to design the containment; the mass and energy released to the containment in the event of a loss-of-coolant accident is given as a function of time.

Results

The results of NSSS standardization as far as software is concerned can be quickly summarized by citing the improvement in engineering information flow that has been achieved. In 1965, preparation time for the various information packages for the Indian Point No. 2 nuclear steam supply system ranged from 19 to 34 months; by 1968, the benefits of a maturing product began to improve the schedule for information release and the range was reduced to 4 to 14 months; today, with the Standard Information Package concept, engineering information can be provided within two months after award of the NSSS contract.

By means of the Standard NSSS, and associated software standardization efforts, significant reductions in total plant schedules have been and will continue to be achieved.

Designing Heavy-Duty Blower Rotors for Reliability

Joseph H. Hoffman

The mechanical design of rotors for heavy-duty centrifugal blowers has been complicated in recent years by increases in blower size and speed. Large size and high speed also increase the seriousness of rotor failure, so the design process must result in reliable rotors.

The sizes and speeds of heavy-duty centrifugal fans have increased to such an extent in the past 10 years that traditional approaches to design and operation have had to be replaced with more sophisticated techniques previously reserved for centrifugal compressors and steam turbines. Also, pressures have increased so much that the machines should no longer be classed as fans; they are really centrifugal blowers.

The changes have come about as the result of a number of factors. Increases in size of steam generating stations together with the customer's desire to hold the number of blowers to a minimum has pushed wheel diameters beyond the 13-foot mark to achieve the needed air-handling capacity. (Maximum diameter 10 years ago was 9 feet.) Emphasis on air pollution control has added such cleaning devices as bag houses and wet scrubbers to the system, thus increasing the pressure drop and requiring the blowers to generate 2, 3, and even 4 psi pressure. To achieve such pressures, blade tip speeds are approaching 40,000 feet per minute in some cases.

(This does not mean that all fans have gone that route. "General-line" fans for ventilating and exhaust systems, such as those in office buildings and tunnels, continue to be lower speed machines and, in general, of smaller size.)

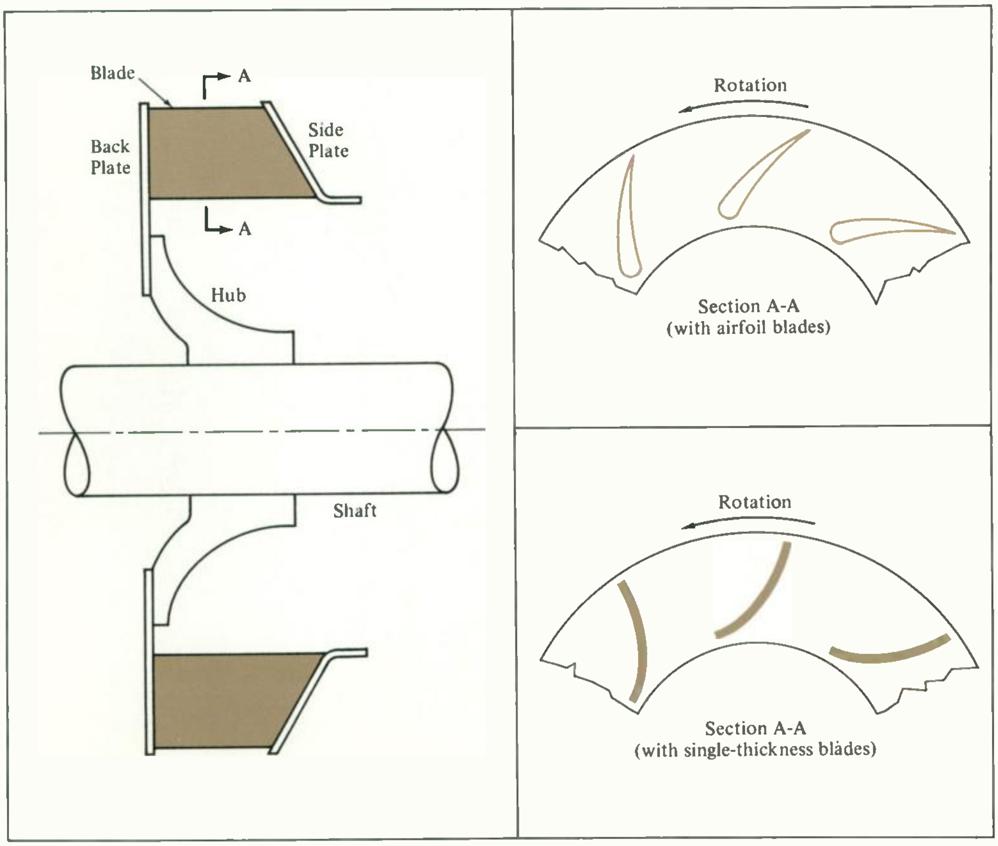
A heavy-duty centrifugal blower must operate reliably because much, and maybe all, of the user's process depends on its operation. Reliability requires mechanical integrity of the rotor, the most highly stressed part of a blower. (Housing design is not discussed here; it is a separate subject involving quite different analytical techniques and considerations.) The rotor is defined as the blower wheel mounted on its shaft (Fig. 1).

Mechanical design of centrifugal blower rotors includes many interrelated considerations, so it is referred to as a design system. The major considerations are stress analysis, material selection, critical speed, fabrication procedures, and proof testing. They are of equal importance; the design system must include all, and the success of the rotor depends on how well they are matched and performed.

Stress Analysis

Determining the stresses that will be imposed on the parts is the first step because most of the other steps depend on it. A blower wheel is a complex structure, requiring sophisticated analysis. Wheel stresses are calculated by computer with a program prepared by the Westinghouse Analytical Department. The calculations are based on the latest analytical methods developed for and employed in the field of centrifugal machinery.

The hub, side plate, and back plate are analyzed by shell theory and the finite difference method. Airfoil blades are sectioned axially and each section calculated as an independent beam. Single-thickness blades are analyzed by flat-plate theory. Stresses in each part are calculated on the basis of the strain from the individual part and the effect each has on the other. For instance, the side plate and back plate each are stressed because of their own rotation and, in addition, because of the weight of the blades each must carry. The blades are stressed because of their own rotation and, in addition, because of the difference in radial expansion between side plate and back plate. The load on the back plate is transmitted partially to the



1—(Left) *A heavy-duty blower rotor consists of a fabricated "wheel" mounted on a machined shaft. Mechanical design of a wheel starts with thorough stress analysis of all the parts and of the complete wheel.*

(Right) *Completed wheels are dynamically balanced on their own shafts. This one is of 114-inch diameter and is airfoil bladed.*

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hub, causing it to bend somewhat; the hub bending, in turn, also causes the back plate to bend.

The computer's speed permits even the most complex calculations to be made at many locations, providing more extensive and accurate analysis than could ever be done by hand. Therefore, the analysis provides a true and total stress profile of the complete wheel from the bore of the hub to the outer perimeter of the side plate. Instead of just calculating at the points of "assumed" maximum stress, the points of maximum stress are *located* by calculation. Stresses can be calculated at as many locations as desired within limits established by the program. The number normally required to obtain a complete picture is 9 on the hub, 24 on the back plate, 8 on the side plate, and 30 on the blade, but the program can handle more if necessary.

This program is applicable to all wheel designs except those with straight radial blades, which are analyzed with a different program because of special conditions peculiar to a radial-bladed structure.

Material Selection

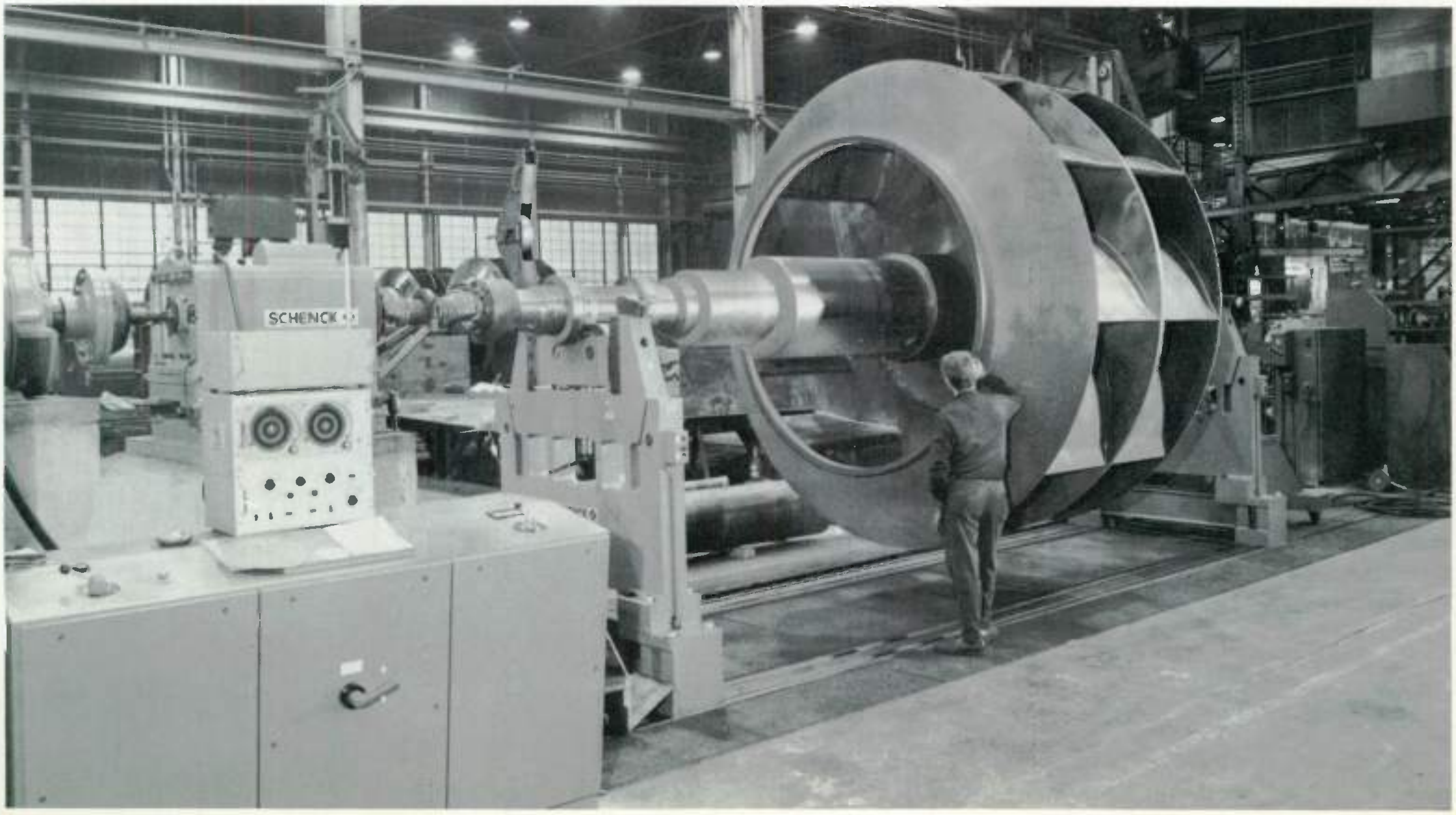
This step is just as important as stress analysis because the choice of steel depends on, among many other things, the stress level allowed. No standards have been established for the centrifugal machinery industry, nor are there any society standards for fans and blowers. However, ASME has established allowable stress levels for many steels for nuclear vessels and pressure vessels. After reviewing that and other data, including the Sturtevant Division's own history, and consulting with related Westinghouse divisions, a set of rules has been established and is used in current designs for allowable steady-state stresses.

Those rules help select materials, but there are still many questions such as what are the mechanical properties of the plate, what are the properties of a weldment of the plate, is the material available in the sizes and shapes needed, and how much does it cost.

Mechanical properties of materials used in heavy-duty products at the Sturtevant Division are listed in Table I. Before the materials in the table were selected, and before any material is approved for use, a satisfactory answer must be obtained to each of the above four questions. Data on mechanical properties such as strength are readily available for a temperature of 70 degrees F; long-time elevated temperature properties are not readily available, but a steel is not used if those values are not obtainable.

For welding procedures, a special qualifying specification has been established. The weldment of each material must pass the tensile and bend tests of the ASME Boiler and Pressure Vessel Code. Those tests are performed in the plant. In addition, the weldment is given a controlled thermal severity test to determine its susceptibility to cracking when welded in a restrained condition. A weldment is made at the plant by production welders and sent to the Westinghouse Research Laboratories for analysis. This test has been the downfall of many steels.

Despite all the testing and research that



precede the use of a material, the final all-inclusive test is operation on the job. All the materials in Table I have operating experience. The newest is Type 6 in the table; it was first applied in 1967 and has been running since 1969. The next is Type 3, which was first used in 1964 and has been running since 1967.

Materials are procured to Purchasing Department Specifications prepared by the Westinghouse Corporate Standards Department. Those specifications are used Company-wide and include chemical requirements, physical requirements, tests to be performed, reports to be submitted, basis for rejection, and so on. This practice was instituted years ago because of the need for such a document. Within the past 10 years, however, ASTM has been issuing an increasing number of specifications suitable for use in purchasing, and such society specifications are used whenever they can be applied.

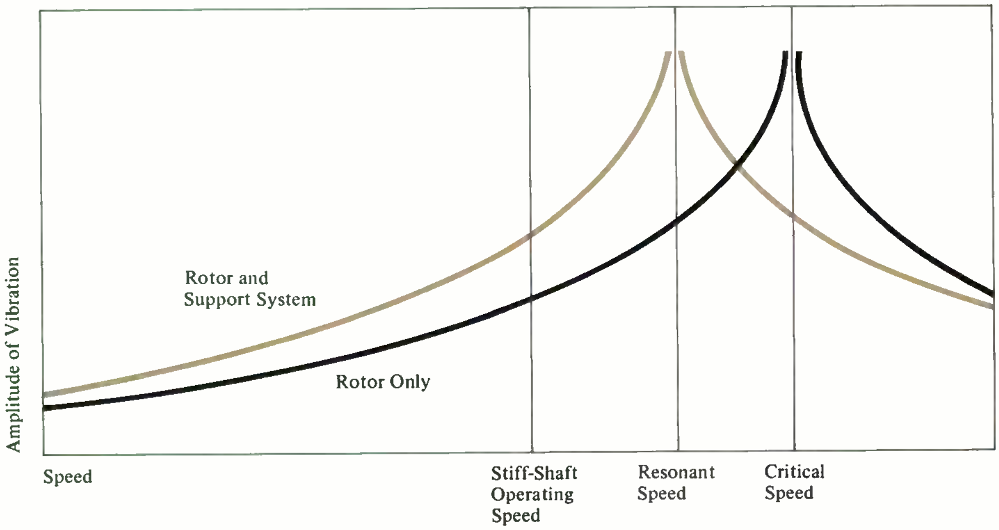
Critical Speed

The stress analysis program also calculates the weight and mass moment of inertia (WR^2) of each part of the wheel, so, with the final selection of material (completion of the wheel design), the wheel weight is known. Having the wheel weight permits design of the shaft. Bending stresses from the static loads and torsional stresses from the power input establish the basic shaft dimensions. As with the wheel, materials must be selected and allowable stress levels established. But the overriding influences on shaft proportions are the critical and resonant speeds of the rotor. (The critical speed of the rotor is defined as the speed that is equal to the natural frequency of the rotor only, mounted on rigid supports; resonant speed is the speed that is equal to the natural frequency of the combined spring-mass system of rotor, bearing housing, oil film, and bearing supports but excluding the foundation.)

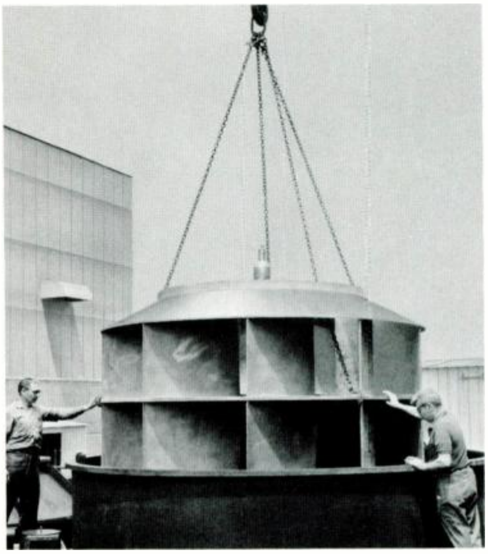
Problems with the resonant speeds of rotors arise as a result of the combination of exciting forces and the natural frequency of the rotating mass and its supports. The solution, therefore, deals basically with mechanical vibrations of an elastic system and primarily with the static deflection of the shaft. Several analytical methods are available for calculating lateral critical speeds (those involving vibration perpendicular to the shaft).

Table I—Materials of Construction

Type	*Strength at 70 Degrees F*		*Temperature Range (degrees F)*
	Tensile	*Yield*	
1	72,000	32,000	−20 to 900
2	70,000	50,000	−20 to 800
3	115,000	100,000	−20 to 650
4	70,000	40,000	750 to 900
5	80,000	50,000	650 to 900
6	115,000	100,000	650 to 900



2—Destructive rotor vibration in service is prevented by accurate analysis and proper design. Stiff-shaft design keeps operating speed below the first resonant speed. The graph also illustrates the relationship of critical speed to resonant speed.



Another 114-inch airfoil-bladed wheel is being lowered into a test pit for overspeed testing. All welds are inspected after the test.

For the simplest case of a single concentrated mass on a flexible shaft on two rigid supports, the first critical speed (N_{c1}) corresponds to the natural frequency of lateral vibrations in one plane:

$$N_{c1} = 187.7\sqrt{1/y},$$

where y is static deflection of the shaft.

While that formula might provide some information on relatively small low-speed rotors, it is an oversimplification and is misleading for the large high-speed rotors in today's central stations and gas cleaning systems. The flexibility of the oil film, bearing housing, and bearing pedestal must be taken into consideration to calculate resonant speed. The more popular methods of analysis are the Rayleigh, Stodola, influence-factor, and Holzer-Myklestad-Miller methods.

