Westinghouse ENGINEER

September 1970

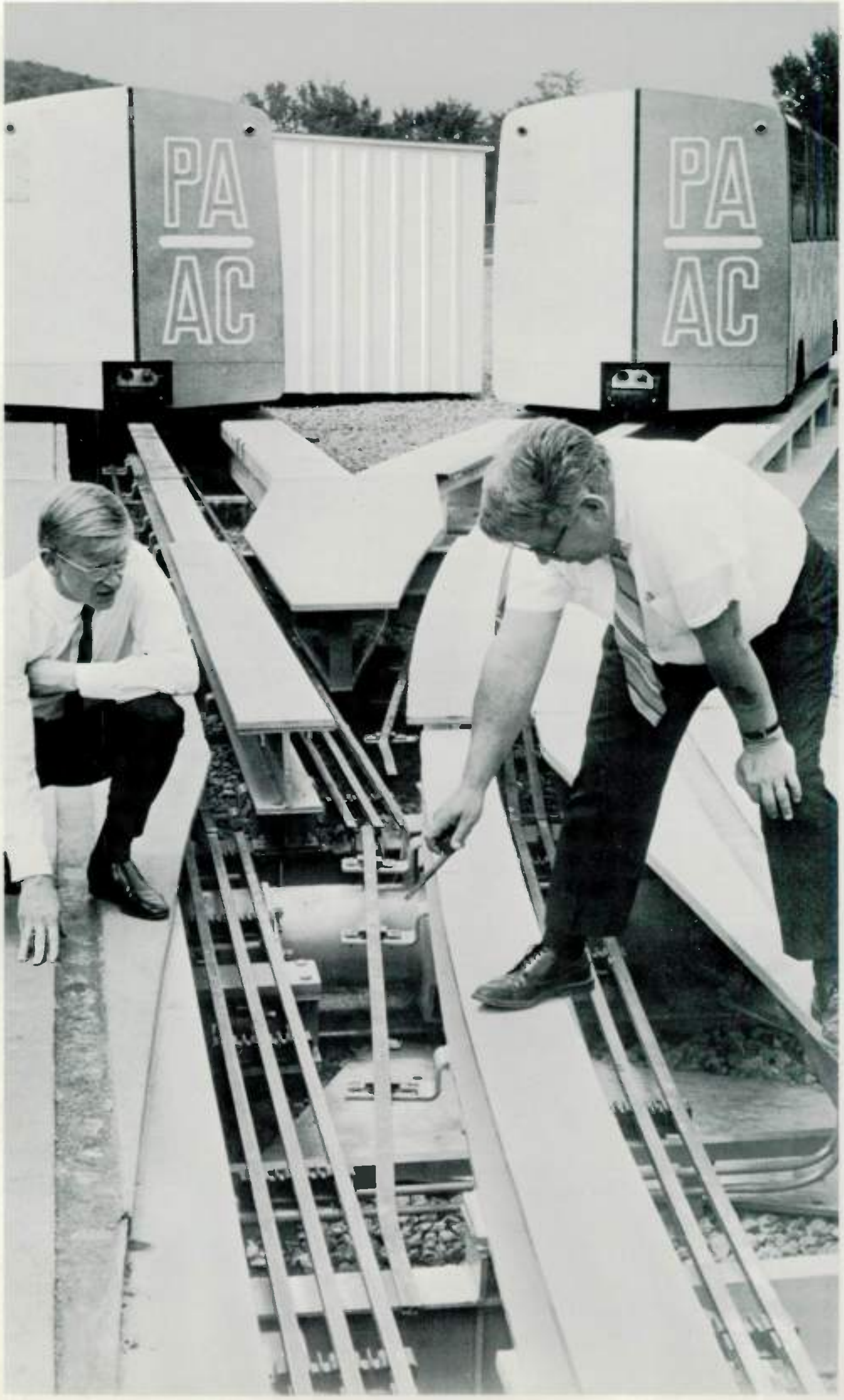
Transit Expressway Switch Is Demonstrated

A track switch recently installed in the Transit Expressway demonstration loop enables vehicles to move from the original 9340-foot roadway onto a new 1050-foot spur line and back again. The demonstration loop is in South Park near Pittsburgh, Pennsylvania. Its new spur line has a 10-percent grade for realistic demonstration of performance.

The Transit Expressway consists of lightweight computer-controlled cars moving on rubber tires over their own right of way. Its vehicles are noiseless, are electrically powered and thus fume-free, and can be scheduled to operate around the clock at any interval needed to meet passenger demand. Westinghouse is carrying out the demonstration under sponsorship of the Port Authority of Allegheny County. An 11-mile revenue line to be constructed as part of the Port Authority's Early Action Program for rapid transit will have about 25 switches such as the one being demonstrated.

The switch is a simple mechanism. Its only moving part moves laterally to align a straight section of the center guide beam with the straight roadway or to align a curved section with the "turn-out" segment of the roadway as shown in the photograph. The curve at the switch is of 150-foot radius, and rated vehicle speed on it is about 25 miles per hour. The switch is actuated by a five-horsepower motor. It was designed and engineered by Richardson Gordon Associates, Titzel Engineering, and Westinghouse.

The Transit Expressway demonstration project is funded by the U. S. Department of Transportation, with additional funding by the Pennsylvania State Department of Community Affairs, Allegheny County, and Westinghouse.



Westinghouse ENGINEER
September 1970, Volume 30, Number 5

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

Mailing address: Westinghouse ENGINEER
Westinghouse Building
Gateway Center
Pittsburgh, Pennsylvania 15222.

Published bimonthly by the Westinghouse Electric Corporation, Pittsburgh, Pennsylvania. Printed in the United States by The Lakeside Press, Lancaster, Pennsylvania. Reproductions of the magazine by years are available on positive microfilm from University Microfilms, Inc., 300 North Zeeb Road, Ann Arbor, Michigan 48106.

The following terms, which appear in this issue, are trademarks of the Westinghouse Electric Corporation and its subsidiaries: Prodac; Tracpak; New World; Magnatrak; Magnapak.

Front cover: The new SFV line of power circuit breakers features modular design for economical assembly of various ratings. The breakers are symbolized by artist Tom Ruddy and described in an article beginning on the following page.

Back cover: Launch tubes for the U. S. Navy's fleet ballistic missile submarines are made at the Westinghouse Missile Launching and Handling Department, Sunnyvale, California. The workmen are checking liner pads that will support the Poseidon missile laterally and mitigate shock.

New Power Circuit Breakers Employ SF_6 Gas for All Functions

R. E. Kane
C. F. Cromer
W. H. Fischer
Z. Neri

Power circuit breakers in this decade will have to satisfy demands not only for increased ratings but also for reliability, ability to function under multiple contingency situations, pleasing appearance, quiet operation, versatility, and reasonable installation and maintenance costs. The new SFV circuit breakers designed to meet these needs use sulfur hexafluoride gas for operating, insulating, and interrupting functions.

The new SFV circuit breaker line is a successful blend of capability with flexibility and with economy of application. One type of contact, blast valve, operator, and mechanism is used for all ratings, thereby minimizing total parts inventory. Moreover, a modular interrupter design allows the user to meet requirements of higher ratings simply by exchanging or adding components to the basic module. Extreme attention has also been paid to the breaker's exterior to provide an interesting but unobtrusive appearance.

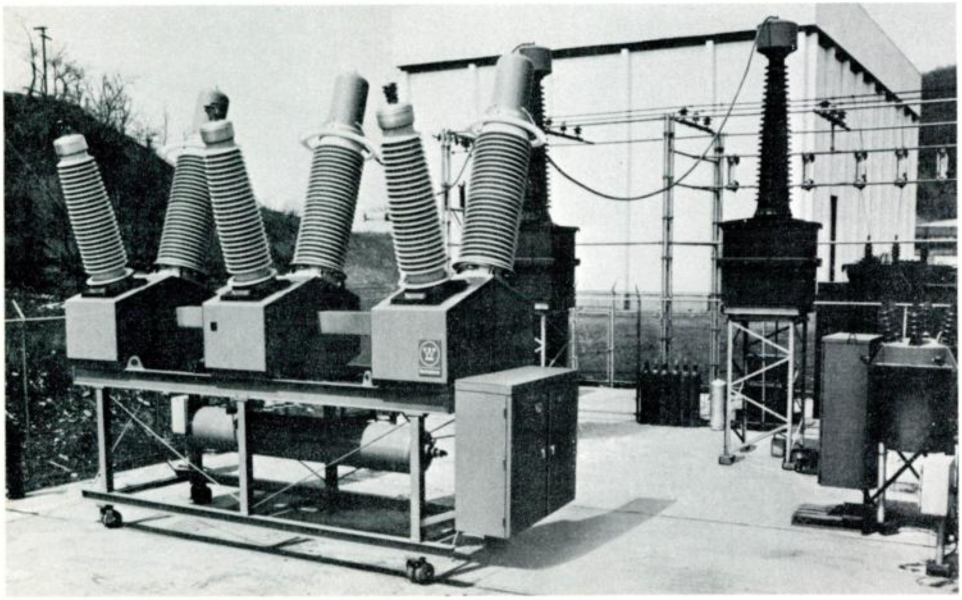
The breaker is so quiet in operation as to be a good neighbor anywhere. It presents no fire hazard since it contains sulfur hexafluoride gas (SF_6) rather than oil as the insulating medium.

