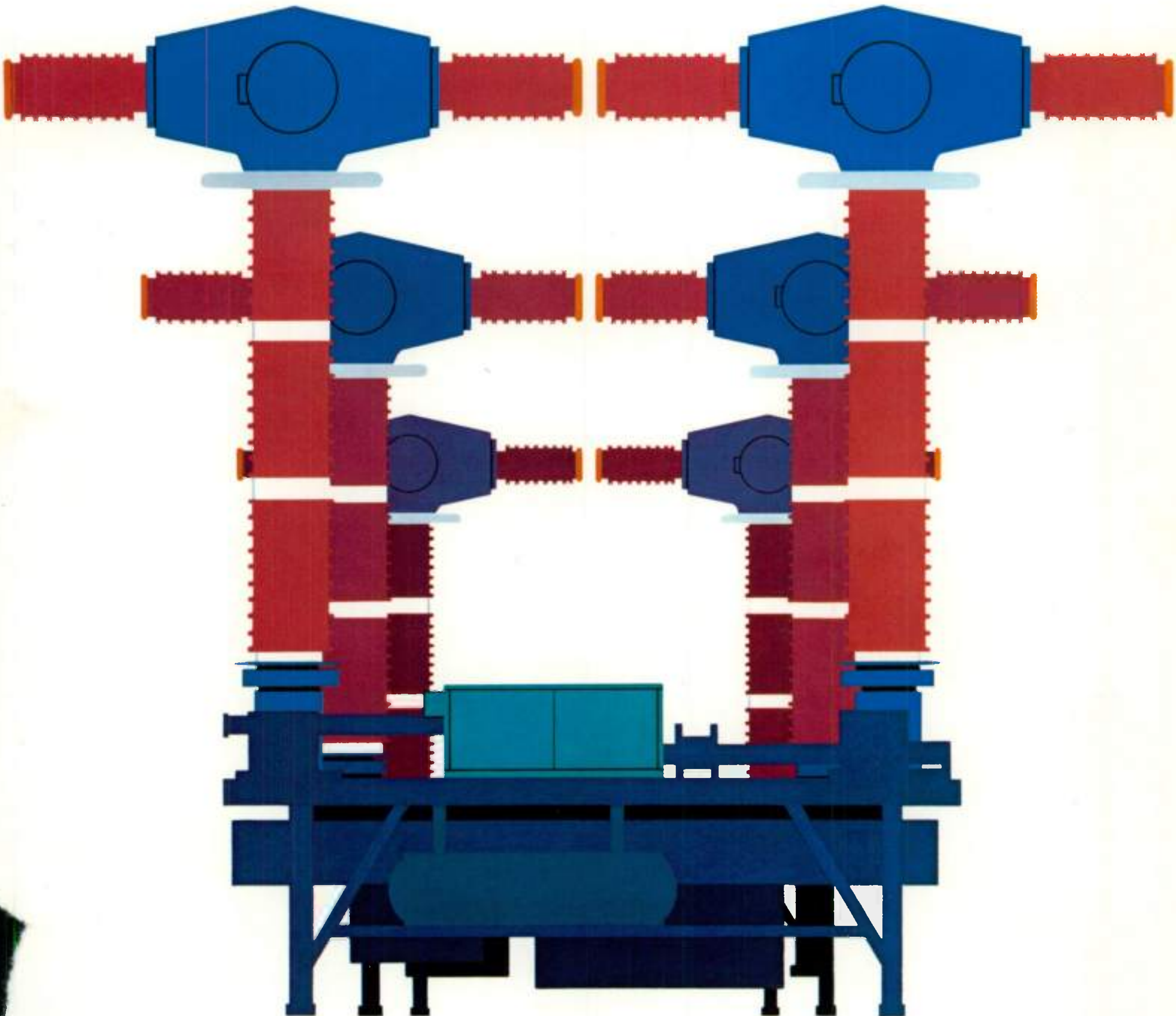
Westinghouse ENGINEER September 1973



An Automatically Controlled Electrical System (ACES) was supplied to NASA by the Westinghouse Aerospace Electrical Division for evaluation and possible use on advanced spacecraft. In this partial mock-up of the space-shuttle cockpit at NASA's Manned Spacecraft Center, the engineer is using the ACES data entry and display panel to punch in a combination of loads and power for a simulation run. The five consoles in the background simulate electrical loads for the nose, air-lock, electronics, intervehicular activity, and tail compartments of a hypothetical shuttle. (For additional information, see *NASA Tests New Type of Power Management System*, p. 156.)

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Front Cover: The advantages and requirements of independent-pole circuit breaker operation are discussed in the article that begins on the following page. The Westinghouse SFA breaker, with three separate operating mechanisms (one per phase), is ideally suited to this application. Artist Tom Ruddy depicts the SFA breaker in this month's cover design.

Independent-Pole Circuit Breakers Improve System Stability Performance

C. L. Wagner
H. E. Lokay

Efforts to resolve two conflicting trends in the utility industry have brought independent-pole operation of power circuit breakers to the forefront in system stability design.

The first trend resulted from increasing efforts to improve power system stability performance, initiated primarily by the 1965 Northeast power interruption. That event demonstrated both the very real possibility, and the dire consequences, of a cascading instability situation on a power system. Utilities began to insist on having and meeting system stability design criteria that eliminated the possibility of any situation that could produce such a system catastrophe.

However, efforts to meet stiffening stability design criteria are opposed by the continuing trend to larger and larger turbine generator units, which have reactance values and inertia constants that make it more difficult to meet stability criteria, and by the requirement of locating large generators remote from load areas. During the search for solutions—high-speed generator excitation, turbine fast valving, transmission line series capacitance, etc.—it was realized that independent-pole operation of circuit breakers offers the most realistic solution because it removes the most serious threat to system stability—a three-phase fault in combination with a stuck breaker with three "hung" poles. Furthermore, this solution is relatively easy to achieve.

The adoption of higher transmission voltages has already brought about live-tank breaker designs with separate pole-operating mechanisms, which can be readily converted to independent-pole operation. Relaying developments to improve reliability have produced the primary and secondary relay concept, which is also easily adapted to independent-pole operation. Further work on improving independent-pole operating reliability led to the SLB pole-failure relay, which insures synchronized operation of breaker poles. And finally, the SPCU relay, originally designed to solve relaying ambiguities with series capacitors, can also provide the ultimate in independent-pole operation. Since the SPCU relay operates on individual phases, it can be readily modified to provide individual phase outputs for controlling each breaker pole separately.

These various facets of independent-pole breaker operation will be discussed in a three-article series. This, the first, describes the advantages and requirements of independent-pole operation. The second article will discuss pole disagreement relaying and the SLB relay developed for that purpose. The final article will describe the SPCU relay and its application to selective-pole tripping, the ultimate in independent-pole operation.

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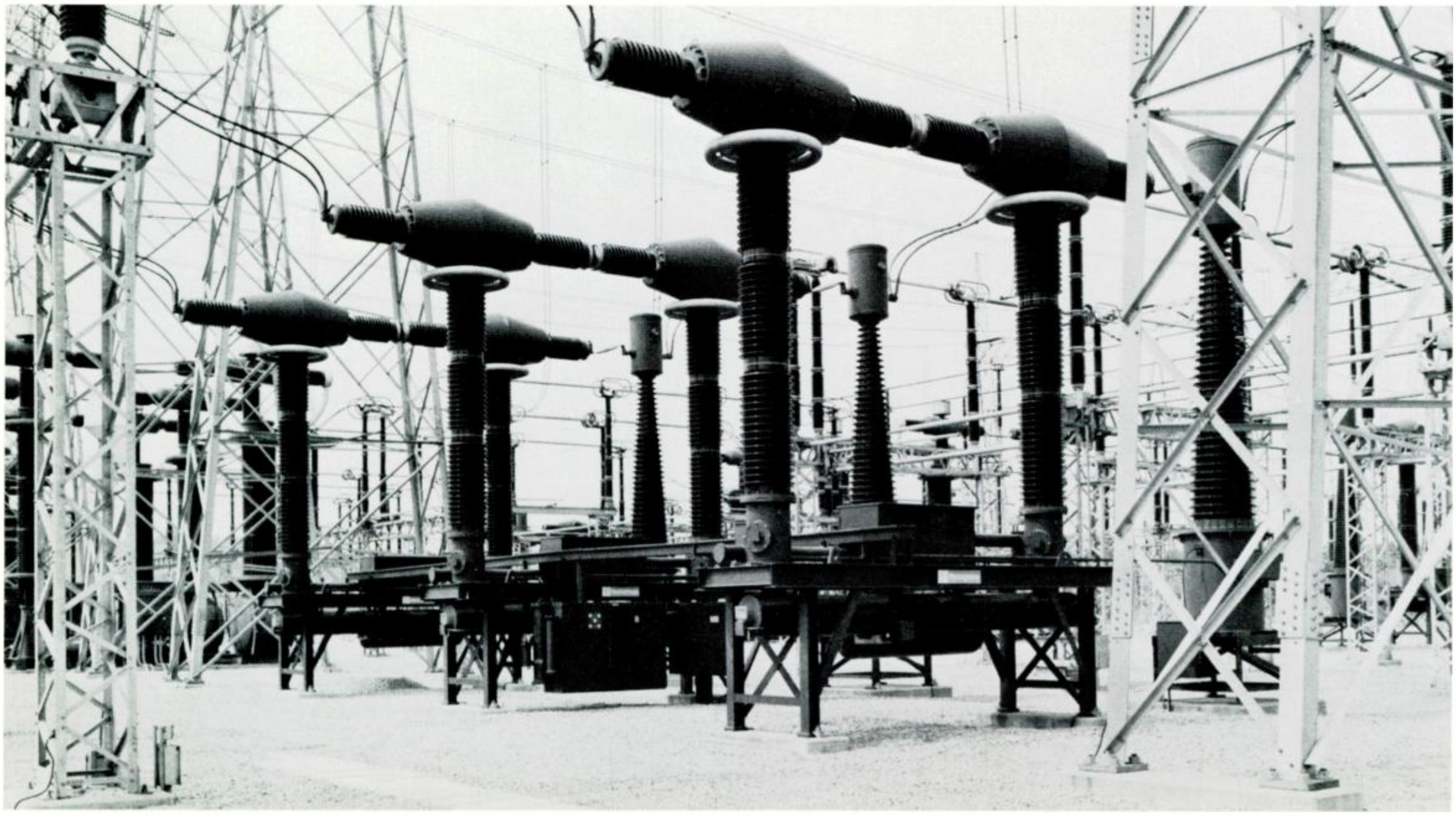


Several methods for improving power system/generating unit stability performance are available today; fast turbine-valve control, high-speed excitation systems, reduced unit transformer reactance, and reduced system impedance (by means of series capacitors or additional transmission lines) are the more commonly recognized approaches. Another technique now receiving attention is independent-pole circuit breaker operation combined with a protective relaying scheme necessary to insure that type of breaker operation.

Before discussing the effect of independent-pole operation on system stability, the differences between independent-pole operation, single-pole tripping, and selective-pole tripping should be clarified. Although the benefits of the three schemes to system stability may be similar, there are significant differences in relaying requirements.

Independent-pole operation refers to the use of separate mechanisms for each phase of the breaker so that failure of one pole to operate will not restrict the operation of other poles. Live-tank EHV gas and air breakers have always been designed with separate operating mechanisms for each pole, but EHV oil breakers and dead-tank gas breakers have only recently been offered with this feature. Although the breaker poles operate independently of each other, the relaying system is arranged to trip all three poles for any type of fault.

Single-pole tripping, widely used in Europe, has had only limited application in the United States. Separate operating mechanisms are used on each phase and the relaying is designed to trip only the faulted phase for single-line-to-ground faults; all two- and three-phase faults are cleared by opening all three breaker poles. The relaying is more involved than required for independent-pole operation, but in a few applications, such as where a large generating unit is tied to a system over a single transmission line, the use of this scheme prevents the loss of the machine for all but multiphase faults.

Photo—This SFA 550-kV breaker, installed at the Hatfield Substation of West Penn Power Company, employs one operating mechanism per phase for independent-pole operation.

Selective-pole tripping is a new system now available with "segregated phase comparison relaying." (The Westinghouse SPCU relay used for this purpose will be discussed in the third article in this series.) With the SPCU relay controlling separate pole mechanisms, only affected phases are tripped for any type of fault. For example, the faulted phase is tripped for a single-line-to-ground fault; both affected phases are tripped for a phase-to-phase fault or a phase-to-phase-to-ground fault; all phases are tripped for three-phase faults. If more than independent-pole operation is needed to insure system stability, selective-pole tripping provides the ultimate in stability benefits. As will be shown, however, independent-pole operation can often provide enough stability improvement to satisfy many system applications.

Critical Fault-Clearing Time

Advances in the art of turbine-generator design that have provided a continuing increase in kilowatt and kilovar outputs without increasing machine size have also increased generator reactance and decreased its inertia constant. Both of these trends are unfavorable to the maintenance of system stability during system disturbances. The interrelationships of generator transient reactance (X'_d), turbine-generator inertia constant (H), and equivalent system reactance (X_s) were investigated in a recent general transient stability study.[1] That study was designed to duplicate the various fault conditions used for system design criteria, including the most severe: (1) a three-phase permanent fault; (2) the fault occurring on the line side of a breaker near the generating plant; and (3) all three poles of the circuit breaker failing to open on primary relaying. This severe fault condition is rapidly becoming the most common system stability design criterion.

To obtain a range of critical fault clearing (CFC) times—the period within which a fault must be cleared to avoid unit instability—various combinations of generator transient reactance, inertia constant, and system reactance were examined. Study results are partially summarized in Fig. 1 for equivalent system reactances of 10, 25, and 40 percent (on plant MVA base). Those system reactance values represent multiple transmission lines, and the study assumed that upon clearing the fault, 75 percent of the high-voltage transmission would remain (i.e., postfault X_s is 1.33 times prefault X_s).

The color areas in Fig. 1 suggest the expected range of unit X'_d and H values for recent and future designs of 1800- and 3600-r/min units. Those areas approximate the complete range of unit MVA ratings. Older units still in service have typical values either within those color areas or slightly to the right and/or downward.

Briefly summarizing the study results shown in Fig. 1, critical fault clearing times for systems with present and future machines range from about 9½ cycles for 10-percent equivalent system reactance down to 4½ cycles for 40-percent reactance. As indicated, CFC times for 1800-r/min nuclear units and 3600-r/min fossil units are about the same because the higher speed units with lower H constants also have lower transient reactance values.

Another way of summarizing those same study results shows CFC times for a three-phase fault near the plant as a function of system reactance for representative existing and future turbine generator units (Fig. 2). The study results can be related to existing systems by comparing them with an earlier survey of system reactance values as seen from the high-voltage bus of generating plants looking into the power system.[1] The survey indicated that more than 80 percent of today's plants see system reactances of 25 percent or less; the majority see reactances of about 15 percent. This suggests that any reasonable equipment design criterion for stability performance should be to accommodate systems with reactances of 25 percent or less.

Breaker Failure (Backup) Relay Systems

Critical fault clearing times required by any given set of system/turbine-generator-unit parameters must be compared with the fault-clearing times provided by available breaker and relay systems to obtain an indication of stability performance during faults. Representative operating times required for the various functions of both existing and future breakers and relays are listed in Table 1. The range shown for each function reflects variations in the type of devices used and the opinions of relay engineers. Briefly summarizing the information shown, if a circuit breaker fails to open on primary relaying, present breaker-failure relay systems provide a representative clearing time of 12 cycles; 9-cycle clearing is anticipated with future systems.

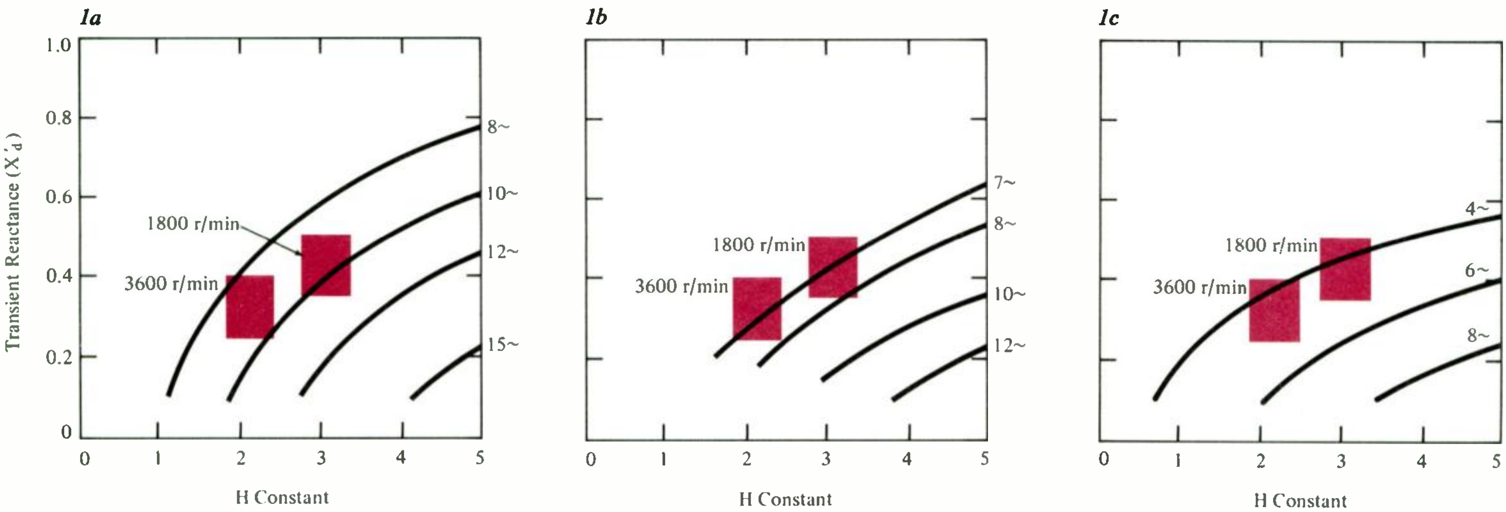
Table 1—Required Operating Times for Breaker Functions

Function	*Time (cycles)* Present	Future
Primary Relay	1.0-2.0	0.50-1.50
Circuit Breaker Clearing	2.0-3.0	2.00-2.50
Current Detector Dropout	0.5-2.0	0.25-0.50
Margin	3.5-6.0	3.00
Auxiliary Relay	1.0	0.25-0.50
Backup Breaker Clearing	2.0-3.0	2.00-2.50
Total Time	10.5-17.0	8.00-10.50
Total Time (representative)	12	9

Comparing Table 1 with Fig. 1, it can be seen that even systems with reactance as high as 40 percent provide adequate CFC times to permit the 3- to 5-cycle period required for normal primary fault clearing. Thus, no stability problem exists so long as the primary protection system functions correctly. However, when the design fault criterion includes *failure of primary relaying*, then the total breaker-failure system clearing time of 12 cycles is the value that must be compared with system CFC time. For this condition, Fig. 1 indicates that unit stability could not be maintained even for system reactances as low as 10 percent. In fact, the 9-cycle future backup relay system is only marginally adequate for 10-percent system reactance and would not be able to maintain unit stability for systems with higher reactance values.

Advantages of Independent-Pole Operation

The addition of transmission capacity or series capacitors to reduce system reactance significantly below 10 percent would be an expensive solution to the system stability problem. A more practicable approach is to reevaluate the application of the present fault criterion used for system design—to determine the actual risk of simultaneous occurrences of the three basic conditions of the criterion (three-phase fault, near the plant, and all three poles failing to open on primary relaying) and look for ways to reduce the possibility of their occurrence. Easing the requirements for any one of those conditions



1—Critical fault-clearing time (*cycles*) *for a three-phase fault on the line side of a circuit breaker at the plant high-voltage bus is shown as a function of X'd and H constant for equivalent system reactances of* (a) *10 percent*, (b) *25 percent*, *and* (c) *40 percent*.

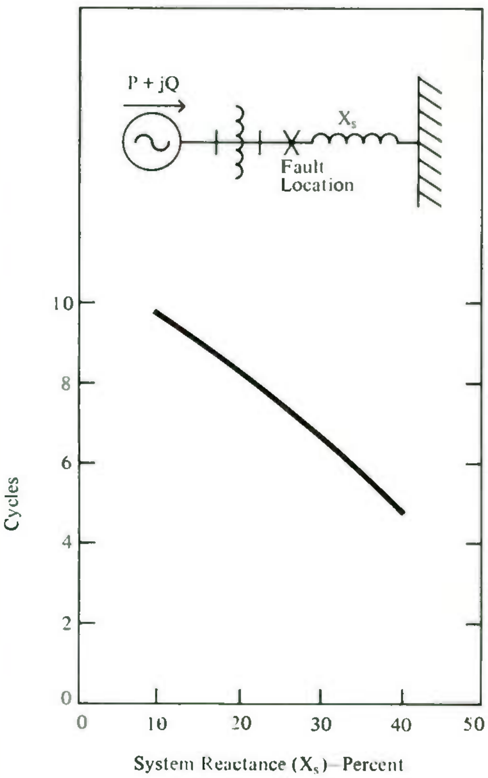
would bring the CFC times of most systems within the capabilities of future (or in many cases present) backup systems. For example, from the study[1] previously mentioned, CFC times were plotted as a function of generator transient reactance and H constant for double-line-to-ground faults and a system reactance of 25 percent (Fig. 3). For that condition, typical unit CFC times are 9½ to 10 cycles, which is about the same time as projected for new breaker-failure relay systems (Table 1).

The second fault condition—that the fault be near the plant—was studied to determine the minimum distance the fault must be from the plant (in miles of 345- or 500-kv transmission) to provide a 9-cycle CFC time. Assuming reactance and inertia values of new turbine generator units, the relationship between system reactance and distance is shown in Fig. 4. For example, with an equivalent system reactance of 25 percent, a three-phase fault must be within about 8 miles at 345 kV or 16 miles at 500 kV to cause instability (less than 9-cycle CFC time). Thus, while there is no logical way of reducing this design criterion, the study results do show that a fault would have to occur relatively close to the plant to endanger system stability.