Both critical and resonant speeds are calculated by computer with a program prepared by the Analytical Department and using the Holzer method. All rotors are designed for "stiff shaft" operation, meaning that the first resonant speed is above the operating speed (Fig. 2). The degree to which operating speed approaches resonant speed, in the Sturtevant design, depends on how well the rotor will remain balanced during its time in operation. Blowers handling clean air, such as forced-draft applications, experience little or no wear, collect no dirt, and so retain their original balance for great lengths of time. Dirty applications, on the other hand, such as induced-draft blowers for coal-fired boilers, are subjected to wear and dirt buildup and tend to lose their balance in less time than do clean-air blowers. For those applications, the rotors are usually designed to be less sensitive to unbalance.

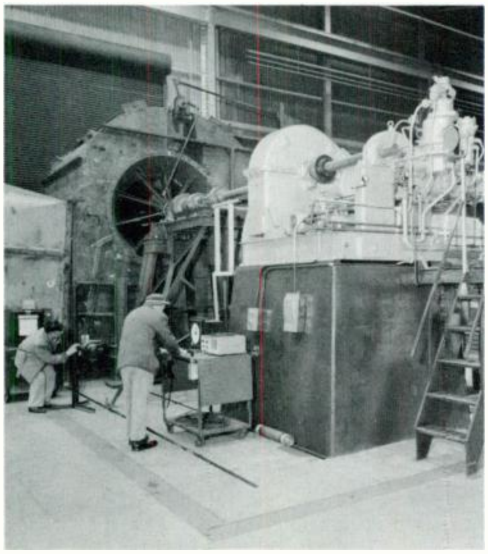
As noted above, the resonant speed calculation does not include the effects of the foundation. The lower the value of foundation spring constant and natural frequency, the greater the sensitivity of the installation to unbalanced forces.

Fabrication Procedures

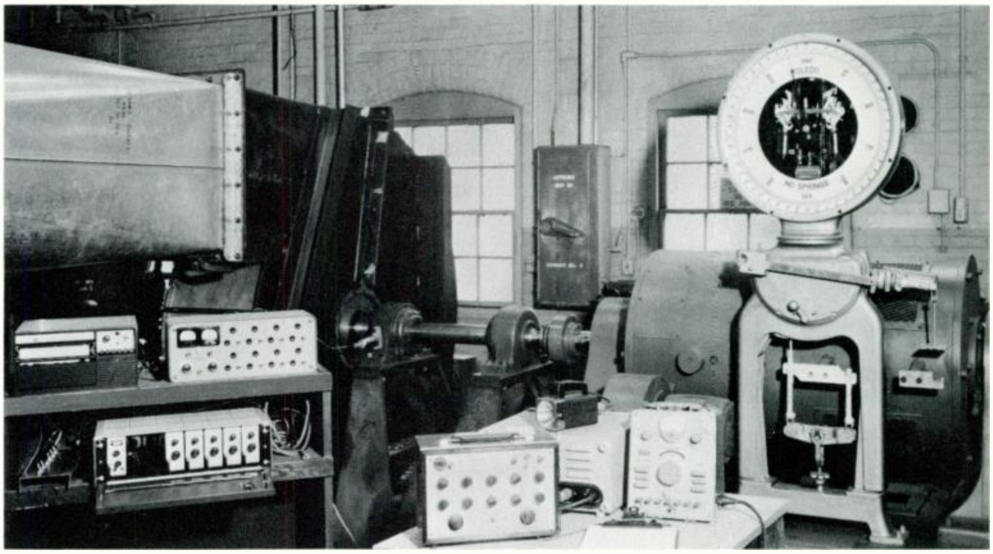
Shop drawings are not prepared unilaterally but reflect continuing discussion and feedback among the marketing, engineering, and manufacturing departments. Part sizes, material form, subassemblies, surface finish, and tolerances are all part of the fabrication procedures that are intertwined with previous decisions on materials, allowable stress levels, and so forth.

Also, a system of process specifications is used. Basically, any set of instructions that is lengthy and detailed is prepared on separate sheets and is given a PS (process specification) number. This number is then called for on the drawing, and the process specification is transmitted separately to the shop. The main benefit is uniformity and standardization. In welding, for example, a particular steel is joined every time by the latest procedure.

Some of the main areas in which process specifications are used are welding (manual arc, MIG, electroslag, and spot welding, with separate specifications for different kinds of steel), metal severing, stress relief, dynamic balancing, bearing babbitting, nondestructive weld examination (by magnetic-particle, radiographic, Zyglo, dye-



Assembled blowers can be operated before shipment in this running test facility. Pressure, volume, and power are being measured in the run shown here; the facility also can be used for strain-gage testing and for measuring damper torques, vane torques, and rotor thrust.



Development of a new aerodynamic design often involves construction and test of a model. Testing consists of taking readings of pressure and power at various air flows; performance curves can then be prepared from the data.

penetrant, post-emulsifier, and ultrasonic methods), and weld testing. The nondestructive examination methods are used as needed and where they can be applied.

On all welded wheels for high tip speeds (which is a majority of them), the welded structure is stress relieved. This is a very important step because it virtually eliminates stresses unavoidably produced during welding, helping to assure the mechanical integrity of the completed product.

Proof Testing

The procedures just described should produce a successful rotor. However, additional procedures are applied to verify the analyses and fabrication techniques used.

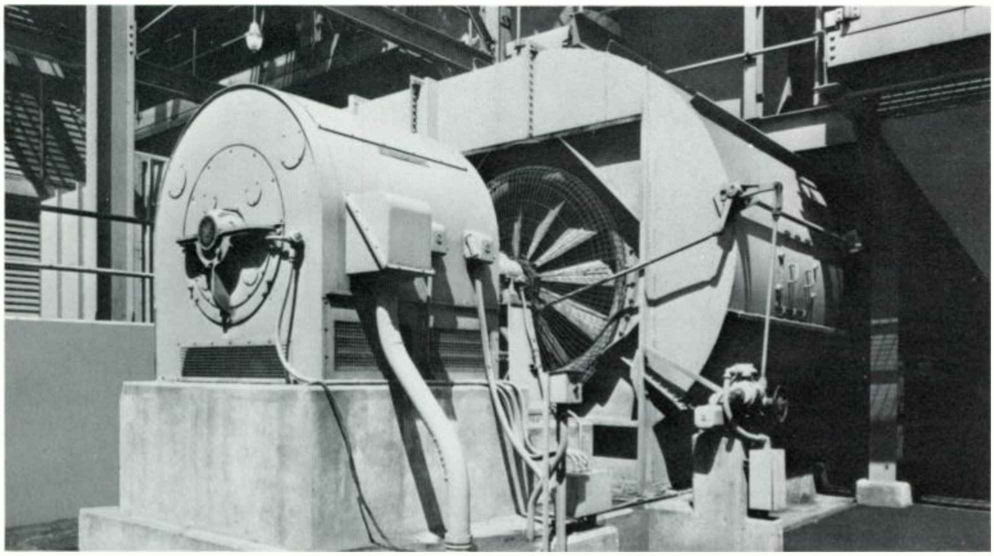
Probably the most conclusive procedure available is the overspeed test, which is performed if the customer specifies it. It consists of running the wheel at a speed higher than its maximum specified operating speed for a short time. The wheel is run inside a steel tank, sunk into the ground. During the test the tank is evacuated to just a few inches of mercury to avoid overheating and to keep the power requirement down. After spinning the wheel, all welds are examined for cracks.

The overspeed test is an excellent check on fabrication techniques and firmly establishes that the wheel can run at its specified speed, but it is not an all-inclusive test. It does not verify the ability of the rotor to resist fatigue failure, which can occur after an extended period of time (3 to 9 months or even longer). This type of failure is caused by vibration and is becoming an increasingly significant factor as sizes and speeds go up. To guard against it, the first of each size, speed, and aerodynamic type is tested for natural vibration frequencies. Standard practice is to set the rotor on supports so the wheel is clear of the ground, attach a mechanical vibrator, shake the wheel through a range of frequencies, and note the natural frequencies of all parts.

The above tests are after the fact, so to speak. There is also a continuing program of strain-gage testing that helps optimize the stress analysis and more accurately predict stresses on sizes and designs other than the ones tested. Measurements during the tests include both steady-state (equivalent) stress and vibratory stress. Most of these tests are conducted in the laboratory, but one was done at the job site under operating conditions on a 114-inch wheel at full speed of 900 r/min. The measured values were within 15 percent of calculated values on the side plate and center plate and 40 percent lower than calculated on the blade, demonstrating that the analytical procedures used are sound and safe. Other on-site strain-gage tests can be run with any customer's cooperation.

Conclusion

The record of blower rotors made by the Sturtevant Division over the years has been superb. Use of the latest technology in design, manufacture, and testing assures continued reliability as blower sizes and speeds increase.



This blower is installed in a central-station generating plant for forced boiler draft. Constant-speed motors are the usual drives for such blowers when the required horsepower is below 10,000. Above that rating, steam turbines are sometimes used.

UHV Test Center Offers a Wide Range of High-Voltage Testing

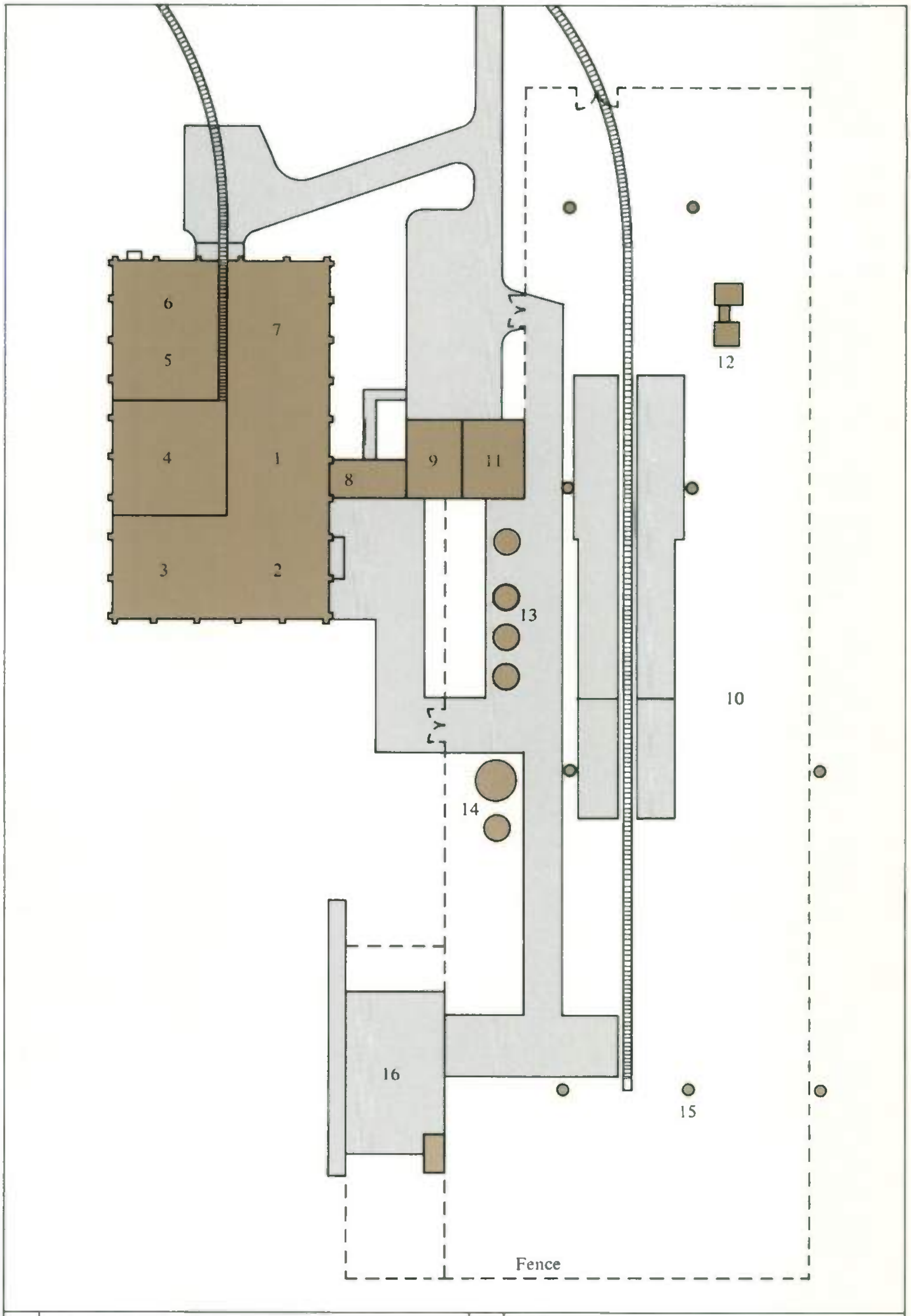
D. L. Whitehead
C. D. Fahrnkopf
J. J. Brado

The newly completed EHV indoor laboratory together with an adjoining UHV outdoor laboratory are fully equipped to make lightning impulse, switching impulse, and power frequency tests on equipment of the highest voltage ratings. Aside from serving Westinghouse needs, the facilities and consulting services of the test center are available to outside customers on a contract basis.

High-voltage power circuit breakers and other high-voltage equipment must have insulation levels high enough to withstand transient overvoltages from lightning strokes and switching operations normally expected on a transmission line. To prove an equipment design, impulse and switching surge voltages as well as continuous 60-Hz test voltages are applied up to levels much higher than the rating of equipment being tested. For example, the test voltages used for 765-kV equipment include power frequency withstand test voltage of 960 kV rms, switching surge crest voltage of 1300 kV, and lightning impulse crest voltage of 2250 kV.

A laboratory capable of testing at these voltages must have the added capability to test at somewhat higher voltage levels in order to do development work, to find the limits of a design, and to provide for losses and safety factors. Such a laboratory, for testing equipment in the extra-high-voltage range up to and including 765-kV equipment, is the new EHV indoor laboratory. To make high-voltage testing practical and economical for equipment of the ultra-high-voltage class (above 765 kV), a UHV outdoor laboratory is used in conjunction with the indoor facilities. Together the two laboratories make up the Westinghouse UHV Test Center.

A program for enlarging the original high-voltage laboratory to test circuit breakers for 765-kV ratings and up was



1	Indoor Laboratory	9	Motor-Generator Room
2	4000-kV Impulse Generator	10	Outdoor Laboratory
3	Proposed High-Current Impulse Generator	11	Outdoor Laboratory Control Room
4	Wet Test Area	12	6400-kV Impulse Generator
5	Sunken Oil Tank	13	1600-kV Cascade-Connected Transformers
6	Radio Interference Test Area	14	Water Tank Test Area
7	1000-kV Transformers	15	75-Foot-High Wood Poles
8	Indoor Laboratory Control Room	16	Endurance Laboratory

1—In this plan view of the UHV Test Center, color indicates buildings and equipment, gray represents paved areas, and numbers identify facilities.

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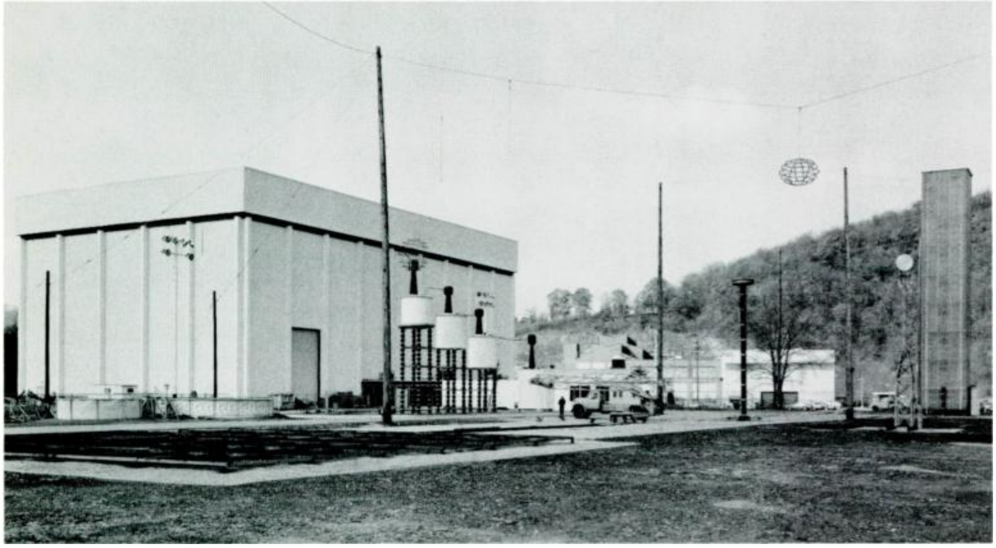
planned in three phases starting in 1964. In the first phase, the outdoor laboratory was built near the division's manufacturing plant but some distance from the existing 50-year-old indoor laboratory, which was later razed. This outdoor laboratory was expanded in the second phase of the program to be able to test 1100-kV and 1500-kV equipment, at which time it was called the UHV laboratory. The third and final phase included building the new EHV indoor laboratory adjacent to and integral with the UHV outdoor laboratory, thereby completing the UHV Test Center. Since the center occupies a land area of slightly more than 8 acres, sufficient space is available for testing even the largest structures for any possible future voltage rating.

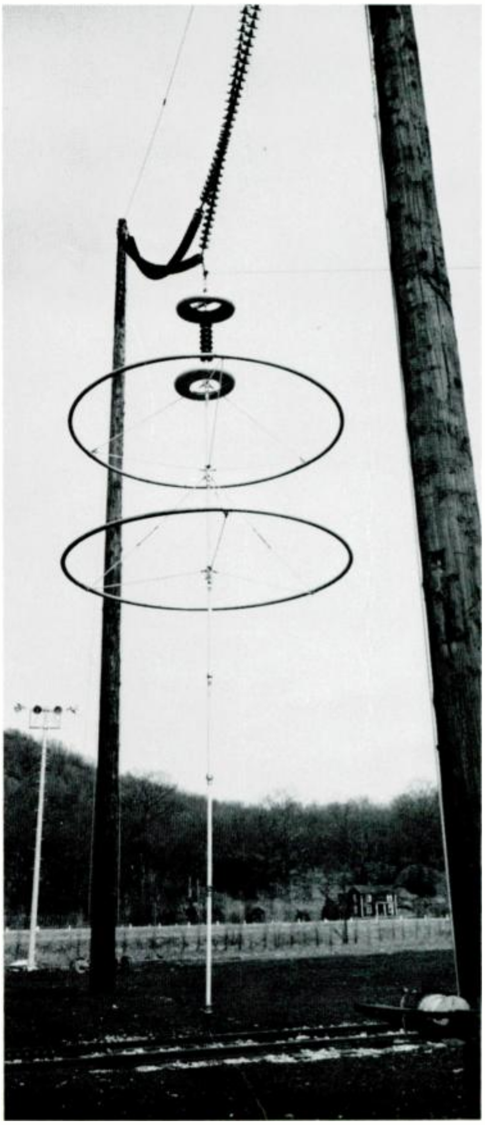
The EHV indoor laboratory can perform tests that cannot be made satisfactorily out of doors, such as wet flashover tests and radio interference tests. The laboratory building is 110 feet wide, 180 feet long, and has an overhead clearance of 65 feet. Those dimensions allow space for doing all tests including wet switching surge on 765-kV circuit breakers. Many of the smaller components of 1100-kV and 1500-kV equipment can also be tested in this facility.