Available power ratings range from 115 kV, 5000 MVA through 345 kV, 25,000 MVA, with continuous current ratings ranging from 1200 through 3000 amperes. SFV breakers can interrupt faults of up to 63 kA within 2 cycles, the fastest system protection yet achieved commercially. Starting at normal pressure, three close-open operations at full rating are possible without requiring compressor action. Noise output is only about 85 dB at 30 feet, mainly because there is no external exhaust of the operating medium since the unit is self-contained and recycles SF_6 for all breaker functions. Additional reasons for the low noise output are the relatively small moving elements that require little energy, and the effective internal absorbing of the little impact energy produced.

One control housing contains all the control relays, pressure switches, terminal blocks, and a hermetically sealed gas compressor used to maintain the appropriate pressures within the breaker. Each phase of the breaker has its own housing that provides weather protection for the current transformers, gas heaters, housing heaters, and operating linkages. The three phases are rigidly mounted on an H-beam and interconnected with a trough that provides weather protection for the interphase wiring and interphase linkages. Beneath the breaker housing is a dual-purpose reservoir containing SF_6 gas. During normal breaker operation it contains the gas at 5 psig, but during the maintenance cycle it is used to store all of the gas from the breaker to eliminate the need for a separate gas-handling cart.

A cutaway view of a single phase of a typical SFV breaker is shown in Fig. 1. The electrical circuit from the power line is to a terminal on the interrupter flange at the top of the porcelain column, through the closed contacts of the interrupter, through a conductor attached to the bottom of the interrupter (enclosed in a cylindrical grounded tank called the U-bend), and out of the noninterrupter terminal.

The mechanical system consists of linkages, the mechanism (attached to the center-phase housing) and the individual pole operators (one for each interrupter), located on the top of the interrupter columns. Included in the mechanism are the close and trip coils, which, when energized by signals from the relays, transmit intelligence through an opera-

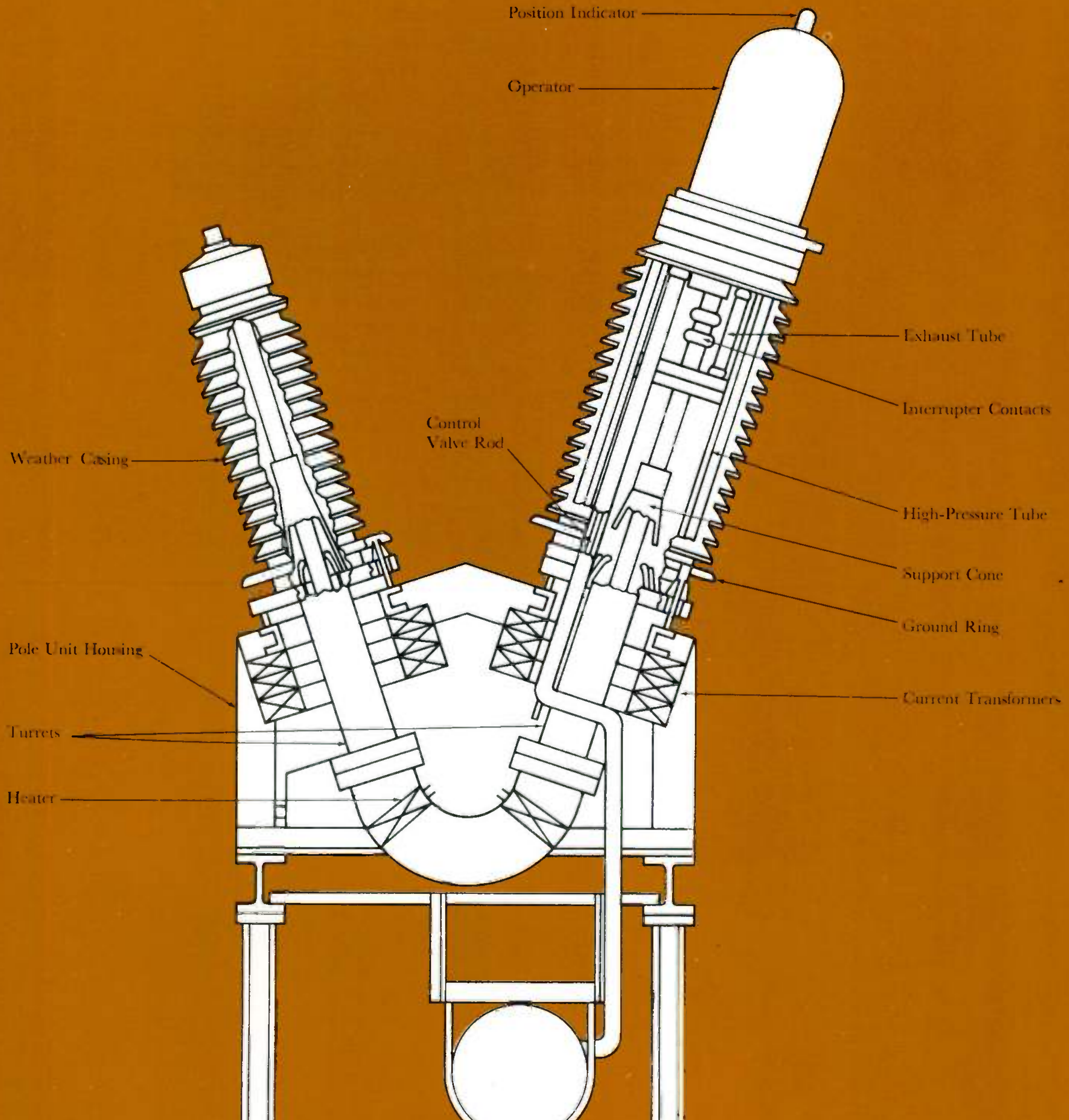


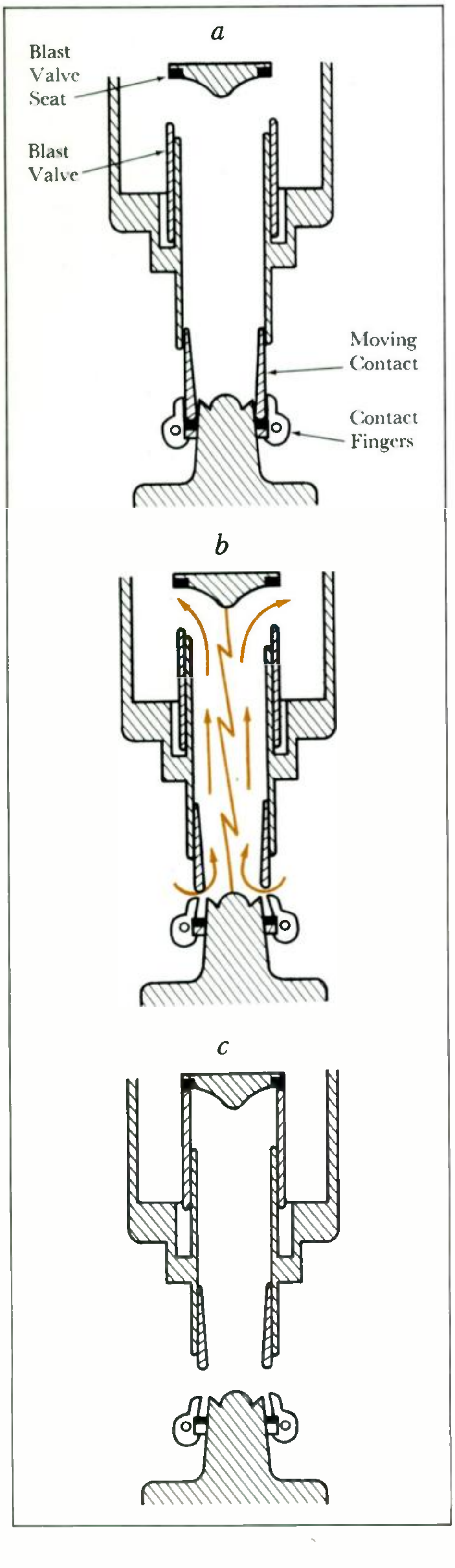
Photo—The new line of SFV circuit breakers, such as this 230-kV, 15,000-MVA unit being prepared for electrical testing, uses SF_6 gas for operation, interruption, and insulation. A central mechanism attached to the far side of the center phase housing controls all the operators and interrupters. Each pole operator is located in the dome atop the larger arm of each phase; the interrupters are inside those arms. The cabinet at right houses a hermetically sealed compressor and all the gas control equipment. Beneath the breaker is an SF_6 reservoir containing low-pressure gas during normal operation and used during maintenance to store all of the gas from the breaker.

1—A single phase of a 138-kV, 5000-MVA SFV circuit breaker is cut away to illustrate its major components. Parts inventory for these breakers is relatively small because a single type of contact, blast valve, operator, and mechanism is used for all ratings.

R. E. Kane is Section Manager, Special Products Development, Power Circuit Breaker Division, Westinghouse Electric Corporation, Trafford, Pa. C. F. Cromer, W. H. Fischer, and Z. Neri are engineers there.