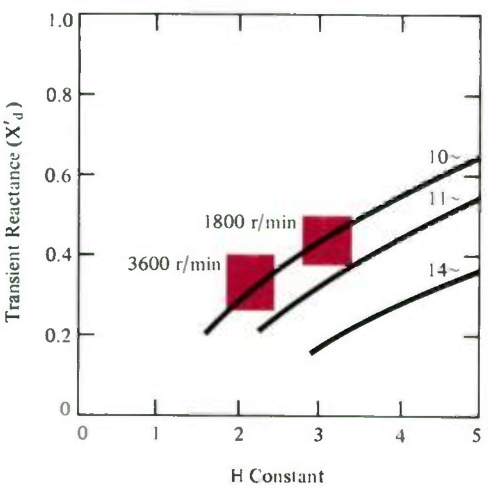
The third condition—that all three poles of a breaker fail to open on primary relaying—is a possibility with those breaker designs that use a three-pole operating mechanism.

On the other hand, presently available system protection schemes with breakers designed for independent-pole operation make a failure of all three poles almost impossible. Separate relay systems, circuit breaker trip coils, and operating mechanisms for each pole almost guarantee that at least two poles will open for any conceivable fault on the system.

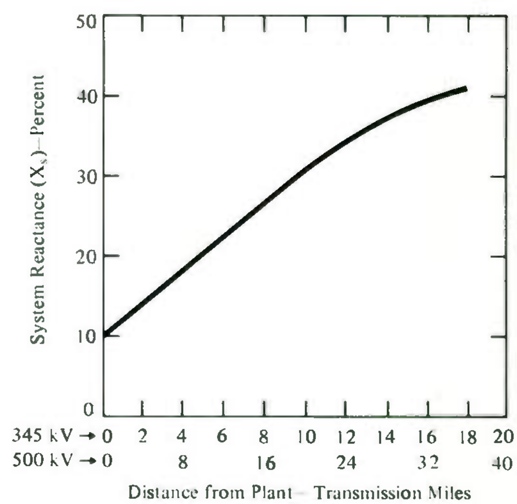
To demonstrate the benefits of independent-pole operation, Fig. 5 shows CFC times that result when only one or two of the breaker poles fail to open. The three-phase fault was assumed to occur for three cycles primary time and then change to a double-line-to-ground or a single-line-to-ground fault because of two or one stuck poles. As indicated, when two poles fail to open the CFC time is increased approximately two cycles compared with the CFC time for a continuous three-phase fault; when only one pole fails to open, CFC time is increased about five cycles. This significant improvement demonstrates the benefits of independent-pole operation of circuit breakers when compared with other means of improving system/unit stability (Table 2). As indicated in the table, independent-pole circuit breaker application with appropriate relaying can yield significant CFC time gains. The almost nonexistent probability of three stuck poles essentially eliminates the need for the three-phase fault criterion.



2—Critical fault clearing time is shown as a function of system reactance (X_s), assuming machine characteristics of existing or future turbine generator units.



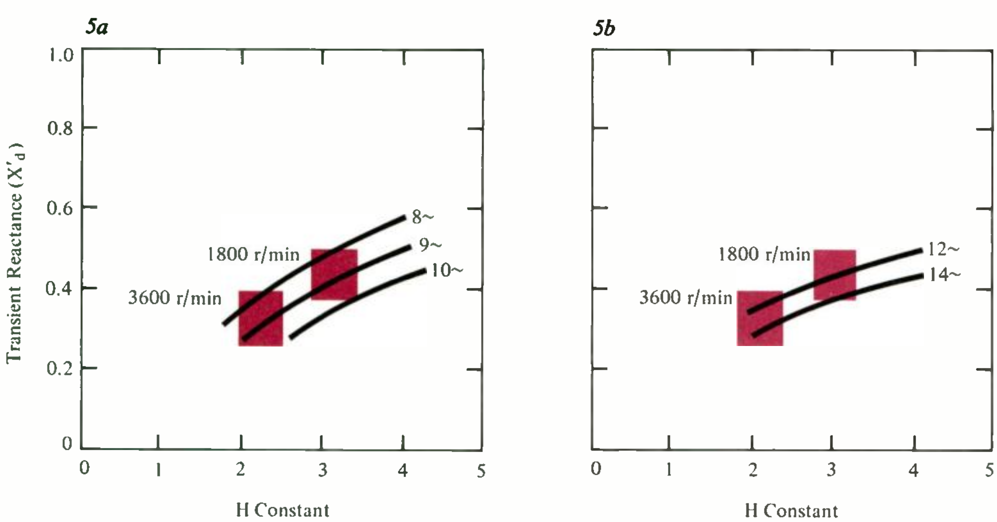
3—Critical fault clearing time is shown for double-line-to-ground faults on line side of circuit breaker at plant high-voltage bus, assuming equivalent system reactance of 25 percent.



4—Required distance of three-phase fault from plant to provide a 9-cycle critical fault clearing time.

Table 2—Stability Control Methods and Their Typical Gains in Systems/Unit Transient Stability

Method	*Critical Three-Phase Clearing Times*
High-Response Excitation Systems	½-1½ Cycles
Turbine Valve Control (all units in plant)	1-2 Cycles
Independent-Pole Circuit Breaker Operation: Two Stuck Poles One Stuck Pole	 1½-2 Cycles 4-5 Cycles
Reducing Unit Transformer Reactance	¾ Cycle for 5-Percentage-Point Reduction
Reducing Ratio of System Postfault Reactance to System Prefault Reactance (depends highly on system conditions)	½-1½ Cycles
Reduce Turbine Generator Normal Power Output	CFC Time × 1.05 for 10-Percent Reduction in Power Output
Reduce Generator X'_d	1 Cycle for 10-Percentage-Point Reduction
Increase Turbine Generator Unit "H" Constant	$\sqrt{\frac{H\ New}{H\ Old}}$ Multiplier (i.e., multiplier = 1.15 when raising H from 3 to 4)



5—Critical fault clearing time as a function of X'_d and H constant for a three-phase fault cleared in three cycles and then two stuck breaker poles (a) *and one stuck breaker pole* (b).

Requirements for Independent-Pole Operation

Before the independent-pole-operation stability criterion can be adopted, however, all breaker positions in the station must satisfy the requirements of independent-pole operation. The complete protection system as well as the breakers must be designed so that failure of any one element cannot prevent at least one pole from operating.

A simplified schematic of the basic elements of a protection system is shown in Fig. 6a. The protective relay analyzes system currents and voltages; when a breaker trip is required, the relay's logic decision closes its contact (PR) to energize the breaker trip coil. However, if the relay system consisted of only the simple circuit shown, failure of any element in the circuit would prevent all three poles of the breaker from opening; thus, the basic system shown does not qualify for independent-pole operation.

Protective Relays—One method for preventing single-element failure is to use at least two relay circuits, as shown in Fig. 6b. In the past these relays were designated *primary* and *backup* because the latter were usually slower and tripped later than primary relays. However, modern practice is to use two high-speed relays that trip simultaneously and merely call them *primary* and *secondary*. One may be solid-state and the other mechanical, one may be phase comparison and the other directional comparison, one may be pilot protection and the other directional-distance, or they can be identical.

For many close-in faults, either or both relays can have two tripping elements; i.e., a directional-comparison system can trip directly on first zone as well as through the pilot channel. Note that both relays in

6—Basic functions of a typical protection system (a) *must be accomplished with a dual relay arrangement* (b) *to prevent single-element failure.*

Fig. 6b would see a close-in three-phase fault, so both would have to fail for the breaker not to operate.

Current Transformers—Separate current transformers are indicated in Fig. 6b for the primary and secondary relays. Although the two units may be mounted on the same bushing, they must be mounted on separate cores and arranged so that a failure in one will not affect the other. As shown, it is also desirable to keep other functions such as metering on separate current transformers.

Potential Devices—While Fig. 6b shows the potential-measuring devices as transformers, more common practice is to use capacitor potential devices, especially on EHV systems. Since it is usually too expensive to install separate devices to obtain redundancy of potential circuits, double secondaries are used to at least isolate the secondary circuits.

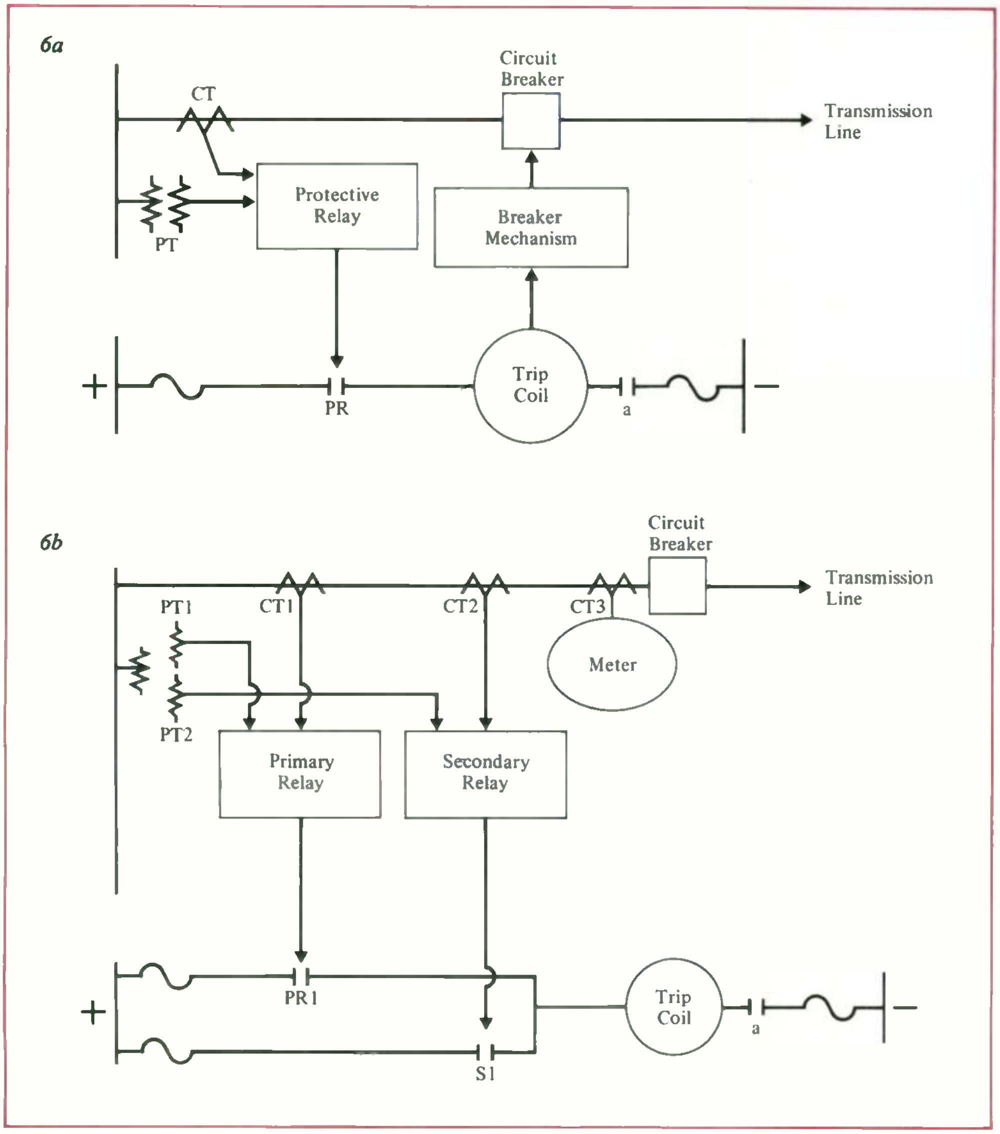
Duplicate Trip Coils—The next redundancy step is duplicate circuit breaker trip coils—the primary relays feed one trip coil circuit and the secondary relays feed the other so that an open or shorted coil in one circuit cannot affect operation of the other (Fig. 7). Most if not all breakers with two trip coils have them mounted on the same latch-and-trip mechanism, which might appear to defeat the redundancy objective. However, in this case, the increased complexity of the additional linkages required for two separate mechanisms would decrease reliability and thereby offset the gains of redundancy.

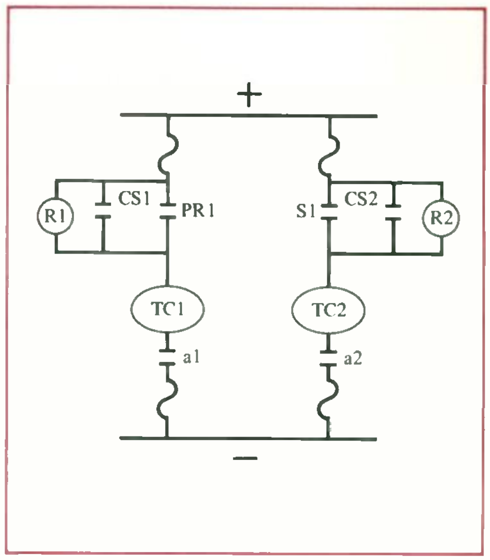
Battery Circuits—Two separately fused circuits from a single battery for the two relay and trip coil circuits are indicated in Fig. 7. Some users provide even further redundancy by use of duplicate batteries in the station with primary protection circuits fed from one and secondary circuits fed from the other.

Separate Operating Mechanisms

Independent-pole operation requires three separate operating mechanisms, one per phase, which are in no way mechanically interconnected. To insure that independence, a "point-of-failure" analysis of the devices and their control systems should be made to guarantee that no single element failure can cause all three mechanisms to fail.

Three separate pole mechanisms require three separate trip coils, or six coils in the double-trip-coil scheme. Usual practice is to connect the three trip coils in series as





7—Duplicate circuit breaker trip coils insure that an open or short in one coil cannot affect operation of the other.

shown in Fig. 8a. Not shown in this circuit are the additional auxiliary contact arrangements, such as the disagreement circuits that are required to prevent accidental single-phase operation of the breaker. (For example, if all three poles do not close in a normal closing operation, the breaker must automatically trip.)

Arranging trip coils in series does have the disadvantage that all three coils are disabled if an open circuit occurs in one coil. The coils can be arranged in parallel to correct this difficulty (Fig. 8b), but a parallel arrangement also has disadvantages. First, just as an open circuit disables a series circuit, a shorted coil disables a parallel circuit. Which of those possible faults is more probable is questionable. Second, as shown in Fig. 8b, "red light" monitoring (*$R1_a$* etc.) of the trip-coil circuits is more complicated, it requires space for three times as many lamps on the switchboard panel, and the added circuitry detracts from reliability. The third disadvantage of parallel operation is the high current that must be handled by the protective relay contacts (*PR1* or *S1*). While trip coils with somewhat reduced current rating might be developed, it is questionable whether enough reduction could be obtained to permit driving six coils in parallel (required with ring buses and breaker-and-a-half buses where one relay must trip two breakers). On the whole, the disadvantages of parallel trip coils outweigh those of series coils, so the series scheme is preferred with one exception—the SPCU scheme shown in Fig. 9.

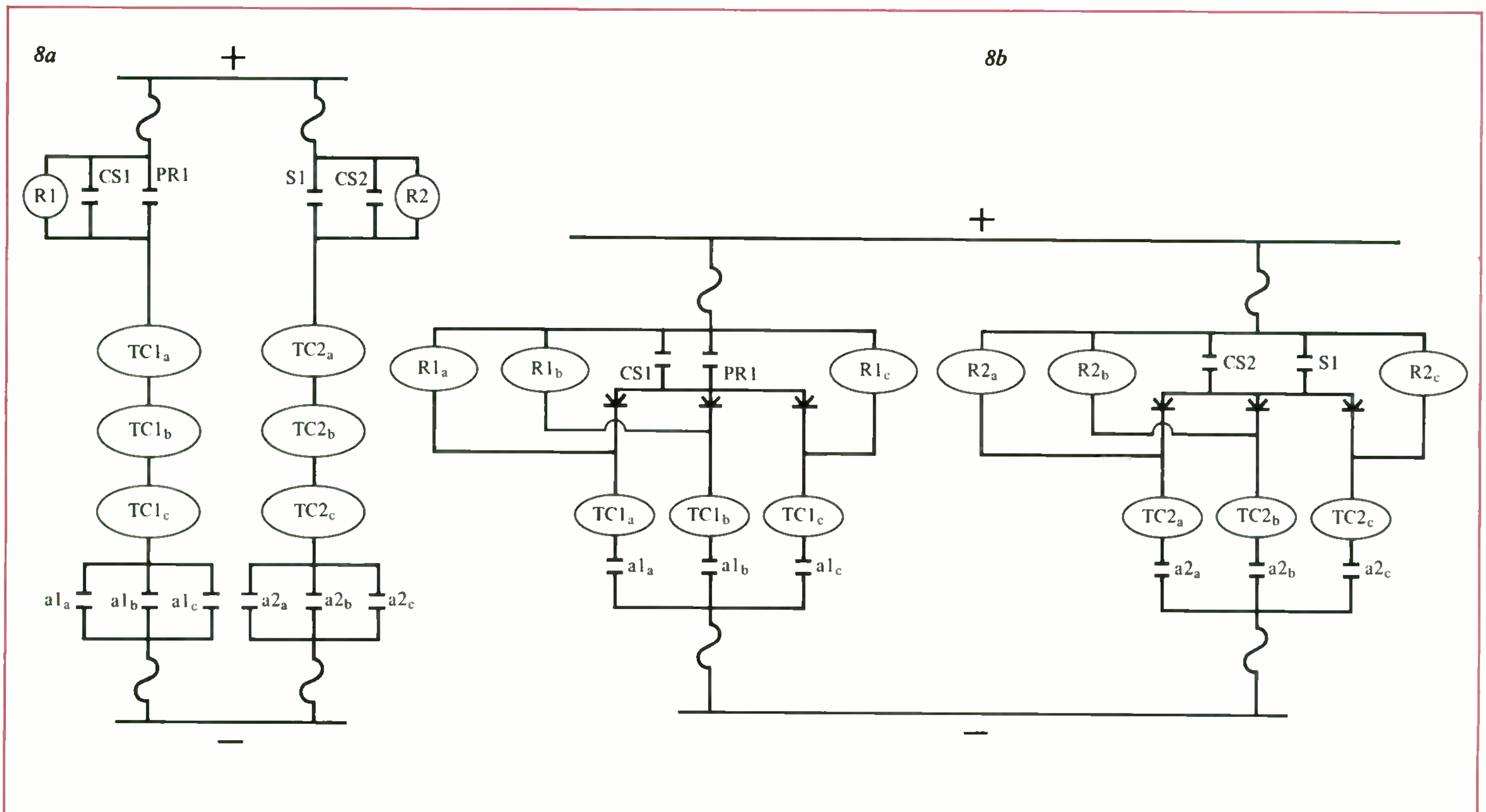
The SPCU relay will be described in detail in the third article of this series. But briefly, the scheme uses separate relay units to detect faults on the three phases and to ground. As shown in Fig. 9, the phase relays energize paralleled primary trip coils, and the ground relay energizes the secondary trip coils in series.

The disagreement circuit that prevents accidental single-phase operation of the breaker is also indicated in Fig. 9. That circuit can be a series-parallel combination of breaker auxiliary contacts, or the SLB relay, or both. (Those circuits will be described in the second article of this series.) In the independent-pole protection scheme, all trip coils are energized by the disagreement circuit after a short (2-cycle) time delay.

Auxiliary Devices and Systems

The operating mechanisms of all Westinghouse EHV breakers are pneumatic, and, while the air is stored in a separate reservoir adjacent to each mechanism, the pressure is maintained by a single compressor. In this regard, the compressor is common to all phases; in certain extreme contingencies, that commonality could cause failure to close all three phases. However, all Westinghouse breakers are tripped by mechanical springs, and, since tripping is the only breaker operation required to maintain unit/system stability, the air system need not be suspect.

Gas and air-blast breakers use SF_6 gas and/or high-pressure air for the insulation and interrupting medium. These systems should be investigated to examine all the possible causes of loss of gas or air pressure



and how they affect the breaker operation. Considering first the insulation system, the Westinghouse SFA breaker[4] retains its full insulation rating in the closed position at zero psig gas pressure. In the open position it is rated at 1.5 per unit crest voltage or greater across the open gap at zero psig gas pressure, but the gas system has been specifically designed to obviate this possibility. For the more credible accident of equalization of pressure in the high- and low-pressure systems, the insulation to ground remains at approximately 100 percent, while the open gas insulation level actually increases due to the higher pressure in the contact zone.

Due to these insulation levels at reduced gas pressure, it is possible to operate with the breaker open or closed at normal system voltages. However, since the interrupting ability of the breaker is reduced at the lower pressures, low-pressure alarms and cutouts are used to either trip and lock out the breaker or open the trip circuit (locking the breaker closed) when pressure is lost. Whichever option is used is up to the user, but for the situation under consideration it would seem prudent to trip and lock out the breaker on loss of pressure to prevent the possibility of a three-phase fault at nearly the same time as a loss of pressure. The probability of both of these severe events occurring at the same time, however, seems negligible.

One credible accident that could occur is a stuck blast valve on one phase during a three-phase fault. This condition could ultimately result in the equalization of the high-pressure gas in all three phases for a closed system, or the complete loss of air in a system that discharges to the atmosphere. This condition was investigated in the SFA design. It was found that while the initial fault would be cleared satisfactorily, should the breaker be called upon to reclose into the fault, the module or phase with the stuck valve might fail to clear. The other two phases, however, would maintain sufficient interrupting capability for at least six seconds (360 cycles) to clear their faults. It remains only to insure that reclosing into the fault is blocked before the six seconds elapse. A similar limit of six seconds or longer applies to broken interphase gas piping and failures of the high-pressure relief valve and/or feed tubes. Thus, for all credible accidents, the gas system is deemed satisfactory and it satisfies the independent-pole operating requirements.