While some general features of the design, equipment, and methods of operation of the test center are necessarily similar to those of other high-voltage laboratories, certain features are unique. They include the grounding and shielding scheme, the construction of the impulse generators, the capability of combining test facilities for special tests, and the use of lifting devices other than an overhead crane.

Overall Plan

A plan view of the overall test center indicates the locations of various test facilities (Fig. 1). Two railroad spurs, one coming into the center of the indoor laboratory and the other running almost the entire length of the outdoor laboratory, are used for transporting the test pieces to and from the testing sites. The indoor lab spur enters through a 28-foot-high 19-foot-wide roll-





2—Included in this view of the UHV outdoor laboratory (above) *are, from left to right: four 60-Hz cascade-connected transformers, a capacitance-type voltage divider, and, at the far right, a 6400-kV impulse generator. Suspended between two support poles (one is visible to the left of the cascade transformers) is a grating sphere, used to enclose aerial connections to make them corona free. The control rooms are in the low glass-front building behind the cascade transformers, and the EHV laboratory building is seen in the left background. A resistance-type voltage divider* (right) *not only measures the voltage produced by the impulse generator but also helps shape the voltage wave for making lightning-type impulses.*

up door and extends 67 feet into the test area. The indoor laboratory building and the main features of the outdoor laboratory are shown in Fig. 2. Various test apparatus of the EHV indoor laboratory are shown in Figs. 3 and 4.

The indoor and outdoor test areas have been laid out to provide maximum voltage clearance between test apparatus and to enable many tests to be made with little or no movement of the test piece. A heavy test piece placed near the center of the indoor laboratory, for example, can be tested on impulse and then on 60 Hz without being moved. Following this, the equipment can be wet-tested to confirm the ability of its insulating components to withstand various voltage stresses during storm conditions. The equipment is energized to the necessary high voltage by the 60-Hz transformers and, if required, is subjected to simulated lightning strokes from the impulse generator. Throughout the test, the equipment is drenched with water from wall-mounted spray racks. A drain surrounds the 3000-square-foot wet test area and returns the water to an underground recycling tank where its conductivity can be controlled to any desired value.

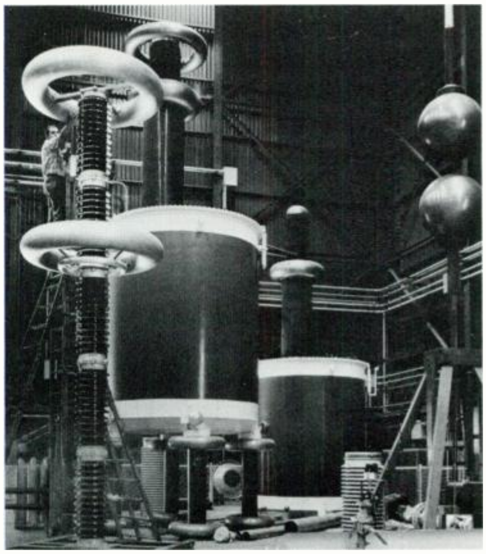
In area *5* of the indoor laboratory is a sunken oil tank (13 feet in diameter and 18 feet deep) on which a high-voltage bushing can be mounted for testing. The lower portion of the bushing extends into the covered tank to simulate normal installation in an oil-filled device. All voltage tests including testing during water spraying can be performed on a bushing mounted on this apparatus.

Shielding—The walls of the indoor laboratory are constructed of two metallic layers with insulation between. The outer layer is of corrugated overlapped aluminum panels 40 inches wide. The inner layer is of steel panels, also corrugated and overlapped, welded to girders that run horizontally on 6-foot centers. In addition to mechanical fasteners at the overlapped joints, the steel panels are tack welded every 3 feet to form a semicontinuous metal shell as well as to provide a ground return path. To complete the shell, the steel wall panels and steel columns are tied into the ground grid beneath the building. The structure is thus not only a shelter but also a grounded metallic shield, making the laboratory, in effect, a Faraday cage (an enclosed region protected from external radio interference). That type of environment is necessary for accurate radio-interference testing.

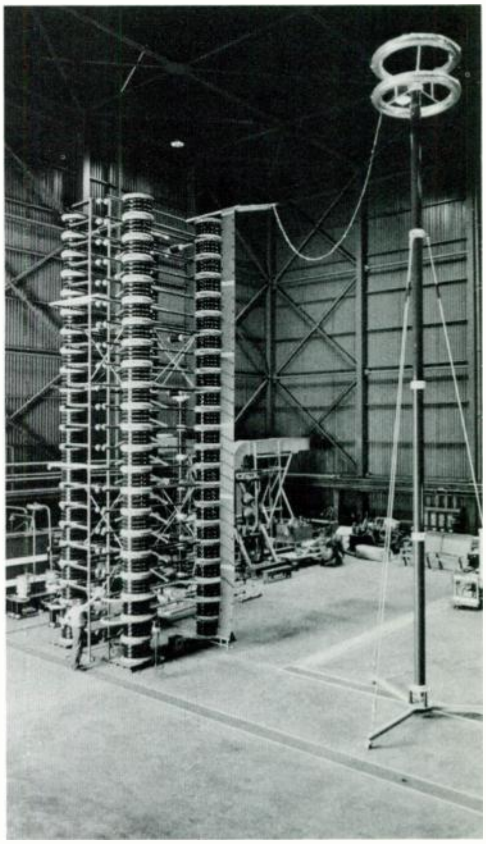
All electrical wiring is in rigid iron conduit for maximum magnetic shielding at 60 Hz as well as good shielding at higher frequencies. In addition, the electrical sources and lines for instrumentation are separated from those for other services.

Grounding—In high-voltage impulse and switching-surge testing, a low-impedance return path from the test piece to the impulse generator is essential. Accurate measurements require a low-impedance ground return path to the test equipment. For safety of the operator as well as for protection of control and measuring equipment, this return path must be connected to earth.

The UHV Test Center is grounded through 32 copper ground rods driven 20 to 30 feet apart. The ground rods are connected into a horizontal grid network of #4/0 solid copper rod 3 feet below the floor. Each of the 30 steel columns supporting the building is connected to this underground grid. Fifteen of the driven ground rods, at junctions in the grid, terminate in risers connected to plates that



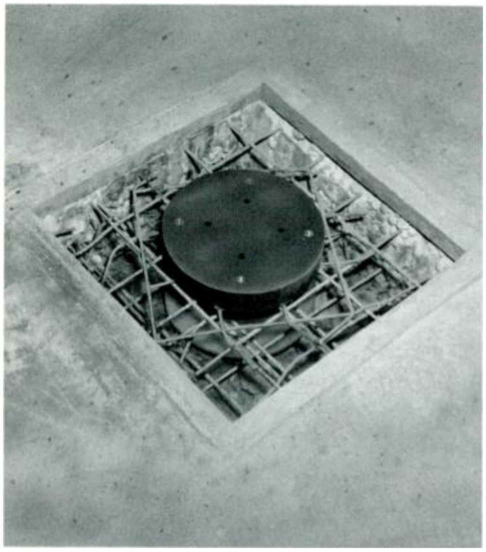
3—Equipment in the EHV indoor laboratory includes, from left to right, a five-element capacitance-type voltage divider, two 500-kV transformers that can be cascade-connected, and a sphere gap device for calibrating the high voltages produced by the transformers.

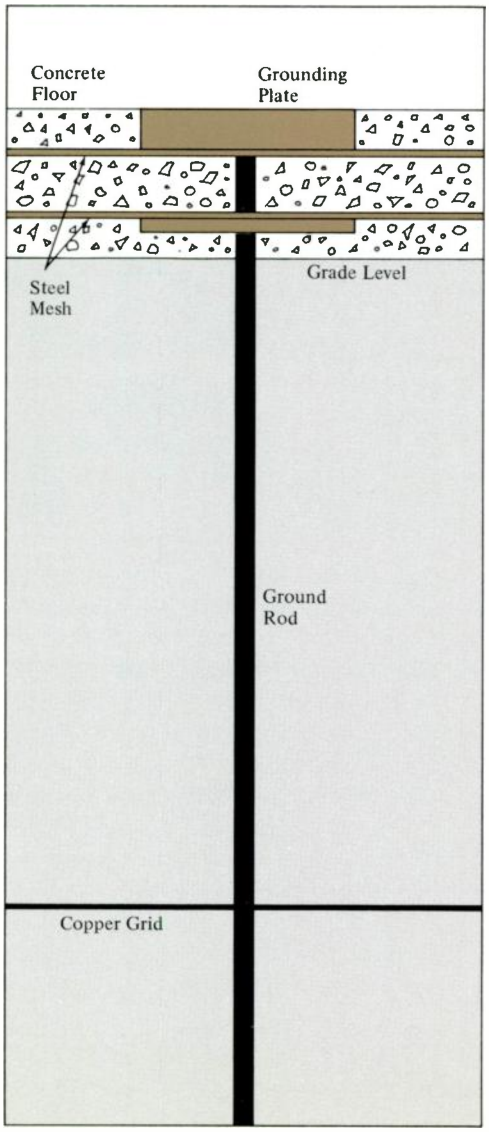


4—The EHV indoor laboratory's 4000-kV impulse generator, at left, is shown with its damped capacitance-type voltage divider.

provide grounding points in the indoor laboratory floor (Fig. 5).

Embedded in the concrete floor are two layers of heavy welded steel mesh 4 inches apart. The mesh is made of 0.125-inch-diameter steel wires welded in 4-inch squares. It not only provides reinforcement for the concrete floor but also serves as part of the ground path since it is connected to the underground copper grid. While the resistance of the steel wire mesh is about six times that of copper of the same gauge, two layers of steel mesh combined with the underground copper grid system provide a low-resistance ground return path comparable to much more expensive types of construction using expanded copper sheets in the floor. Kelvin bridge measurements show resistance between adjacent risers (30 feet apart) on the order of 0.6 milliohms, which compares favorably with that of installations using expanded copper embedded in or under the concrete floor.





5—A cross section of the EHV indoor laboratory grounding scheme shows a grounding plate, at floor level, connected to a copper ground rod that is welded to two layers of steel mesh embedded in the concrete floor. The ground rod is also welded to an intersection point of a copper grid network 3 feet below grade level and then continues another 27 feet into the earth. The two steel mesh layers and grounding plate are shown in the partially poured concrete floor. There are 15 grounding plates in the laboratory floor.

Cable troughs, track rails, and waterways in the wet test area are bonded to the steel grid at frequent intervals. The copper grid under the indoor laboratory is tied into a similar copper grid on 10-foot squares under the outdoor test area.

Lighting—Mercury vapor lamps supply the greater portion of light for general purpose work. In addition, quartz-type incandescent lamps are spaced over the various areas and can be individually controlled. Only the incandescent lights, normally free of interference, are used during radio interference testing or when one section of the laboratory requires a low light level for observing corona without darkening the entire laboratory. The lighting power, designed to compensate for lack of reflection from the dark blue walls, is adequate for all purposes. The interior walls are painted dark blue to make corona observation more effective.

Lifting and Transport—Equipment is transported to and from the test center by both rail and truck. Equipment brought into either the indoor or outdoor test area on the rail spurs can often be tested on the railroad car without unloading.

Trucks can be maneuvered over paved roads and areas so that equipment can be unloaded at the proper test location. A roll-up door located at the end of the indoor laboratory provides entry to a receiving station for truck delivery of smaller items. A jib crane is located in this area for unloading.

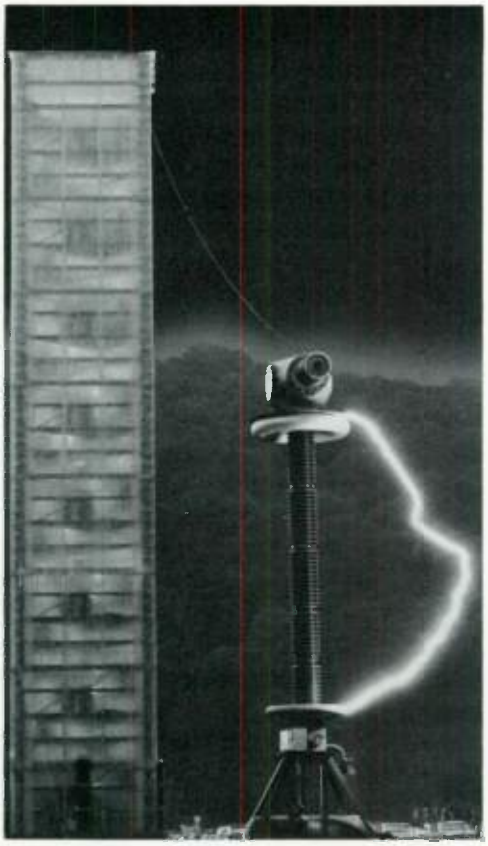
Mobile lifting devices are used in the indoor laboratory instead of the usual overhead traveling crane. The primary lifting device is a 15-ton mobile hydraulic crane with a telescoping boom that extends to 60 feet. This crane is used for unloading trucks and railroad cars and for the erection of equipment to be tested. A supplement to this crane is a two-man bucket truck; the bucket section can be raised to a height of 75 feet.

The large mobile crane and bucket truck greatly simplify the erection of large test items and the making of test connections in both the outdoor and indoor test areas. In addition to the versatility provided by those mobile lifting devices, elimination of the usual overhead traveling crane in the indoor lab allows test pieces, voltage dividers, and other equipment to be suspended from the ceiling at any point in the laboratory. Also, the additional cost of the heavier supporting structure and of the crane itself is saved.

Test Equipment

Test equipment has been chosen to provide a wide range of high-voltage testing. Prime sources of impulse and 60-Hz voltage, as well as the necessary instrumentation to measure and record those voltages, are available as needed in the appropriate areas.

Equipment in the EHV indoor laboratory includes an *impulse generator* with a nominal voltage rating of 4200 kV for producing high-voltage transients similar to lightning strokes and switching surges (Fig. 4). This generator is used for testing insulating properties of high-voltage components up to and including 765-kV equipment. Made up of 21 stages, with each stage consisting of a 0.5-microfarad 200-kV capacitor, the generator has a total energy rating of 210 kilojoules. The cylindrical capacitors form part of the mechanical structure of the four supporting columns.



6—*A flashover test is made on the insulating support column of an EHV circuit breaker. Power for the test is provided by the adjacent 6400-kV impulse generator.*

A *voltage divider* of the damped capacitive type with a rating of 3600 kV is used for measuring impulse and switching surge voltages (Fig. 4). This divider consists of four high-voltage units connected in series with built-in damping resistors to obtain a damped unit-step response. The overall impedance is high, offering little load to the generator source.

Two *60-Hz test transformers* rated at 500 kV rms each are used separately or connected in cascade to obtain a maximum output of 1000 kV (Fig. 3).

A *voltage divider* of the capacitance type is used to measure continuous 60-Hz voltages (Fig. 3). The high-voltage portion of the divider consists of five high-voltage coupling capacitors in series.

A *portable 60-Hz test set* rated at 100 kV rms, 50 kVA is used primarily for testing lower voltage insulation samples.

A *portable DC test set* rated at 200 kV, 5 mA, with reversible polarity is used primarily for measuring surface leakage on insulation.

Auxiliary equipment consists of a standard capacitor rated at 500 kV, a Schering bridge, which measures power factor and capacitance at high voltages, and portable instruments for measuring voltage, current, radio influence, and audible noise.

The UHV outdoor laboratory test devices shown in Fig. 2 include an *impulse generator* with a nominal voltage rating of 6400 kV, used primarily for research and development testing of insulation on equipment of the highest voltage ratings. Made up of 32 capacitor stages, with each stage consisting of 0.25 microfarad at 200 kV, the generator has an overall rating of 160 kilojoules. The generator, 85 feet high on a 13-foot-square base, is supported entirely by post insulators and cap-and-pin insulators that are held together by steel platforms on which the capacitors are mounted. A spiral stairway to the top is formed by fold-down steps between platforms. A fiberglass covering protects the circuit elements from excessive contamination. A feature of this generator is that when charged, all platforms are at the same potential so that leakage between stages is a minimum. Greater overall efficiency and faster charging times results.

A *voltage divider* of the capacitance type is used to measure the longer switching surges and continuous 60-Hz voltages. The high-voltage section consists of nine coupling capacitors in series.

Four *60-Hz transformers* can be connected in cascade for a total output rating of 1600 kV rms. The ground unit is rated at 500 kV, the two intermediate units at 350 kV each, and the line unit at 400 kV.

A *voltage divider* of the tapered resistance type is used to measure lightning-type impulses. The divider is 40 feet high with six high-voltage resistor units in series for a total resistance of 6100 ohms and a voltage rating of 4000 kV. Two grading rings 18 feet in diameter help distribute the electrostatic field across the upper sections of the divider.

Laboratory Operation

Before setting up a high-voltage test, the Westinghouse design engineer or outside customer discusses with the laboratory engineers the specific tests to be made, possible variations in procedure, test facilities and instrumentation required, time to complete the test, and estimated cost.

As in most laboratory testing, the report of test results may vary from a simple pass-fail statement to a complete technical report describing all phases of the test and analysis of results.