1


Position Indicator
Operator
Exhaust Tube
Interrupter Contacts
Control Valve Rod
Weather Casing
High-Pressure Tube
Support Cone
Ground Ring
Pole Unit Housing
Current Transformers
Turrets
Heater

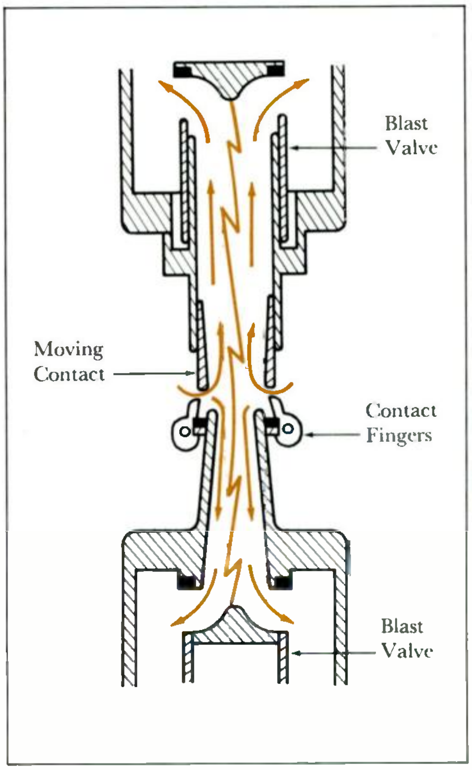


ting rod and control rod to the control valves in the individual operators. The operators use high-pressure SF_6 for their energy source. Position of the control valves determines the position of the operating pistons and therefore the position of the interrupters.

Six current transformers (three on each arm) can be mounted on each breaker phase. Complete protection from all internal and external breaker faults is provided by the mounting scheme. The current transformers are arranged so that all external flashovers cause currents to flow outside them, whereas all internal flashovers cause current to flow internal to them. This is accomplished by insulating the ground rings and turrets surrounding the current transformers from the internal members. (The turrets are cylinders supporting each breaker arm.)

Rapid low-cost field assembly is made possible by shipping completely assembled units (where clearances permit) through 230 kV. Only the subframe and storage reservoir are shipped separately. Breakers rated 345 kV are shipped assembled but with the interrupter and porcelain assembly removed. For installation, the subframe is bolted to the foundation, the reservoir set in place, the breaker bolted to the subframe, the housing lowered, and two gas connections made. The breaker is then ready for gas filling and timing. No field welding is required. Foundation costs are minimal since the breakers have negligible impact loading and only six legs requiring support. The breaker also can be fully assembled at an "off pad" location, equipped with a wheeled base assembly, and moved into position, thereby minimizing downtime.

Since the breaker has its own storage reservoir, the need for supplementary gas handling equipment is eliminated. The only extra item required is a vacuum pump for evacuation before initial gas charging. Because of the relatively small volume of the breaker, the evacuation and charging times are very short. To expedite maintenance, the breakers are designed so that a complete operator-interrupter assembly can be lifted from its housing and a spare quickly installed.



2—*(Left)* The opening action of a single-break, single-flow interrupter is depicted in this series of simplified drawings. With the contacts closed (*a*), high-pressure SF_6 (240 psig) surrounds the outside while the inner volume of the contact nozzle contains the gas at 5 psig. In this position, current flows from the contact nozzle through the moving contact, through the contact fingers, and finally into the breaker's internal conductor. The initial arcing upon contact parting occurs between the moving contact and the fingers, but the rush of high-pressure gas into the nozzle transfers the arc inside and stretches it between two points in the nozzle (*b*). The gas blast valve does not begin to snap shut until the contacts are fully open and the arc has been extinguished (*c*). In this position, high-pressure SF_6 gas is present both inside and outside the contacts.

3—*(Above)* Operation of the single-break, double-flow interrupter is similar to that of the single-flow unit except for the effect of a second blast valve, which provides gas flow in two opposite directions. The flow of gas and the internal arc are shown with the interrupter in an intermediate opening position.

The Interrupter

The new interrupter is the culmination of 15 years of experience building SF_6 breakers, combined with an accelerated research and development program over the past three years. The remarkable interrupting and insulating properties of SF_6 gas have been proven in the laboratory and field and through theoretical work concerning arc behavior in various media. A double-pressure SF_6 technique, which has been in service for over a decade in Westinghouse breakers, is used for the new interrupter with the innovation of a down-stream blast valve.

The basic interrupter module reaches with one break the performance level oil breakers reached with four breaks, previous SF_6 breakers reached with two breaks, and compressed-air-blast breakers met with two with the addition of opening resistors and double the pressure.

The basic module is a single-break, single-flow interrupter with a tubular moving contact that also functions as a gas nozzle (Fig. 2). Full advantage is taken of the interrupting and insulating properties of SF_6 by locating the interrupter contacts in the high-pressure gas region (240 psig). The volume inside the closed tubular contacts is at low pressure (5 psig) and this differential is maintained by the closed contact tip engaging a resilient seal. Thus, maximum pressure differential exists even before the interrupter operates and the arc is drawn.

When the unit is called upon to interrupt, several events occur in sequence. A gas-driven piston in the interrupter operator initiates upward motion of the moving contact as well as upward motion of the blast valve activator. As the contact moves upward, it disengages from the seal allowing flow of high-pressure gas up through the nozzle. Contact is maintained for a short time by momentary overlap of the arcing fingers. The blast valve is held in the open position by two latches. As the moving contact continues to travel upward, it is separated from the arcing fingers and an arc is drawn. The action of the inrushing SF_6 rapidly transfers the arc into the nozzle, thereby stretching and cooling the arc so that it is extinguished at the next current zero. As the moving contact and activator continue to move upward, a trigger engages a cam on the latches, causing them to move outward. This releases the blast valve, which snaps closed, but not until the contacts are almost fully open and current has been interrupted.

On a closing operation, the operator drives the moving contact and blast valve activator downward. The activator engages the blast valve and opens it, allowing gas to flow through the nozzle. The resultant gas blast reduces contact erosion and prevents early prestrike to the fingers. Further motion causes the contact to seal, stopping gas flow and resetting the blast valve latches. The interrupting rating of this single-break, single-flow configuration is 20 kA, and its maximum voltage rating is 145 kV.

A double-flow interrupter is similar, except that the center of the stationary contact is open and a second blast valve added as shown in Fig. 3. The gas flow effecting interruption is in two opposite directions. The second blast valve is the same as the first, and both are connected to the crossarm by insulating rods to assure simultaneous operation. The voltage rating of the single-break, double-flow interrupter remains at 145 kV, but the interrupting rating is raised from 20 kA to 40 kA.

Using the single-break, single-flow interrupter as a basic building block, with various modifications, a complete line of breakers can be assembled ranging from 115 kV, 5000 MVA through 345 kV, 25,000 MVA. (See table.) The interrupting ratings are increased by adding another blast valve (creating a double-flow unit) or by adding line shunt capacitance; higher voltage ratings are achieved by adding a series break or a second interrupter in the other arm of the breaker.

The interrupters for the SFV breaker line have been built to exacting American National Standards Institute requirements as well as more severe standards where considered necessary by Westinghouse engineers. They can switch 500 amperes of line charging currents without the arc restriking. To provide maximum flexibility, the interrupter can switch capacitor banks whose harmonic current rating might be any value up to the continuous current rating of the breaker. Inductive loads can also be switched at values up to the continuous current ratings. Transformer magnetizing currents from 0.03 to 10 percent of continuous current can be interrupted while minimizing current forcing, thereby preventing hazardous overvoltages. All transient recovery voltage requirements for short-circuit faults have been met.

Insulation System

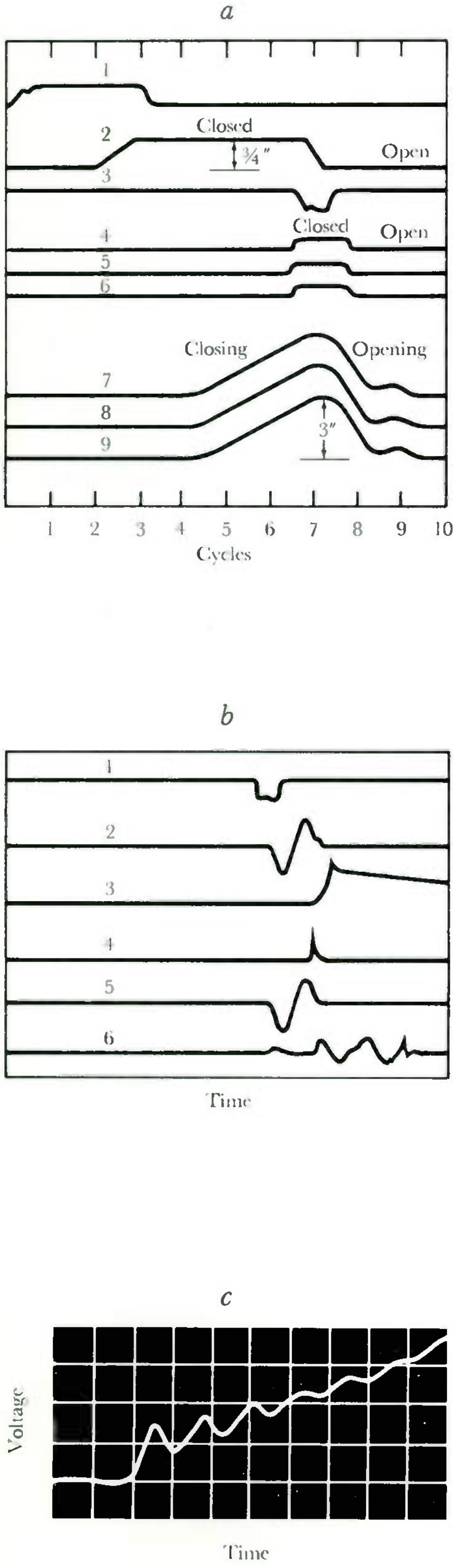
Computer solutions of LaPlace's and Poisson's equations were used to determine voltage stresses in various areas of the breaker. From this information, the

Available Rating Combinations of SFV Circuit Breakers

Voltage (kV)	*Nominal Power (MVA)* *5000*	*10,000*	*15,000*	*20,000*	*25,000*
115	SBSF[1] 20 kA[2]	SBDF 40 kA	SBDF, LC 63 kA		
138	SBSF 20 kA	SBDF 40 kA	SBDF, LC 63 kA		
161		DBSF 40 kA	SBDF, 2I 50 kA	SBDF, 2I, LC 63 kA	
230			DBSF 40 kA	SBDF, 2I 50 kA	SBDF, 2I, LC 63 kA
345					DBSF, 2I 40 kA

[1] SBSF, single-break single-flow interrupter; SBDF, single-break double flow interrupter; DBSF, double-break single-flow interrupter; 2I, two interrupters per phase; LC, line capacitance added to breaker.