Summary

Attaining system/unit stability is extremely difficult on today's systems if the fault criterion is a three-phase fault with all three primary circuit breaker poles failing to open on primary relaying. Even extremely high-speed one- or two-cycle breakers could not provide system stability under all conditions using this criterion. However, use of independent-pole operation, with the protection system designed to insure that type of circuit breaker operation, should make it feasible to substitute "one or two stuck poles" for the three-phase breaker-failure condition because of the extremely low probability of that fault condition ever occurring. With a protection system that insures independent-pole operation, even the fault-clearing times provided by three-cycle breakers are well within the critical times required for system stability.

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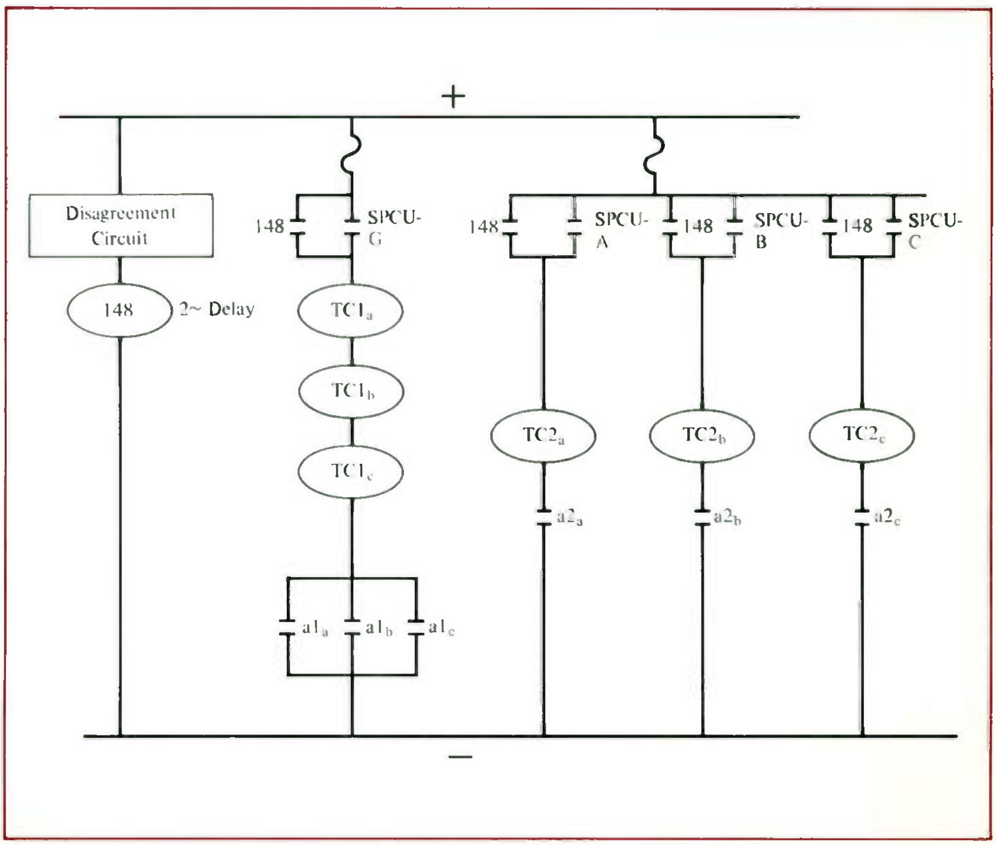
[2]W. L. Hinman, "Breaker Failure Relaying," *Proceedings of the American Power Conference*, 1969, Volume 31, pp. 1012-1020.
[3]W. L. Hinman, "Breaker Failure Relaying," paper presented at 23rd Annual Conference for Protective Relay Engineers, Texas A&M University, April 20-22, 1970.
[4]"Modular EHV Power Circuit Breakers Simplify Installation While Retaining Proven Reliability," *Westinghouse ENGINEER*, July 1973, pp. 112-118.

8—Independent-pole operation requires three separate trip coils, arranged either in series (a) *or parallel* (b).



9—Independent-pole operation with segregated phase comparison (SPCU) relay that trips only the faulted phases. Disagreement circuit is required to insure that all poles operate for all faults.

Direct Numerical Control Increases Productivity of Machine Tools

T. J. Dolphin
D. H. Mullins

Conventional numerical control using punched tape has become widely accepted in the production of high quality parts. Now a direct numerical control (DNC) system presided over by a computer extends numerical control's potential for productivity by eliminating the punched tape from the information process and thereby improving the flow of information to the machine tool.

Direct numerical control (DNC) is a method of controlling many machine tools in an integrated manner from a central point. It employs computers to produce the required information for a number of machine tools, to control and direct the flow of information, and in effect to operate the tools. DNC can also be combined with a shop information system that sends out operator's instructions and gets back production reports and machine utilization information.

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The Westinghouse DNC system can be used with the Westinghouse New World control system or any other numerical control, either point to point or contouring. New World control is a software-structured system that incorporates a minicomputer so that its program can be varied to meet current needs and changed or expanded to satisfy future requirements.[1]

Conventional Numerical Control

Production with conventional numerical control (NC) systems is most often limited by problems with punched tape—the NC tape may not be available when needed, it may be damaged, or the information on it may be incorrect or incomplete.

The various interfaces in the flow of information—from the part programmer to the compiling computer to the punched tape to the machine—make logistics problems inherent in the NC system. Queues are likely to develop at any stage of the process. The greatest source of delay usually is in production of the punched tape and its delivery to the machine tool.

Moreover, tape production is rarely error-free, due to errors made by the part programmer, errors in card punching or compilation, physical damage to the tape during handling, etc. Consequently, several passes are often necessary to remove all errors and finally produce a working tape.

Direct Numerical Control

A direct numerical control (DNC) system changes that discontinuous pattern of information flow, primarily because it does not depend on punched tape. It organizes an entirely new information flow that provides almost instantaneous communication among all elements of the system. In doing so, the system provides four major advantages: it increases the efficiency of the part programmer, permits greater utilization of the machine tools affected, creates a data base for a management information system, and permits more economic utilization of compiling computer resources.

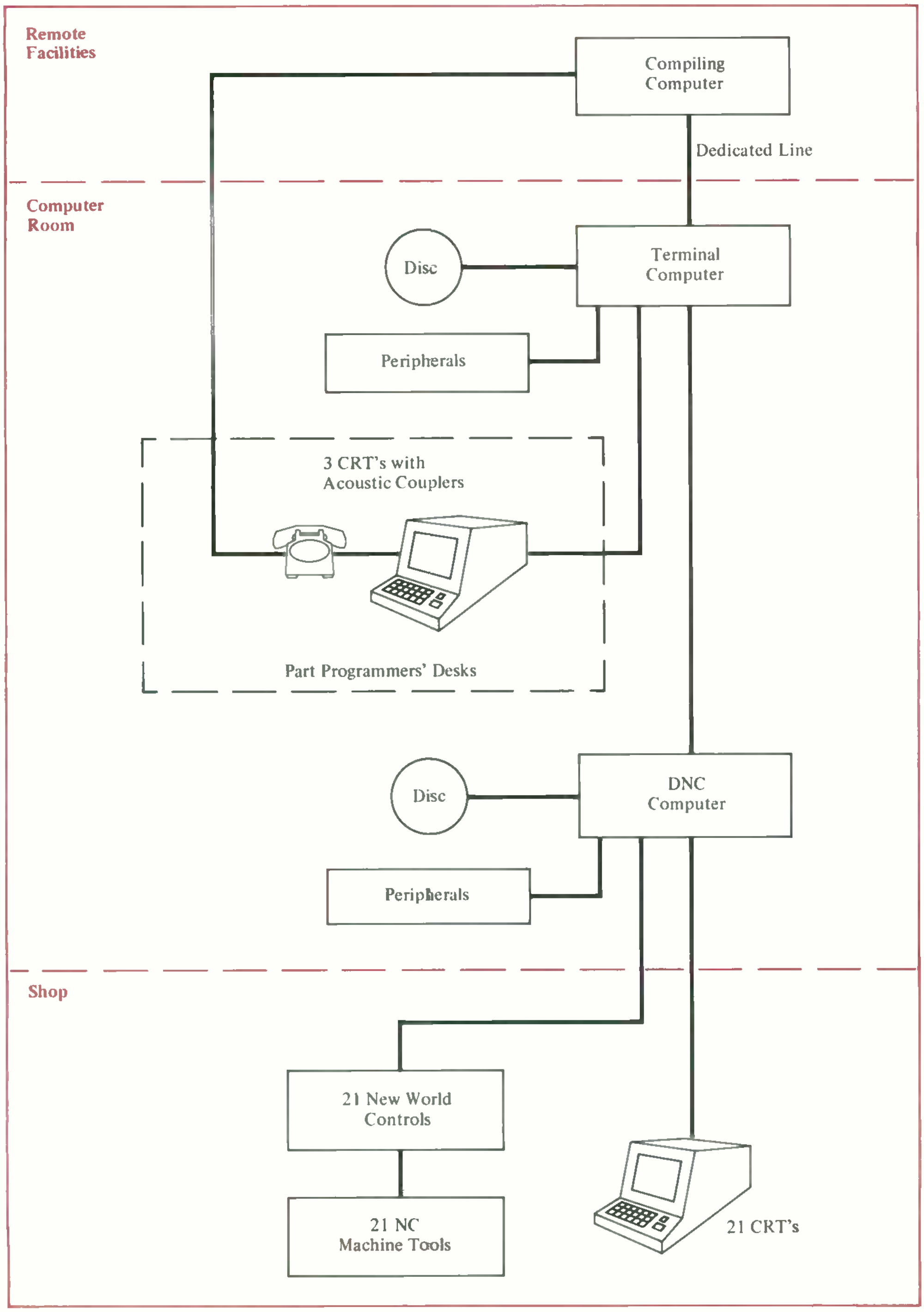
The working center of the DNC system is the DNC computer, which serves as a message switching device for both incoming and outgoing digital information. That information is the direct equivalent of the various punched-tape signals. However, in its new form, the information can be directed between the part programmer and the machine tool control with a minimum of human handling, thus greatly reducing the possibility of errors.

Photo—The CRT terminal in the foreground is one of the input and display stations in the DNC system at the Gas Turbine Plant in Round Rock, Texas (Fig. 1). Machine operators and part programmers can communicate with the DNC computer through the terminals, and they read system data from the display tube in each terminal. At left is the New World numerical control; its tape reader is used only as backup for the DNC system. This station controls a small vertical turret lathe that machines compressor and turbine discs.

1—The DNC system at the Round Rock Plant includes two computers. One serves as a terminal that accepts part programs and relays them to the remote computer, which processes them, interacts with the programmer as he corrects the programs, and sends tape image and printed output back to the computer terminal. That information is stored on disc at the computer terminal to be conveyed, as required, to the DNC computer.

In operation, the DNC computer receives the equivalent of punched-tape information from a compiling facility and directs storage of that information in a disc-type memory unit. Then, on a call from a CRT terminal, the DNC computer directs the machining information from disc memory to a particular machine tool.

CRT terminals are two-way communication devices having a cathode-ray tube for real-time display of data in alphanumerical form and a keyboard for data input. Several levels of system access are available from the various CRT terminals. For example, all the access functions can be available at the terminals used by the production supervisor or any other people who are authorized to make changes in system information. Other terminals would be restricted in access capability. A machine-tool operator on the floor, for example, could call for the necessary machining information from the DNC computer, receive instructions, and report machine status, but he would normally be locked out from direct communication with the compiling computer, other CRT terminals, and certain sections of the disc file. However, if a part programmer needs to make changes in machining instructions while observing that machine tool, the terminal is designed so that he can raise the level of access with a special code, make the necessary data changes, and then return the terminal to its normal status of restricted access.



DNC Now a Proven Product

Westinghouse DNC systems have been installed in three Westinghouse manufacturing plants. The first installation at the Turbine Components Plant located near Winston-Salem, North Carolina, produces rotating and stationary blading, nozzle blocks, and other components for steam turbines.[2] Numerically controlled machine tools are used extensively; some of them are machining centers that perform multiple operations on the surfaces of a part with a single setup. They are directed by a DNC system that began operating in early 1971. (See back cover.)

The second Westinghouse DNC system has been operational about nine months at the Gas Turbine Plant in Round Rock, Texas, an ultramodern facility where the major components of gas turbines are machined and turbines are assembled.[3] (See *Turbine Plant Equipped for High Volume and High Quality*, p. 143.) Its DNC system is similar to that at the Winston-Salem plant but includes some important advances.

The third Westinghouse DNC system is now being installed at the Electro-Mechanical Division, Cheswick, Pennsylvania. This system is a modification of the Round Rock DNC system and will integrate a family of new NC facilities, utilizing New World machine controls, and several existing NC facilities utilizing a variety of machine-tool controls.

These initial DNC installations were designed and assembled by the company's Manufacturing Development Laboratory and the manufacturing engineers of the operating division involved. Now that the DNC system is a proven product, it has been added to the product line of the Manufacturing Systems Department of the Westinghouse Industry Systems Division, which also builds the New World machine tool controls.

Since the DNC system at the Round Rock plant is typical of the most sophisticated system that would be supplied today by the Industry Systems Division, this system will be described in the greatest detail. The other two systems will only be discussed insofar as they differ from the Round Rock installation, to indicate how the basic DNC system can be configured for a particular manufacturing environment.

System Justification—In all three Westinghouse plants, NC was considered a necessity, and calculations showed that a DNC system would increase machine-tool productivity by 10 to 15 percent. Since these were new facilities, one-time savings would also result from reduction in the number of programmers needed and faster debugging of the system at startup.

Productivity improvements were to be realized through lowered work-in-process times and increased machine utilization, provided by such things as reduced tape-reader downtime, elimination of tape changing and tape rewind time, elimination of tape revisions due to part changes by providing on-line editing capability, and optimization of feeds and speeds.

The DNC System for the Gas Turbine Plant

The DNC system at the Round Rock plant controls 21 major machine tools: two stub boring machines, nine horizontal boring mills, two lathes, five vertical boring mills, one special drill, and two special disc lathes.

Each *machine tool* (Fig. 1) has a New World C-Line numerical control, with two to five axes of control. The versatility of the New World control is such that only that one type of NC is needed for all 21 machine tools. Another benefit is that the control program for each machine is stored in that machine's control computer as software. New software can easily be written to modify the existing control program; that new program is then read in and the machine is back in production in a matter of hours instead of the days that may be required for altering a hard-wired control.

A CRT terminal at each machine tool is used to call up programs from the DNC computer, display NC tape data, receive instructions from the DNC computer, and enable part programmers to modify tape data in the DNC computer's mass storage. The DNC computer passes NC tape information to each New World control on demand. Data passes into buffer storage identically as though a tape reader had advanced.

At the *computer room*, the essential DNC elements are a W-2550 computer terminal, a W-2500 DNC computer, and associated peripherals. Peripheral equipment for the DNC computer consists of three CRT terminals (at the part programmer's desks), disc storage, an X-Y plotter, a paper-tape reader and punch, and a teletype; for the computer terminal, it is disc storage, a card reader, a card punch, a printer, a paper-tape reader and punch, and a teletype.

New programming information (source program) is entered at the computer terminal on punched cards. The computer terminal relays that information to the remote computer (a Univac 1108), which compiles it into a part program (object program) equivalent to a punched tape. The resulting tape image and printed output are relayed back to the computer terminal's disc storage and sent from there, as directed, to the DNC computer's disc storage. The DNC computer is the scheduler and on-line store for information required by the machine-tool controls. It has 500 K (16-bit words) of mass storage, which is sufficient to keep programs for about a week of manufacturing.

At the *part programmers' desks*, three CRT's allow two significant capabilities. First, a programmer there can modify part data stored at the DNC computer just as he can from the CRT terminals at the machine tools. Second, he can connect a CRT terminal, via an acoustic coupler and telephone, to the remote compiling computer for direct modification of part programs at the source level before printed output and tape image are communicated from the remote computer to the Round Rock computer room. The latter capability saves time and thereby saves money.

Telephone-type MODEMS (modulator/demodulators) allow for data linking of computers separated by literally thousands of miles. That feature and the high communication speed enable programmers to choose the most useful and economic compiler facilities available. Moreover, the mass memory in the system is large enough to contain machine tape equivalents for more than 24 hours of normal operations, so access to the central compiling computer can be scheduled for the hours when cost is lowest.

Shop Information—Along with the ability to request machine control information, the input capabilities of the CRT terminals are used to create a shop information system. Machine operators report machine status to the DNC system via the CRT terminal. This provides concise records of individual machine-tool productivity and availability on the disc memory. The present status of all machines and the productivity and availability record of each machine can be displayed on the CRT on demand. The shop information system also prints out shift and weekly summary records in an orderly manner. A simple coding format allows an operator to report a host of conditions, such as electrical or mechanical failures that are causing production delays on his machine, broken tools, unavailability of raw parts, or, more

2—The DNC computer at the Turbine Components Plant at Winston-Salem controls a variety of machine tools through their hard-wired numerical controllers. The DNC system is presently being extended from 30 to 40 controlled machines.

typically, that the machine tool is producing parts on schedule.

Operating Advantages—Although the machine tool controls at the Round Rock plant have the capability of reading from punched tape, the very first NC operations were performed via the DNC system. Because of that approach, the DNC system was assumed from the start and tape became only an emergency backup. The system has been down only a few times and only once for more than a few minutes, which was due to human error during the linking of the computer terminal to the DNC computer.

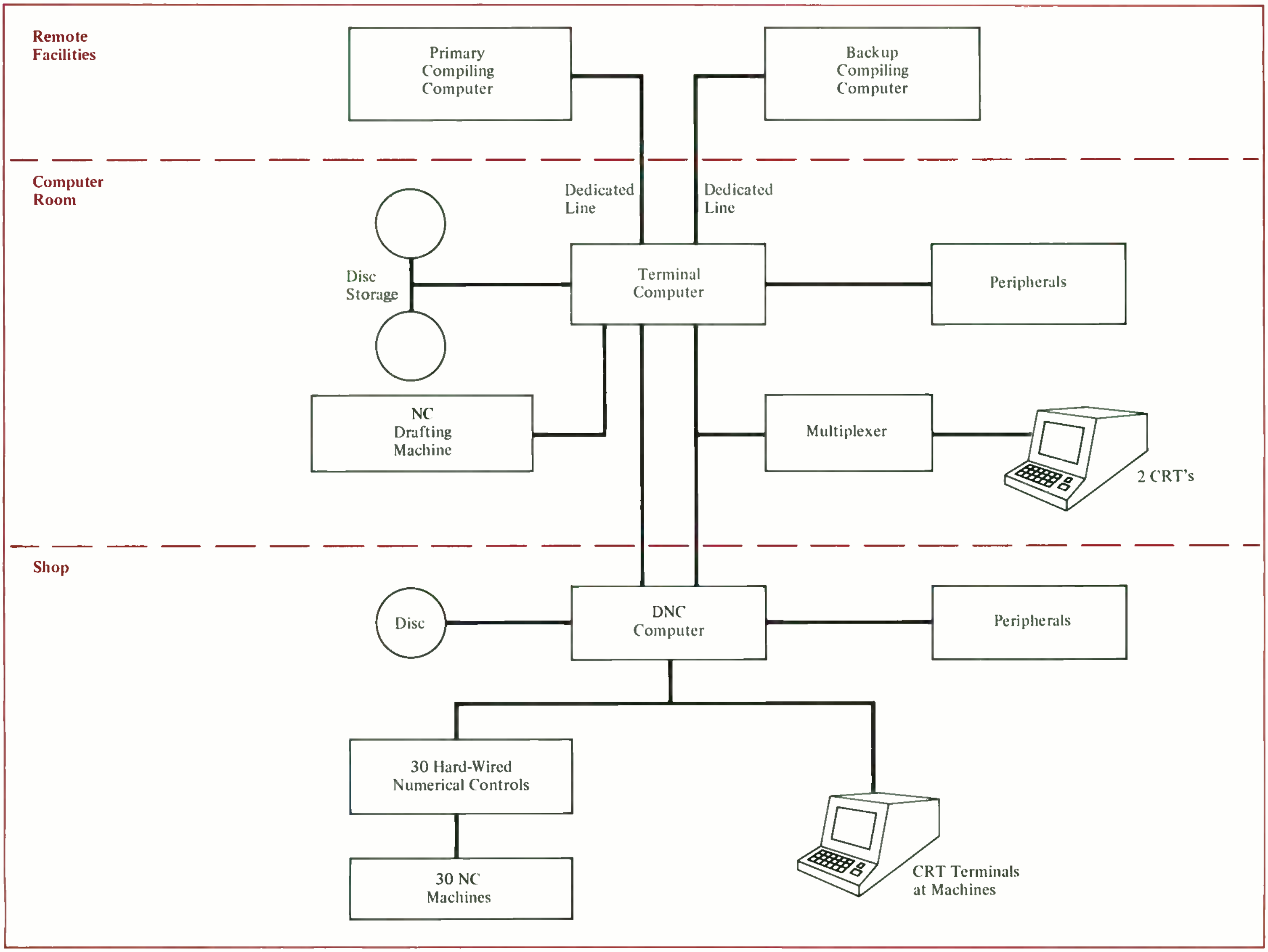
During start-up, DNC simplified the integration of machine tools, New World controls, new compiler software, and new part programs. The ability to make instantaneous modifications to programs proved invaluable. Most of the complex machine tools were acceptance tested in no more than two days. Part-program modifications were made instantly, and feeds and speeds were optimized in far less time than required by the tape system.

Quick commands by programmers at the CRT terminals allowed immediate changes to improve program instructions. For example, increase or decrease in feeds and speeds for actual versus perceived conditions has proved invaluable.

It has also been found that the visual match between the CRT display and the machine-tool readout has increased the confidence of operators. The traditional NC manuscript is displayed on the CRT as well as special instructions concerning machine operation, tool data, and quality-control instructions.