Although the test equipment has been selected and located to obtain optimum efficiency of operation for standard type tests, that does not imply that high-voltage testing becomes routine. On impulse and switching surge testing, for example, the waveforms required by different types of tests and test specimens vary widely with rise times ranging from a few nanoseconds to a millisecond. The various waveforms are obtained from an impulse generator by adjusting certain elements of resistance, inductance, and capacitance in the test circuit.

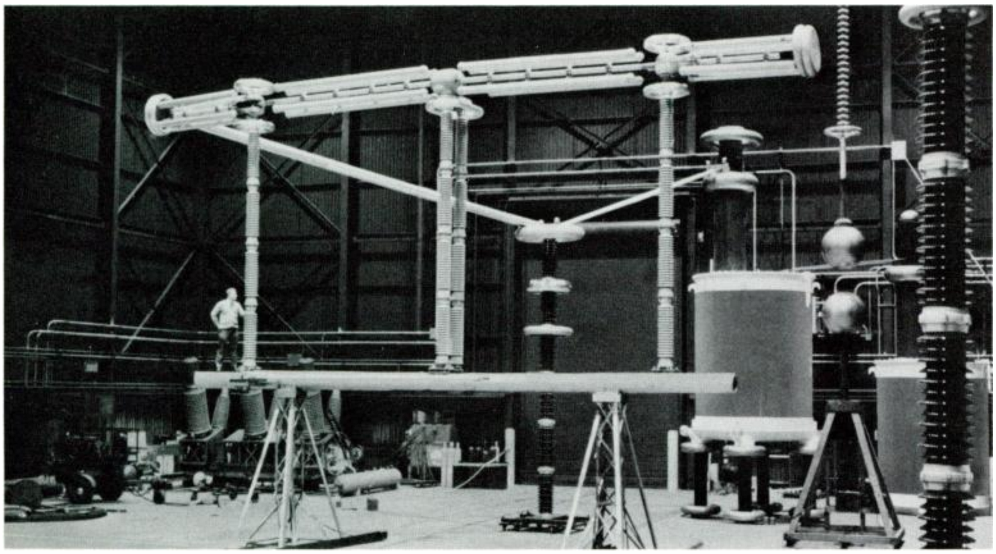
UHV tests often make use of a simulated transmission-tower "window" with movable sides. Various configurations of suspension insulators have been tested in this window to determine voltage withstand levels when exposed to many different waveshapes. Similar tests have been performed on air gaps using various electrode configurations and on porcelain post type insulator systems erected on steel pedestals of various heights. The insulating column of an EHV circuit breaker is being tested with the outdoor impulse generator in Fig. 6.

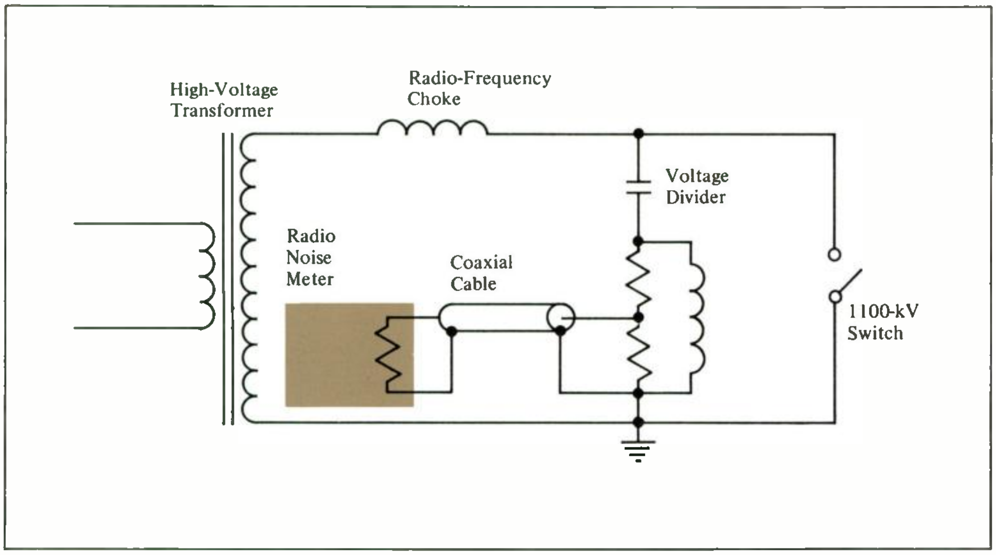
When an impulse test requires a voltage greater than a single impulse generator can supply, two generators can be charged to opposite polarities, connected to opposite ends of a test piece, and synchronized to discharge simultaneously. For example, the effects of switching surges generated by the opening of a high-voltage switch can be simulated with this arrangement by applying positive and negative voltages to opposite ends of the open test switch. The synchronizing device that regulates simultaneous discharge of two impulse generators can also be used to superimpose an impulse voltage wave on any part of a 60-Hz wave. Such a technique is used in simulating lightning effects on energized 60-Hz equipment.

Various studies have been made of the lightning-like arcs produced by impulse generators. For instance, measurements made of a stroke's luminous characteristics show the relationship to its current, voltage, power, and radiation spectrum.

Many interesting and challenging tests are performed using the high-voltage 60-Hz sources. Corona and acoustical measurements are made on simulated transmission lines erected in the laboratory and energized from the 60-Hz source. A method of measuring ozone generated on transmission lines has been developed.

Another type of testing done at the center is measurement of radio interference. As a result of ionization, high-voltage electrical equipment may generate a high-frequency radio influence voltage that propagates by conduction as well as by radiation. Thus, one means of measuring radio interference is to monitor, through an appropriate coupling circuit, the amount of high-frequency voltage produced by an energized test piece. An arrangement for measuring the radio influence voltage during a test on an 1100-kV disconnect switch is shown in Fig. 7.





7—In the EHV indoor laboratory, an 1100-kV disconnect switch, manufactured by Southern States Inc., is mounted and connected in preparation for a radio interference test. As shown in the circuit diagram, the switch is energized to full line-to-ground voltage by the high-voltage test transformer and coupled, through the capacitance-type voltage divider, to a NEMA standard radio interference test circuit. The noise meter in the test circuit detects and measures any high-frequency radio influence voltage generated by the switch during the test. In addition, observations are made during this test to detect any visible corona on the switch.

Conclusion

The newly completed UHV Test Center with its combined indoor and outdoor test facilities should be sufficient for a wide range of high-voltage testing of the highest ratings now contemplated. Accepted measurement and recording techniques are continually being improved while new methods are being studied and evaluated.

Automatic Train Control Concepts Are Implemented by Modern Equipment

R. C. Hoyler

New equipment for applying established design concepts fulfills the promise implicit in automatic train control—efficiency, safety, reliability, and good service.

Automatic train control can enhance both the operation and the safety of rapid-transit systems, and of other people-moving systems for such facilities as airports. Successful design techniques have been worked out and are presently in use[1], but equally important as system design is the equipment required for effective implementation of automatic train control. Capable equipment has been developed for the Westinghouse automatic train controls applied in such systems as San Francisco's Bay Area Rapid Transit (BART).

In such a system, all automatic operations relating to safety are performed by "local" control equipment located on the trains, at wayside centers along the route, and at passenger stations (Fig. 1). This equipment determines what each train can safely do in its immediate vicinity and controls it accordingly. In addition, a central control facility monitors the operation of all trains on the system and determines what modifications should be made to particular trains or groups of trains to optimize operation of the system with respect to schedules, service, or passenger flow. The modifications are sent to the local equipment, which acts on them so long as they can be implemented with full safety.

Safety Functions

Train Detection and Control—Detection determines where each train is located at any given time. Control determines what each train may do, as a function of the speed limit and track occupancy immediately ahead of it, to insure that it maintains safe operation.

A route is quantized into discrete lengths called blocks. In Westinghouse automatic train control systems, a given block is defined as occupied if a train is anywhere in it. Similarly, control is applied for a train anywhere within a block. Information on block occupancy is brought to the station logic from wayside detection points at block boundaries. Control equipment at each station determines the allowable speed for each train in its area, and the resulting speed codes are sent back to their respective block transmitters for transmission to the trains.

In steel-rail systems, trains are detected by coupling a signal into the running rails at one end of the block and detecting it at the other end. If a train is present, its wheels and axles shunt the signal and the signal is not detected at the remote end; the block is then indicated as occupied. Any failure in the signal source, detector,

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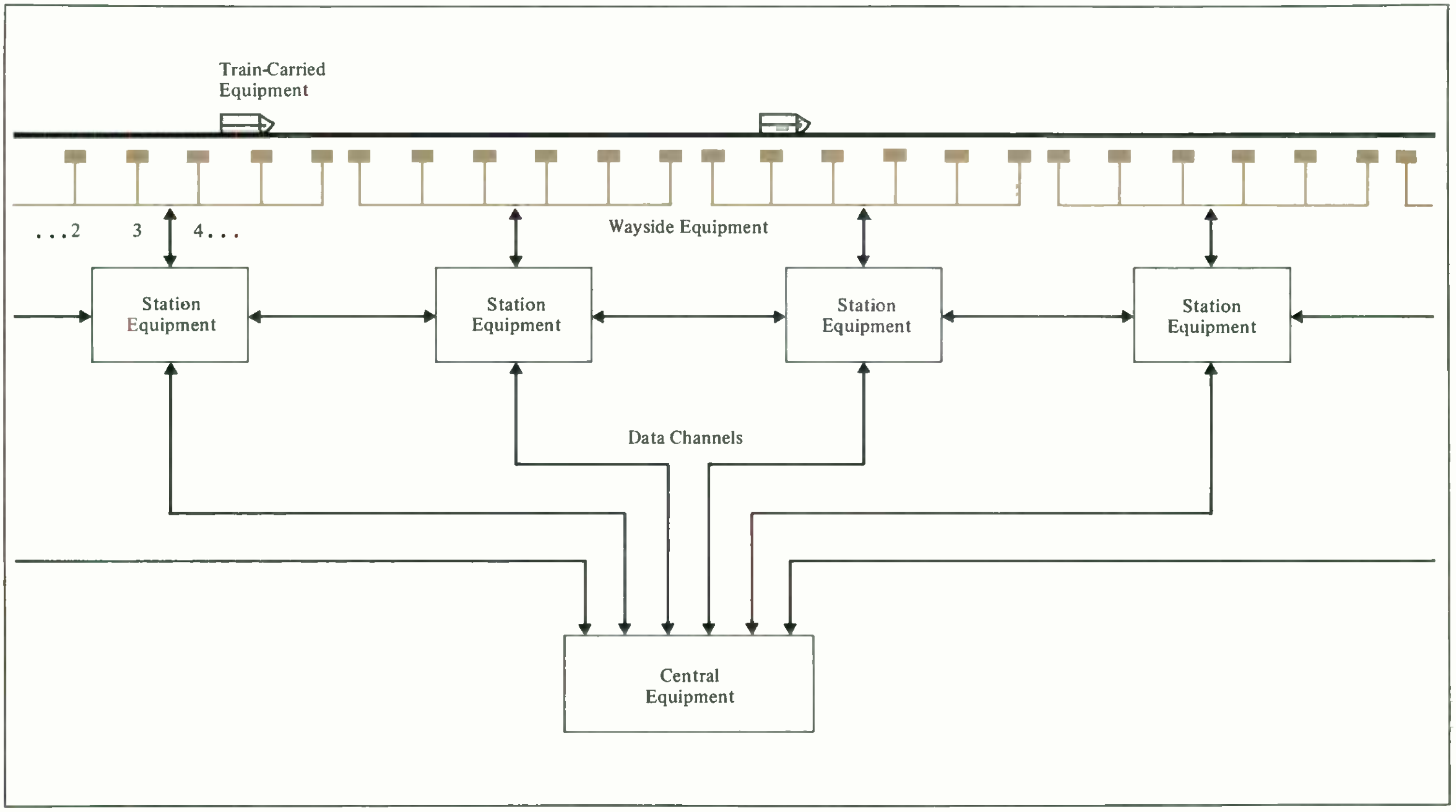
1—Control equipment for automatic train operation in a system such as BART consists of local (train-carried, wayside, station) and central equipment. The former detects trains, determines what each can safely do in its vicinity, and controls each accordingly; the latter monitors and optimizes system operation. Wayside equipments 2, 3, and 4 are numbered here to indicate the relationship between this figure and Fig. 2.



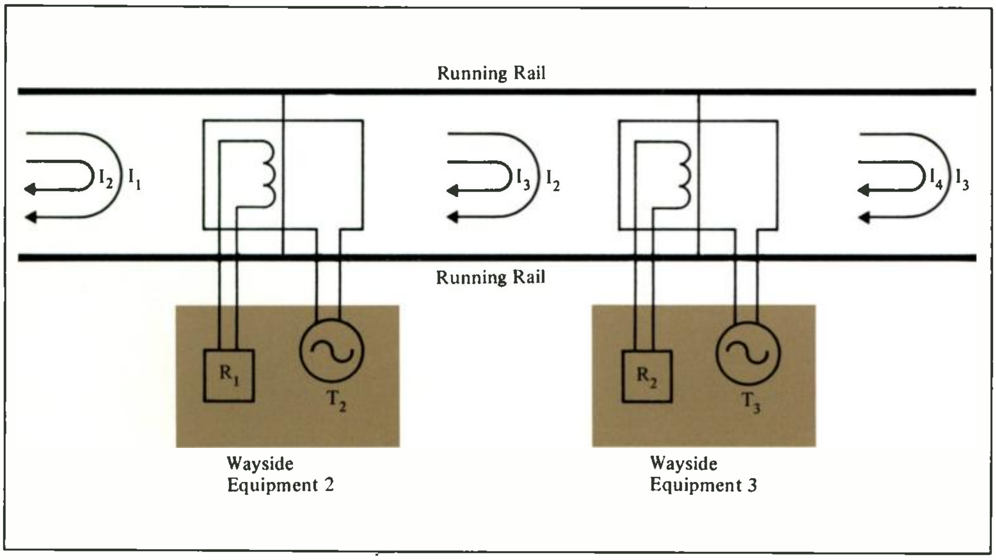
or running rails causes loss of signal and thus indicates the block as occupied, thereby preventing the control equipment from allowing another train into the block. This characteristic is a basic requirement for fail-safety.

At BART, the track is divided into blocks by connecting shunt bars or cables across the running rails at the block boundaries (Fig. 2). A signal used for both detection and control is coupled into the rails at each block boundary by a simple loop arrangement operating as the primary of an air-core transformer. The shunted rails forming the two blocks adjacent to the loop act as a single-turn short-circuited secondary in which the resulting currents flow to be used for detection in one of the blocks and for control in either block, depending on the desired direction of running.

A receiving coil located on the shunt bar at each transmitting location is used to detect the signal from the transmitter at the opposite end of the block and thereby determine occupancy of the block. For example, transmitter T_2 in Fig. 2 causes current I_2 to flow in the rails on either side of it. The current is detected by receiver R_2 to determine occupancy in that block, and it also is used to control any train approaching wayside equipment *2* from either direction.

The shunt bar is at a voltage null for the local transmitting loop, so very little current from the local transmitter flows in it. However, to prevent currents due to unbalance of the local circuit from interfering with the receiver detecting the remote signal, four separate frequency pairs are provided in the system. This signal separation is required to prevent an unsafe condition that could occur if the signal source for one block is incorrectly received by the detection circuitry for another block. Generally only three frequency pairs are used, but the fourth is available to simplify the frequency selection in the areas around switches or where blocks may later be added or removed to alter system operating characteristics.

Moreover, coding the detection signal with speed commands provides much greater signal separation than can be obtained by frequency selection alone. The speed commands are transmitted in the form of six-bit comma-free codes, formed by selection of only those combinations of 1's and 0's that are unique for all cyclic shifts of any code.[1] By cyclically shifting the phase of the code transmitted in successive blocks, the *speed code* information to the train remains unchanged as a unique combination, but the station *detection* equipment can differentiate between the shifted codes received from adjacent transmitters by carrying out a bit-by-bit comparison. Since four sets of carrier frequencies and six speed-command phase shifts are used, it is possible to have a separation of at least 24 track circuits before a given signal could be repeated, thus minimizing the chance that an incorrect detection signal will be received: an improper signal would be attenuated below the receiver threshold before it could travel that distance.



2—For train detection, the BART track is divided into blocks by shunt bars between the rails. Each wayside equipment has a transmitter (T_2 etc.) that induces an electrical signal (I_2 etc.) in the running rails at block boundaries. The signal is picked up by a receiver (R_2 etc.) in the wayside equipment at the opposite end of the block. A train is detected when it enters the block and short circuits the signal, preventing the signal from reaching the receiver. The same signal is used to convey speed control commands to the trains. Signals are distinguished from each other by frequency selection and by coding.

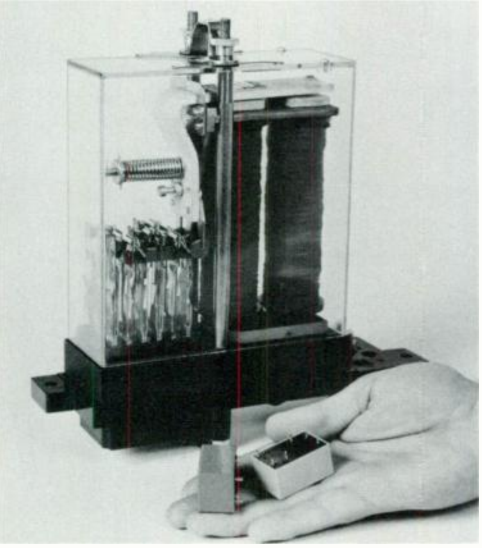
For rubber-tired or air-cushion vehicle systems, the train detection problem is a bit different because the inherent presence of vehicles does not short-circuit any running rails. The method used consists of sending a coded transmission from the rear of the train to the wayside detection equipment. Presence of this signal transfers occupancy from one block to another in the direction of running, so one block cannot be indicated as unoccupied unless the next block has become occupied. Transmission from the rear insures that the rear of a parted train will be detected. Failure of the continuous signal initiates an alarm and the wayside logic maintains an occupied indication in the last previously occupied block, thus preventing a collision from a following train.