[2] Interrupting current.



4—Typical timing curves (*a*) are drawn from oscillograms recorded for a close-open operation of a 138-kV, 10,000-MVA SFV circuit breaker. Curve *1* is the current curve for energization of the mechanism pilot valve; *2* is the travel curve of the mechanism operation (¾ inch total travel); *3* is the current curve for energization of the trip coil; *4, 5,* and *6* indicate the closed-position duration of the three main breaker contacts; and *7, 8, 9* are travel curves of the main contacts (3 inches total travel).

The most severe test of a breaker's fault interrupting ability (*b*) is switching short-line faults (faults occurring on the transmission line ½ to 1 mile from the breaker). A synthetic test circuit was used to duplicate the high voltage and current that occur on a line during such a fault. The typical oscillogram shows currents and voltages associated with a short-line fault interrupting test on a 138-kV, 10,000-MVA breaker. Curve *1* is breaker trip current; *2* is total current through the breaker (30 kA); *3* is synthetic-circuit recovery voltage (192 kV); *4* is synthetic-circuit current (3 kA at 600 Hz); *5* is source current (30 kA at 60 Hz); and *6* is source voltage (22 kV). The recovery voltage transient that appears across the opened breaker after interruption of the current consists of two components—a transient produced by the shorted transmission line and one generated from the bus side of the breaker. Most severe is the line-side component because of its fast rate of rise.

The line-side component (*c*), which occurs at the beginning of the recovery-voltage transient shown in *b*, is time-expanded here to show its rapid rise and oscillatory nature. The voltage axis is 31.4 kV per block and the time axis is 10 microseconds per block.

insulating components were sized and positioned such that their intrinsic voltage withstand capabilities were not exceeded. Three kinds of insulation are used in the new design—SF_6 gas, solid insulation, and air.

SF_6 Insulation—The high-pressure system (240 psig of SF_6 at 75 degrees F) surrounds the interrupter and acts as the interrupting medium when the breaker opens. It also supplies the insulation between contacts when the breaker is in the open position, and between the conductor and the U-bend. The medium-pressure system (25 psig) insulates the high-pressure tube from the porcelain weather casing. The volume directly inside the closed contacts, the gas storage reservoir, and the lines leading to it compose the low-pressure system (5 psig). High-pressure gas is exhausted into this system during interruption.

Air Insulation—Computer techniques were used to determine the electrical stresses that would be experienced in the air surrounding the insulating structure of the breaker. Taking into account the dielectric strength of the air, the proper sizing and shaping of external shielding and weather casings were determined so that external flashovers could not occur.

Solid Insulation—The main solid insulation members include the high-pressure tube, the exhaust tubes, and the support cones. The high-pressure tube, located in the interrupter side of the breaker, not only supplies the insulation to ground and encloses the high-pressure gas but also acts as the main structural member. To provide these electrical and mechanical properties, it is fabricated from a reinforced epoxy composite. An extensive testing program was conducted to verify the properties. Impact characteristics were verified by using half-scale models which were flanged, weighted, pressurized, and dropped from varying heights into a sand pit. Other tests at varying temperatures were devised to illustrate fatigue life under pressure cycling. The final mechanical verification consisted of a life test on a full-scale tube assembly with all static and dynamic operating loads applied while pressure-cycling from zero to design pressure at the maximum design temperature.

Weather casings for the standard 115- and 138-kV units have been designed for a 46-inch strike and 118-inch creep, the 161- and 230-kV breakers for a 68½-inch strike and 175-inch creep, and the 345-kV breaker for a 106-inch strike and 289-inch creep. Design work is currently in progress to supply creep distances of over 200 inches for special applications with the 230-kV breaker.

Gas System

The gas system comprises three separate pressure areas—240 psig for interruption, 25 psig for insulation, and 5 psig for storage. From the low-pressure storage reservoir, the gas first passes through a low-pressure filter containing molecular sieves that remove contamination and moisture from the gas. It next enters a check valve and passes through an oil-lubricated piston-type compressor. The small amount of oil picked up during compression is removed from the gas in the oil separater. A solenoid valve allows oil in the separater to return to the compressor oil sump. The gas next passes through the high-pressure filter, which also contains molecular sieves for added assurance that the SF_6 flowing into the interrupter structure is free of any contaminants. After leaving the high-pressure filter, the gas goes through a check valve, more filters, and into the three-phase high-pressure system.

Since SF_6 gas at this pressure (240 psig) liquifies at about 50 degrees F, band type heaters are connected around the U-bend to keep gas temperature at 75 degrees. The high convection coefficient of the gas at that pressure insures almost constant temperature throughout the high-pressure areas (U-bend and interrupter). No heat is required in the medium- or low-pressure areas, as liquifaction at those pressures occurs at well below the minimum temperatures. The compressor, which is used to maintain the high-pressure system, is regulated by a governor in the low-pressure system. It is turned on when the low-pressure system reaches 10 psig and off at 5 psig.

The insulation system is fed from the high-pressure region through a 25-psig regulator. If the insulation pressure reaches 30 to 35 psig, a relief valve returns the excess gas to the low-pressure system. If it goes above 35 psig, the excess gas is released to the atmosphere through another relief valve.

The high-pressure system is also protected by relief valves that open to discharge gas to the low-pressure area if 295 psig is exceeded.

To eliminate the potential problem of losing total pressure from the reservoir, a relief valve is connected on the downstream side of the low-pressure rupture disc. If the disc should fail, gas will be released through the relief valve to the atmosphere only if the pressure exceeds 295 psig. The low-pressure rupture disc is set to fracture at 315 psig.

Five gas-system assemblies were endurance life tested in a special environmental chamber. Compressor operation was checked at high and low temperatures as well as during thermal cycling.

The dynamic seals used to separate the high- and low-pressure SF_6 areas are operable from 0 to 300 psig, have a temperature range from −40 to 180 degrees F, and have a leak rate of no more than 1 psi per hour when new, and no more than 2.5 psi per hour after 2000 operations. Their life expectancy is 20 years. The seals have a C-shaped configuration formed by a stainless steel expander on the inside of a Teflon jacket. Since the seals contain no elastomer, there are no aging problems and they can sit for long periods of time without adhering to the sliding surface.

Operation Under Abnormal Conditions

Pressure Reduction—Some breaker designs utilize motor-operated disconnect switches to deenergize the breaker if complete loss of operating gas pressure should occur. This represents an unneeded expense for SFV breakers since total loss of pressure is hardly possible, barring the unlikely event of a complete porcelain rupture. The only remotely possible gas failure point is a leak or rupture from the high-pressure to the low-pressure system, conceivably caused by a stuck blast valve. If this occurs, the high- and low-pressure gas systems would equalize.

Two conditions could then exist: First, if the temperature of the gas were maintained (i.e., all heaters in service), the equalized pressure would be about 120 psig. At this pressure, the breaker has full insulation level to ground and across the open contacts. Second, should the heaters be out of service and the ambient temperature sufficiently low, the equilized pressure would be reduced. For example, with the heaters deenergized for 8 hours and an ambient of −20 degrees F, the equalized pressure is 60 psig. At this pressure, the breaker still has its full 60 hertz and switching surge capabilities. The impulse level, however, is reduced to 75 to 90 percent of rating.

Loss of Auxiliary Power—During the November 1965 Northeast power system disturbance, several circuit breakers were unable to operate due to loss of air pressure and unavailability of auxiliary station power to operate the compressors. This situation caused delays in service restoration to certain customers. Such contingencies were considered in the design of the SFV circuit breaker line. The operating system has been designed with enough gas capacity for three close-open (CO) operations of full interrupting rating, or four operations with derating, without requiring compressor operation. It is assumed that these operations would occur within the first hour after loss of auxiliary power. For longer time periods without auxiliary power, the breaker is able to operate at reduced ratings. For example, suppose that the breaker is carrying half its continuous current rating, the heaters and compressor are deenergized, and the ambient temperature is −20 degrees. The internal heat generated even after 8 hours is sufficient to maintain the gas pressure at such a level that the breaker can be opened or closed with an interrupting capability of at least 10 percent of its rating.

With the breaker deenergized for prolonged periods under these conditions, however, the gas pressure will be reduced to about 60 psig. Since the operator requires an 85-psig pressure differential to operate, the normal operating controls will not function. Assuming that the breaker is open and the bus to which it is connected is deenergized, it can be mechanically cranked closed from the top of the operator. The bus would then be reenergized and the breaker could carry current. As the breaker cannot open under this condition, the trip coil must be deenergized and backup protection must be relied upon for any faults on the load side. After station power has been restored and the compressor and gas heaters are energized, the breaker will return to its full operating capability.