Winston-Salem DNC

The Winston-Salem facility presently has 30 machine tools under DNC control (Fig. 2). These consist of 11 types of machine tools and 7 varieties of hard-wired numerical controllers, the majority capable of circular and linear interpolation. The "behind the tape reader" (BTR) approach of the Westinghouse DNC system allows these machine controllers to be operated from

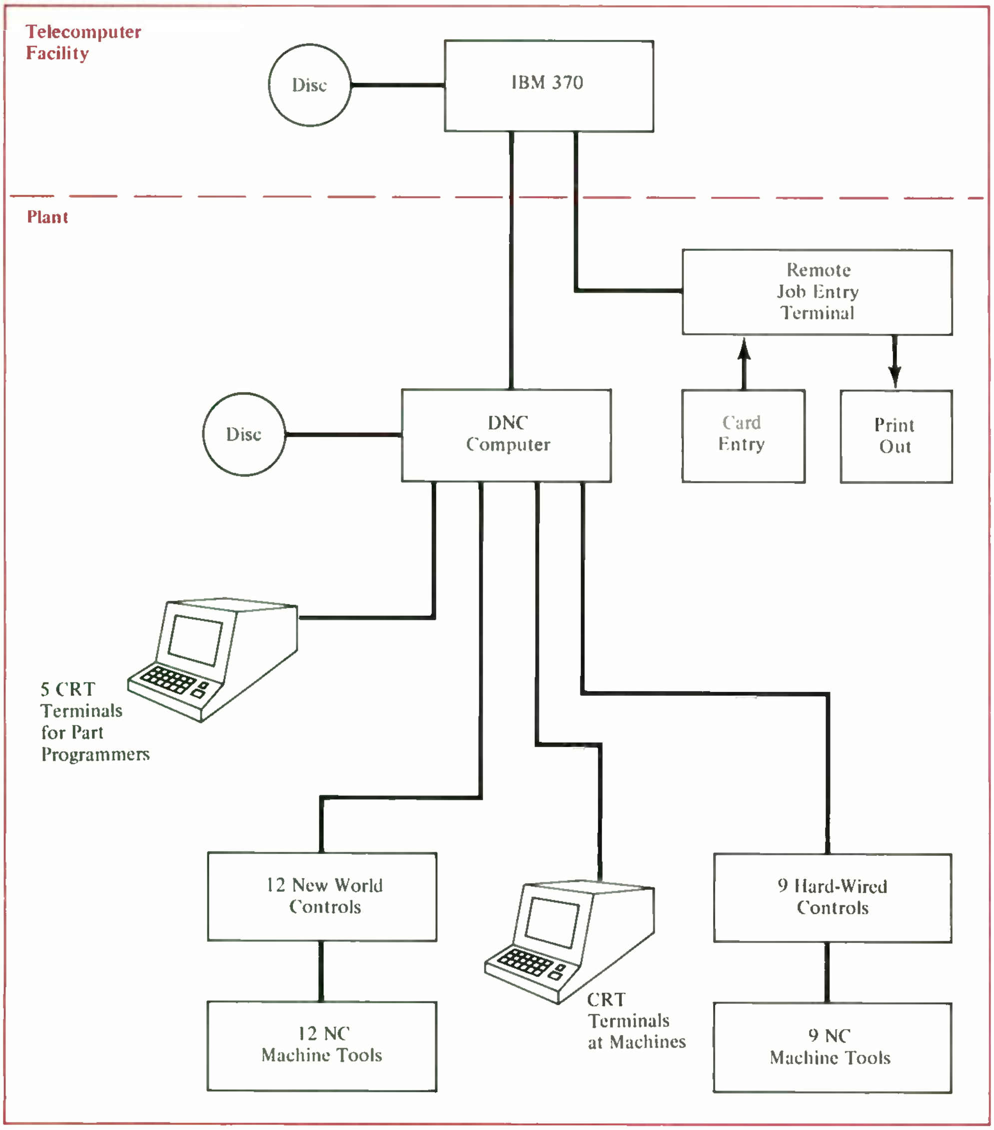


the DNC computer with only a minimum modification necessary to accept data from the DNC computer rather than their own tape readers. If necessary, a machine controller can be switched back to its own reader as an emergency backup.

The flexibility of the DNC system has permitted continuing improvements to the Winston-Salem system. For example, the communications terminal computer was recently changed (to a W-2550) and additional disc storage was added to provide greater system speed and capacity. At the machine-tool level, the system is being expanded from 30 machines presently under DNC control to 40 machines.

The maximum number of machine tools that can be controlled by a single DNC computer is determined primarily by the total number and type of machines under control and the types of parts being produced. As a minimum, approximately 5 to 10 machine tools are required to make a system economically justifiable. This minimum number depends on the mix of parts being produced and the length of run.

3—A dial-up link controls remote source editing and compiling from the DNC system, such as at the Electro-Mechanical Division plant at Cheswick, Pennsylvania.



Cheswick DNC System

The DNC system now being installed at the Electro-Mechanical Division is for controlling 21 machines, 12 with New World controls and 9 with hard-wired controls (Fig. 3). It will be expanded to include 35 machines, 25 with New World controls and 10 with hard-wired controls.

The basic difference in this system is primarily in the use of a shared general-purpose computer terminal rather than a computer terminal dedicated to the DNC system. At the Cheswick installation, all compiling is done at the Westinghouse Tele-Computer Center (WTCC), a large general-purpose computing facility that provides a complete range of computing services. Source part programs are transmitted to WTCC from the remote general-purpose terminal and stored on disc. Upon command from any of the DNC system CRT's, a dial-up link can be established with WTCC, a part program (source) edited, and the recompiled object program (tape image) returned over this link to the DNC computer. The data-linking capability of the DNC computer is an important feature for this type of application because it provides source program editing and compiling right at the machine tool.

Conclusions

The Westinghouse DNC system has progressed through a series of developmental steps, with each step a proven accomplishment before progressing to the next. The three systems now installed at Westinghouse plants demonstrate that developmental process and illustrate the adaptability of the DNC system. Not only can the system control new machines but it can be retrofitted easily to NC machines already in service. Since the system is software oriented, refinements and modifications are easily made and new applications readily designed so that it can continually expand in scope.

REFERENCES:
[1]John L. Patrick, "Numerical Control for Machine Tools is Adaptable and Expandable," *Westinghouse ENGINEER*, September 1970, pp. 137-142.
[2]R. N. Hallstrom and H. T. Johnson, "A Direct Numerical Control System in Operation," *35th Annual Machine Tool Electrification Forum*, Pittsburgh, Pa. (May 25 and 26, 1971).
[3]D. H. Mullins, "Direct Numerical Control," *37th Annual Machine Tool Electrification Forum*, Buffalo, New York (June 12 and 13, 1973).

Turbine Plant Equipped for High Volume and High Quality

Advanced production machines and methods in a new plant greatly increase manufacturing capacity for high-quality gas turbines.

Manufacturing time for gas turbines is substantially reduced by a new production facility of the Westinghouse Gas Turbine Systems Division. The plant, located at Round Rock, Texas, employs advanced methods, advanced machine tools and controls, exacting quality control procedures, and stringent tests to assure fast production of reliable gas turbines. It presently produces the W-501 gas turbine system, which includes modularized packages for starting, mechanical-electrical auxiliaries, and piping for coolant air, lubrication, and fuel.

The plant has 27 major machine tools and 10 major test facilities. Twenty-one of the machine tools are controlled by Westinghouse New World numerical controls (Fig. 1, 2, 3). They are interconnected by a direct numerical control (DNC) system to enhance productivity, maintain up-to-the-minute management information, and provide strict control of manufacturing. (See *Direct Numerical Control Increases Productivity of Machine Tools*, p. 138.)

Each machine station also has a keyboard and cathode-ray display tube (CRT) for communication with the DNC computer. The keyboards are used by part programmers to perform on-line editing of part programs right at the machine tools, and they are used by the machine operators to call up the proper part program once a part is mounted on the machine. The CRT provides a visual display of data and instructions for the machine operator.

Each component is inspected during manufacture. Machine-tool operators make about 75 percent of the inspections and are responsible for the quality of their own work.

An on-line production control and business computer system schedules production, monitors material flow, and, subject to approval, orders materials from plant suppliers.

Use of air pallets to transfer heavy parts to and from machine tools further

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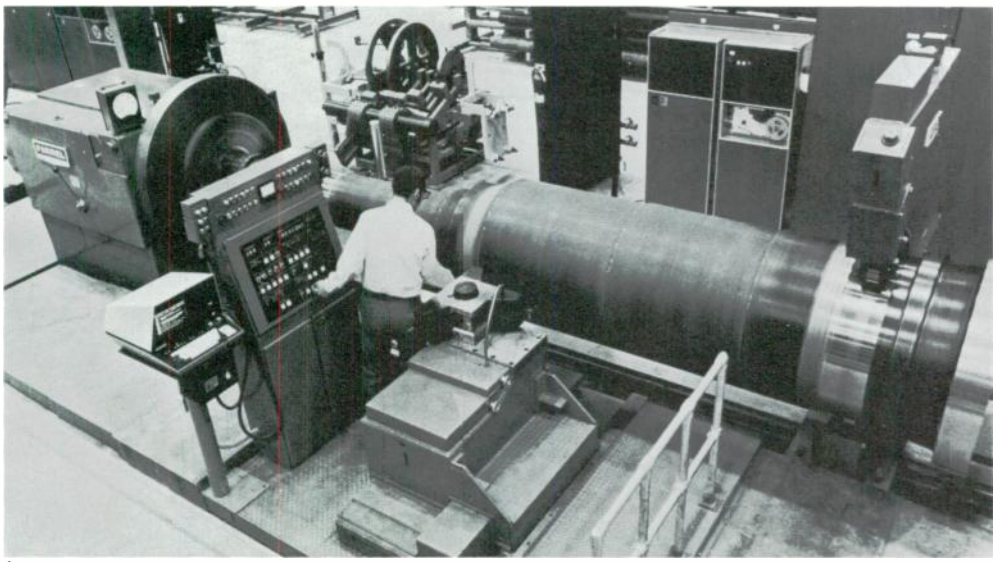

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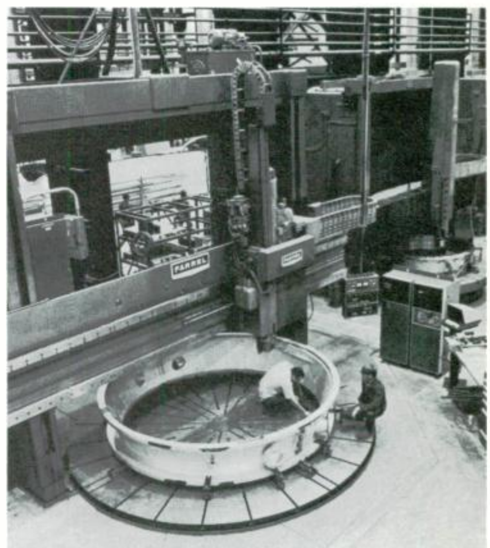

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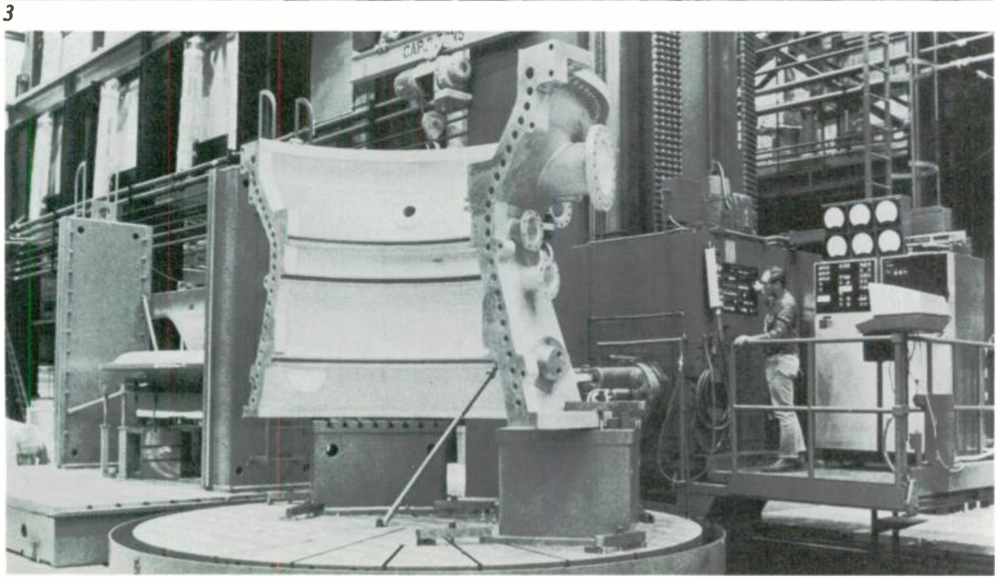

1—Rotor shafts are machined on one of two numerically controlled lathes. All of the NC machine tools in the plant have Westinghouse New World controls connected to a DNC system.

2—An exhaust extension is being set up for machining on the 16-foot vertical boring mill in the foreground. The 10-foot vertical boring mills in the background are machining blade rings.

3—This turbine casing base is set up on a 14-foot rotary table for machining with an 8-inch-bar horizontal boring mill. The mill can perform machining operations either at the rotary table, where precise angular positioning can be provided, or at the air-pallet work station seen in the left background. Workpieces can be transferred to the air-pallet station, and accurately located, within a few minutes.

enhances productivity. Each pallet measures 12 by 18 feet, has a 60-ton capacity, and has a T-slotted surface similar to conventional machine-tool tables. Workpieces are set up on fixtures and clamped to the pallets in a staging area before being transferred to a machine, eliminating setup delays at the machine as well as delays associated with crane operations. The pallets have urethane air bearings that expand downward when inflated to raise the pallet off the floor by about ¾ inch. The air bearings are orificed to allow escape of enough air to float the pallet. Two retractable wheels driven by air motors move the pallet under the guidance of an operator (Fig. 4). Each machine station has a special floor-level base on which the pallet is locked in place to a 0.001-inch positioning accuracy (Fig. 5).

The machine tools at the plant were designed to maintain high machining accuracy while speeding production. For example, a continuous broach cuts blade serrations into discs better than twice as fast as was previously possible (Fig. 6).

The field-orientation principle of manufacturing is used throughout the plant. If the weight of a part can cause a deflection, the part is machined in the same position it will have in the field (Fig. 7).

Casings are assembled in a vertical stack facility that eliminates deflection problems since all joints are vertical rather than horizontal. Vertical stacking also produces good contact at the joints between sections.

Rotor discs are machined in a vertical position on a disc-turning lathe. A special disc drill bores accurate holes through the turbine discs. Tolerances in the order of 0.0001 inch are achieved to guarantee snug fitting of the rotor bolts and to provide a smooth passage for cooling air. The drill uses the trepanning principle in which chips are returned through the center of the tool instead of externally, thus avoiding marring of the surface and making reaming and polishing unnecessary.

Compressor discs are shrunk on the rotor shaft in a numerically controlled stacker (Fig. 8). They are aligned on the

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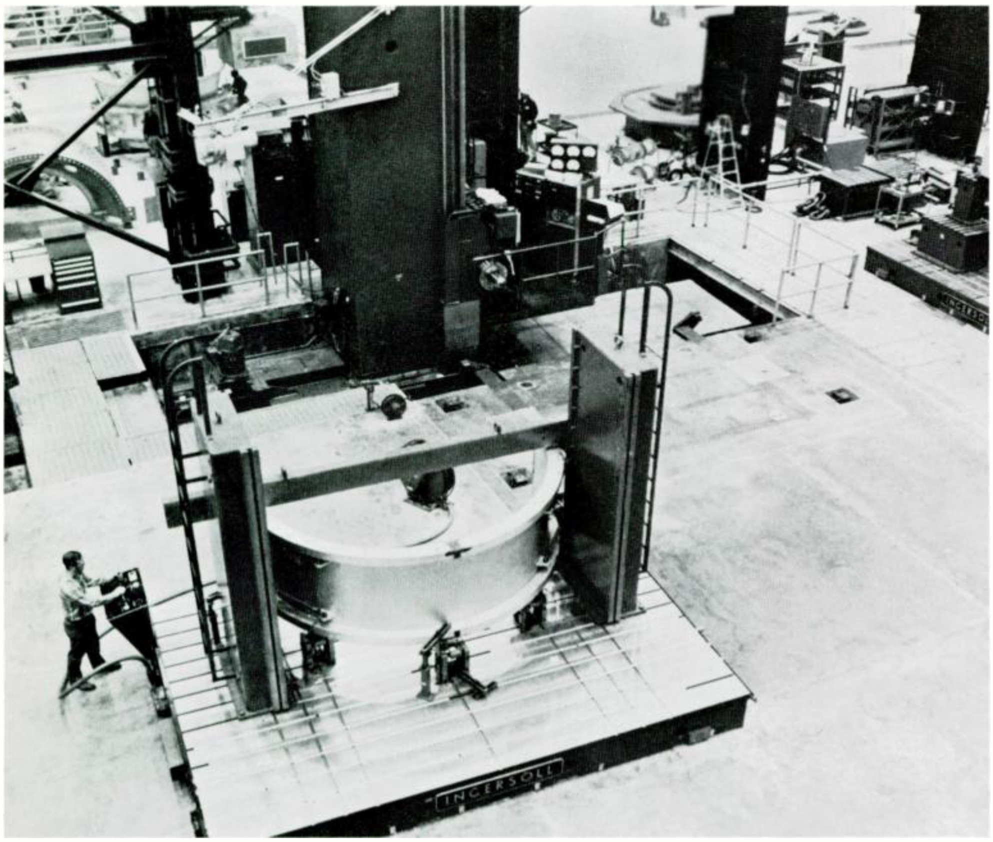

4—Casing sections, which can weigh up to 20 tons each, are transferred to and from the machine tools by air pallets. Here a combustor casing base is being moved from the staging area to a 7-inch-bar horizontal boring mill.

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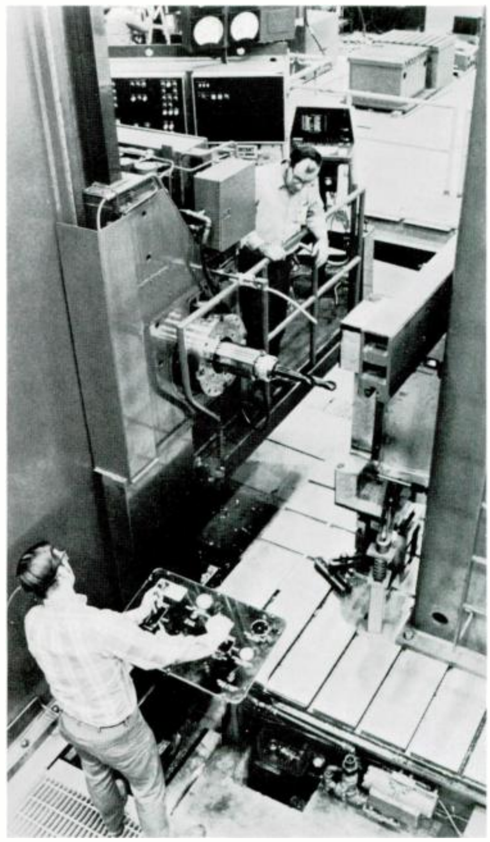

5—The pallet is brought up against stops on the machine tool, and then dowel pins are engaged with mating inserts under the pallet to locate the pallet accurately. The air supply is shut off for final clamping.

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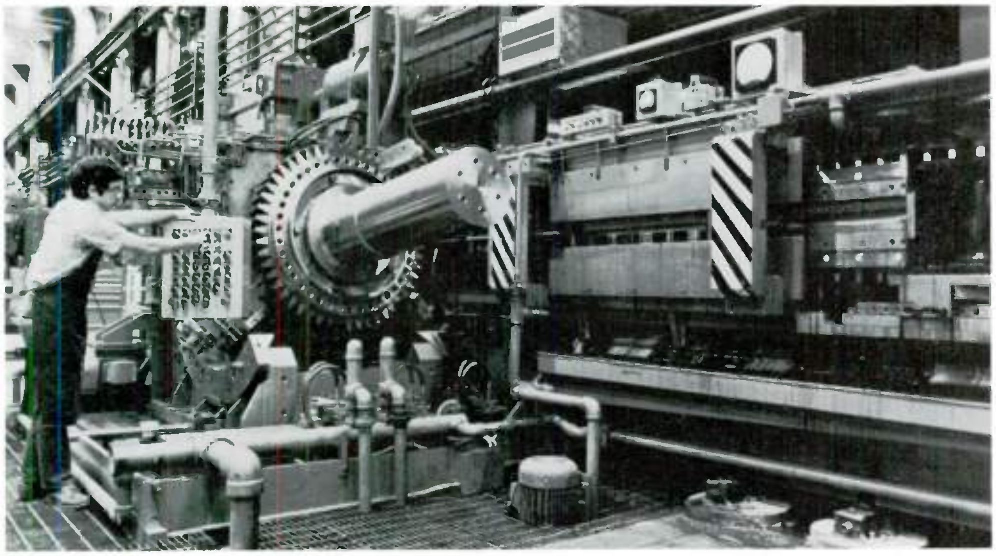

shaft with electronic measuring devices to compensate for minute deviations, producing an inherently well balanced rotor.

The rotor is spin-balanced in two sections at low speed; then the compressor section is spin-balanced and tested at full speed and 20 percent overspeed. (This is done for both the unbladed and fully bladed rotor.) Since the rotor is accurately balanced during manufacture, it can be spin-balanced to a very fine tuning.

Completed gas turbines are fire-tested on a selected basis in a test house adjacent to the plant. An automated control system sequences the test operations, monitors critical functions, and stores the data.