Multiplexing—A large amount of "vital information" (controlling the safety of the system) is carried between each wayside equipment location and the station for that area. To minimize cabling requirements, time-division multiplexing is used. Signals and synchronization to and from up to 31 locations can be carried over three pairs of wire, with a fourth pair providing power.

The multiplex system is similar to those used in the telephone industry and elsewhere, except that its function for carrying safety and speed signals requires that it be fail-safe under all conditions. For example, it must not be possible for a short circuit, open circuit, or other possible failure to indicate an unoccupied condition for a block when it is occupied or to allow the speed command for one block to get to another block requiring a more restrictive speed command. The multiplex system design ensures that under all possible failure modes the system will revert to a more restrictive condition, such as indication of occupancy whether or not a train is present and control at a lower speed limit than otherwise required.

Westinghouse has developed a line of solid-state fail-safe logic to perform many of the functions of the relatively cumbersome vital relays conventionally used in railroad and transit signal and control systems (Fig. 3). Their use results in smaller equipment size and weight, lower power consumption, and higher reliability.

Speed Encoding—Speed control signals are generated automatically at the station as a function of occupancy, switch position, speed limit, direction, and other operating requirements. Six-bit comma-free codes can provide up to nine phase-unique signals, which satisfies the requirement for eight speed commands ranging from 0 to 80 mi/h at BART. Six repetitive pulse signals, each corresponding to a particular bit position in the speed code, are provided as the building blocks for the speed encoding equipment. Fail-safe electronic gates combine these repetitive pulses into speed codes which are selected to be sent to each track circuit according to its predetermined operating requirements and logic inputs. The BART system contains approximately 1700 track circuits, each of which can transmit any of the eight speed commands.



3—Small solid-state logic circuits (foreground) perform many of the fail-safe functions of the much larger vital relays (background) used in conventional railroad signal and control systems. They are applied on trains and in wayside and station equipment.

The speed command code for each block is sent from the station to the appropriate wayside controller, where it is frequency-shift modulated onto the appropriate audio frequencies, amplified, and coupled to the track. In addition, at the station the code is compared bit by bit with the code returned from the receiver at the remote end of the block to determine whether or not the block is occupied. That information is used as one of the controls for the speed encoding equipment.

Train Operation

Speed Regulation—Receiving coils located on the vehicle, above the rails and just ahead of the front wheels, pick up the speed command signals generated at the wayside. The signals are filtered, amplified, limited, demodulated, and digitally decoded to determine which of the available speed commands is being transmitted (Fig. 4).

To optimize system operation, performance adjustments can be commanded to the train at each station. The speed commands, then, represent the *maximum* speed limit; they are interpreted relative to the performance adjustment to request a running speed. The requested speed interpretation is compared with actual speed as obtained from an axle tachometer. If actual speed is too low, more propulsion is demanded; if it is too high, a suitable amount of braking is initiated. Undesirable repetitive cycling between propulsion and braking is minimized by use of a deadband around the balancing speed, in which no transitions take place. As speed drifts away from the balancing speed due to grades or loads, propulsion or braking is increased continuously to maintain the speed within 2 mi/h.

A continuous trainlined signal called the "P signal" causes all of the powered cars in a train to contribute the same amount of propulsion or braking. Control equipment in each car interprets the P-signal request; it also determines whether braking is to be electrical (by use of the motors as generators), friction braking, or some combination of the two. Parting of the train or malfunction of on-board control equipment opens the P-signal trainline and causes a full braking request.

Propulsion and Braking Control—Acceleration is a function of the amount of current supplied to the motors. Thus, it can be controlled by various combinations of motor and resistor connections, or it can be controlled continuously by modulating the current on and off at a high rate with a variable duty cycle. The latter method is performed by a solid-state control system known as a chopper, which can be controlled continuously from full power to full electrical braking for the smooth and accurate operation required in a modern automatic system. It is the type used in the BART system.

Slip-slide protection is required on steel-wheel steel-rail systems, where tractive effort may exceed adhesion. Slipping or sliding wheels damage both wheels and rails as well as reducing the effectiveness of propulsion or braking. Equipment that detects these conditions is used to remove the command for propulsion or braking until the situation is corrected.[2]

Rubber-tired systems generally do not require slip-slide control because the desired acceleration and braking rates are limited by passenger-comfort criteria and are well within the adhesion limits. Even on glare ice, for example, rubber tires can provide a braking rate of approximately 2 mi/h/s without skidding.

Braking is provided in response to the P signal by electrical and friction braking, with the majority being electrical. Friction braking is used to make up any difference between the brake request and the amount provided electrically; the blending of the two is controlled electronically to provide a constant net result. Friction braking generally occurs only at low speeds (when the motors are turning too slowly to generate enough power for braking) or under electrical failure conditions. Restricting the use of friction brakes in this way minimizes wear and maintenance on them. The response of the braking system is made extremely fast so that accurate stops can be made with the programmed stopping system.

Programmed Stopping — Station stops must be made at a high average deceleration to minimize time and headways. However, passenger comfort must not be degraded by a deceleration rate that is too high, by changes in deceleration rate while trying to maintain a predetermined stopping profile (speed/distance pattern), or by a final stopping jerk. In systems where station platforms have doors to conserve heating and air conditioning, the stopping point must be accurate within inches to align vehicle and platform doors.

The basic requirements of programmed stopping equipment are to determine the velocity and position of the train with respect to the final stopping point and to use that information to control propulsion and braking. Although it is possible to obtain general velocity and position information from wheel rotation, variations in wheel diameter and adhesion can cause cumulative errors affecting the speed, accuracy, and comfort of the stop. Therefore, Westinghouse systems determine position by counting transpositions in a wayside cable located in the station area (Fig. 4). The method gives absolute position regardless of size or sliding of wheels. The time derivative of distance provides an accurate measure of velocity, again independent of wheel effects.

The wayside transposed cable consists of two parallel wires spaced two inches apart and transposed every 12 inches. It extends along the track through the entire final stopping distance, where the speed is 36 mi/h or less. It is energized with a constant ac carrier that is detected on the vehicle by coils coupled inductively to the cable. Two receiving channels are used, with the receiving coils for each longitudinally separated by 6 inches. The signals are separately filtered, amplified, and then compared in a phase detector. As the train moves along the transposed cable, the signals received on board change phase every 6 inches, thereby providing position information to that accuracy. The number of cycles of a high-frequency crystal oscillator counted between phase changes determines average velocity over the 6 inches. This position and velocity information is then processed by a small on-board programmed-stop computer to determine the required braking effort.

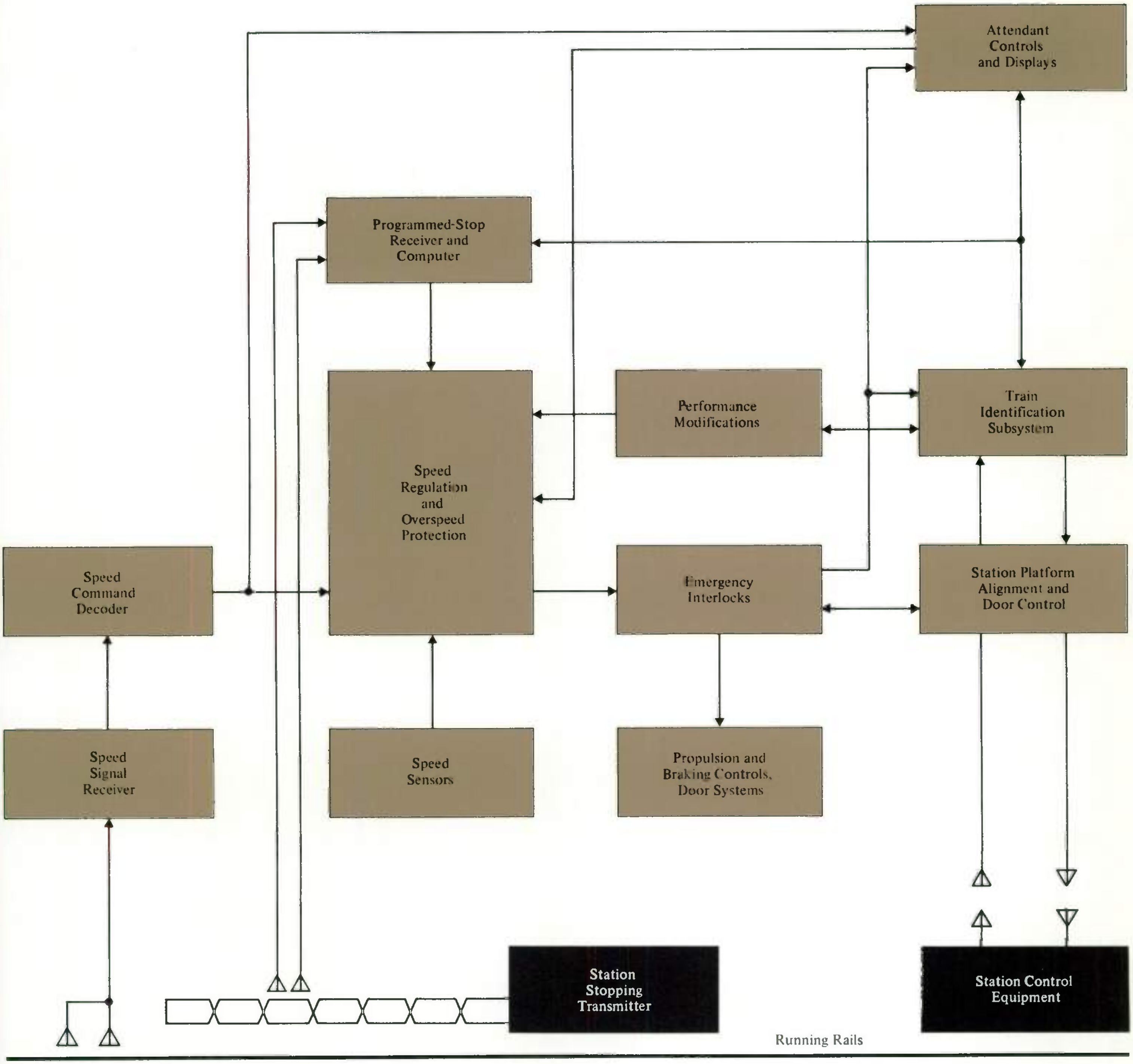
The ideal theoretical stopping profile (Fig. 5a) consists of a flare-in portion (where the initial condition is gradually changed to the stopping deceleration), the stopping deceleration, and the flare-out (where the stopping deceleration is gradually reduced to zero at the end of the stop to eliminate the final jerk). Since the train can approach the stopping profile with a wide range of initial velocity and acceleration, the actual point of flare-in can vary considerably. Therefore, the programmed-stop computer first analyzes velocity and acceleration to determine the transition point at which flare-in must occur to provide an optimum stopping profile.

For the final stop, attempting to maintain a predetermined stopping profile such as that in Fig. 5a could cause passenger discomfort resulting from high momentary deceleration rates to correct for speed or position errors within the practical equipment tolerances (Fig. 5b). Consequently, the Westinghouse programmed-stop computer calculates what new profile is needed at each update point to achieve an accurate stop from that position and velocity (Fig. 5c). Since the profile is calculated at update points every 6 inches, the stop is extremely smooth and accurate. Actual operation shows the stopping accuracy to have a standard deviation of ±2.5 inches under varying conditions of train weight, train length, brake coefficient of friction, grade, and instrumentation errors. Because digital calculation is used, no adjustments are required to initially or consistently achieve this accuracy. The equipment can, of course, be programmed to stop in different positions (for example, to center various length trains on a station platform) or to reduce deceleration demand under poor conditions of wheel adhesion.

The train-carried programmed stop equipment consists of eight printed-circuit boards. It calculates the required deceleration according to the equation $V^2/2d$, where V is the present velocity and d is the distance to go to a reference target point located a few feet closer than the actual stopping point. With those few feet to go, the calculation for the required deceleration is changed to $2V^2/3d'$, where d' is the distance to the actual stopping point. This expression represents deceleration at a constant jerk, and it eliminates the final jerk at the moment of stop by gradually reducing deceleration to zero as velocity approaches zero. The distance at which flare-out is initiated is determined by the point at which the two equations are tangent for the desired jerk limit. In practice, it is sufficient to switch over to a reduced (but nonzero) deceleration signal during the flare-out for final stop. This fixed braking effort also prevents the train from rolling after it has stopped.

Door Controls — Once the train has stopped at the station, automatic door controls cause the doors on the appropriate side of the train to open. To determine that the train has properly berthed at the station before the doors are opened, a set of wayside and vehicle communication antennas located within the acceptable stopping limits must be aligned. In addition, vehicle door controls are interlocked with zero speed to prevent automatic opening before the train has come to a stop.

Opening of the doors initiates operation of a timing circuit that removes the control signals after the preset station dwell time has elapsed. This allows the doors to close unless their "safety edges" strike something; in the event of repeated interruption, an automatic announcement asks the passenger to stand clear of the doors. Once



4—Train-carried control equipment processes signals picked up by three sets of receiving antennas. One antenna set receives speed commands from the running rails; one set receives position information for programmed station stopping from a transposed cable near each station; and one set receives information from wayside transmitters to open the doors at stations, to receive performance modifications that alter the running characteristics, and to modify train identification. A transmitting antenna identifies the train to the wayside, station, and central control equipment.

the doors have fully closed, the train responds to the proceed signal.

Train Identification—An identifying signal containing the train number, length, and destination is continuously transmitted by each train. It is received by wayside equipment in advance of each station and route divergence and at turnback zones (where trains reverse direction). The information is used to control destination signs on the platform, switch positions and routing ahead of the train, and train scheduling from the turnbacks. The signal consists of a 36-bit code providing for up to 999 trains, 50 destinations, and 9 train lengths as well as including synchronization, framing, and error correction information. Its frequency and transmission characteristics are similar to those of the other train control signals.

Interlocking

The basic functions of interlocking are to prevent movement of switches directly in front of or under trains, prevent movement of trains into improperly aligned switches, and prevent movement of trains into conflicting routes. Interlocking techniques using vital relays have been employed by the railroads for many years. The fundamental principles are also used on BART, but they have been improved to satisfy the more stringent operating requirements there.

Ordinarily, the switches in an aligned and locked route can be unlocked once the train has passed through and cleared the switch. This state is determined by observing the consecutive occupancy and unoccupancy of the switch and adjacent areas. But since a momentary detection failure that corrects itself could appear to be a train passing through, the switch could be unlocked and moved in response to another request before the train had actually arrived at the interlocking.

A more positive procedure is to ensure train presence in the switch by an active signal from the train. Only if this signal is received will subsequent unoccupancy allow the switch to be unlocked. If the signal has failed, normal time locking takes effect, which prevents the switch from being moved until an oncoming train has had time to stop or otherwise enter the switch area. This arrangement is used on BART, where the use of time locking under normal nonfailure conditions would unnecessarily increase headways. The authorization used to enable this type of unlocking is the train identification signal, which is transmitted continuously from the train and detected by wayside receivers in the interlocking area.

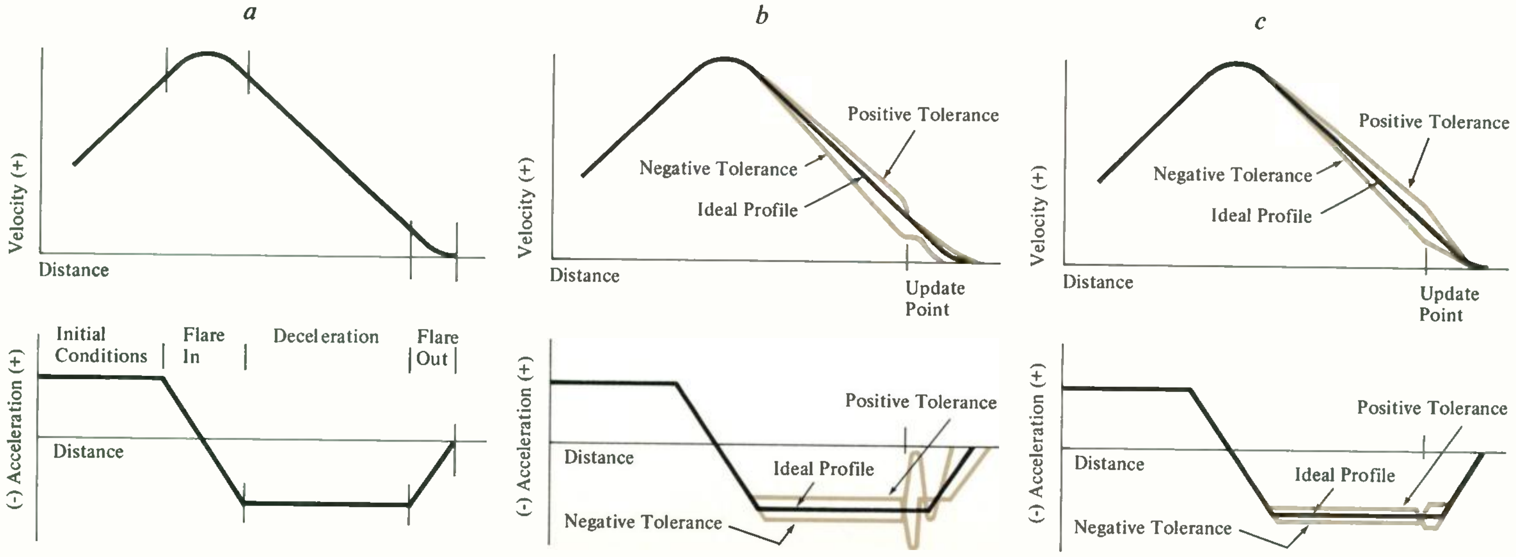
System Operation

Central Supervision—The system described so far would operate fully automatically with complete safety, but it is not the optimum for a large system. Expected delays such as passengers interfering with doors or the lack of an overall control strategy to cope with rush hours, major events, and equipment degradations would cause perturbations. The perturbations could, depending on system size and complexity, grow to major proportions in much the same way that a slight slowdown by a motorist in heavy freeway traffic can cause a major traffic jam behind him.