Since 8 hours at −20 degrees is a rather severe condition, cranking would be necessary in only rare instances. If only a 4-hour interval at −20 degrees were experienced, the gas pressure would still be high enough for the operator to function. Also, if the low-pressure gas system were bled down to supply the required differential, the breaker could stand an ambient of −20 degrees for 7 hours or of −15 degrees for 8 hours. In all these possible operating conditions, the breaker will maintain essentially full insulation levels.

Test Program

Timing—A 138-kV, 10,000-MVA production prototype breaker has been put through a complete series of timing tests. Typical contact parting times were about 1.10 cycles, with a contact parting velocity of 17 ft/s. For closing, the contact touch time was 6.50 cycles; it can be increased, if desired, by means of an adjustable time-delay relay. An oscillogram of a close-open operation in which the contact parting time is 1.30 cycles is shown in Fig. 4a.

Interrupting—A series of tests, in accordance with ANSI and NEMA standards, has been performed with five mechanisms and five interrupter units in two complete prototype breakers to verify interrupting performance. The mechanisms and interrupters were selected randomly, insuring true representation of production breakers. A series of 324 tests at charging currents from 25 to 900 amperes verified restrike-free performance of the interrupters. (The 900 amperes is the testing limitation of the laboratory and not of the breaker.) On the basis of the absence of mechanical damage normally associated with high inrush currents, the interrupter has been extended to high-capacitance currents.

To provide the necessary power for testing transient recovery performance on interrupters, synthetic circuit techniques were used to generate high voltages at high currents. Bus fault interrupting tests were made at 30, 60, and 100 percent of rated current. At least 24 short-line fault tests were made at each rating covering the arcing range to verify transient recovery voltage response (Figs. 4b and c).

Reclosing duty was verified for breakers using double-flow interrupters by 56 open, close-open, and close-and-latch tests from 3000 to 64,000 amperes. Total rms asymmetrical currents were as high as 81,400 amperes. Instantaneous reclosing duty was checked with a duty cycle of CO, 0 seconds, CO, 6 minutes, CO, 0 seconds, CO, 30 minutes, CO.

Environmental—Tests simulating various field conditions were run on the breaker, its subassemblies, and components. The operations were conducted with full line-to-ground voltage across the terminals, using duty cycles of OCO (open, close, open) and COC while the ambient temperature was cycled from −40 degrees to 120 degrees F. Individual mechanisms were tested through 12,000 mechanical operations, 2000 of which were at −40 degrees. An interrupter-operator assembly was thoroughly life tested and then installed in a breaker in which a full series of electrical tests were run.

Frame and Tank—Extensive tests have verified the adequacy of the frame and tanks. These tests included a hydrostatic burst test on a 138/230-kV turret, brittle lime coated, which was pressurized to nine times its rating without rupturing or cracking the lime coating. Measurements were made under a variety of conditions to gather data on strain and stress on the tanks, frame, linkages, and interrupter parts.

A test on a single phase of a three-phase, 138-kV unit determined the effect of wind and terminal loading on the breaker components. The terminal load was simulated with a cable connected to the terminal and loaded with a winch. Wind loads were simulated in a similar manner to verify the 100-mph design. The stresses measured from these tests were of the order expected, with the stresses in the tank components found negligible.

Frequencies have been measured on the various structural components of the three-phase breaker to verify the design for earthquake loading. The X-bracing used in the subframe gives lateral and longitudinal strength to withstand the forces produced by seismic disturbances of 0.2-g magnitude.

Strain-gage measurements were made during a 3-second test (78 kA rms) and a special momentary test (95 kA rms) to determine the stress magnitudes associated with high currents through the breaker. Two phases of a 138-kV, three-phase test unit were used so both interphase and intraphase forces could be evaluated. The motion of the conductor relative to the tank through which it passed was found to be extremely small, and the stresses induced in the tank and frame were also very low.

Shipping—Preliminary shipping tests were made to evaluate impact loads expected during shipment. With a single-phase, 230-kV test breaker fastened to a flatcar, a "ram" car was released to run down an incline and collide with the breaker car. The information gained from impact recorders attached to the breaker proved valuable in determining shipment preparations for production units.

In another test, a complete three-phase, 138-kV breaker was used with weights added to the interrupter-side and non-interrupter-side assemblies to simulate a 230-kV configuration. The breaker was mounted on the flatcar in the manner proposed for production shipments. Impact and vibrational analyses were made at impact speeds up to 8.5 mi/h. No breaker damage was found.

Numerical Control for Machine Tools Is Adaptable and Expandable

John L. Patrick

The New World numerical contouring control system incorporates the main frame of the Prodac 2000 minicomputer, making it the first programmable all-stored-logic numerical control. The benefits are ease and economy in applying the control to any production tool or system, and adaptability to new control schemes as they develop. Locating the all-important position loop inside the computer allows use of the full power of the computer to implement the various path control strategies.

The hard-wired numerical control systems in common use today are special-purpose computers, designed to perform specific machining functions such as drilling, turning, or milling. Paradoxically, the rapid technological changes in electronic components in the past decade have not made this control approach more flexible (that is, adaptable to a variety of applications). Instead, they have caused it to become very fixed functionally and highly inflexible because so much of the wiring is in a form that cannot be altered economically.

The result is that, with the conventional approach, control builders have not always been able to meet changing user requirements. Now, however, the use of a software-programmed computer as the numerical-control logic element reverses the trend, giving the user flexibility while still taking advantage of today's component technology.

When the first solid-state numerical control was introduced in 1960, it and the other controls available *were* highly flexible. The logic elements were committed to printed-circuit boards, and the hard-wired program was the wiring that interconnected these boards. The industry was able to respond to the user's needs by altering wiring. Control functions expanded and new features were added, so the number of printed-circuit boards per control increased along with the back-plane wiring. Unfortunately, the size and cost of these highly flexible controls prevented wide use.

The first integrated-circuit numerical control was introduced by Westinghouse in 1965, and others soon followed. They were smaller in size and lower in cost than the earlier numerical controls, so they received wide user acceptance. However, the small size of the integrated logic elements permitted more logic elements to be mounted on a printed circuit board; the interconnections for these elements moved from the back-plane wiring to committed etched circuits, thus introducing a first order of inflexibility.

Today, medium-scale and large-scale integrated functional circuits are being incorporated into numerical controls, creating a higher order of inflexibility. Printed-circuit-board etched circuitry is transferred into the component, and more back-plane wiring is transferred to the printed-circuit board. So much of the hard-wired program is fixed and cannot be altered that a numerical control would have to be completely redesigned to meet a user's changing needs.

The new software-structured numerical control, called the New World system, more than restores to the user the flexibility of the earlier solid-state controls. Its program can be varied to meet current needs and changed or expanded to meet tomorrow's needs. At the same time, the system provides the benefits of low cost and reliability offered by integrated circuits and medium-scale integration.

The New World contouring control incorporates the main frame of the Westinghouse Prodac-2000 minicomputer. It is the first available system that is wholly software implemented: the main frame carries out all logic functions by means of a software package. The positioning servo loops, operator panel functions, and machine status information are all closed through the main frame. The only function not in software is the emergency stop circuit.

Since the logic system is software, it does not have the restrictions and inflexibility associated with hard-wired numerical control using functional printed-circuit-board logic. It is flexible—readily adaptable to any contouring, contouring/

New World stored-logic numerical control system provides the machine tool to which it is applied with a control computer whose program is readily altered. It is capable of both contouring and multifunction point-to-point control. The operator's panel, at right in the photos, can be removed for remote mounting; the blank panel at the left is for the machine builder's devices. The computer main frame is housed in the drawout assembly at left in the lower photo. A printed-circuit-board cage above it holds the input/output interface, position loop circuits, auxiliary function buffers, tape reader control, and so on.

John L. Patrick is Manager, Numerical Control Product Group, Industrial Systems Division, Westinghouse Electric Corporation, Buffalo, New York.