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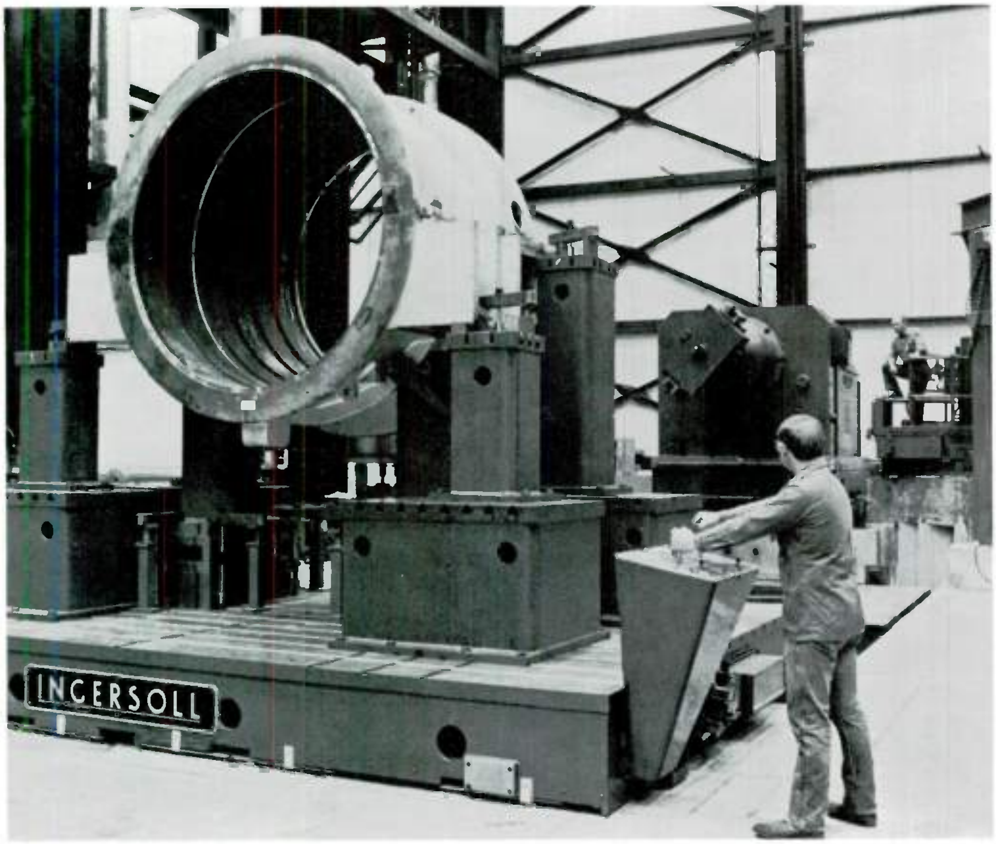

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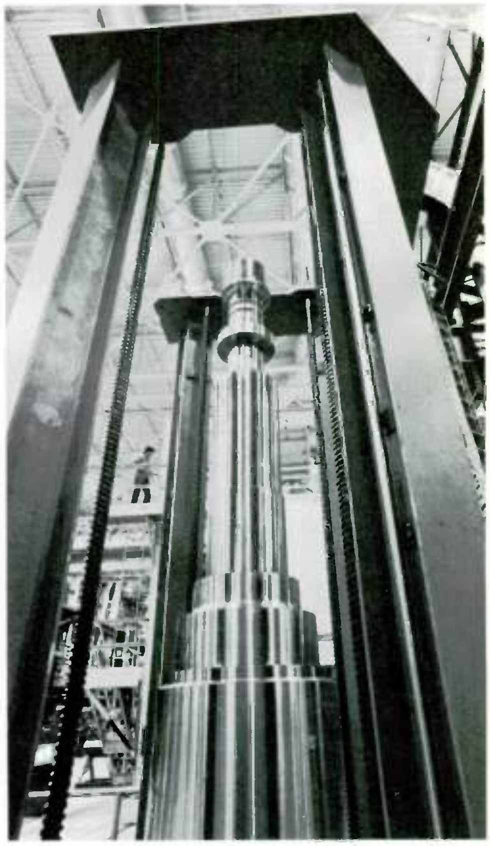

6—Blade serrations are cut into rotor discs with a continuous broach.

7—Casing sections are oriented in their field position for machining to eliminate later deflections caused by their weight. Here a compressor casing is being transferred to the work table of a stub boring, facing, and grooving machine.

8—Compressor discs are stacked on the shaft by this machine, which orients the discs in such a way as to minimize imbalance. Numerical control makes the stacking more accurate than has previously been possible.

Acid Digestion–A New Method for Treatment of Nuclear Waste

R. E. Lerch
C. R. Cooley
J. M. Atwood

The volume of combustible waste material contaminated by plutonium can be concentrated by a new process called acid digestion. The process decomposes the waste material in hot concentrated sulfuric acid in the presence of a nitric acid oxidant and retains the plutonium in the residue.

Low-level radioactive solid waste, such as contaminated paper and plastic materials, is currently being generated and buried at the rate of 2.7 million cubic feet per year (equivalent to a 50-foot-deep hole the size of a football field). These wastes are generated during fabrication of fuel, during operation of nuclear reactors, and during reprocessing of nuclear fuel. The radionuclide concentrations in most of these wastes are too low to permit economic recovery of useable plutonium, and its great bulk makes it expensive to handle, transport, and permanently store. Since half or more of the waste is combustible or compactable, ways of reducing the volumes of these waste materials and at the same time making them noncombustible to eliminate the flammability hazard are being developed.

Typical disposal methods being used today are incineration and compaction. However, neither is entirely satisfactory.

Incineration systems for radioactive waste are expensive to build and operate and, generally, are rather poor in performance. Particular problems encountered include handling of the solid feed, corrosion of the off-gas system, and particulate entrainment in the off-gases. The requirements for fissile material accountability and the diversity of combustible wastes also complicate the operating problems. Incineration does yield good volume reduction (about 50) and weight reduction (10 to 20), and it does convert the waste to a noncombustible state.

Although compaction can provide a volume reduction of 4 to 8, the flammability hazard during shipment and storage of compacted waste is similar to that of noncompacted waste. Furthermore, there is no reduction in weight (except for fewer containers), and special sorting is necessary because some materials (metal, rubber, and plastic) do not compact readily.

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Acid Digestion

Acid digestion is a new process being developed at the Hanford Engineering Development Laboratory to treat contaminated combustible waste materials. The process decomposes waste materials in hot (230-270 degrees C) concentrated sulfuric acid in the presence of nitric acid oxidant. The waste materials are converted into noncombustible residues of considerably less volume. The process readily converts such waste materials as ion-exchange resin, polyvinyl chloride, polyethylene, wood, paper, rags, styrofoam, latex rubber, and neoprene rubber into a low-volume noncombustible chemical residue. Average volume and weight reductions on mixed waste are about 60 and 6, respectively. Table 1 lists the volume reduction achieved on specific materials. As indicated, volume reductions of 100 have been demonstrated for many typical materials. For example, a commercial pressurized-water reactor uses twenty-seven 55-gallon drums (about 200 ft^3) of ion-exchange resin per year in its primary coolant system and five hundred 55-gallon drums (about 3600 ft^3) in its secondary coolant system. The acid digestion process can convert those 527 drums of resin to less than six 55-gallon drums of noncombustible residue.

During the fabrication of nuclear fuel, nearly a kilogram of combustible waste can be generated for each kilogram of fuel produced. This amounts to thirty-eight 55-gallon drums (about 280 ft^3) per metric ton of fuel produced, assuming a bulk density of 0.125 kg/liter of waste. By use of acid digestion, those 38 drums of waste can be converted to less than one 55-gallon drum of waste.

The Digestion Process

The acid digestion process being developed by Westinghouse Hanford uses the following chemical reactions:

$$C_mH_n + n/2\,H_2SO_4 \rightarrow nH_2O + n/2\,SO_2 + mC, \qquad (1)$$

$$C + 2H_2SO_4 \rightarrow 2H_2O + 2SO_2 + CO_2, \qquad (2)$$

$$3C + 4HNO_3 \rightarrow 4NO + 2H_2O + 3CO_2. \qquad (3)$$

Sulfuric acid (H_2SO_4) serves both to carbonize the waste material (C_mH_n) and then oxidize it to CO_2, as shown in reactions (1) and (2) respectively. Reaction (2) is somewhat slow, however, and nitric acid (HNO_3) is a better oxidant as shown in equation (3). Addition of nitric acid also suppresses SO_2 evolution in favor of NO_x. Sulfuric acid provides the high-temperature medium for carrying out the reactions. Temperatures near 270 degrees C are particularly necessary for digestion of plastic materials such as polyvinyl chloride and polyethylene. Nitric acid alone at atmospheric pressure will not destroy most of those waste materials.

Control of Digestion Process

Decomposition gases from the acid digestion process, consisting primarily of carbon dioxide, carbon monoxide, sulfur dioxide, nitrogen, oxides of nitrogen, and chlorides (when chloride-containing plastic materials are decomposed), are immediately released

Table 1—Typical Waste Materials Destroyed in the Acid Digestion Process

Material	*Reaction Temperature Required, °C*	*Volume Reduction*
Ion-Exchange Resin*	270	100
Polyvinyl chloride (PVC)	270	100
Polyethylene	270	100
Wood	200	100
Paper	200	100
Plexiglass	270	100
Styrofoam	230	100
Nylon	100	100
Tygon	270	60
Charcoal (coconut)	270	50
Graphite (powdered)	270	20
Plastic Tape	270	20
Latex Rubber	270	20
Neoprene Rubber	270	20
Iron	200	10
HEPA Filters	270	8
Machine Oil	200	5
Hypalon	270	5

*Destruction of ion-exchange resin was accomplished for all types of resin including macroreticular.

from decomposition of the waste materials. Although the initial off-gas generation rates are high they are easily controlled by regulation of the reaction temperature, initial nitric acid concentration, and the rates of nitric acid or waste addition to the hot acid mixture (Fig. 1). For example, reducing the initial reaction temperature from 270 to 230 degrees C for destruction of polyvinyl chloride reduces the decomposition rate by a factor of 6. By starting at room temperature rather than 270 degrees C, 10 to 20 times more waste can be charged to the reaction vessel while maintaining the same off-gas rate.

The mixture of off-gases released during acid digestion is amenable to clean-up using standard techniques (Fig. 2). For example, oxides of nitrogen and sulfur dioxide are further oxidized by contact with oxygen and then removed by water scrubbing, which converts them back to their respective starting acids. Carbon monoxide and carbon dioxide pass through the off-gas scrubbing system essentially unchanged. Chlorides, normally in the form of hydrogen chloride gas (HCl) or nitrosyl chloride gas (NOCl), are stripped from the off-gas into the water scrub. Nitrosyl chloride is hydrolyzed and remains in the water up to a nitric acid concentration of eight molar. When the nitric acid concentration exceeds eight molar in the scrubber system, nitrosyl chloride is released to the process off-gas ventilation system along with the carbon dioxide and carbon monoxide.

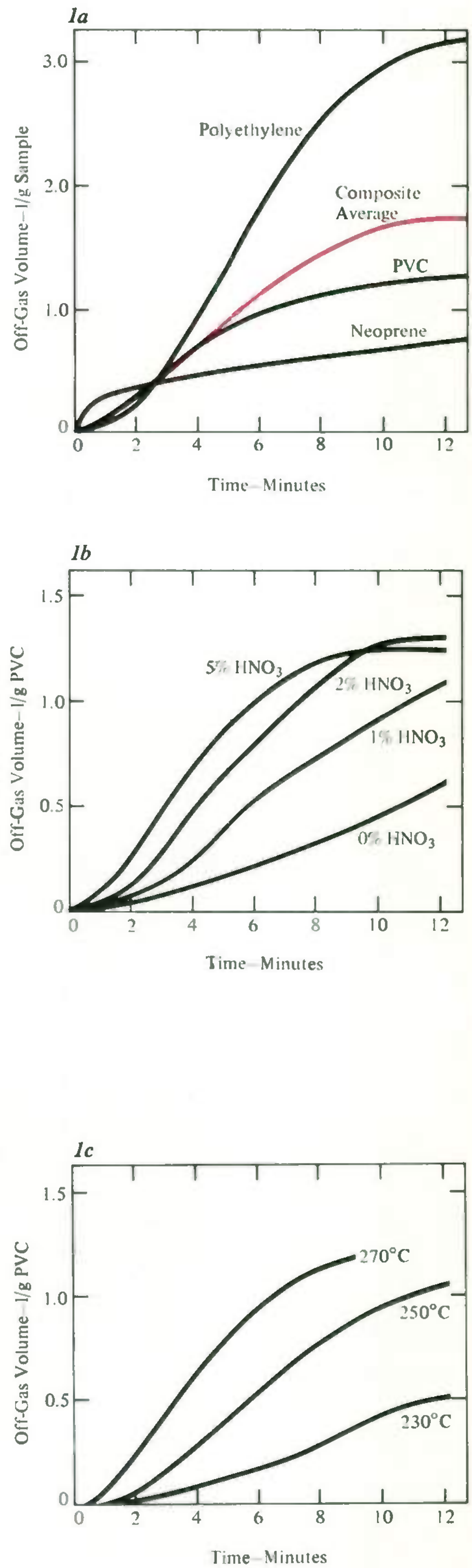
Residue Characteristics and Plutonium Recovery

Solid residues accumulated by the acid digestion process are eventually separated from the acid solution by settling, filtration, or vacuum distillation. The residues are primarily inorganic sulfates of inorganic filler materials present in the starting waste. The residues are noncombustible and show no self-sustaining reactions even when heated to 800 degrees C in air. As mentioned earlier, the final residues are normally only a fraction of the starting volume of waste (Table 1).

Plutonium in the original waste materials becomes part of the residue by converting to either plutonium (III) or plutonium (IV) sulfate in the presence of sulfuric acid. Both compounds are insoluble in the presence of high concentrations of sulfate ion and semisoluble in the presence of nitric acid and sulfuric acid. More than 99 percent of the plutonium stays with the residue, provided the initial plutonium concentration is sufficient to exceed the solubility of plutonium sulfate. The plutonium can be subsequently recovered by leaching the residue with dilute nitric acid. However, when the amount of plutonium is too small to be worth recovery, the entire residue can be shipped to a repository.

Safety

The safety aspects of the acid digestion process have been investigated in depth because of the possible formation of explosive nitro-organic compounds. Nitrocellulose was of particular concern since nitration of cellulose is normally performed in nitric acid/sulfuric acid/water solutions. However, the particular conditions of high temperature and high sulfuric-to-nitric acid ratios used in the acid digestion process are not conducive to nitration reactions. The absence of nitro-organic compounds was confirmed by spectral analysis of digester solutions taken during various stages of acid digestion. In all cases, no nitro-organic compounds were found. In additional tests, typical nitro-compounds such as nitrobenzene, nitrotoluene, and picric acid were destroyed when they were added to sulfuric acid at room temperature, then heated to 150 degrees C in the acid digestion process.



1—Off-gas generation is a function of time, digester-acid composition, and temperature: (a) *digestion of polyethylene, polyvinyl chloride (PVC), neoprene rubber, and a composite of all three is shown for a solution of sulfuric acid (95 volume percent) and nitric acid (5 volume percent) at 270 degrees C;* (b) *control of the reaction by adjustment of the starting nitric acid concentration is shown for digestion of PVC at 270 degrees C;* (c) *control of the reaction by adjustment of reaction temperature.*

Scale-Up Studies

The acid digestion process is being demonstrated on a pilot-plant scale (Fig. 3). All-glass equipment is being used for the process because of the very corrosive nature of the acid and the off-gases. Other materials normally used for handling sulfuric acid, when tested for corrosion resistance in the acid digestion system, were found to be unacceptable.

The pilot plant is assembled from commerically available glassware. It consists of a 200-liter digester, an 18-inch-diameter by 6-foot oxidation-adsorption column for the oxides of nitrogen, and a 12-inch-diameter by 6-foot acid reoxidation tower. Gas-handling lines and recovery-acid lines are made of Teflon-lined neoprene tubing, glass, or 304L stainless tubing depending on their particular use. Teflon gaskets and seals are used throughout the pilot plant. All other valves, heat exchangers, pumps, and flowmeters are fabricated of less chemically resistant materials because of less severe operating conditions.

The 200-liter digester is the maximum "shelf" size available. It permits 20 to 50 pounds of waste to be processed on a 24-hour batch cycle or 50 to 100 pounds per day to be processed with continuous or frequent waste addition. The digester is heated by means of a 16-kilowatt heating mantle. Maximum heat-up and cool-down rates of the digester are 100 degrees C per hour.

The 18-inch-diameter oxidation-adsorption column is used for initial contact of off-gases, oxygen, and scrubbing solution. The digester off-gases and oxygen are combined at the bottom of the column and flow counter to the scrubbing solution. Oxides of nitrogen are oxidized and then absorbed as nitric and nitrous (HNO_2) acids by the scrubbing solution.

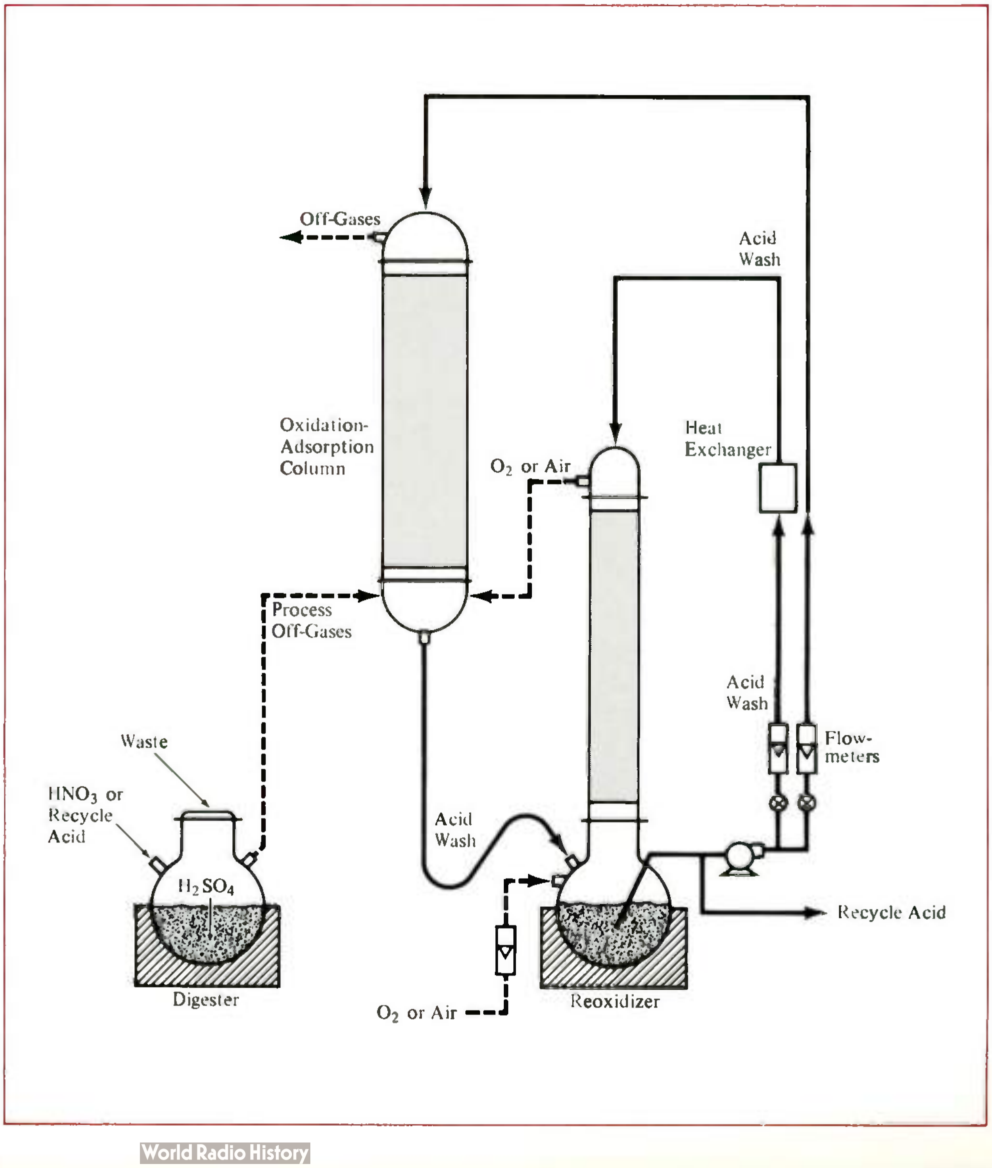
The 12-inch-diameter reoxidation column collects and recycles the scrubbing acid to the large column, and oxidizes any nitrous acid to nitric acid. The scrubbing acid is cycled between the columns until its acidity is high enough for recycle to the digester (probably about 45 percent in nitric acid).

Conceptual Flowsheet

A conceptual flowsheet has been developed for processing 100 kg of solid waste per 24-hour day, i.e., about four 55-gallon drums of combustible waste from a plant producing 100 kg/day of mixed-oxide fuel. The conceptual acid digestion plant would convert the equivalent of 1200 drums of waste per year into less than 24 drums of residue. Greater than 95-percent recovery of the oxides of nitrogen and sulfur dioxide is anticipated for recycle acid to the process.

Although the acid digestion process has been investigated primarily on a laboratory scale, results to date indicate the process has several attractive features:

1) The process appears readily usable



2—The acid digestion and gas-cleanup process consists of a digester, oxidation-adsorption column, and reoxidizer. Off-gases from the digester combine with oxygen or air at the bottom of the oxidation-adsorption column and flow counter to an acid scrubbing solution. The scrubbing solution absorbs the oxides of nitrogen and sulfur dioxide, and other waste gases flow out the top of the column to the building off-gas system. The scrub solution returns to the reoxidizer, where it contacts additional oxygen or air to oxidize any nitrous acid to nitric acid. The scrubbing acid is then pumped back to the top of the columns. Periodically, scrubbing acid is removed from the wash stream and recycled to the digester.

in small equipment at the point of waste generation, thereby improving fissile material accountability and eliminating excessive waste handling and storage.

2) Acid digestion can handle a wide variety of waste materials without extensive sorting.

3) The process is operated at atmospheric pressure and can be easily regulated by controlling the reaction temperature, the nitric acid addition rate, or the waste addition rate.