Overall system optimization is provided at BART by a large central computer that, along with a backup unit, monitors system operation and calls up various corrective strategies when required.[3, 4] These strategies include changing system capacity, modifying dwell times, modifying run times, and providing service around a disabled train or section of track. The computer also controls system display boards (Fig. 6). In addition, it monitors and keeps records on various aspects of the system not directly related to automatic train control.

A completely automated transit system operates much the same as an automatic telephone exchange, i.e., without human intervention under normal and some anticipated abnormal conditions. Manual inputs and controls are used if necessary to modify the existing operation or to operate the system during an unanticipated situation.

Information to and from the computer and all local data terminals at BART is carried by high-speed telemetry equipment, which allows the central equipment to monitor each of 8000 items at least once a

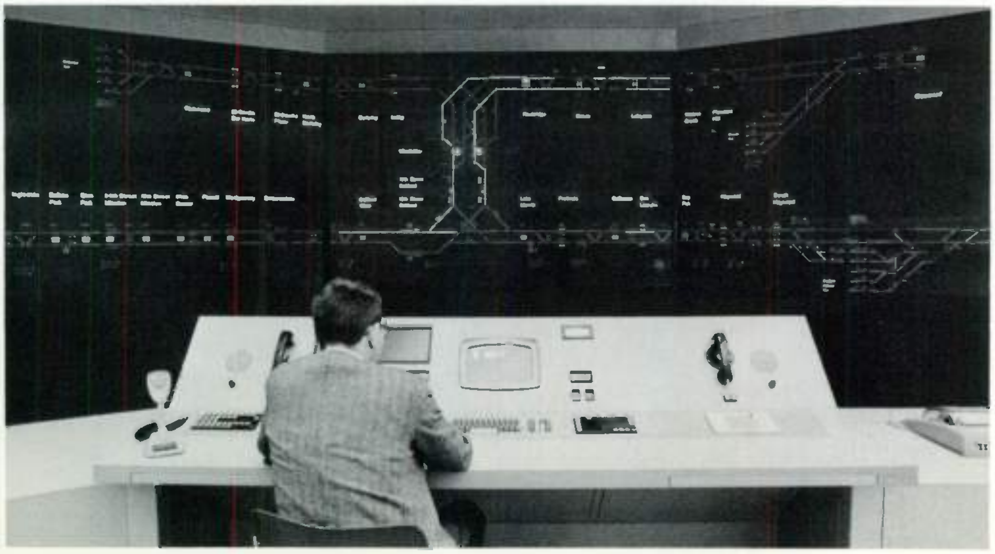


second. Smaller systems do not require this supervisory capacity and consequently are considerably simpler; in many systems a computer is not even needed for train control optimization, although it can always be so used if it is available. In no case, however, does the computer or its associated equipment enter into the safety of the system. That is controlled by the local safety equipment, which can be influenced by the computer only in the safe direction.

Passenger Aids—An automatic system provides opportunities to add a number of passenger aids relatively simply. For example, the identification information transmitted by the train for routing is also used to indicate the destination of the train approaching the platform. Train length information can indicate the precise location of doors when the train stops. The signals that control the doors can also initiate recorded announcements or animated graphics and maps on the vehicle. Central supervision provides immediate information on schedule changes, delays, and so on that can be coordinated with platform indications.

5—(Below left) *An ideal programmed stop* (a) *would halt the train without jerk and without position error. In practice, however, tolerance errors in the equipment prevent attainment of such accuracy. A stopping system could get back to the predetermined profile at update points, but it would cause uncomfortable jerks* (b). *Instead, the Westinghouse programmed-stop computer generates a new profile at the update point to achieve an accurate and comfortable stop* (c). *Only one update point is illustrated; in practice, there is one every 6 inches.*

6—(Below) *System display boards at BART provide information on train positions, routes, and other data. They are controlled by the central equipment, which also includes a large computer that monitors and optimizes system operation.*



As with modern automatic elevators, an on-board train attendant is not required. Automation provides a higher degree of service, reliability, and safety than could be provided by a human operator.

On centrally supervised systems, one person can monitor all trains on a system to cope with any breakdowns. Emergency situations on the track are minimized by such means as fail-safe equipment, exclusive protected rights of way, and hazard detectors. Any social problems on the train should be handled by the police rather than by railroad personnel. However, two-way voice communication between trains and the central dispatcher is desirable to provide the capability of handling situations that do require personal attention. These include giving instructions to passengers under unusual conditions and allowing passengers to report problems.

Conclusion

Many or all of the functions presently performed by operators on transit systems can be controlled automatically, efficiently, and safely by application of new equipment and techniques to established concepts. Since even the most reliable equipment can eventually fail, Westinghouse automatic train control equipment is so designed that failures cannot cause the system to operate in an unsafe mode.

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What Are the Prospects for Substation-Computer Relaying?

G. D. Rockefeller

An experimental substation-computer relaying system designated Prodar 70 has been on test at Pacific Gas and Electric's Tesla terminal since February 1971. This joint P G & E/Westinghouse project was designed to verify technical feasibility of digital computer relaying. Although results to date are promising, much further effort will be required before theory can be reduced to practicable hardware.

Although substation computers do not yet handle protective-relaying functions, experience with the experimental Prodar 70 system[1,2] is proving the technical feasibility of performing high-speed fault protection with a stored-program digital computer. As computer hardware costs continue to decrease and relaying sophistication rises, economic feasibility of the computer approach seems inevitable some day. But when?

This question leads to other pivotal considerations: Can hardware costs be spread among the various relaying tasks within the substation, or shared with non-protective functions? Will users allow credit for added values offered by the computer? Do digital computers provide adequate reliability for relaying? Can software costs be spread among various installations?

The IEEE Power System Relaying Committee is grappling with these questions with the hope of contributing to the orderly marriage of the computer and relaying disciplines.

Early Work

One of the earliest theoretical studies[3] considered a computer relaying system performing all substation protection—for lines, buses, and transformers—with a single computer processing *instantaneous* values of ac currents and voltages (sampled every 0.5 millisecond). Unfortunately, as the relaying task was organized for that study, modern general-purpose computers would have been at least one order of magnitude too slow! Conventional relays do an enormous amount of parallel processing in a short time during a power system fault. The study indicated that further effort on hardware and programming would be required before computers could emulate the simultaneous processing achieved with conventional hardware. The Prodar 70 experimental system is now testing some of the first developmental efforts in adapting digital computers to the protective relaying application.

Prodar 70 Project

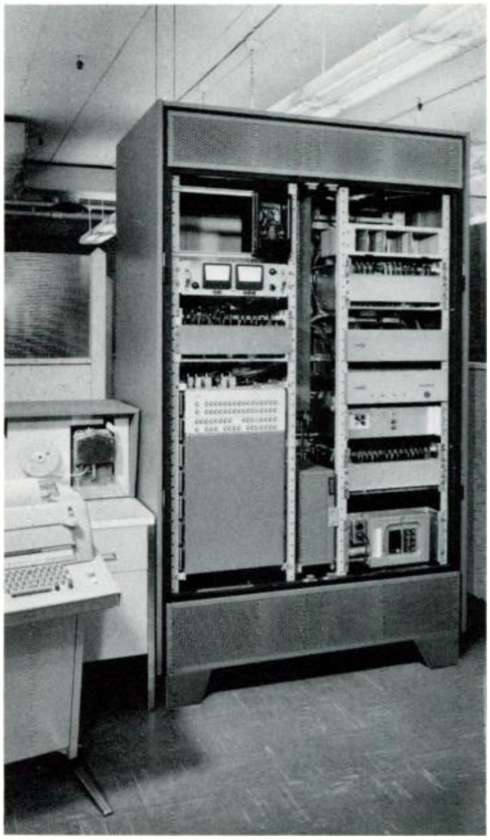
Prodar 70 is a time-shared process-control digital computer system designed to provide high-speed phase- and ground-distance fault protection for a single transmission line. The equipment function compares with conventional three-zone phase- and ground-distance relays.

Major components of the system include a Westinghouse P-2000 process control computer, an analog signal-conditioning package, a medium-speed multiplexer-digitizer, a data buffer interface, and an analog-to-digital control unit (Fig. 1). A stored computer program performs all of the relaying functions by processing sampled values of currents and voltages, input to the computer via an analog-to-digital converter.

The Prodar 70 hardware was initially checked as a system in the laboratory on a 600-volt miniature power system. Simulated tests included line energizing, out-of-step conditions, and faults. A series capacitor in the model power system also permitted the program to be checked for proper directional sensing for capacitive faults.

Those laboratory tests tended to prove the technical feasibility of the concept, and its performance was found to compare favorably with that of conventional electromechanical and solid-state relays. Thus, while the experimental system had obvious deficiencies and limitations, field evaluation was justified.

The Prodar 70 relaying system was placed in experimental service in February 1971 on the Tesla terminal of a 38-mile 230-kV line on the Pacific Gas & Electric system.



1—The Prodar 70 computer system hardware is shown during laboratory tests prior to its installation on the Pacific Gas and Electric Company's system. The computer main frame occupies the lower half of the left-hand side of the cabinet. The cabinet also houses input/output panels and peripheral gear required for the relaying application.

2—(Right) *Experimental installation of Prodar 70 computer system on 230-kV transmission line.*

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The major components and subsystems of the Prodar installation are shown in Fig. 2. The analog-to-digital converter reads the *instantaneous* value of each ac signal every 1.33 milliseconds (ms). The P-2000 computer stores the data and examines it for a power-system disturbance. When conditions are normal, the computer proceeds to nonprotective tasks, such as diagnostic programs to check for a hardware failure. When a disturbance is detected, elaborate distance-relay logic looks for trouble on the protected line. If the fault is found to be on the protected line, the computer provides a breaker trip output (which in this installation connects only to an automatic oscillograph for monitoring). The analog-to-digital input data is stored and processed during the fault, and output to a paper-tape punch for later off-line analysis. Significant software events related to each disturbance are logged on the typewriter.

The Prodar 70 system's performance has exceeded expectations based on experience with conventional relaying systems at a comparable stage of development. There have been no false breaker trip outputs. The system has functioned properly during two internal and 37 external faults. For the only zone-1 fault encountered thus far, the computer "tripped" in 23 ms, as compared with 39 ms required for conventional electromechanical relays. The only hardware problem during over two years of combined laboratory and field service was a main-frame failure during very hot weather, when the ambient temperature near the main frame may have exceeded its 55-degrees-C rating.

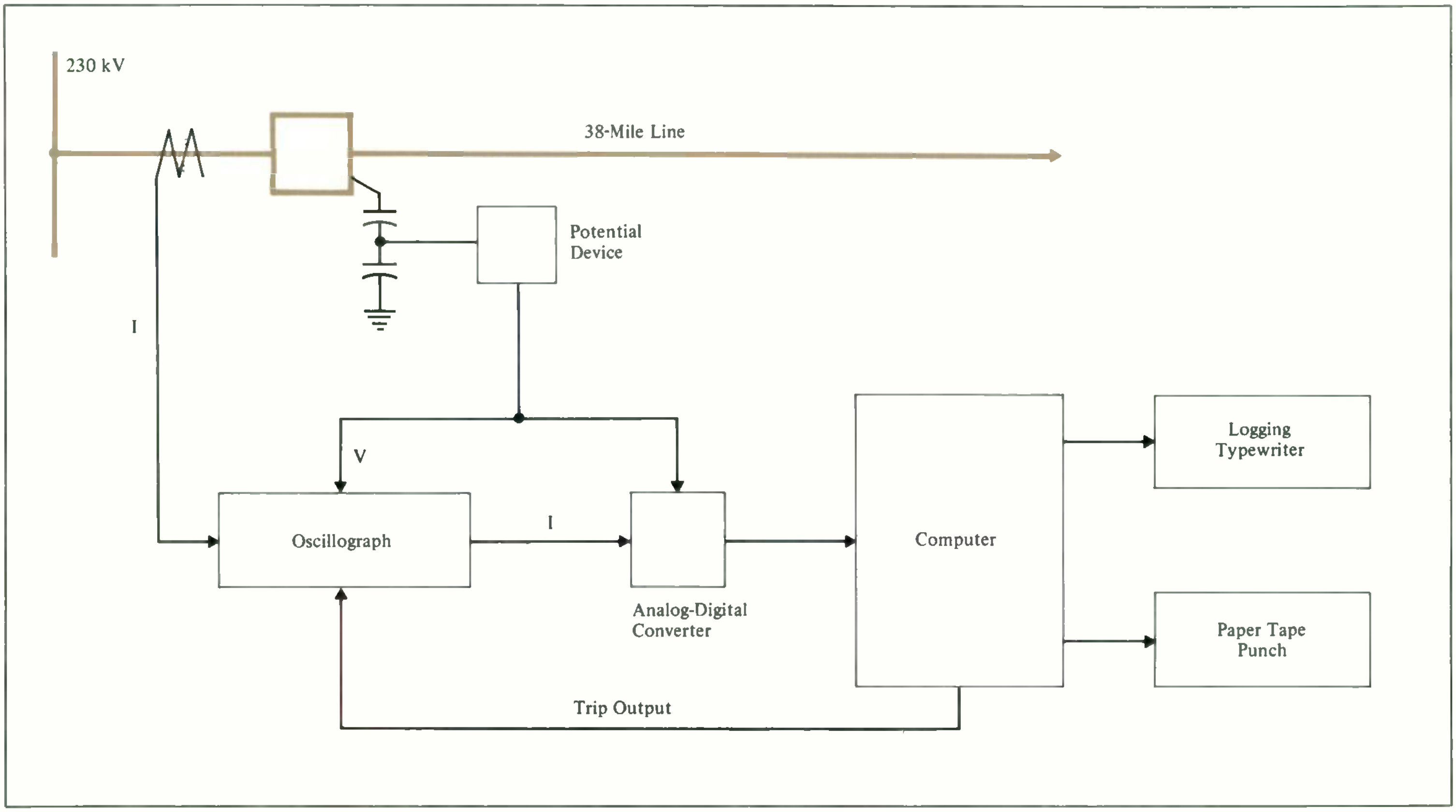
Thus, operating performance of Prodar 70 has been outstanding. Unfortunately, Prodar 70 cost is an order of magnitude higher than the relays it would replace, although the project has never focused on minimizing costs. A major economic breakthrough will be required before computer relaying can be competitive. What can be done to achieve this breakthrough?

Combining Substation Functions

Since much of the information gathered for data acquisition and control is also sensed by protective relays, the merger of the relaying function with the control and data acquisition functions seems technically logical. Nonprotective jobs can be delayed several seconds when the computer is required to perform relaying tasks, so control and data functions can easily time-share computer hardware with the relaying function. Thus, although the critical role of protective relaying has historically set it apart from other substation functions, growing sophistication in computer hardware and its application can eventually lead to the amalgamation of all computer-performed functions. From an economic standpoint, that merger may be an essential step to making computer relaying competitive with conventional hardware.

A Single Main Substation Computer?

To sense and locate faults, conventional protective relays employ various analog processes operating simultaneously: level detection of abnormally high current, low frequency, or low voltage; magnitude com-



parison of voltage and current; and phase-angle comparison of voltage and current. All of those analog processes can be approximated digitally—but the step-by-step nature of the digital computer requires information processing procedures that are inherently serial rather than parallel. Thus, the substitution of a serialized digital processing program for many parallel-operating analog devices will consume time, even with the fastest digital computers.

One approach to minimizing computer time requirements is to develop digital processes that can shortcut the one-for-one duplication of analog processes, yet yield the necessary information for relaying purposes.[1,4,5] For example, the Prodar 70 program does not match the separate signal processing found in each of the three distance zones of conventional relays. Instead, it calculates the apparent line impedance to the fault—a single set of processing—and successively compares the result to stored limits representing the R-X characteristics for the three distance zones. There is every reason to believe that many more techniques of this type will be developed as more experience is gained with computer relaying.

Another basic approach is to organize the data-gathering process with "analog interface" hardware that can relieve the computer of some of its information processing chores (Fig. 3). In its simplest form, conventional fault-detector hardware could interrupt control and data-acquisition tasks only when a disturbance occurs. However, this approach would leave a considerable processing burden with the computer because it would still have to process raw ac data to determine which line or apparatus is faulted.

In a more complex version, the analog interface could perform all sensing and phasor manipulation, relegating to the computer only the digital logic and timing tasks for protective relaying. In this case, the computer would replace a relatively small part of the dedicated relay hardware, and the computer system would have to justify itself primarily on the basis of its control and data-acquisition functions.