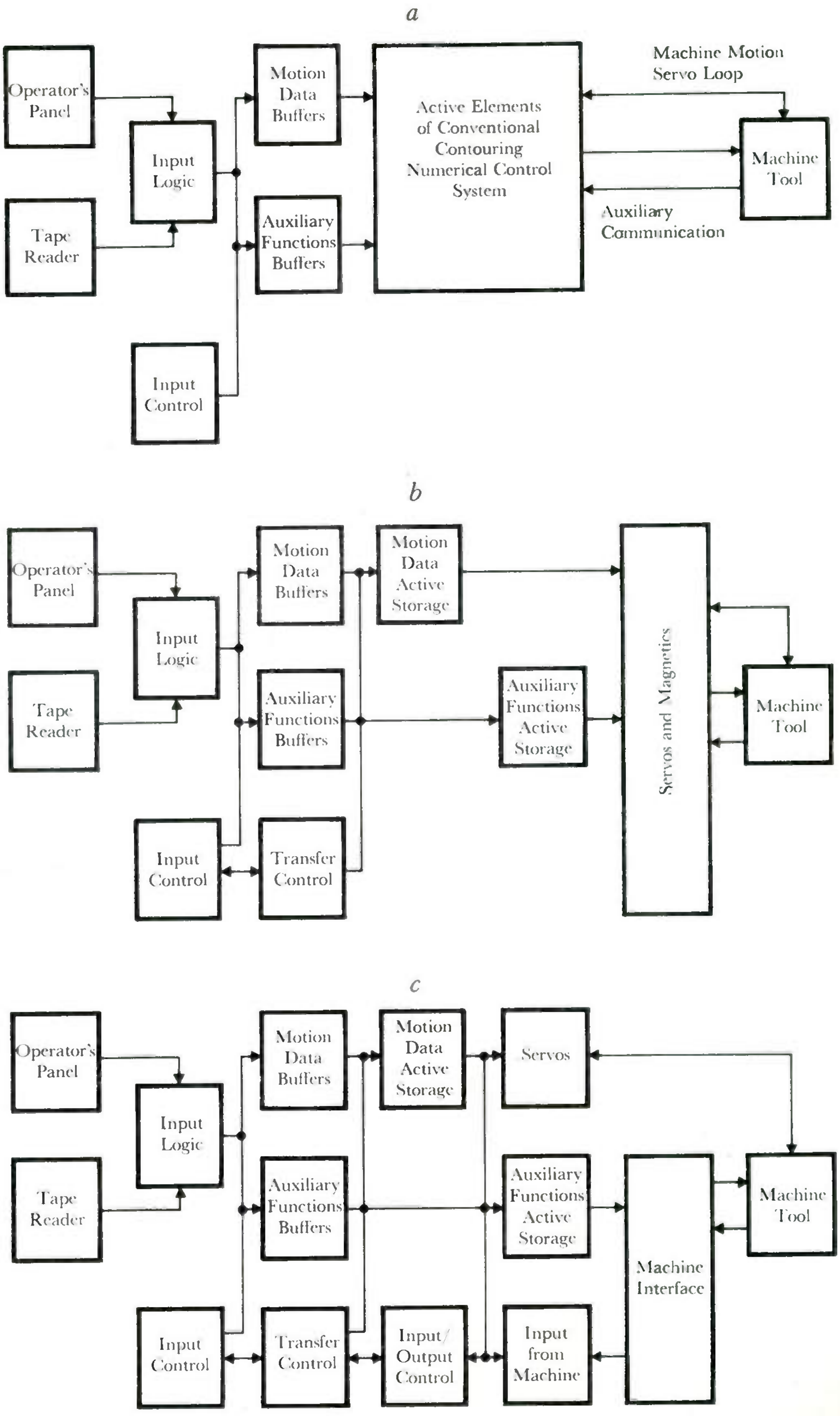
positioning, or positioning application. New control algorithms and adaptive control technology can be added at low cost with little machine down time.

The system meets the user's present-day needs—offering him all the benefits of conventional hard-wired controls—while remaining fully adaptable to tomorrow's requirements such as incorporation into the hierarchy of a computer-aided manufacturing system. It can meet those future needs easily since it has the inherent ability to expand functionally and to monitor itself. A machine-tool user can avoid sudden costs and risks by gradually installing tools with their own computerized control systems; when he thinks the move is justified, he can then convert to total factory automation because the computerized systems are easily adaptable to data linking with a central control computer while hardwired systems are not.

Functional Organization

Using a computer to control one machine would be too expensive if the system used traditional contouring-control technology. Consequently, the hardware and functional organization of the stored-logic numerical control (SLN/C) is drastically different from that of the conventional numerical contouring control. The accompanying diagrams illustrate the differences.

A generalized numerical control system of the conventional type is diagrammed



1—A numerical control, as indicated in these generalized diagrams, has a logic system that enables an operator's panel and a tape reader to communicate with a machine tool. In the conventional approach (*a*), data from the tape reader is first held in buffer storage until needed. Next (*b*), the data is transferred to active storage, where motion data is interpolated. To actuate the machine tool, the motion data active storage activates a servo system to move the machine members (*c*). Similarly, auxiliary functions are accomplished through the external machine interface. All of the logic, control, and storage functions in this conventional approach are hard-wired programs and therefore cannot be changed economically.

in Fig. 1a. An operator's panel and a tape reader want to communicate with a machine tool, and the logic system that enables them to do so is the numerical control. Various data (such as commands for machine member motion and velocity and for auxiliary machine functions) are first entered into the control via tape. The information is held in buffer storage until the machine tool requires it. Although buffer storage isn't necessary for all contouring controls, it provides high response and therefore makes the system efficient in use of time. Next, the buffered data is transferred to active storage (Fig. 1b), where motion-command data is interpolated. (Interpolation is the process of generating all the intermediate points between programmed end points to produce curves and straight lines.)

The output of a conventional contouring control activates a machine tool as indicated in Fig. 1c. The motion data active storage interpolates the data and activates the servo system to move the machine members. Auxiliary functions operate on the machine through the external machine interface magnetics (motor starters, circuit breakers, and their associated control relays). The machine response to the auxiliary functions is fed back through the interface to the control. The blocks in the figure for input logic, control, buffer storage, and motion data active storage are hardwired functional programs in the conventional type of N/C. Together, they comprise a special-purpose computer to control a machine tool in the contouring mode.

In the Westinghouse SLN/C system, however, all of the hard-wired programs of a conventional control are implemented as software in the Prodac 2000 minicomputer (Fig. 2). This approach makes the SLN/C significantly different from the hard-wired approach in the area of motion control; auxiliary-function control remains conventional because it requires only data transfer through the control system.

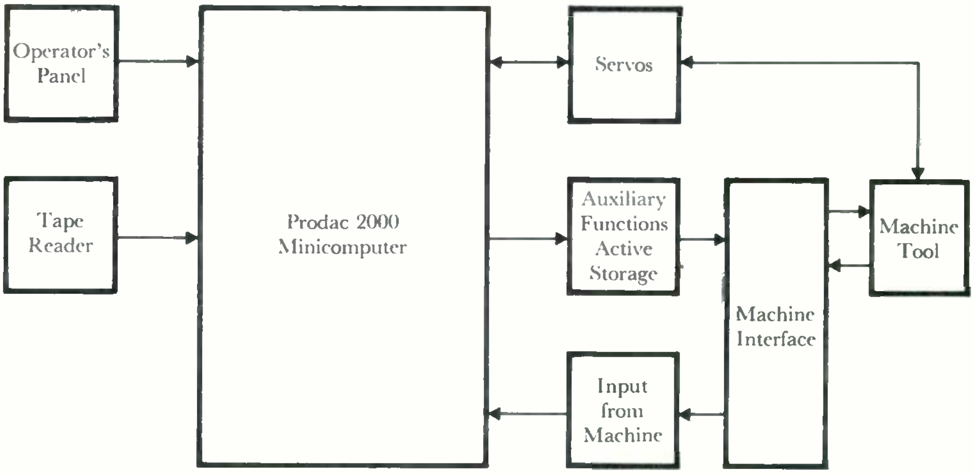
Motion Control

Changing from the conventional hard-wired approach and implementing a contouring control in software requires a very different kind of motion control. A conventional contouring numerical control is organized as a pulse-train scaler to generate component vector commands that are applied to a machine's members to achieve the desired tool path and velocity (Fig. 3a). It is really two distinct and separate systems. One system comprises the digital motion interpolators. The other system, the position servo loops, is fed information from the interpolators. Communication between the two systems is one way, so there is no way to tell if the drive systems become mismatched until a bad part is produced.

When the feed rate number, representing desired cutting velocity and X- and Y-axis motion information, is transferred from buffer storage to the scaling registers, pulse trains are established that are proportional to the desired velocity for each axis. These pulse trains are developed from a constant pulse source. The pulses are fed to their respective up/down counters. The counters, acting as integrators, present a digital value to the digital-to-analog converters that represents position error.

The analog position-error signals are presented to the machine's feed drive systems. These systems, being balanced, begin to accelerate. In due course, the pulse generators begin to feed back pulse trains proportional to the instantaneous velocity of the drives. (Pulse generators are used to simplify this comparison, but, in practice, analog feedback techniques are generally applied.) These pulses count down the up/down counters. When the feedback pulse-train rate equals that of the command pulse train, steady-state velocity is achieved.

In the software-structured system (Fig. 3b), a program called SYNC develops digital numbers that represent the desired velocity for the sample period. They are transmitted to velocity registers and then converted to an analog signal for the velocity loop of the servos. During the next sample period, SYNC accepts the accumulated pulses from the feedback buffers and determines if the drives are moving at the proper velocity. If they are



2—In the New World stored-logic numerical control system, all of the programs are implemented as software in a computer. This approach makes the control more adaptable and more expandable. It can operate on instructions from any punched tape or from a central control computer. The system's memory is not lost if power fails.

not, it adjusts the number in the velocity registers. The software-structured system knows at all times what is happening with the position loops, which is not true of the conventional dual-system contouring numerical control.

Software Structure

To help achieve the proper software/hardware tradeoffs, traditional practices for computer software structure were adandoned. For example, the classical executive routine approach for housekeeping and control was excluded because it would consume an excessive number of core-memory locations. We developed a variation of the computer software organization designed for aerospace applications to handle navigational and fire-control problems simultaneously.

Two programs reside in the minicomputer, one designated as SYNC and the other as MAIN. SYNC is a synchronous program that runs once about every ten milliseconds. Its job is to sample the feedback buffers and determine where the machine-tool slides are with respect to where they should be, then calculate a new velocity command that will maintain the desired path for the next ten milliseconds. Once the motion calculations are complete, SYNC samples all the pertinent operator's panel switches and machine tool limit switches to determine if they have changed since the last synchronous period. If they have, the SYNC program reports the changes to the MAIN program.