4) The process minimizes or eliminates liquid effluents if excess moisture from the decomposition reactions can be discharged through normal ventilation systems after recovery and recycle of the principal acids.

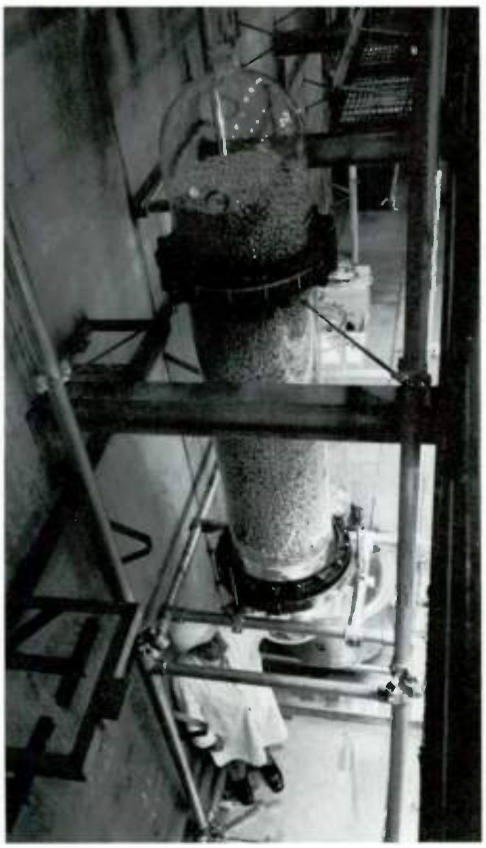
5) The process maintains plutonium in a readily recoverable, nonrefractory form which is leachable from the process residue.

Future Studies

Further studies are planned at Westinghouse Hanford to provide the basis for more detailed evaluation of technical feasibility and for assessment of the economic aspects of the process. Supporting research and development is required on several specific technical items including: selection of the off-gas treatment and acid recovery-recycle system; definition of the throughput capacity limitation of the process and the charging scheme (full bags or chopped material); selection of the characteristics of a solid residue compatible with disposal regulations and associated processing requirements; and confirmation of the safety of the process and establishment of operating ranges for safe operation.

3a

3b



3c

3—The glass pilot plant built for scale-up studies of the acid digestion process (Fig. 2) includes a 200-liter digester (a), *an 18-inch-diameter oxidation-adsorption column* (b), *and a 12-inch-diameter reoxidation column* (c). *The digester is heated by means of a 16-kW heating mantle. The large column, shown being filled with ½-inch Intalox saddles, is used for recovery of the oxides of nitrogen and sulfur dioxide while the smaller column is used for oxidation of any nitrous acid to nitric acid. Acid is periodically removed from the glass flask at the bottom of the small column and recycled to the digester.*

Environmental Monitoring Helps Resolve Pollution Problems

John J. Paulus

Environmental monitoring is a fact of life for electric utilities, industries, and government agencies today. The complex task of establishing a monitoring program is greatly simplified by a total systems approach in which functioning systems of sensors, data acquisition equipment, towers, enclosures, data processing and report services, and supportive consulting are supplied by the Westinghouse Meter Division's Environmental Systems Center.

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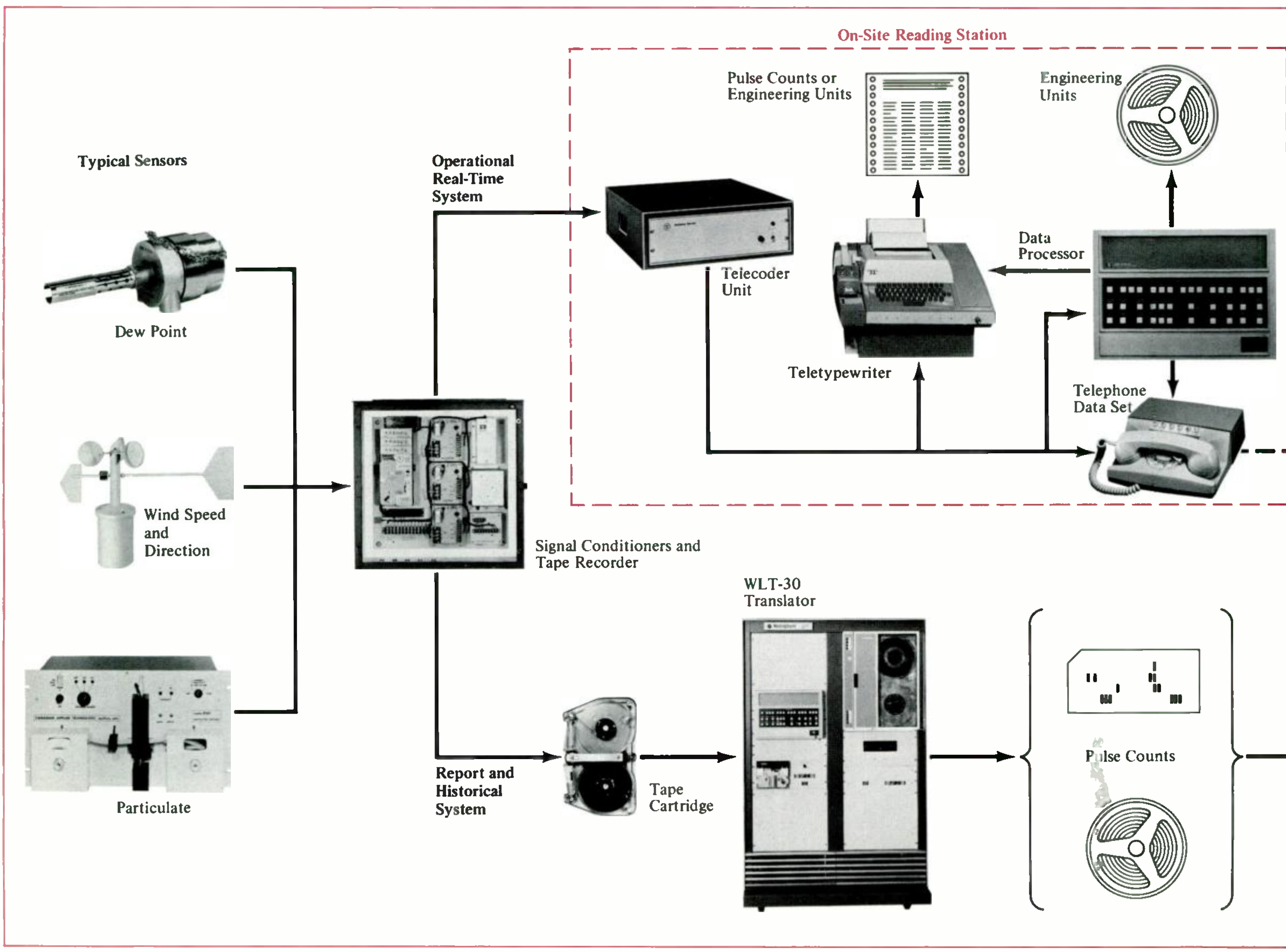
An environmental monitoring system has been developed to help electric utilities, industries, and public agencies resolve their pollution problems. Called the Adviser Environmental System, it automatically senses, records, and transmits environmental conditions, and it provides data in a form ready for computer analysis.

The system is made up of environmental sensors, sensor calibration and support equipment, enclosures and towers, and two parallel data acquisition systems: a *Report and Historical System* and an *Operational Real-Time System* (Fig. 1). In the Report and Historical System, sensor data is collected at the monitoring site and recorded by magnetic tape cartridge recorders. The tape cartridges are gathered monthly, and their information transferred by machine onto computer magnetic tape, computer punch cards, or directly into an ordinary business computer.

The Operational Real-Time Data Acquisition System enables environmental parameters to be read on site or from a remote location. Real-time sensor data can be sent to the reading center on command, at regular intervals, or anytime a preset pollutant limit is exceeded.

Environmental Sensors

A great variety of sensors can be used with the Adviser Environmental System to measure environmental conditions. In fact, any



type of sensor that generates an electrical signal proportional to the parameter it is monitoring—weather, air quality, water quality, noise, or radiation—may be employed. Emphasis in this article is placed on air quality and meteorological sensors because relatively consistent legal standards have been set and are being enforced at federal, state, and local levels for specific air pollutants.

Air Quality Sensors

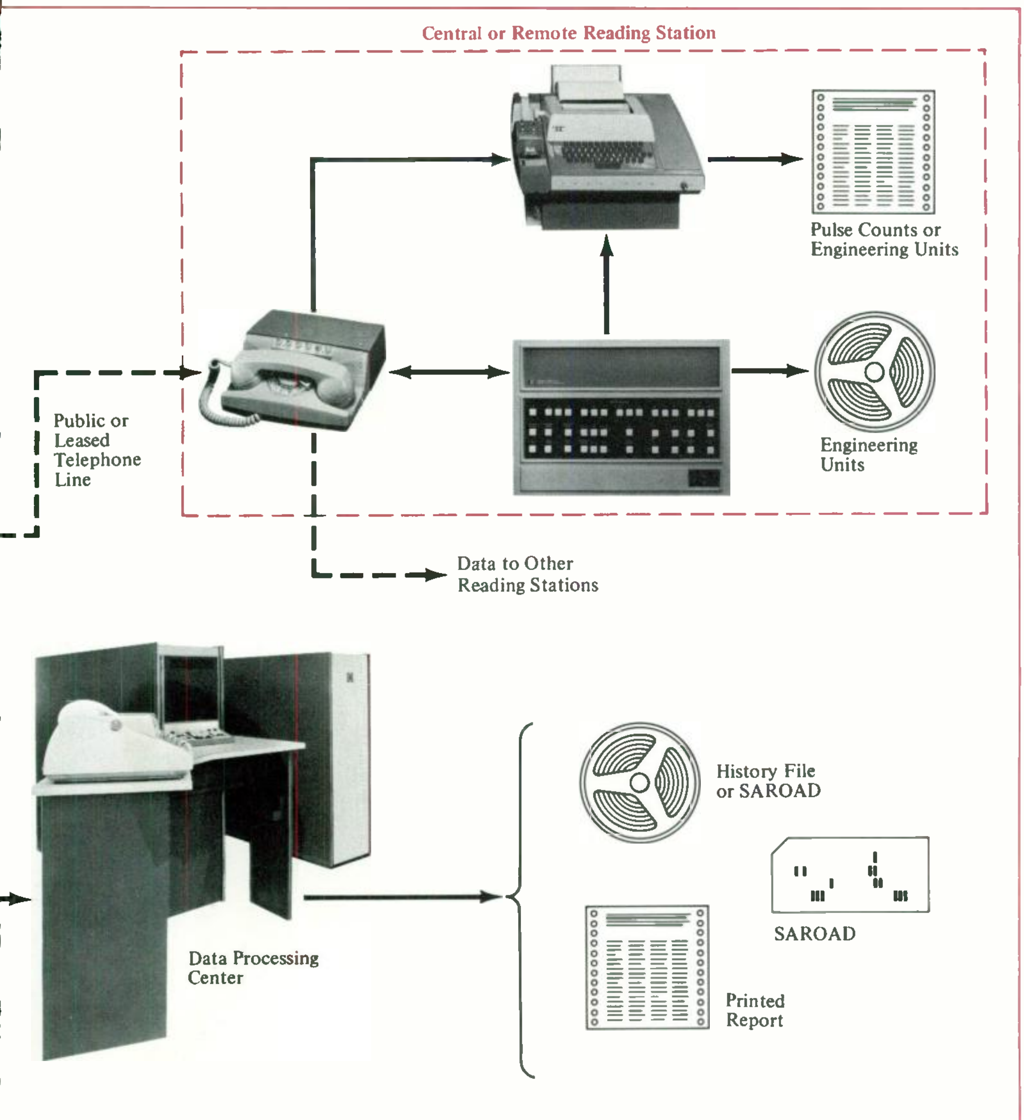
Ambient (outside) air quality standards, i.e., maximum permissible pollutant concentrations, have been set by the U.S. Environmental Protection Agency for six air pollutants: sulfur dioxide (SO_2), particulate matter, nitrogen dioxide (NO_2), oxidants (expressed as O_3), hydrocarbons (HC), and carbon monoxide (CO). Most state and local standards apply to the same pollutants, are at least as stringent as the federal standards, and contain varying requirements for monitoring. Many other air pollutants exist and may be monitored in the future, but since the above six pollutants are the primary object of current air pollution regulatory efforts, sensors for them are briefly discussed.

Sulfur Dioxide—A "flame photometric" sensor is one modern reliable means for continuously measuring ambient SO_2 concentrations. This type of sensor detects the light emitted in a specific wavelength band by sulfur-containing compounds burning in a hydrogen flame. Total sulfur content of the air is measured, which is in most cases predominately SO_2. Other types of continuous SO_2 sensors that can be used with the Adviser System employ "coulometric," "conductimetric," and "colorimetric" methods of detection.

Particulate Matter—Currently, only two devices are generally accepted for routinely measuring ambient particulates—the "high volume sampler" and the "filter tape sampler." Both devices draw air through a filter. In the high volume sampler, the weight of particulate matter on the filter (manually determined) is used to measure particulate concentrations, whereas in the filter tape sampler, the percent light transmission through the filter (automatically determined) provides the means for measuring particulate levels.

Nitrogen Dioxide—The most modern continuous sensors for NO_2 employ photometric detection of "chemiluminescence" resulting from the flameless gas-phase reaction of nitric oxide (reduced nitrogen dioxide) with ozone. A second common type of sensor for NO_2 measurement employs colorimetric detection.

Photochemical Oxidants—In air pollution usage, photochemical oxidants usually refers to ozone gas. Ozone is formed as a result of photochemical reactions involving sunlight, oxygen, and pollutants such as hydrocarbons and nitrogen oxides. The most modern acceptable ozone sensor employs photometric detection of chemi-



1—The Adviser Environmental System monitors air quality, water quality, and meteorological conditions around an area or facility. Several representative sensors are shown. In the Report and Historical System, *sensor data is continuously recorded on tape cartridges, which are periodically gathered and their data translated into computer language on cards or tape. Computer processing of the data provides an accurate record of pollutant emissions correlated with time and weather. Operating either independently or in parallel with the recorders is an* Operational Real-Time System, *which enables an on-site or remote reading station to acquire sensor data on command. A number of options and output types from both data acquisition systems are indicated. An automatic alarm system is also available to present data immediately if sensor readings exceed predetermined values.*

luminescence, which results from the flameless reaction of the ozone with ethylene gas.

Hydrocarbons—Hydrocarbon measurements are expressed as "total hydrocarbons" and "nonmethane hydrocarbons." Since methane is an abundant naturally occurring gas, regulatory standards apply only to nonmethane hydrocarbons. They are detected by burning a gas sample in a hydrogen flame that ionizes the hydrocarbon molecules. The ions are collected at electrodes, producing the electrical output of the sensor. A gas chromatograph separates methane from nonmethane hydrocarbons prior to entry into the flame ionization detector.

Carbon Monoxide—A proven sensor for continuously measuring carbon monoxide is the nondispersive infrared analyzer. This sensor makes use of carbon monoxide's characteristic absorption of infrared radiation at a specific wavelength to determine concentrations. A flame ionization sensor may alternatively be employed to sequentially measure CO concentrations, if preceded by a gas chromatograph to separate CO from hydrocarbons in the sample.

Meteorological Sensors

Air quality data must be correlated with meteorological conditions to be of maximum benefit. Meteorological parameters commonly monitored in air pollution programs and radiation safety programs include wind speed and direction, horizontal wind direction fluctuation, vertical temperature gradient, and ambient temperature. Other parameters monitored are dewpoint, relative humidity, barometric pressure, precipitation, solar radiation, and visibility. Some parameters are more important than others, depending on the objectives of the monitoring program undertaken.

Wind speed and direction—Generally, these are the most important factors in meteorological monitoring, since wind direction indicates where emissions may be transported and wind speed is often (with exceptions) inversely proportional to pollutant concentrations. Wind speed is measured by a cup or propeller anemometer, and horizontal wind direction by a damped directional vane. Instruments are also available for measuring the vertical component of wind direction.

Horizontal wind direction fluctuation and vertical temperature gradient—These parameters characterize the degree of atmospheric mixing, an important determinant of air quality. Horizontal wind direction fluctuation is a statistical parameter calculated electronically from the movements of the wind direction vane. Vertical temperature gradient is measured with two temperature sensors placed at two levels at least 30 meters apart on a meteorological tower. The most accurate sensors for continuous temperature measurements employ platinum resistance elements housed in aspirated thermal radiation shields.

Ambient Temperature—Air pollution is affected by ambient temperature in several ways. Temperature influences chemical reaction rates in the atmosphere, the rise of pollutants released from sources, and the amount of fuel consumed for heating and air conditioning purposes. Temperature measurements are sometimes required to convert air quality measurements to reporting units.

Water Quality Sensors

The number of significant water pollutants and water quality parameters is enormous. In the past, careful manual laboratory analyses were required to accurately measure water quality parameters. The trend today is toward continuous measurements, using electrical output sensors and automated analyses. The Adviser Environmental System has been interfaced with continuous sensors to measure dissolved oxygen, pH, conductivity, turbidity, temperature, water level, and flow. As more automated sensors are developed, some of the many water parameters that may be monitored by the system include biochemical oxygen demand (BOD), chemical oxygen demand (COD), total oxygen demand (TOD), total organic carbon (TOC), various nitrogen and sulfur containing compounds, chlorides, chlorine, phosphates, and a wide variety of ions.

Who Uses Environmental Monitoring Systems?

Electric utilities and industries use environmental monitoring to obtain licensing for new facilities, determine compliance with governmental regulations, warn of hazardous pollutant concentrations, and provide guidance for investments in pollution control equipment. In addition, monitoring provides guidance for expansion of generating or manufacturing facilities and the location of new facilities, and it enables development of efficient economical procedures for coping with pollution episodes.

Environmental monitoring instrumentation is being increasingly employed by nuclear power plants. For example, plant-site meteorological conditions must be monitored and analyzed for at least one year before a construction permit is granted by the Atomic Energy Commission, and continuous monitoring is required during plant operation (Figs. 2, 3). Nuclear power plant meteorological monitoring enables estimation of the dispersion and consequences of radioactive releases for safety analyses and environmental reports. Similar studies, using meteorological, air quality, and water quality monitoring systems are also being voluntarily undertaken by many utilities and industries before constructing and operating any facilities with a potential for environmental effects.

Environmental monitoring systems are used by governmental agencies at the federal, state, and local levels. The U. S. Environmental Protection Agency, for example, is monitoring various pollutants with nationwide networks to develop pollution control strategies, and it has funded numerous environmental research projects that require continuous monitoring. In addition, the EPA requires certain new air pollution sources to continuously monitor their stack gases.

Federal law has required that states monitor six types of air pollutants to measure progress toward their goal of attaining national primary ambient air quality standards in 1975. States are also setting and enforcing emission standards, stack monitoring requirements, and ambient air monitoring requirements for specific sources of air pollution. Many local governmental agencies have also found it helpful to operate air monitoring networks.

The Federal Water Pollution Control Act Amendments of 1972 require extensive water monitoring programs on the part of state government, local government, and industry. Under the Act, the EPA has thus far published interim wastewater effluent guidelines that include recommendations of water monitoring requirements for specific industry types. Permanent standards and monitoring guidelines will be proposed in October of this year.

Signal Conditioners

Signal conditioners interface environmental sensors to the data acquisition systems by converting the electrical signal outputs of the sensors to pulse rates. Each signal conditioner generates pulses at a rate proportional to the output of its sensor; the maximum rate is 100 pulses per minute or 6000 pulses per hour. Each pulse is an integration with respect to time of the parameter concentration or other value being measured by the sensor. The total number of pulses generated over a specified time interval is proportional to the true average of the parameter for that interval.

The rating of the signal conditioner for use with a particular sensor is chosen to match the output of that sensor. For example, signal conditioner ratings corresponding to sensor outputs include: 0-1, 0-5, and 0-10 volts dc; 0-10 and 0-200 millivolts dc; 4-20 milliamps dc; 300-600 ohms; and 16-to-1 pulse divider.

Report and Historical Data Acquisition System

The Report and Historical Data Acquisition System is used by utilities and industries to develop monthly, quarterly, or annual environmental reports for internal evaluation and planning and for reporting to regulatory and licensing agencies. The major components of the system are magnetic tape cartridge recorders and the translator (Fig. 1).

Magnetic Tape Recorder—The pulses from the signal conditioners are sent to slow-speed magnetic tape recorders where they are recorded on ¼-inch tape cartridges. The recording system is based on the proven concepts of the Westinghouse Pulse-O-Matic System, which has been used by electric utilities since 1957 for applications such as billing, load surveys, engineering studies, rate studies, and research.[1,2] Over 35,000 recorders and 85 translators have been supplied internationally. The recorders can be surface mounted indoors on a wall or inside a cabinet, or flush mounted in a wall or rack; they can be mounted outdoors in special weatherproof cabinets. To minimize the possibility of data loss, the recorders are always located with their signal conditioners at the monitoring site.

The recorders have four tape channels. Environmental data is recorded on three channels, while on the fourth, a time pulse is recorded for each interval, which can be either 1, 15, 30, or 60 minutes. A battery carryover arrangement is available as an option with the recorders to provide continuous time-interval recording in the event of a power outage.

Up to 36 days of data can be continuously recorded on one tape cartridge. At the end of the desired measurement period, usually one month, the tape cartridges are removed from the field recorders and returned to a central location for translation. Accompanying each cartridge is an identification Field Data Cartridge Form, which lists start and stop times, sensor interruptions, power interruptions, and other pertinent information. This information is used in translation and to thoroughly reference the data from each cartridge.

Tape Translation—The recorded data on the tape cartridges is read by a translation device. The machine counts the number of pulses on each channel and writes the totals for each time interval on ½-inch computer tape (Fig. 1). Also written on the computer tape is the identification information for each cartridge being translated. An entire month of data from three sensors, contained on one cartridge, can be read in less than 3 minutes and written on about 3 feet of computer tape. The translated pulse-count data can also be written on punched cards.