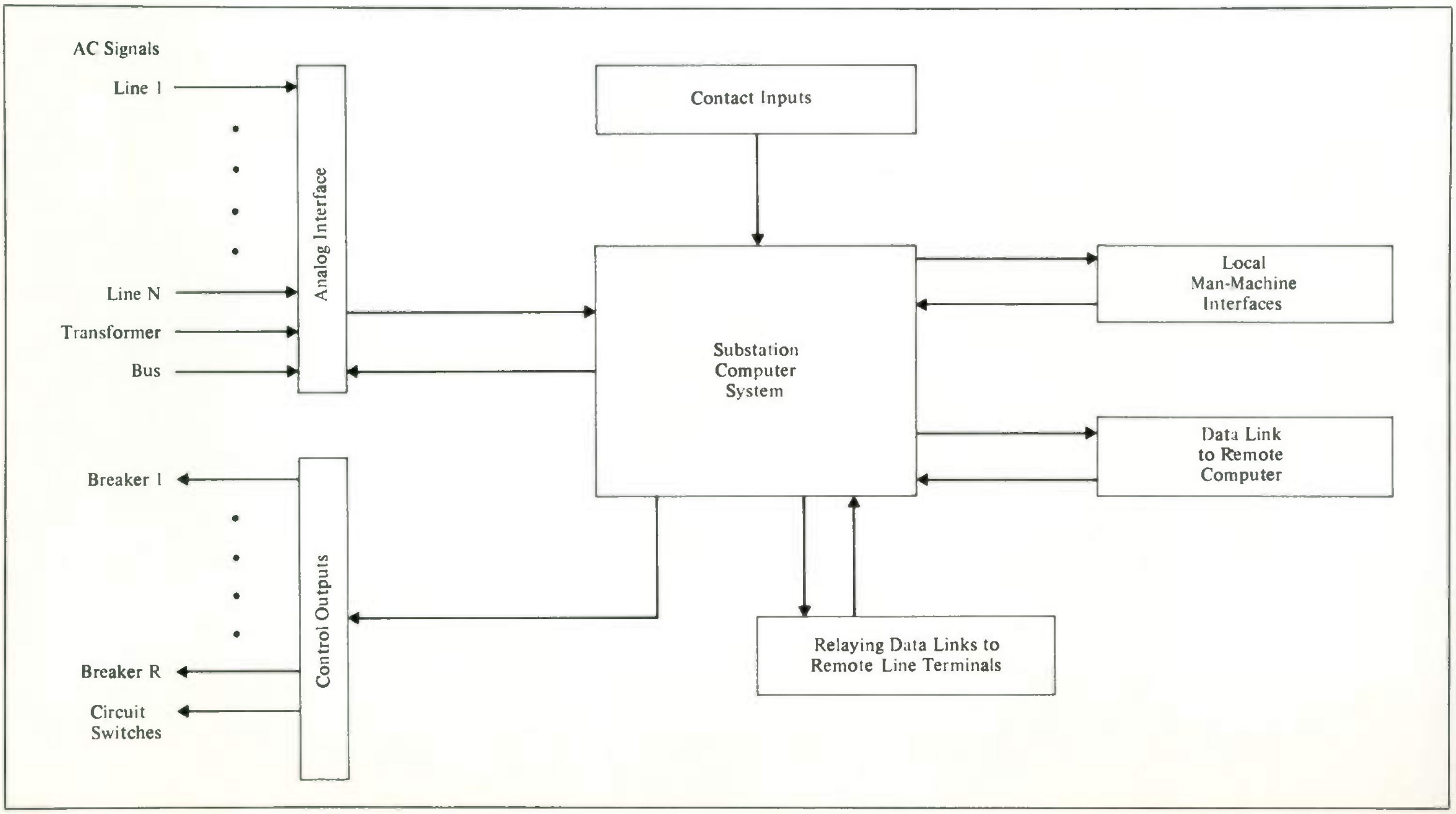
Or Computer Island Complexes?

Rather than confine all information processing to a single main substation computer, the processing chores could be divided among several smaller computers (islands) within the substation (Fig. 4). Island complexes would probably require more hardware than a single computer, but the equipment would be much closer to the monitored ac signals and to the apparatus being controlled. This proximity would cut control cable costs substantially, and reduce current-transformer burden and surge exposure. Furthermore, failure of an island computer would involve only a portion of the station.

Either a main substation computer or island computers should perform both protective and nonprotective tasks, with the

3—(Left) *Centralized system for substation protection, and control and data acquisition, uses a single computer.*

4—(Right) *Several computer island complexes within a substation may reduce control cable costs and eliminate reliance on a single computer.*



analog interface consisting of analog-to-digital converters and other specialized hardware to ease the computer's processing burden. The island concept involves decentralization of both control and protection functions. If, for example, the station contains three voltage levels, a separate complex could be built for each level.

The ultimate in islanding would be a computer system dedicated to each line (or bus or transformer). In this case, the computer would not have to identify the area or zone of the fault, so a faster and simpler computer program would result, and a misoperation would cause a minimum number of undesirable breaker trips. Also, single-line equipment would be inherently modular, so that substation expansion could be easily accommodated by adding another computer module each time a transmission line is added. On the other hand, equipment savings accrue with larger computer complexes because arithmetic and memory hardware can be shared. Larger complexes may also simplify interfacing with the control and data-acquisition functions because the connections would not be scattered among so many relay equipment locations.

Computer Advantages and Disadvantages

While the computer promises a number of advantages, some of which will not be apparent until its technology is assimilated into the relaying art, none of them will sell the computer until it is economically competitive and as reliable as conventional relays. Nevertheless, what are some of the advantages foreseen?

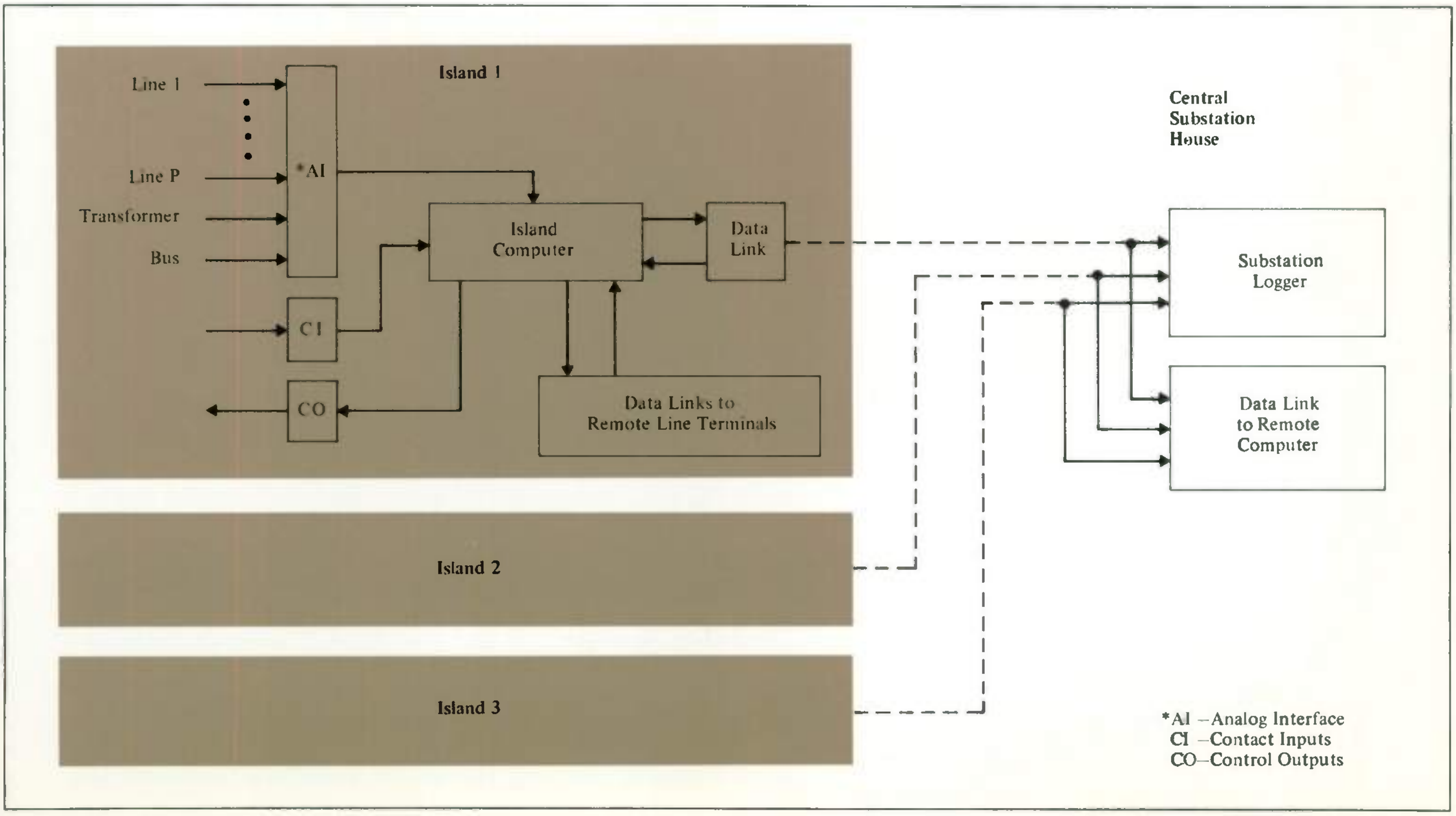
First, the computer offers a large writable memory with a fixed hardware configuration, a combination that provides great flexibility. "Relay settings" in memory can be readily modified (rewritten) under local or remote computer control or manually. Adaptive settings responsive to system switching or generation changes would improve relay performance. Writable memory also facilitates the customizing of the protection scheme to suit the needs of the installation and the utility's preferences. Furthermore, substantial cost saving could result from eliminating the need for relay technicians to go to the stations to change settings as the power system configuration evolves.

Second, with the capability of assimilating and processing massive amounts of information, the computer may provide greater sophistication and faster trip speeds than conventional hardware can achieve at reasonable cost.

Third, much of the computer hardware can be readily self-monitored with diagnostic programs, an important advantage because relaying equipment remains idle virtually 100 percent of its life.

What about the computer's disadvantages? Its most serious technical problems concern time requirements for processing. Present minicomputers do not offer parallel processors—they perform only one arithmetic or logic operation at a time. This makes it difficult, even with submicrosecond memory cycles, to match the speed of modern solid-state relays that are characterized by many parallel operations.

Another disadvantage is the rapid obsolesence of hardware that makes it difficult



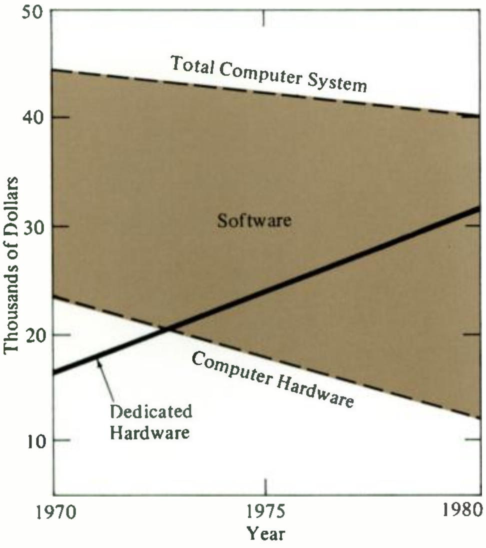
for a user to keep up with equipment developments, particularly in a low-volume activity such as relaying.

The computer system, from both a hardware and software viewpoint, represents a radical departure from conventional relaying practices; computers are more difficult for the user to operate and maintain, and, since they must frequently be located at great distances from population centers, maintenance services may not be readily available.

And as with the computer's advantages, some of its disadvantages will only become apparent with extensive application.

Computer Economics

The continuing pressure for improved power system reliability will continue to increase relaying sophistication and complexity; moreover, higher power system voltages introduce additional relaying problems and further accelerate that trend, all of which is reflected in the steadily increasing costs projected for conventional relaying hardware (Fig. 5).



5—Economic justification of computer relaying by 1980 will require substantial credit by the user for added or future values not provided by dedicated relay hardware.

In contrast with relaying hardware, the cost of computer hardware is steadily dropping. For example, the increasingly attractive prices quoted for minicomputers today attest to improvements in large-scale-integration technology. However, a minicomputer alone (particularly one with only 4K of memory) does not make a sophisticated relaying system in itself, and considerable additional hardware is needed. Furthermore, a computer system would not be inexpensive even if hardware costs could be completely neglected, because good programs can be written only by highly skilled personnel. Fortunately, advances in software know-how help offset the increasing sophistication required in relay computer programs, so the total cost of a computer relaying system should continue to decrease with time.

The importance of software costs is indicated in Fig. 5, even though the basis for the specific values shown on the axes is somewhat nebulous. To the extent that software costs may be spread among a number of installations, the crossover date when computers become less expensive than dedicated hardware may be accelerated. Credit for added values offered by computers could likewise hasten the day of economic competitiveness.

Computer Relaying Reliability

Quantitative reliability comparisons between computer and conventional relay systems do not necessarily yield meaningful results. Computer hardware statistics relate to failure to function, but a computer component failure per se does not necessarily enter relaying reliability statistics. If a hardware "failure" between maintenance inspections does not result in undesired breaker trip or does not interfere with a desired breaker trip, it has not affected relaying reliability. On the other hand, a relaying "failure" could occur with no computer hardware failure, due to relaying system design limitations or setting errors that cause undesired breaker operation (or lack of operation). Programming errors or limitations could also contribute to relaying system "failures." Thus, software reliability is just as important as hardware reliability, and both must be assessed in any overall evaluation of system reliability.

Probably the most effective means for reliability comparisons are experimental systems such as the Prodar 70 installation, where the computer faces the same operational conditions as conventional relaying devices.

Summary

The Prodar 70 experience has shown encouraging promise for the computer's ability to provide on-line high-speed fault protection. However, much work and study lie ahead before the pioneering effort of the Prodar 70 installation can be converted into practical competitive relay systems. The industry, particularly through the IEEE, will continue such practical evaluations to aid the orderly assimilation of this new tool into the relaying art.

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Pressure-Chamber Tests of *Deepstar* Simulate 2300-Foot Dive

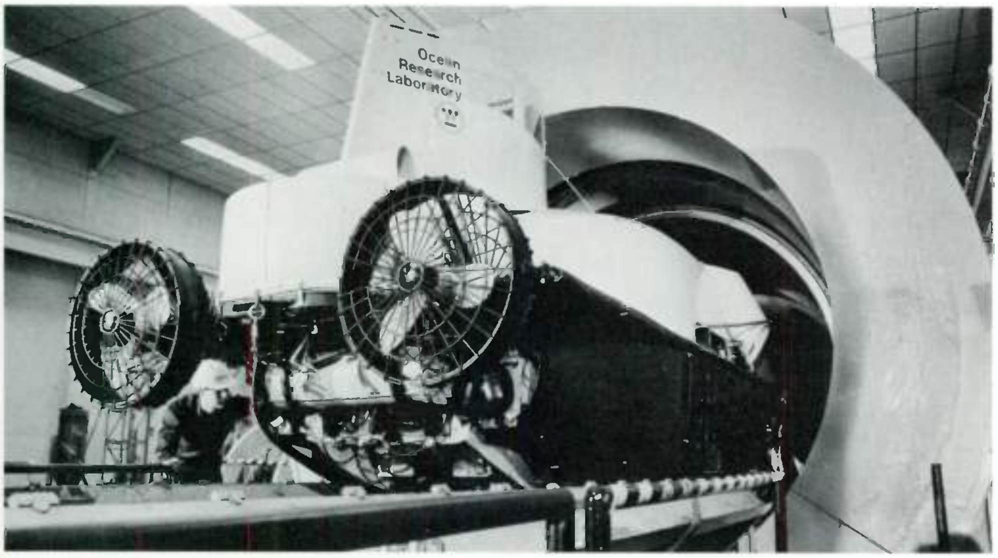
The dive-worthiness of *Deepstar 2000*, a Westinghouse research submersible, was tested recently at the U. S. Navy's Ocean Environment Simulation Facility to assure the safety of its three-man crew in upcoming dives. It was the first time a complete manned submersible had been checked out in a pressure chamber.

The *Deepstar* had completed 55 dives, most recently in the San Diego Trench during September 1970. The vessel was then transported to Annapolis, Maryland, to be reactivated and tested for dives that are scheduled for the Atlantic continental shelf this year.

Both unmanned and manned tests of the submersible were made in the large pressure chamber (10-foot inside diameter) of the simulation facility, which is part of the Underwater Systems Branch of the Naval Ship Research and Development Center in Annapolis. To simulate a 2300-foot dive, the water-filled chamber was pressurized to 1000 lb/in^2.

The first test was unmanned and used leakage detectors inside the pressure hull to test hull integrity. During the second test, three crew members were in the submersible to operate its systems. (If an emergency situation had developed, the water inside the chamber could have been dumped in less than two minutes.) All of the *Deepstar's* systems were checked for proper operation; they include life support systems, primary and backup communications, closed-circuit television, and photographic equipment. The tests were sponsored by the Westinghouse Ocean Research Laboratory.

Deepstar 2000 was built at the Westinghouse Ocean Research and Engineering Center near Annapolis. It has been used for geological, biological, physical, and chemical research in the ocean and as a test bed for prototype instrumentation. The submersible is 20 feet long, 7 feet wide, and capable of carrying two scientists and a pilot to depths of at least 2000 feet. It can operate for as long as 8 hours with a maximum cruising speed of 3 knots.



Deepstar 2000, *a research submersible, was placed in a pressure chamber for unmanned and manned tests of hull integrity and dive-worthiness. The pressure chamber is part of the Navy's Ocean Environment Simulation Facility.*

Large Stop Valves Serve PWR Primary Loops

Stop valves are often included in the primary coolant loops of pressurized-water nuclear reactor systems. They permit isolation of the coolant pump and steam generator from the reactor so that maintenance can be performed on those components without having to drain the entire reactor system.

When a utility elects to include isolation valves in a Westinghouse reactor system, two of them are provided for each primary loop. At the new Zion, Illinois, site of Commonwealth Edison Company, for example, the size of the plant required four loops, so eight valves were needed. The first of two 1040-MWe plants at that site is scheduled for operation by the end of this year. The valve sizes (port diameter) for those plants are 27½-inch for the cold-leg portion of the loop and 29-inch for the hot-leg portion.

Design parameters for a typical 29-inch valve include pressure of 2500 psia and temperature of 650 degrees F, and the valves are designed to provide a minimum of 400 operating cycles over a 40 year lifetime. The flow rating required at the normal operating pressure of 2235 psia is 99,000 gal/min.

The valves must close and seal reliably, they must not jam shut, they must open properly against the system differential pressures, and they must not leak coolant water to the environment. Those requirements are met by a combination of design features in large valves being produced for nuclear plants by the Westinghouse Electro-Mechanical Division.

The valves consist of six major component groups: body and channel-guide assembly, bonnet assembly, disc and stem assembly, packing gland assemblies, yoke, and motor operator. (See next page.)

The disc and stem assembly consists of a gate, having two parallel discs, raised and lowered by the motor-actuated stem to the open and closed positions. The discs are guided in their travel by lugs that slide in channel-shaped guides in the valve body. Springs are used to maintain separation of the discs and provide a seating force in the closed position at low system pressures. At higher pressures, the springs allow system pressure to push the upstream disc off its seat and thus allow pressure to equalize around that disc; system pressure then forces the downstream disc's seating face tightly against a mating seat ring in the body to seal the valve. The springs and guides also insure uniform parallel separation of the discs and thereby help prevent binding and wear during operation.

In the open valve position, which is the normal position during plant operation, primary sealing around the stem is achieved by backseating the conical stem head against the mating surface of a backseat in the bonnet. In this position, the disc gate is contained within the bonnet area, permitting unrestricted water flow through the valve body.