MAIN operates on the information SYNC reports. It is cyclic, handling everything in proper turn. MAIN controls the tape reader, does the preconditioning calculations for the motion data, develops the data for the digital displays, keeps track of the various offsets, etc. Only two things interrupt MAIN's cyclic chores: the start of the SYNC program and the need for more data from the tape reader. Thus, MAIN does have a simple executive routine characteristic: the ability to be interrupted, jump to the tape reader input and motion data precalculation subroutines, and then return to where it left off.

By organizing the control programs in this manner, core memory for five axes of contouring was kept close to 4000 locations. If the conventional approach were followed, memory locations would have exceeded 8000, and that size would have made the system noncompetitive in cost.[1]

Hardware

Achieving the proper tradeoffs between hardware and software also required modifying the standard Prodac-2000 minicomputer from its conventional process-control computer configuration to one specifically suited for the control of contouring machine tools. The standard internal data handling was maintained, but the input/output (I/O) structure was extensively redesigned. The external interrupt structure, which is expensive in both hardware and software, was restricted to just five interrupts (those necessary for safe operation of the system—power failure, feedback fault, buffer storage overflow, start SYNC, and start tape reader). The clock was redesigned as a crystal control and temperature-stabilized with an oven. The I/O addressing structure and data transfer buffers were reorganized to meet the specific contouring control requirement. These hardware reductions and improvements lowered the base implementation cost below that of the traditional approach in minicomputer peripheral equipment.

The Prodac-2000 is a 16-bit machine with basic core memory of 4K, expandable to 32K in the contouring N/C application. It has hardware multiply and divide, and a power interrupt circuit protects the resident control programs and various offsets when power fails.[2]

The control package, built for the factory floor, is housed in a totally enclosed nonventilated cabinet. It operates in ambient temperatures ranging from 32 to 120 degrees F and at humidity up to 95 percent. It requires 120-volt, single-phase 60-hertz power and consumes approximately 1000 watts.

The unidirectional photoelectric tape reader operates at 300 characters per second. Bidirectional and 500-character-per-second tape readers are optional.

The control package was designed for ease of preventive maintenance and service. It has hinged back doors for access to the power supplies and fuses, although the bulk of any servicing would be performed from the front.

Software Benefits

Structuring a contouring control in software gives the user flexibility along with the benefits of current component technology. Flexibility is achieved by having all the logic functions in the computer's core memory so they can readily be modified, changed, or expanded.

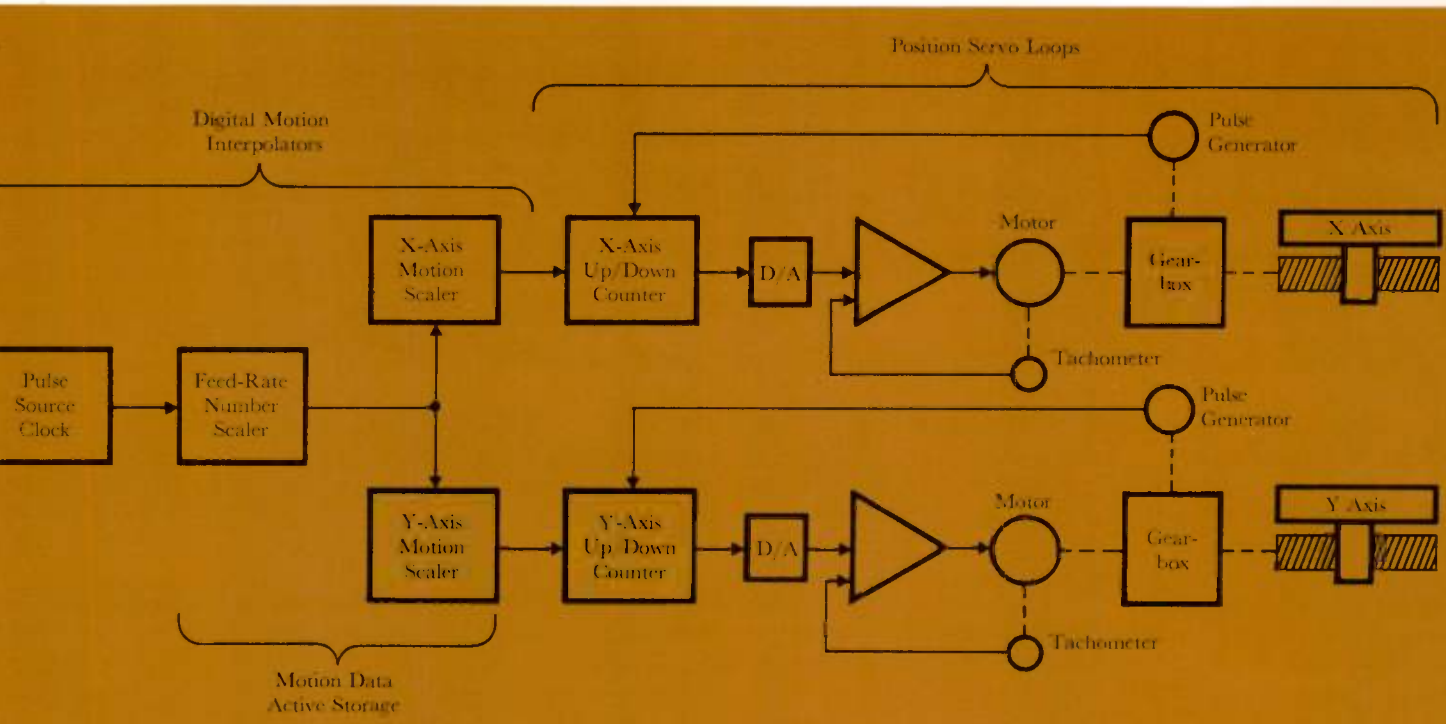
With the logic functions in software, the systems supporting hardware doesn't change. The only hardware variables are the quantities of printed-circuit boards required to handle the input/output for an application, and the type of operator panel chosen. For example, all the boards associated with an axis are interchangeable with the same boards of the other axes. All input attenuators are interchangeable, as are the input filter boards. Output boards, such as lamp drivers or relay drivers, are also interchangeable with other boards of the same type. Having interchangeable boards allows service personnel to see if troubles shift with the boards as they are interchanged, and it also minimizes the user's spares inventory.

The only boards in the system that don't repeat are the clock subsystem, the tape reader control subsystem, and the computer main frame. But they are designed so that the identity of a malfunctioning board is obvious.

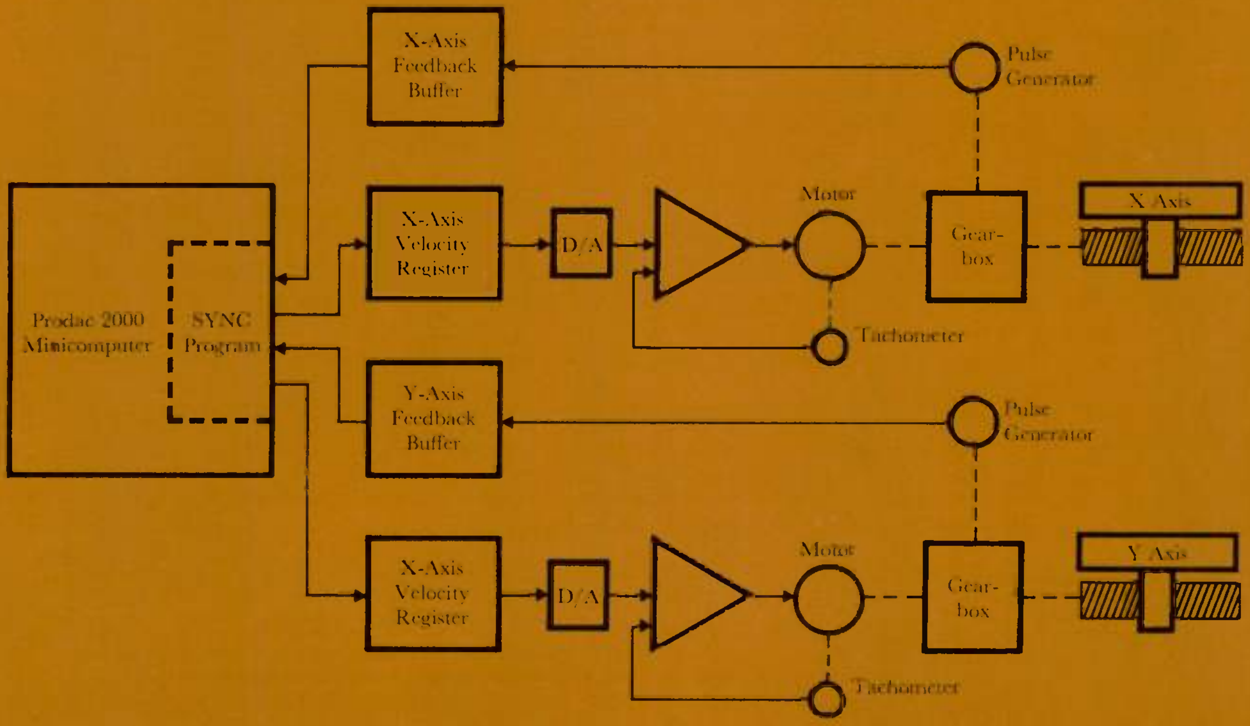
Generally, the software-structured contouring control is easier to service when it does fault. The reasons are the logic simplicity of the computer's main frame, and the nonlogical function characteristics

3—Motion control in the conventional approach (*a*) is essentially a pulse-train scaler that generates commands for the machine-tool members. It is really two separate systems as indicated, with communication between them in only one direction. In the New World system (*b*), motion control is handled by the computer. Two-way communication between its SYNC program and the position loops keeps the control constantly informed of what the loops are doing.

a


Position Servo Loops
Digital Motion Interpolators
Pulse Generator
X-Axis Motion Scaler
X-Axis Up/Down Counter
D/A
Motor
Gear-box
X Axis
Tachometer
Pulse Source Clock
Feed-Rate Number Scaler
Pulse Generator
Y-Axis Motion Scaler
Y-Axis Up/Down Counter
D/A
Motor
Gear-box
Y Axis
Tachometer
Motion Data Active Storage

b


X-Axis Feedback Buffer
Pulse Generator
Prodac 2000 Minicomputer
SYNC Program
X-Axis Velocity Register
D/A
Motor
Gear-box
X Axis
Tachometer
Y-Axis Feedback Buffer
Pulse Generator
X-Axis Velocity Register
D/A
Motor
Gear-box
Y Axis
Tachometer

of the input/output circuits that communicate with the machine tool, operator's panel, and tape reader.