The WLT-30 translator, supplied by the Westinghouse Environmental Systems Center, has a number of capabilities and options that permit adaptation to the specific needs of a user's system. It is made up of a cartridge tape reader, special interface boards, data processor, buffered teleprinter input/output, magnetic tape writer, and a basic operating program that enables validity checks on field tape data. Most peripheral equipment commonly used in the computer industry can be added to the WLT-30 such as a card reader, paper tape reader, high-speed printer, XY-plotter,

2

3

2—Meteorological conditions at a nuclear power plant site must be monitored for at least one year before the Atomic Energy Commission will grant a construction permit. Continuous monitoring is also required during plant operation. This typical 250-foot tower supports meteorological sensors that measure ambient temperature, vertical temperature gradient, wind speed and direction, and dewpoint.

3—The precipitation gauge is another meteorological sensor often deployed at a nuclear plant site. This one employs a tipping bucket arrangement to generate an electrical pulse output with each 0.01 inch of rainfall collected.

moving-head disc system, and a synchronous data set adapter to permit connection to a large computer.

Many utilities already own translators (some of earlier design) for use in billing and load surveys and can use them for translating environmental data. However, since the translator is expensive, it is sometimes uneconomical to own a translator for environmental monitoring systems with only a few recorders. A later section of this article describes translation, data processing, reporting, and storage services offered by the Westinghouse Environmental Systems Center to meet this need.

Operational Real-Time Data Acquisition System

The Operational Real-Time System enables on-site or remote reading stations to acquire environmental sensor data on an immediate basis (Fig. 1). The central component in the system is a Westinghouse Telecoder unit, which can operate in parallel with the Report and Historical System or independently. The Telecoder unit continuously receives and counts the pulses generated by up to 20 sensor signal conditioners. After each time interval (preselected as either 1, 5, 15, 30, 60 minutes or longer), the Telecoder unit transfers the numerical pulse-count quantities to its storage registers. Up to 96 time intervals of data per sensor can be stored in the registers depending on the type of electronics cards used. The pulse-count output of the Telecoder unit is in teletype-compatible ASCII code.

At the monitoring site reading station, there are two possible routes for the Telecoder unit data. The first route is hardwired directly into a teletypewriter that prints out interval-by-interval pulse counts of all the parameters that were stored in the Telecoder unit. The second route is hardwired through a data processing unit, which converts the pulse-count data into standard engineering units and performs other processing such as calculating 1-hour, 3-hour, and 24-hour running averages. The output of the data processor can be printed by the teletypewriter, sent to a magnetic tape writer, which produces a permanent record of the data on ½-inch computer tape, or sent to other reading stations.

For sensor readings at a remote station, the ASCII-coded data is converted by a telephone data set into audio signals that are transmitted over a public or leased standard voice-grade telephone line. The signals are received at the remote reading station by another telephone data set that converts the audio signals back to a format suitable for input to a teletypewriter, CRT display, or data processor. The data processor, as in the on-site system, can convert the data to engineering units, perform limited additional processing, and produce a computer tape record. It can also be programmed to automatically send its processed data to any number of other reading stations.

Real-time information may be obtained from the Telecoder unit by manual inter-

4—A typical Environmental Readings Report lists all average hourly values of several sensor parameters for one day.

ENDING TIME	SOLAR RAD LY.	TEMP DRY BLB DEG(F)	WIND SPEED MPH	WIND DIRECT DEG	SULFUR DIOXIDE PPM	SULFUR DIOXIDE AO3HR PPM	SULFUR DIOXIDE A24HR PPM	PARTI-CULATE COH/MFT
01:00	0.00	70.72	7.0	185	0.001	0.000	0.002	0.646
02:00	0.00	72.04	12.1	215	0.001	0.001	0.002	
03:00	0.00	70.51	9.0	194	0.001	0.001	0.001	0.673
04:00	0.00	67.93	5.1	175	0.001	0.001	0.001	
05:00	[illegible]	66.73	3.6	165	0.001	0.001	0.001	0.661
[illegible]		[illegible]				[illegible]	0.001	
24:00	0.00	71.08	3.6	171	0.000	0.000	[illegible]	
HIGHS	1.31	86.56	22.6		0.320	0.281	0.071	3.085
AVG	0.46	77.41	13.2	225	0.071	0.071	0.036	1.527
LOWS	0.00	66.73	3.6		0.000	0.000	0.001	0.551
TOTAL								

rogation, automatic interrogation, or automatic alarm. A remote station can *manually interrogate* the Telecoder unit by placing a telephone call to it. The Telecoder unit can be manually interrogated on site from the keyboard of a teletypewriter. Either an on-site or remote data processor can be programmed to *automatically interrogate* the Telecoder unit on a preset schedule. The *automatic alarm* is activated whenever a sensor reading exceeds a predetermined value. An automatic call unit transmits an alarm message and all Telecoder unit environmental data to the remote reading stations.

Data Reports and Storage

As mentioned earlier, users of environmental monitoring systems frequently cannot justify the investment in their own translation and data processing equipment. Therefore, the Westinghouse Environmental Systems Center offers standardized data processing services, which include the Historical Report Service, the One-Time Report Service, and the Environmental Field Data Translation Service.

The *Historical Report Service* includes translation, processing, and storage for future use of the data collected by the Report and Historical System, and processing and storage of the data collected by an automatically interrogated Operational Real-Time System. The standard outputs are an Environmental Readings Report (ERR) and a History File Computer Tape. The ERR lists on one page each parameter's hourly average in engineering units at each monitoring station (Fig. 4). Also listed is the daily high, low, and average of each parameter to provide an indication of whether regulatory standards may have been exceeded and a check on the validity of the data record.

The History File Computer Tape is a compact record of all pulse-count data and supporting information collected by a monitoring system over a period of up to one year. The tape is maintained by Westinghouse. The data stored on the tape may be input to a computer at any time to supply monthly, quarterly, or annual reports in a variety of available Westinghouse formats. For example, some formats show correlations of high pollutant concentrations with meteorological conditions, and others present statistical parameters that summarize the data to provide a concise picture of pollutant levels. A particularly useful optional output of the Historical Report Service is the data record provided on computer tape or punched cards formatted according to SAROAD, the standard coding and formatting system most often required for utility and industry environmental reports submitted to regulatory agencies.

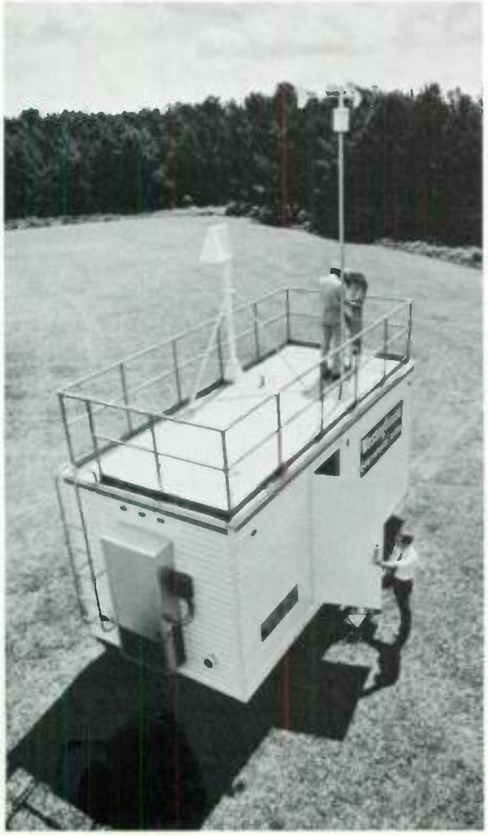
The *One-Time Report Service* is available for the customer who simply wants his data processed into appropriate engineering units. Standard outputs include a computer tape and printed report of the monthly field tape data. This service also offers as an option a computer tape or punched cards record of the data formatted according to SAROAD.

The *Environmental Field Data Translation Service* is designed for the customer who uses his own data processing equipment and wants all his field recorder data translated into computer format on computer tape or punched cards.

Additional Considerations

The success of an environmental monitoring program depends on several considerations in addition to the hardware and data processing already described. For example, to provide consistently accurate data, the sensors must usually be supplemented with calibration and support equipment, and they often must be mounted within specially designed heated and air conditioned enclosures (Fig. 5). Meteorological sensors must be mounted on 20- to 400-foot towers for proper exposure to the atmosphere. Other key factors in obtaining meaningful information from monitoring systems are the locations of the monitoring stations, the careful operation and maintenance of the stations, and the handling of the data generated by the stations. In accepting these additional responsibilities, the Westinghouse Environmental Systems Center can provide a *total monitoring system* that is both efficient and economical and that provides the most useful data.

5—The Westinghouse Environmental Mobile Station is fully equipped with sensors, recorders, and signal conditioners to continuously monitor air quality and meteorological conditions. The station is heated and air conditioned and may easily be towed to the monitoring site.



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[1]C. J. Snyder and D. D. Weers, "Magnetic Tape Recording on Electric Utility Systems," *Westinghouse ENGINEER*, September 1965, pp. 130-6.

[2]Delbert D. Weers, "Pulse-O-Matic Metering Concept," presented at the Annual Meeting of the Air Pollution Control Association, New York, New York, June 22-26, 1969.

Technology in Progress

NASA Tests New Type of Power Management System

A new approach to solving problems of electrical power reliability and management in future aerospace vehicles is being tested for possible use on advanced spacecraft, including the space shuttle. Engineers at NASA's Manned Spacecraft Center and Marshall Space Flight Center are evaluating the system, called the Automatically Controlled Electrical System (ACES).* ACES was developed by the Westinghouse Aerospace Electrical Division, which supplied two systems under contract to NASA.

Simulations are being run at the NASA facilities to arrive at the combination of electrical equipment and methods that will best suit the spacecraft. (See inside front cover.) ACES promises to provide high system reliability, improved electrical performance, and automatic control of the electrical loads. System life-cycle cost should be lower than in other approaches because system response can be readily changed through software rather than by making costly hardware changes.

In present aerospace electrical systems, feeders lead from the power source to cockpit switches and thermal circuit breakers to permit control of electrical loads by the flight crew. Hundreds of other heavy wires then run from the cockpit to the loads in a typical vehicle. In ACES, feeders go from the generators to load centers located at the electrical "center of gravity" for various parts of the craft, and power is switched at the load centers by remote control.

An ACES is composed of remote power controllers (hybrid electronic switching circuits that perform the switching functions), a distribution control center (a general-purpose digital computer), remote input/output units that multiplex and demultiplex control signals, and a data entry and display panel that provides manual control and displays system status.

Electrical load control and sequencing are accomplished with logic programmed into the distribution control center. Signals from control switches and sensors are transmitted to the center on a multiplexed data bus. There, logic equations are solved and control signals transmitted to turn the appropriate remote power controllers on or off. Indication signals are also processed by the distribution control center and transmitted to the appropriate subsystem status indicators. The distribution control center can also be programmed to automatically reset any remote power controller that has tripped because of circuit overload.

The ACES automatically sheds loads in accordance with a programmed priority schedule to prevent overloading of the power source when a portion of the generating capacity is lost. Control, sequencing, and load priority changes can be made to suit different application requirements simply by reprogramming the distribution control center. The system also provides automatic self-checkout, start-up, and shutdown sequencing.

*Manvel A. Geyer and Dwayne F. Rife, "Automatic Control of Aircraft Electrical System Reduces Wiring and Improves Reliability," *Westinghouse ENGINEER*, July 1971, pp. 114-9. D. E. Baker, D. A. Fox, and K. C. Shuey, "Solid-State Remote Power Controllers for Electrical Systems," *Westinghouse ENGINEER*, Sept. 1971, pp. 135-9.

W-1101 Gas Turbine Power Plant Designed for 50-Hz Operation

The W-1101 Econo-Pac power plant, which is rated initially at 96,000 kW for peak power, is now available in Europe from Ateliers de Construction Electriques de Charleroi (ACEC), a member of the Westinghouse Electric Group. As manufactured by ACEC, the packaged power system has been designed specifically for 50-Hz peaking and medium power operation. The standard configuration has an open air-cooled generator directly driven by the cold end of the 3000-r/min W-1101 gas turbine.

The system has multifuel capability with automatic fuel transfer, requires no cooling water, can be operated remote and unattended, and has quick starting capability. It is controlled by a fully automatic electropneumatic control system. Use of modular preassembled packages simplifies erection and minimizes site requirements.

The W-1101 gas turbine is a single-shaft machine with the rotor supported by two bearings, which minimizes alignment problems and facilitates maintenance. Other features aimed at ease of maintenance include combustor baskets that can be removed without lifting the cover and a special rollout feature that permits easy access to an entire row of vane segments.

Airport Transit System Eliminates Much Walking

An underground transit system that will eliminate much of the walking for air travelers has gone into operation at Seattle-Tacoma International Airport. Its lightweight electric-power vehicles carry passengers around the system (Fig. 1). The vehicles can be scheduled so a passenger never need wait more than about 2½ minutes for service.

The Satellite Transit System, as it is called, uses Transit Expressway technology developed by the Westinghouse Transportation Division for urban transit and such specialized applications as airports, shopping centers, and college campuses. It has many features in common with the passenger shuttle system at the Tampa International Airport in Florida, which was opened in 1971 and has carried more than 25 million persons.

The system's two loops link the main terminal building with two satellite terminal buildings, and a shuttle links the loops to each other (Fig. 2). Nine vehicles are presently in use: two single cars and one two-car train operate on each loop, and one car operates on the shuttle. The cars are automatically controlled, electrically powered, air conditioned, and rubber tired. The system can carry about 400 passengers every five minutes on each loop. When expanded to ultimate capacity, probably by 1980, 25 vehicles will be used to transport 1200 passengers every five minutes on each loop.

The installation includes an automatic vehicle control system, voice and video communication system, power distribution system, automatic station doors, a guideway, two transfer tables, and maintenance facilities. A central control console with a display is used to monitor and control the operation of the entire system under the supervision of a central digital computer.*

*Ralph Mason, "Automated Transit System Reduces Walking in Expanding Airport," *Westinghouse ENGINEER*, January 1971, pp. 8-14.

A lobby directory shows the passenger his location in the terminal and the most efficient route to his boarding gate, and illuminated signs above the station doors tell him which vehicles are in service.

When a vehicle or train stops at a station, vehicle doors are automatically aligned with station doors and both sets open simultaneously. The wide doors enable large numbers of passengers to move in and out of each car in a short time.

Recorded verbal announcements coordinated with sequentially lighted graphic panels inside the car indicate where the car is and where it is going. Just before reaching the next station, the automated announcement informs the passengers of gates and facilities served by that station.

Two modes of automatic train operation are used: continuous and on-call. In the continuous mode, the trains operate continuously, stopping at each station for the standard dwell time and then moving on to the next station.

In the on-call mode, the trains wait in the stations with doors closed until called by a passenger pushing a call button. The doors open, the passenger boards, and the vehicle begins a complete round trip, stopping at each station.

The vehicles are designed to carry 106 passengers each. Their suspension features a combination of air bag and leaf spring, providing a ride comparable to that of a fine passenger car. The air bag also serves as a leveling device, keeping the vehicle floor at the height of the station platform as passenger load varies. The vehicle rides on pneumatic tires, with two dual sets on each axle. It is steered by guide wheels that lock the vehicle to a center guide beam.

1—Passengers are now carried to and from airplanes by an underground transit system at Seattle-Tacoma International Airport.

Electric power is converted from ac to dc by a full-wave thyristor control on the vehicle. The control delivers infinitely adjustable dc voltage to a 100-horsepower series-wound traction motor mounted on one of the trucks. It is applied through a jerk-limited automatic control for smooth acceleration and for fast response to propulsion commands. As the vehicle reaches the desired speeds, or if it is required to slow down, the automatic control adjusts and maintains motor torque and speed to the required operating level.

The braking system is also automatically controlled under jerk-limited conditions. The brakes are truck-type drum friction brakes, air operated and equipped with fail-safe spring-loaded emergency actuators.

Control of the vehicles is completely automatic, with three functions involved: train protection, train operation, and line supervision. Equipment is located at central control, along the wayside, and on the cars.

The automatic *train protection* system employs a "fixed block" arrangement. Trains are detected continuously by monitoring a special transmission from each train through a receiving antenna located along the roadway. The vehicle transmission is checked at each boundary to verify proper operation.

Speed commands are generated for each block according to block occupancy, speed limits, station stops, and transfer-table operation. The speed signals are carried to the speed coding equipment on the cars by an antenna running the full length of each block along the wayside and by receiving antennas on each vehicle. The vehicle equipment decodes the received signal and commands the propulsion and braking equipment accordingly. Separation of trains is achieved by transmitting different speed commands to each block. A train automatically sets to zero the allowed maximum speed of the block through which it last traveled; thus, if a train stops, the train traveling behind it in the same direction runs into the zero-speed-limit block and stops within it, avoiding a collision.

Automatic *train operation* equipment controls the operation of the trains within the safety envelope of the train protection system. It handles acceleration and deceleration, station stopping, door control, reverse running, communications, and train makeup. After a train has stopped, wayside signals open the vehicle and station doors. The signals are also used to reset the sequence of the annunciator and graphics in the vehicle. At the same time, the vehicle sends signals to the wayside, giving information on the status of onboard equipment.

Automatic *line supervision* equipment monitors the system's operations, indicates its status on an operational mimic display board, and records certain operations. Through manual input keying, it requests changes in performance, modes, and routing. It automatically requests changes in performance or modes through the com-

2—The central control room includes this display of the two loops and connecting shuttle that make up the system. The display continuously shows the operator the position of each vehicle and the direction of travel.

puter monitoring equipment, optimizing the system's operation.

Graphic illustration of train position and direction of travel, and continuous supervision of the power supply system, are provided at the central control room (Fig. 2). A Westinghouse P-2000 digital computer in the control room constantly monitors information from the wayside controls for instantaneous representation on the display panel.

The Satellite Transit System is part of an expansion program that includes a new runway, high-speed taxiways, and new concrete aprons around the satellite terminals. A multilevel parking structure is included in the terminal complex, and electric stairs and elevators provide convenient pedestrian movement to various levels of the complex. The Richardson Associates of Seattle were architects for the expansion.

Cycloconverter System Will Power Large Yankee Dryer

Conventional dc types of drive for the "Yankee dryer" component in paper machines have been superseded in a new machine by an ac system consisting of a cycloconverter and a synchronous motor. The system has successfully passed combination tests at the manufacturing plant (photo), and it has been installed in the paper machine at the user's facility.

Because the system employs an ac motor with its rotor mounted directly on the drive shaft of the dryer, the motor has no commutator and no bearings. Consequently, it will require less maintenance expense than would a conventional dc drive. The shorter ac motor also requires less space and simplifies the overhung mounting of the rotor. Moreover, the drive system is quieter than a conventional dc system.

A Yankee dryer consists essentially of a large drum, heated internally by steam, with an adjustable-speed drive system. The drum is mounted on a hollow shaft that carries the heating steam. It turns at low speed, and the paper passes over it and is dried for subsequent winding and slitting. Drives for Yankee dryers have been dc heretofore and have had two types of motor arrangement: a large low-speed dc motor mounted on the drive shaft or a smaller high-speed dc motor driving through a combination of gearing and chains. For speed control, the motors were supplied with adjustable-voltage dc power from a static converter or from an m-g set.

The Yankee dryer driven by the new system has a drum more than 15 feet in diameter. Its drive motor is a conventional 550-hp 100-r/min 15-Hz machine with 18 poles. The motor can start and operate in synchronism over the entire speed range, so no starting winding is required. It was built by the Westinghouse Large Rotating Apparatus Division, while the cycloconverter was built by the Industry Systems Division.

The cycloconverter is an all-static system that transforms 2300-volt three-phase 60-hertz power from the ac line directly to adjustable-voltage adjustable-frequency ac power. Output frequency is variable from zero to 15 hertz for speed regulation of the motor. Speed regulation is accurate within ±0.1 percent of top speed. The cycloconverter requires no interstage rectification; controlled firing of a set of thyristors in each of the three ac lines modulates the lineside frequency.

Firing of the thyristors is controlled by a QB-16 regulator, which is a hybrid digital/analog device with all-static logic. This type of regulator is shipped and installed preprogrammed to suit the initial application, but it can be reprogrammed any time to accommodate changing operations.

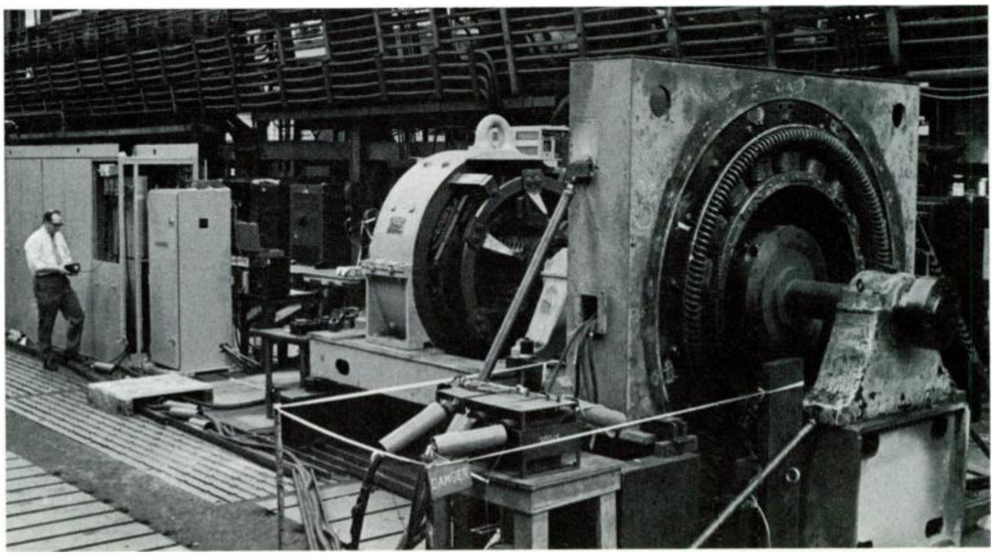
The combination of cycloconverter and synchronous motor has many other potential applications where low adjustable speeds are required.*

Transformer Gas Analysis Locates Faults and Prevents Outages

Extensive data gathered over several years by engineers at the Westinghouse Sharon Transformer Division show that the study of gases from oil-filled transformers can detect faults early enough to avoid costly outages and equipment damage. Therefore, gas analysis has become an important protective maintenance procedure.