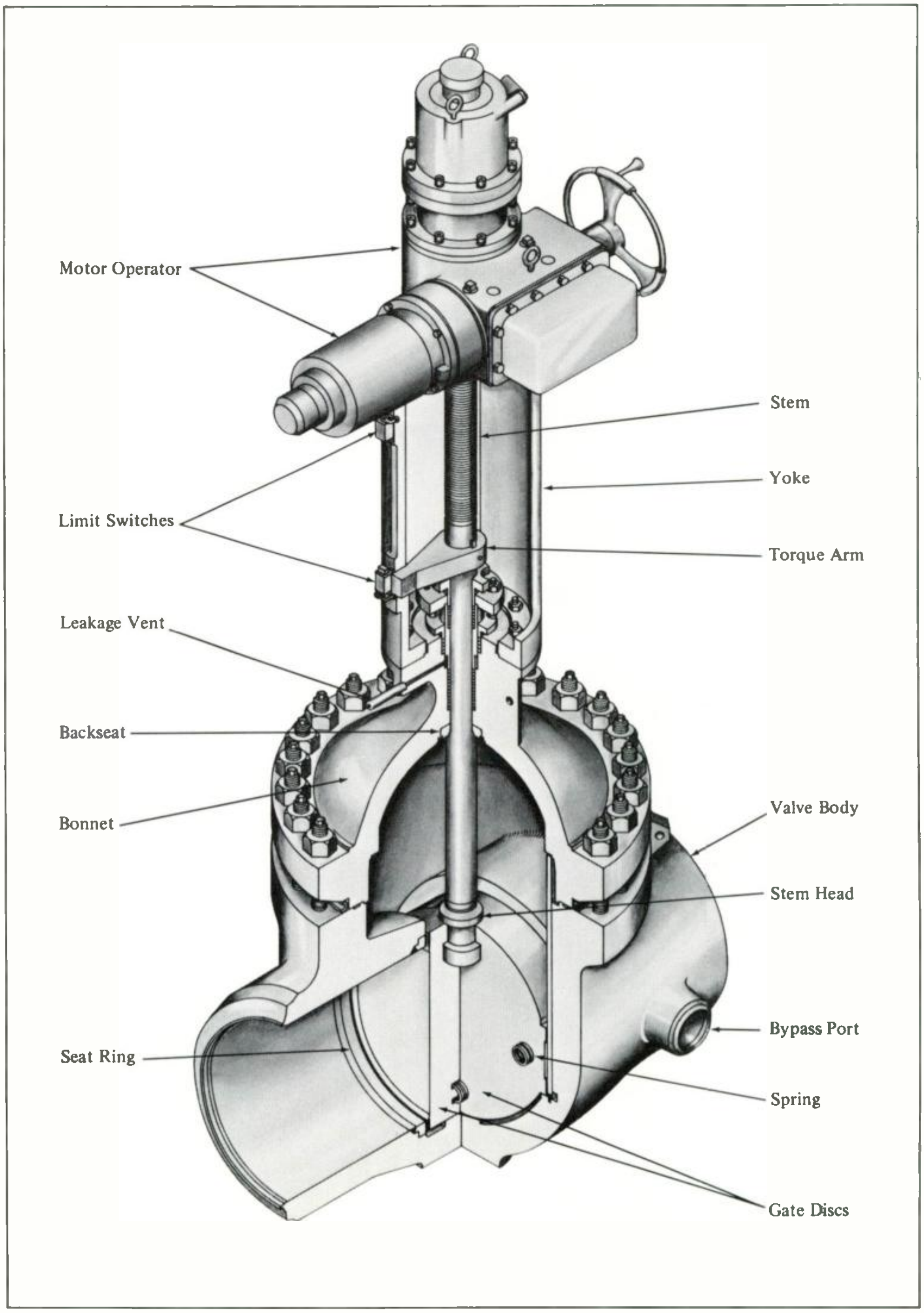
Packing glands and packing around the stem at the bonnet top provide backup sealing around the stem when the stem is in the backseated position and primary sealing when the valve is closed. Any leakage that might get through the packing is vented and accumulated in the waste processing system.

The yoke assembly, installed on the top of the bonnet, provides spacing for the necessary stem travel and mounting for the motor operator.

Stem movement is actuated by a gear nut rotating on a threaded part of the stem. The gear nut is normally driven through a gear train by a totally enclosed nonventilated motor with Class H insulation, but manual operation also is possible by use of a handwheel. Torque imparted to the stem by the gear nut is prevented from reaching the discs by a torque arm that slides vertically in a slot in the yoke; the reaction force on the torque arm is transmitted to the sides of the yoke slot, thus preventing binding and potential wear between disc and seat rings.

Within the motor operator, a double torque switch controls the thrust exerted on the gate discs in both the opening and closing directions. This switch is used to control the backseating of the stem head into the backseat (open position) with a fixed thrust established by design. Also, gate closing force is regulated by this switch. The gate is stopped if the discs encounter an obstacle or if the thrust exceeds the set value.

Limit switches within the motor operator govern the open and closed positions of the gate. They also perform various other control and monitoring functions, such as position indication (open or closed), direction gate is moving, and interconnection with other reactor plant controls. In addition, there are four external limit switches mounted on the yoke (two each at the top and bottom of the yoke slot) that serve as redundant interlocks for reactor system control.



An 8-inch bypass port in the valve body provides for water circulation in that part of a loop that includes the coolant pump and steam generator. The bypass is provided by an interconnecting pipeline between the hot- and cold-leg valves when both valves are closed. This provision permits water in the loop to be heated by circulation, before loop startup, to prevent thermal shock to the valves and other system components.

A vent is provided in the body to relieve pressure that could be caused by water entrapment. Without it, water trapped under pressure inside a closed valve (if loop pressure on either side of the valve drops) could impose loads between discs and seats high enough to prevent opening the valve. In addition, excessive differential pressure could be caused during closure by displacement of water between port sealing and termination of disc movement.

Large stop valves for PWR power plants isolate loops from the reactor when service is required on the loops. They are designed for reliable operation and sealing. The valve in the photograph is of 27½-inch port diameter. Shown being prepared for testing, it has since been installed in Commonwealth Edison's second plant at the Zion, Illinois, site. The two plants there each have eight of the valves.

Modular Construction Facilitates Control-System Packaging

A new form of modular control-system packaging departs from previous methods in which control components were assembled in a room already located at the operation site. Instead, control equipment is assembled in the modules, the equipment is tested with a dynamic simulator, and personnel are trained—all without leaving the factory. Then the modules are shipped to the operation site (without disassembling the control equipment), with the module structures serving both to protect the equipment in transit and to house it when the modules are brought together as a control room at the site. The method was devised and is now being used by the Westinghouse Computer and Instrumentation Division.

The method has two major advantages, both of which mean reduced time and cost to the buyer. First, the assembly, testing, and training take place within easy reach of the resources necessary for such activities, thus avoiding the cost of sending trained men and equipment to the plant site to perform those duties. Second, the control package can be assembled while the foundation pad for the modules is being prepared at the plant site. Final placement of the modules at the site is fast and easy because all control cables and plant electric power cables are of the quick-connect type.

The modules are of steel construction, with rigid frames for the sides, roof, and subflooring. All equipment used is of proven reliability and has merely been extended into the modular concept. Both the modules and the control systems housed in them are adaptable to many control applications.

The first application is a control room for a new Westinghouse PACE power plant in southwestern Oklahoma. PACE (Power at Combined Efficiency) plants are combined-cycle generating units consisting of two gas turbines and a steam turbine. The gas turbines' exhaust heat, otherwise wasted, is utilized to generate steam for the steam turbine. The plants consist largely of predesigned and factory-assembled equipment packages, so design time and field construction are minimized.

Each of the three modules for the PACE control room is 40 feet long by 12 feet wide by 10 feet high. The control system housed in them employs two Prodac-2000 computers. Control equipment, a voltage regulator, and protective relaying are integrated in the system, enabling one operator to control the 260-MW power plant. Control functions include sequencing, reference levels, unit protection, and emergency shutdown.

Products and Services

Hi-Torque adjustable-speed drives consist of solid-state single-phase controls in combination with dc motors for flexibility and reliability at low cost. Matched motor and control packages range in ratings from 1/15 hp to 1 hp; separate controls are available for motor ratings up to 3 hp. Models HTC-007 through HTC-050 (1/15 through 1/2 hp) use 115-volt ac input and provide a speed range of 20 to 1. Models HTC-075 through HTC-300 (3/4 through 3 hp) are available in either 115- or 230-volt ac input; their speed range is 30 to 1. The motors are shunt wound with Class B insulation and are designed to operate with the SCR controls. *Westinghouse Medium AC Motor and Gearing Division, 4454 Genesee Street, Box 225, Buffalo, New York 14240.*

Analog instrumentation for utility power plants, both fossil-fueled and nuclear, is an advanced system using all printed-circuit-card control and computing elements. Called the 7300 Series, it is similar to printed-circuit-card systems successfully applied by Westinghouse for many types of analog control, but this is the first designed for nuclear power applications in compliance with IEEE Std. 279. It satisfies the stringent requirements for nuclear steam-supply system control and protection channels as well as balance-of-plant control systems. The equipment mounts in 16-slot card frames. Rate, reset, and gain adjustments are facilitated by use of thumbwheel switches on the front edges of the cards, easily accessible for system tuning. Individual cards and a complete powered prototype system have successfully passed performance and environmental tests, including seismic tests that meet or exceed the requirements of IEEE Trial Use Guide No. 344. In general, the printed-circuit cards are interchangeable function for function and, since there are hierarchies of functions in each group, the highest level card in a given group can be used as a spare for all lower levels of the same general function. Prefabricated cables and multipin plug connectors minimize wiring of individual terminals to save time and cost in installation. *Westinghouse Computer and Instrumentation Division, 200 Beta Drive, O'Hara Township, Pittsburgh, Pennsylvania 15238.*

Analog Instrumentation

Carrier start distance relay, Type SDU-1, is a solid-state unit for use as the phase carrier start relay in directional comparison blocking systems. It can also drive a timer in a backup function. The relay consists of three single-phase distance units. Since its operating characteristic includes the origin on an R-X plot, it is nondirectional and capable of sustained operation with the potential circuit shorted. Where required, it can be supervised by another relay. It is designed for rack mounting and permits access to all adjustments and output test points on its three printed-circuit boards. *Westinghouse Relay-Instrument Division, Orange Street, Newark, New Jersey 07101.*

Oil-filled potential transformer, type MSV, is designed for line-to-ground connection on 230-kV and 345-kV transmission systems. Its primary winding consists of several core and coil assemblies connected in series or cascade and mounted vertically inside a porcelain bushing. Distributing the total voltage among several coils reduces the amount of insulation material required from that required with conventional single core and coil construction, thus reducing height, weight, and cost. (The conventional single core and coil potential transformer, type APT, will continue to be available for 230-kV systems.) The unit has two secondary windings, both tapped to provide double ratios. *Westinghouse Sharon Transformer Division, 469 Sharpsville Avenue, Sharon, Pennsylvania 16146.*

Consultant's Guide to Uninterruptible Power Supply Systems is a 150-page book describing static uninterruptible power supply (UPS) systems and comparing them with several forms of rotating systems. It is intended to provide a useful background for engineers working in this field, so it includes tables for estimating costs, space, environmental factors, and other important considerations for the most frequently specified UPS configurations. The unique Westinghouse AccurCon design concept is explained, along with its contribution to high system reliability. Other topics include batteries, rectifier-chargers, electromagnetic interference, room design, and auxiliary power sources. Appendices contain sample specifications for several kinds of single- and three-phase UPS systems. Price of the book is $10. *Westinghouse Industrial Systems Division, 4454 Genesee Street, Box 225, Buffalo, New York 14240.*

Some Pitfalls in Transformer Primary Control is the latest in the Westinghouse Tech Tips series on selection, application, use, and maintenance of power semiconductors and subsystems. It tells how to identify and avoid problems caused by poorly designed or damaged thyristor firing-circuit packages used for phase control of transformer primaries. The booklet explains basic circuitry and tells how to isolate causes of such common problems as erratic blowing of fuses without load shorts, equipment shutdown by overcurrent logic, current surges in the power bus, and strange sounds from the transformer laminations. *Westinghouse Semiconductor Division, Youngwood, Pennsylvania 15697. (In Europe, Compagnie Westinghouse Electric, 80 Avenue Victor Hugo, 75 Paris 16e, France.)*

About the Authors

W. Howard Arnold, Jr., is Engineering Manager of the Westinghouse PWR Systems Division, responsible for the engineering of all Westinghouse light water commercial reactors. He joined Westinghouse in September 1955 as a Senior Engineer in the Company's commercial atomic power activities, where he helped design the first generation of commercial reactors. He became an engineering supervisor in 1957 and a section manager in 1959.

In 1962, Arnold joined the Westinghouse Astronuclear Laboratory and held several key positions on the NERVA project, including that of NERVA Program Manager. He was appointed Manager of the Weapons Department of the Astronuclear/Underseas Divisions at Baltimore in 1968, where he contributed to the solving of some of the MK-48 torpedo technical difficulties. He returned to commercial atomic power in November 1970 to assume his present position.

Arnold graduated from Cornell University with an AB in Physics and Chemistry (1951), and he earned his AM and PhD in Physics from Princeton University (1953 and 1955).

Deryk R. Grain graduated from the British University of Bristol in 1959 with an Honors Degree in Mechanical Engineering. Before attending the University, he had served as an engine fitter apprentice at H. M. Admiralty Dockyard, Sheerness.

Following graduation, he joined the British Ship Research Association where, in cooperation with the United Kingdom Atomic Energy Authority, he worked on development of small reactors for marine applications. From 1965 to 1967 he was Chief United Kingdom Site Representative on the conversion of the Westinghouse-built BR3 reactor for the Anglo-Belgian Vulcain Experiment in Mol, Belgium.

Grain joined Westinghouse Nuclear Energy Systems in 1968. His initial assignments were as a Lead Fluid System Designer in the Systems Group of the PWR Systems Division. His present position is Manager of NSSS Coordination, responsible for control and development of the Westinghouse Standard NSSS concept.

Joseph H. Hoffman graduated from Villanova University in 1946 with a Bachelor of Mechanical Engineering degree. He joined Westinghouse and served as a salesman for heavy-duty fans. In 1955, he left to work with Ingersoll-Rand Company in the design of centrifugal compressors.

Hoffman returned to Westinghouse in 1961 as a design engineer in the Sturtevant Division. He was made Chief Mechanical Engineer in 1964 and Manager, Heavy Duty Engineering, in 1966. He is responsible for product design and development, order engineering, and sales assistance for all of the Division's heavy-duty products.

Among the engineering developments Hoffman has been responsible for are a new sleeve bearing for heavy-duty products and a hollow-shaft rotor for use in a high-temperature pelletizing plant. He is a registered professional engineer.

Daniel L. Whitehead, Sr., graduated from the University of Tennessee with a BSEE degree in 1939, and he earned his MSEE from Cornell University in 1941. Later that year he joined Westinghouse via the graduate student training program and soon began working in the former Central Station Department. He was made Engineer in Charge of the Anacom computer in 1947. Working for the Power Circuit Breaker Division, he progressed from Manager, High-Voltage Section, Engineering Laboratories, in 1952 to Section Manager, General Engineering Laboratories, in 1964 and to his current position as Manager, Engineering Laboratories, in 1968. He is responsible for operation of the High-Power Laboratories, General Engineering Laboratories, and UHV Test Center.

Whitehead has participated in the design and development of projects such as the Anacom, the 6400-kV impulse generator, the UHV Test Center, and gas-insulated transmission systems and substations. He is coauthor (with R. H. Perry) of the *Engineering Manual* published by McGraw-Hill, and he has lectured at the University of Pittsburgh graduate school of electrical engineering since 1946.

C. Donald Fahrnkopf attended the University of Illinois, earning a BS degree in Engineering Physics in 1938 and a BSEE degree a year later. He received his MSEE from the University of Pittsburgh in 1951.

Fahrnkopf joined the Westinghouse Central Engineering Laboratories in 1940, where he worked on radio interference test techniques. His work has also included analog and digital computer programming, and he is currently a Staff Engineer in charge of the Instrumentation and Techniques Group, Power Circuit Breaker Division Engineering Laboratories. His major responsibilities include developing and improving test facilities, test methods, and measurement techniques. He was primarily responsible for development of the Synthetic Test Facility for the High-Power Laboratory.

Joseph J. Brado earned his BEE degree from Cleveland State University in 1957. During his first three years of college, he worked for Westinghouse as a summer student at the High-Voltage Laboratory, Power Circuit Breaker Division, Trafford, Pennsylvania. He joined Westinghouse in 1957 on the graduate student training program and was first assigned to the Photometric Laboratory of the Lighting Division at Cleveland. Brado later transferred back to the Trafford facility to work as a test engineer. In 1964, he became Engineer in Charge of the High-Voltage Laboratory (now expanded into the UHV Test Center). Last year he was made Supervisory Engineer of the UHV Test Center, where his responsibilities include planning and coordination of tests.

R. C. Hoyler is Manager of Negotiations Support in the Transportation Division, responsible for technical liaison and application engineering. He has contributed to the development of a number of subsystems relating to automatic control of trains, including the ones for signaling, fail-safe multiplexing, and train identification described in his articles in this issue and in the July 1972 issue.

Hoyler graduated from Cornell University with a BEE degree in 1963, and he earned an MS degree in electrical engineering at New York University. He has since done additional graduate work at New York University and at Carnegie-Mellon University. Hoyler joined Westinghouse in 1966 at the Research Laboratories, transferring the following year to the Transportation Division. His major responsibilities have been in design and application engineering of systems and subsystems for automated transit.

G. D. Rockefeller graduated from Lehigh University in 1948 with a BS in electrical engineering and went to work for Metropolitan Edison Company. He joined the Westinghouse Relay-Instrument Division in 1951, where his main responsibility has been the application and system design of protective relaying. In 1968 he received his MS degree from Newark College of Engineering.

Rockefeller has seven patents to his credit, and he has written texts on protective relaying and symmetrical components for International Correspondence Schools. He is a member of the Power System Relaying Committee of the IEEE Power Group.

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This large stator is a part of one of two 1200-MW generators built for Tennessee Valley Authority. The completed machines are each 40 feet long, and each can supply the electrical requirements of a city the size of Nashville, Tennessee.