Only a few basic types of fault occur in transformers, and those faults are usually accompanied by formation of particular decomposition gases. (The gases are in addition to those formed during normal transformer operation by gradual break-

*S. J. Campbell, "Static Power Supplies with AC Machines" *Westinghouse ENGINEER*, March 1972, pp. 34-8.
J. G. Trasky and A. H. Hoffman, "Evaluating Drives for Large Grinding Mills," *Westinghouse ENGINEER*, Jan. 1972, pp. 19-25.



The system was tested before shipment. From left to right are cabinets that house the cycloconverter and regulator, a generator used to load the motor, and the motor. The rotor of the synchronous motor was mounted on a temporary shaft for the tests because it has no shaft of its own; in service, it will be mounted directly on the drive shaft of the dryer.

This combustible limit relay monitors the percent of combustible gases in the gas space of a transformer.

down of oil and other insulating materials.)

Arcing faults produce high percentages of hydrogen and acetylene with some other hydrocarbons of low molecular weight. Carbon dioxide and carbon monoxide may also be found, depending on the location of the arcing. Sparking faults are characterized by the presence of hydrogen with some methane and ethylene and traces of acetylene. These gases result entirely from breakdown of oil caused by poor connections, loose metal parts, or damaged core belt insulation. Carbon dioxide and carbon monoxide are absent because the fault is not associated with cellulose.

Hot spots or localized overheating show about equal amounts of hydrogen and methane with some ethylene. The amount of ethylene increases with increasing temperature. Carbon dioxide and carbon monoxide are also usually present since there is cellulose associated with hot spots. Faults of this type are found in coils, static plates, and taped connections. Hydrogen is usually the only gas found in units with corona discharges. Small amounts of methane are sometimes found, and carbon dioxide if cellulose has broken down.

Thus, it is important first to determine if combustible gases are being formed and at what rate. The Westinghouse combustible limit relay is a useful tool for monitoring the percent of combustible gases in the gas space of a transformer. Once every 24 hours, a gas sample is automatically pumped from the transformer through the test unit, which uses a platinum sensor to burn any combustible gases. The additional heat from the burning gases changes the resistance of the sensor in proportion to the amount of combustible gases present. An electronic relay activates an alarm circuit if the gas concentration exceeds a preset alarm limit, and a miniature recorder shows the level of combustible gases for each test.

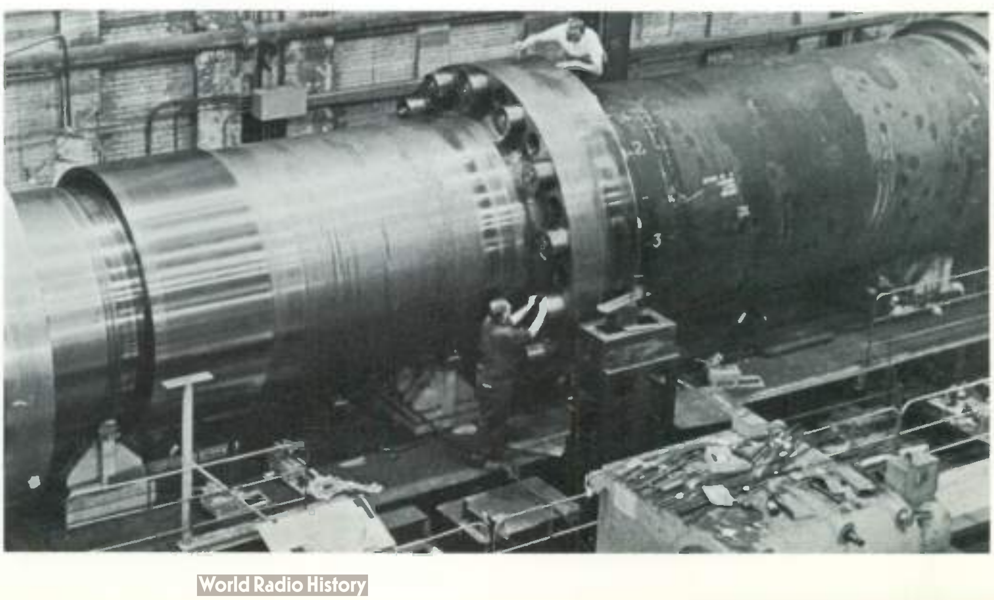
If an excessive amount of combustible gas is being formed, analysis of a gas sample by the Sharon Transformer Division can determine whether a fault actually exists and, if so, how severe it is. The analysis service employs such tools as the mass spectrograph and gas chromatograph to help reveal the different kinds of faults and their probable locations.

Largest Hydrogenerators Being Built for Grand Coulee Plant

The world's three largest hydroelectric generators are being manufactured by the Westinghouse Large Rotating Apparatus Division at East Pittsburgh. Rated at 600,000 kW each, the generators will be installed in the power plant of the U.S. Department of the Interior, Bureau of Reclamation, at Grand Coulee Dam.

The main generator shaft (on the right in the photo) is 23 feet long, more than 8 feet in diameter, and weighs 125 tons; the turbine shaft (on the left) weighs 193 tons and is 20½ feet long. Bolt holes at the ends of the two shafts are shown being reamed to assure proper alignment of the main shaft. The two shafts were later separated for shipment to the site.

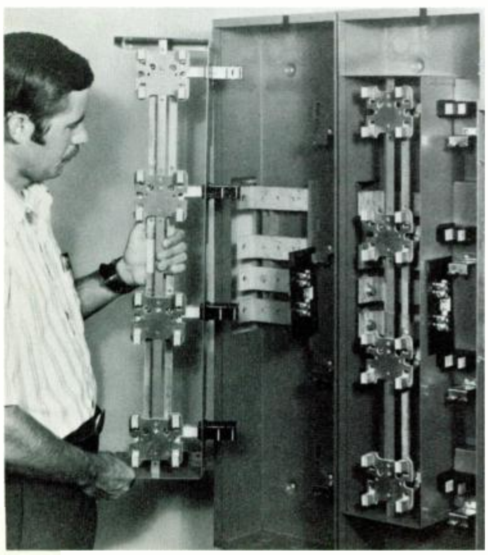
Generator and turbine shafts for Grand Coulee generator are being fitted to each other.



Products and Services

F-800 insulation system applied when form-wound motors are rewound produces a durable high-strength insulation that withstands severe applications. Stator coils are completely encapsulated with a powder coating having an epoxy resin base. The system provides full Class-F insulation, long creepage paths to ground, superior mechanical strength, excellent temperature properties, resistance to chemical contamination, sealing against moisture and other contaminants, abrasion resistance, and easy cleaning. *Westinghouse Apparatus Service Division, Westinghouse Building, Pittsburgh, Pennsylvania 15222.*

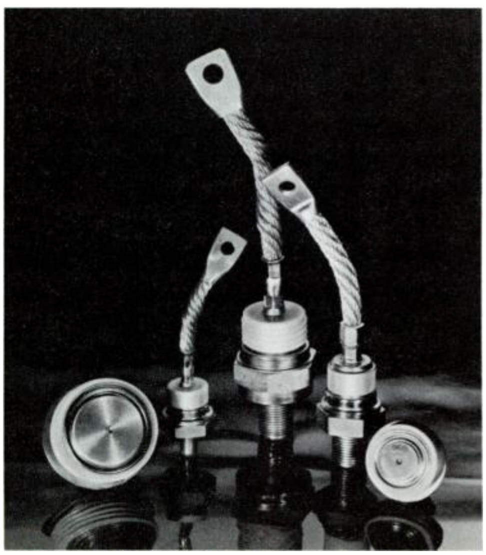
Quick-Stack meter centers are designed for apartment and light-commercial watt-hour service meters. The meter-breaker units stack up to six high, yet the centers are just 60 inches tall. The barrier and stab assembly lifts out as shown, making the stack light enough to be easily handled by one man while also providing a spacious area that makes wire pulling easy and quick. Load wires can be brought in from top or bottom, whichever is easier for the installer. One simple bus connector adjustment converts the stack to three-phase service whenever required. Servicing is easy because meter socket jaws can be removed without removing the stack cover; that feature also allows safe servicing of one circuit without shutting down power to the others. The meter centers are designed to accept standard four-jaw meters, but fifth and sixth jaws can be field mounted. *Westinghouse Bryant Division, 1421 State Street, Bridgeport, Connecticut 06602.*



Quick-Stack Meter Center

SA 550 wire feeder for MIG welding maintains the selected motor speed setting at up to 200 percent overload and is line voltage compensated. Its solid-state control features a wide range of wire feed speeds, positive wire feeding, and motor control circuits to insure consistent feeding with changing operating conditions. The basic unit is intended for use with an air-cooled torch and has an electrode speed range of 60 to 750 inches per minute. Options include solid-state arc spot timer, automatic inch and touch start for fully automatic welding, electrode sizes 0.030 inch to 0.094 inch, water cooling system, and high-speed range (90 to 1125 inches per minute). *Westinghouse Industrial Equipment Division, P.O. Box 300, Sykesville, Maryland 21784.*

High-power silicon diodes with fast recovery are especially useful as feedback diodes in inverters, as "free-wheeling" diodes in phase-controlled SCR bridges under inductive loads, and as bridge diodes in high-frequency rectification circuits. Their basic function is to limit reverse current buildup that could damage solid-state devices during recovery. Recovery times of 1.5, 2, or 3 microseconds can be specified. Although fast, recovery is "soft," thus avoiding high di/dt's that could cause damaging voltage spikes in inductive circuits. The family consists of five basic devices—three stud mounted (R502, R602, R702) and two in the Pow-R-Disc hockey-puck package (R622, R722). The stud-mounted diodes come in ⅜-inch to ¾-inch packages with ratings up to 1600 volts at rms currents from 125 to 625 amperes. The Pow-R-Disc diodes are also rated to 1600 volts, but with rms currents from 550 amperes to 1250 amperes. Both standard and reverse polarities are available. *Westinghouse Semiconductor Division, Armbrust Road, Youngwood, Pennsylvania 15697.*



High-Power Silicon Diodes

KW JIC industrial battery charger meets design standards specified by the Joint Industrial Council for effective maintenance, worker safety, and reliable operation of controls. Solid-state components and printed circuitry make it relatively small and light and also result in low operating temperature so that the unit can be mounted on walls, floors, or in stacks without auxiliary cooling. Built-in protection is provided against short circuits, overcharging, overheating, voltage fluctuations, and power surges. Start and finish rates are adjustable, with cutoff determined by cell voltage. The charging cycle is automatically normalized against ambient temperature variations. Chassis layout provides for easy access to all internal components, and the charging capacity can be altered by substituting one control board. The charger is available for operation with all standard ac input voltages. It measures 29 by 28 by 21 inches high. Model ratings cover 6 to 24 cells with capacity of 380 to 1400 ampere-hours. *KW Battery Company (a subsidiary of Westinghouse Electric Corporation), 3555 Howard Street, Skokie, Illinois 60076.*

About the Authors

Charles L. Wagner received his BSEE from Bucknell University (1945) and his MSEE from the University of Pittsburgh (1949).

He joined Westinghouse in 1946, and after completing the graduate student course was assigned to the Engineering Laboratories where he helped develop the analog computer ANACOM.

In 1950 Wagner moved to the Electric Utility Engineering Department to become a Sponsor Engineer. His work there consisted of assisting electric utility and industrial customers with equipment application, system planning, and design. In 1962, he became Project Manager of the VEPCO 500-kV project and also Engineer-in-Charge of the Relaying and Metering Groups for the other Westinghouse EHV study projects. He is presently Manager of Transmission Systems Engineering in the Transmission and Distribution Systems Department.

Wagner is a Fellow in the IEEE, Chairman of the IEEE Switchgear Committee, member of the IEEE Power Systems Relaying Committee, and chairman of the ANSI C37 Committee on Power Switchgear. He is an instructor in the University of Pittsburgh Graduate School and a Registered Professional Engineer in the State of Pennsylvania.

H. E. Lokay joined Westinghouse in 1951 after graduation from the Illinois Institute of Technology with a BSEE. He received his MSEE from the University of Pittsburgh in 1956.

Upon completing the graduate student course, Lokay joined the electric utility distribution engineering group of the Electric Utility Engineering Department. In 1959, he was made a Sponsor Engineer in that department to work with electric utilities and consulting engineering firms on equipment application and systems engineering problems.

In mid-1967, Lokay was named Manager, Generation—Rotating Machinery, in the Power Generation Systems Department. His group's activities included working with Westinghouse divisions and electric utilities on engineering and associated problems in the area of power generation and in generation planning. Lokay moved to his present position of Manager, Economic Analysis, in the new Water Reactor Division—Marketing in late 1972.

A frequent contributor to these pages, Lokay has also written a number of IEEE Transactions papers and technical magazine articles. He was co-editor of Volume III of the Westinghouse *Electric Utility Engineering Reference Book.*

T. J. Dolphin graduated from Rensselaer Polytechnic Institute in 1950 with a BEE degree, and he has since added an MS in electrical engineering and an MBA from the State University of New York at Buffalo. He joined Westinghouse in 1951 in the former Systems Control Division, where he worked in engineering and management positions on the design of automatic control systems for the metalworking industry.

In 1964, Dolphin was appointed assistant manager of the Cold Mill Systems group in the former Industrial Systems Division, and in 1971 he became manager of the Automatic Manufacturing Systems group. He retains that post in the new Industry Systems Division.

Dolphin is a licensed professional engineer in the state of New York.

David H. Mullins is Manager, Technical Services, at the Westinghouse gas turbine systems plant at Round Rock, Texas. There, he is responsible for the following departments: quality control, manufacturing engineering, industrial engineering, numerical control, tool engineering and tool service.

His work with turbines began in mid-1967 when he came with Westinghouse as a manufacturing engineer in the Division at Lester, Pennsylvania. A year later, he was transferred to the Turbine Components plant at Charlotte, North Carolina, to be supervisor of Tool Engineering. In 1970, he returned to Philadelphia to be Manager of Manufacturing Planning. He was appointed to his present position early in 1971.

Mullins graduated from General Motors Institute with a BSME in 1964 and received an MBA from Drexel Institute of Technology in 1969. He was Foreman of the maintenance department at the Fisher Body Division of General Motors prior to joining Westinghouse.

Ronald E. Lerch graduated from Pacific Lutheran University in 1961 with a BA in Chemistry and received a PhD in Inorganic Chemistry from Oregon State University in 1966. Dr. Lerch joined the Pacific Northwest Laboratory of Battelle Memorial Institute as a research scientist following graduation. He worked on chemical process studies dealing with separation of isotopes, reprocessing of nuclear fuel, and release of radioiodine from irradiated fuels

Dr. Lerch joined Westinghouse in 1970 in the Fuels Recycle group at the Hanford Engineering Development Laboratory. He is a senior research scientist in the Radioactive Materials Processing group at HEDL. His primary research interests are in process development and demonstration associated with reprocessing of LMFBR fuels and with nuclear waste management.

Carl R. Cooley is Manager of the Radioactive Materials Processing group at the Hanford Engineering Development Laboratory. He joined Westinghouse in HEDL's Fuels Recycle group in 1970. Major responsibilities include directing research and development in fuel reprocessing, radiation exposure, sodium disposal, waste management, and effluent control technology.

Cooley graduated from Kansas State University in 1950 with a BS in Chemical Engineering. After one year at Eastman Kodak, he joined General Electric Company at Hanford. Principal research areas at Hanford included recovery of ^{90}Sr, solvent extraction processes for irradiated fuels, and waste treatment. He also earned an MS in Chemical Engineering from the University of Idaho in 1958.

Cooley joined Battelle-Northwest in 1965 and served as manager of Waste Solidification Engineering, directing a pilot plant demonstration of the solidification of high-level radioactive plant waste.

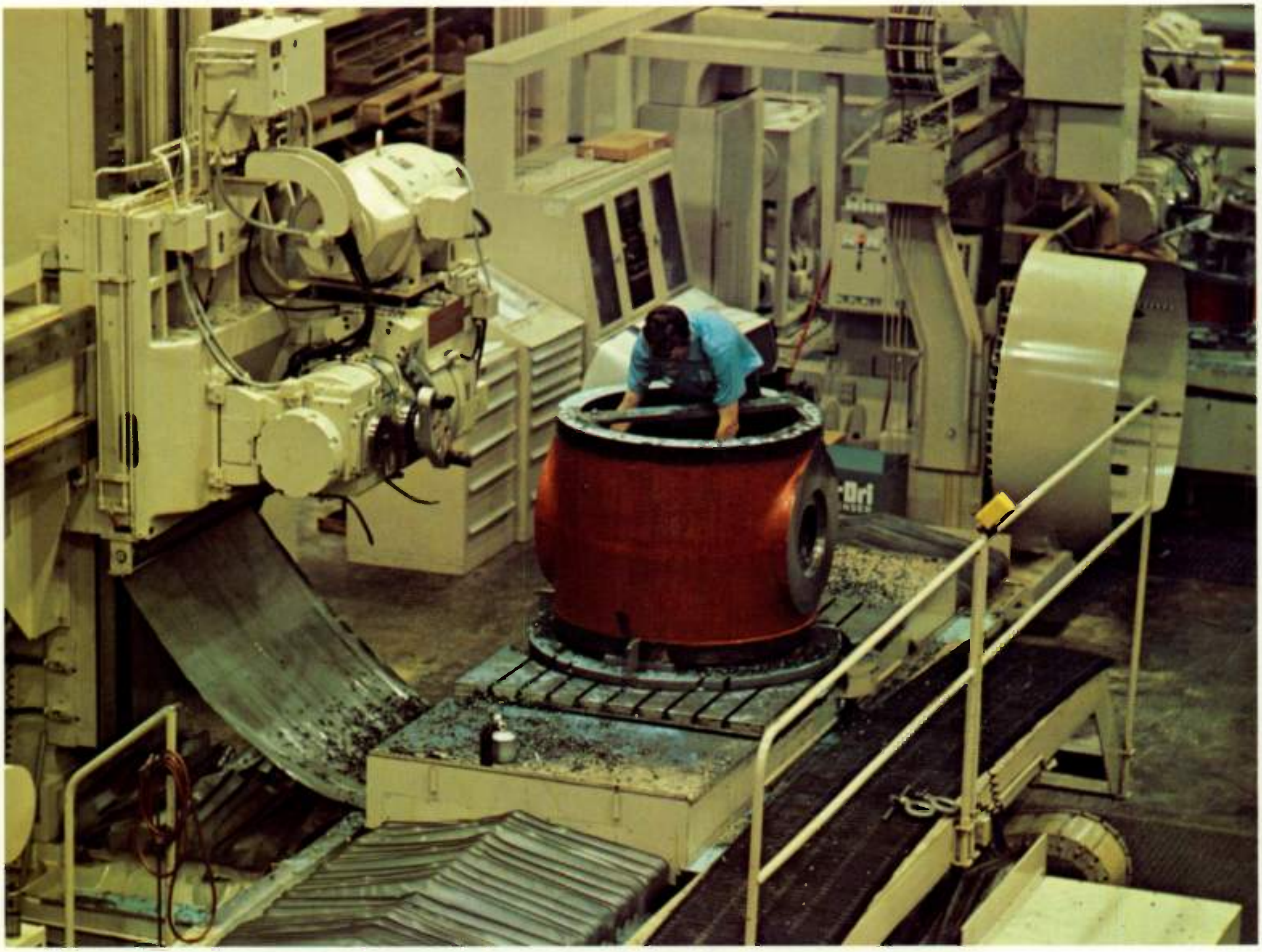
John M. Atwood is Manager of Sodium Technology at the Hanford Engineering Development Laboratory. He joined Westinghouse in 1970 when HEDL was formed and was responsible for organizing the Fuels Recycle group, which he managed from 1970 to 1973. Primary responsibilities include development and application of sodium technology to FFTF and LMFBR programs.

Atwood graduated from the University of Colorado in 1948 with a BS in Chemical Engineering. After obtaining an MS degree from Colorado in 1950, he joined General Electric Company as a reactor engineer at Hanford. Major assignments at Hanford have included production and power reactor technology, coolant systems development, and fuels reprocessing. He served as manager of various groups under General Electric and Battelle-Northwest while at Hanford including Process Systems Development, Corrosion Research and Engineering, Process Control, and Equipment Development. He also spent two years with the U.S. Atomic Energy Commission in Washington, D.C., where he organized and directed the Gas Cooled Reactors Branch in the Division of Reactor Development.

John J. Paulus graduated from the University of Wisconsin in 1971 with a BSCE degree (Sanitary Engineering), and he earned an MSCE degree (Air Resources Engineering) the following year from the University of Washington. While an undergraduate, he did investigation work on air, water, and solid waste problems for the State of Wisconsin Attorney General's Office.

Paulus joined Westinghouse in 1972 as an environmental applications engineer at the Meter Division's Environmental Systems Center. One of his first assignments was representing the company at the Swedish Environment Forum held in conjunction with the United Nations Conference on the Human Environment. His major responsibilities include serving as project manager for key air monitoring projects and defining monitoring system requirements for utility, industrial, and state customers. He also assists in interpreting environmental regulations and developing data service programs and formats for air quality and meteorological data.

Westinghouse Electric Corporation
Westinghouse Building
Gateway Center
Pittsburgh, Pennsylvania 15222



The first Westinghouse installation of direct numerical control (DNC) was at the Turbine Components Plant located near Winston-Salem, North Carolina. Typical machine tools under direct numerical control are these OmniMils, used for machining a nuclear intercepter valve body (foreground) and a gland case half (background). For a description of Westinghouse DNC, see the article beginning on page 138.