The logic simplicity of the main frame permits the use of diagnostic software to localize a fault. When resident control programs are removed and diagnostic programs read in, the system checks itself. The location of the fault is determined by observing the maintenance panel and the operator's panel. These diagnostics are specifically designed to localize problems within the control system. The same concept can be extended to diagnose electrical faults on the machine tool.

A test tape furnished with the system permits a quick check to determine if the SLN/C is functioning as a control. This test tape allows the machine operator to check the system when he suspects a fault and decide whether to call the electric serviceman or the parts programmer. The tape is also a help to the parts programmer, for the same reasons, when he is checking out a parts tape.

The software structure gives the control the ability to accept other contouring systems' part-program tapes. When a user desires to duplicate or replace an existing machine and control system, he now has a choice of controls. This ability to accept other systems' tapes preserves his tape library. Also, he can produce tapes with his existing postprocessor (the off-line computer program that prepares tapes for numerical control). By programming, the user can alter the tape code format from the standard supplied (EIA) to one that is more efficient (such as binary) or one that suits his particular needs (such as ASCII).

As new and better ways are evolved in controlling a machine tool, the user can take advantage of them by removing the resident control programs and reading in new ones. Also, a user can easily add options at a later date such as more tool offsets or cutter radius compensation. And as adaptive, optimum, and learning control techniques are developed, they can be added to the software program. Thus, a software-structured numerical control can easily be kept up to date.

Closing the position loops through the computer allowed incorporation of an acceleration/deceleration program. This program is used when any axis is starting from zero velocity and when the magnitude of the velocity change for any axis exceeds a predetermined magnitude. In the case of a velocity change, the logic decelerates to zero velocity and then accelerates to the new velocity; the machine servos experience a smooth change. By incorporating this feature into the control, the size of the post-processor program is reduced by 25 to 33 percent, thus reducing off-line computer time by approximately the same amount and allowing the postprocessor to run in a smaller computer. Also, it permits the parts programmer to prepare tapes manually for parts that do not have free-form contours. And part tapes are shorter, thus reducing the duty cycle of the tape reader and thereby increasing mean time between failures.

By adding core memory, the external relay logic can easily be implemented in the control. This is very desirable for complex machine tools. The magnetics enclosure is reduced in size, thus saving floor space, and the overall system becomes more reliable by elimination of the logic relays.

The modular construction of the software not only permits flexibility, it also allows system expansion into noncontrol functions. The SLN/C can be a miniature manufacturing system. For example, add to it an automatic send/receive set and self-monitoring programs and the control can report when interrogated, telling such things as the amount of time feedrate override was off the 100-percent setting and the running time in tape mode.

By establishing additional memory core locations, repetitive machining patterns can be stored. Part tapes can be edited at the machine site by storing the corrected blocks of data via manual data input and ignoring the tape data. New machine canned cycles can be added to meet a particular need.

The SLN/C provides the fundamental building blocks for a computer-aided manufacturing (CAM) system. It permits the user to work his way into CAM from the shop floor. This can be accomplished in steps:

1) Add a data link between the control and an off-line computer. The user can incorporate the desired monitoring and status programs in the control and interrogate those programs with the off-line computer.

2) Add status pushbuttons to the control so the operator can report why he is not cutting metal, thus expanding the monitoring and status capability of the system.

3) Add an operator communication system to the control, such as a simple keyboard, automatic send/receive set, or cathode-ray-tube display with keyboard. With it, the operator can communicate with the off-line computer, requesting part programs and bypassing the tape reader.

By choosing the more sophisticated equipment (item 3 above), the user has the hardware complement for one machine under CAM. At that point, his capital equipment expense has been relatively low and he has got there in an orderly manner, learning by each step. He now has the experience and knowledge needed to justify putting his whole shop under CAM and to define how it should be done.

Conclusion

The Westinghouse New World stored-logic contouring control does not have to become obsolete. It can be installed to meet present needs and then expanded later to carry out new functions or options.

Moreover, it can be integrated easily with off-line computers to attain any desired level of sophistication in computer-aided manufacturing. That approach is more practical, and more immediately useful, than trying to institute CAM from the top down.

REFERENCES

[1] W. C. Carter, "Criteria for Computerized Contouring Control," 34th Annual Machine Tool Electrification Forum, Pittsburgh, Pennsylvania, May 26-27, 1970.

[2] G. L. Kilgore, "Selecting a Minicomputer for Process Control," *Westinghouse ENGINEER*, May 1970, pp. 88-93.

Propulsion Control for Passenger Trains Provides High-Speed Service

J. E. Moxie
B. J. Krings

The electric control and propulsion systems in the Penn Central railroad's new Metroliner trains are major steps in railroad technology. They accelerate a train smoothly to 150 mi/h in about three minutes and automatically apply motoring or braking force as needed to hold the selected speed.

In the new high-speed Metroliner trains running between New York City and Washington, D.C., the operator simply sets a control lever for the speed that suits track conditions. A solid-state control system then automatically accelerates the train to the selected speed and keeps it there by applying power or dynamic braking as required. It also holds acceleration or braking rates to predetermined values and reduces power or releases braking if the wheels slip or slide.

The control maintains the selected speed within 2 mi/h up to 70 mi/h and then within 2 percent, regardless of load, grade, and wind. Although the system as now used requires the operator to select speed manually, it could be reconnected to respond automatically to trackside signals to start, change speed, or stop.

Half of the Metroliner cars have Westinghouse propulsion, control, and auxiliary systems. Their thyristor voltage control for accelerating provides high efficiency, smooth performance, and low maintenance requirements, and thyristor control of dynamic braking provides infinite steps and ease in obtaining variable braking rates. The Metroliners are the first railroad cars in the United States to have dynamic braking for mainline intercity service.

The Penn Central, with the U. S. Department of Transportation, is using the Metroliners as part of a demonstration project to test passenger reactions and equipment performance in high-speed runs between New York and Washington. In a similar program, the Penn Central and SEPTA (South Eastern Pennsylvania Transportation Authority) will provide Metroliner service between Philadelphia and Harrisburg, Pennsylvania. The cars for both programs were manufactured by the Budd Company.

Since the Metroliners' purpose is to provide modern high-speed service, they have both high acceleration and high speed capabilities. The acceleration rate is slightly higher than 1.0 mile per hour per second (mi/h/s) to speeds in excess of 100 mi/h, at which point the acceleration rate decreases. Acceleration is still possible at 160 mi/h; although there are no plans to exceed that speed, the available tractive effort is useful to maintain speed on grades and against head winds.

Car Equipment

Power is taken from the 11-kV catenary by a pantograph and passed through the main transformer, which is rated at 1370 kVA. Its primary is made up of two separate windings connected in parallel for normal 11-kV 25-hertz operation, but the windings can be connected in series by a no-load tap changer; the transformer can then be used on 25-kV 60-hertz power. The two-voltage primary is used because the Penn Central plans to change its system to operate from 60-hertz commercial power. The transformer has four secondary windings, one of which is used for the auxiliaries and the remaining three for traction (Fig. 1).

Power for traction is varied by ac line switches and an ac thyristor switch. The line switches are air-operated devices equipped with dump valves for fast operation. The thyristor switch is composed of thyristors connected in parallel in two legs; one leg conducts current in the positive half cycle and the other in the negative half cycle.

Rectification is provided by high-voltage high-current silicon diodes. Diodes and thyristors are protected by RC circuits, voltraps and fuses.

Traction motor power is distributed to two parallel circuits, each containing a dc line switch, a motoring reactor with its surge suppressor, and the two traction motors of a truck (in parallel). In operation, all four motors are in parallel. The permanent parallel connection is inherently less subject to wheel slipping than is the conventional two-series two-parallel connection.

The motor for each axle is part of a Tracpak drive, which consists of a dc motor and a gear unit combined in a single assembly. The motor is rated 600 volts 300 hp, with peak output of 640 hp during acceleration. It is a four-pole, series-wound, commutating-pole motor designed for high-speed railway service. The armature has a four-circuit winding, is fully cross-connected, and has a commutator with a large number of bars to provide maximum commutating capacity and electrical stability.

The gear unit is a parallel double-reduction unit with a ratio of 2.36 to 1. Precision helical gearing conservatively applied insures long life.

The Tracpak drive has a completely resilient suspension system, with no metallic contact between the drive unit and the axle or truck. Torque is transmitted to the axle through a large double-disk resilient coupling. The unit is mounted to the truck through two resilient mounting assemblies designed to compensate for the lateral motion encountered in a truck with all four wheels independently suspended.

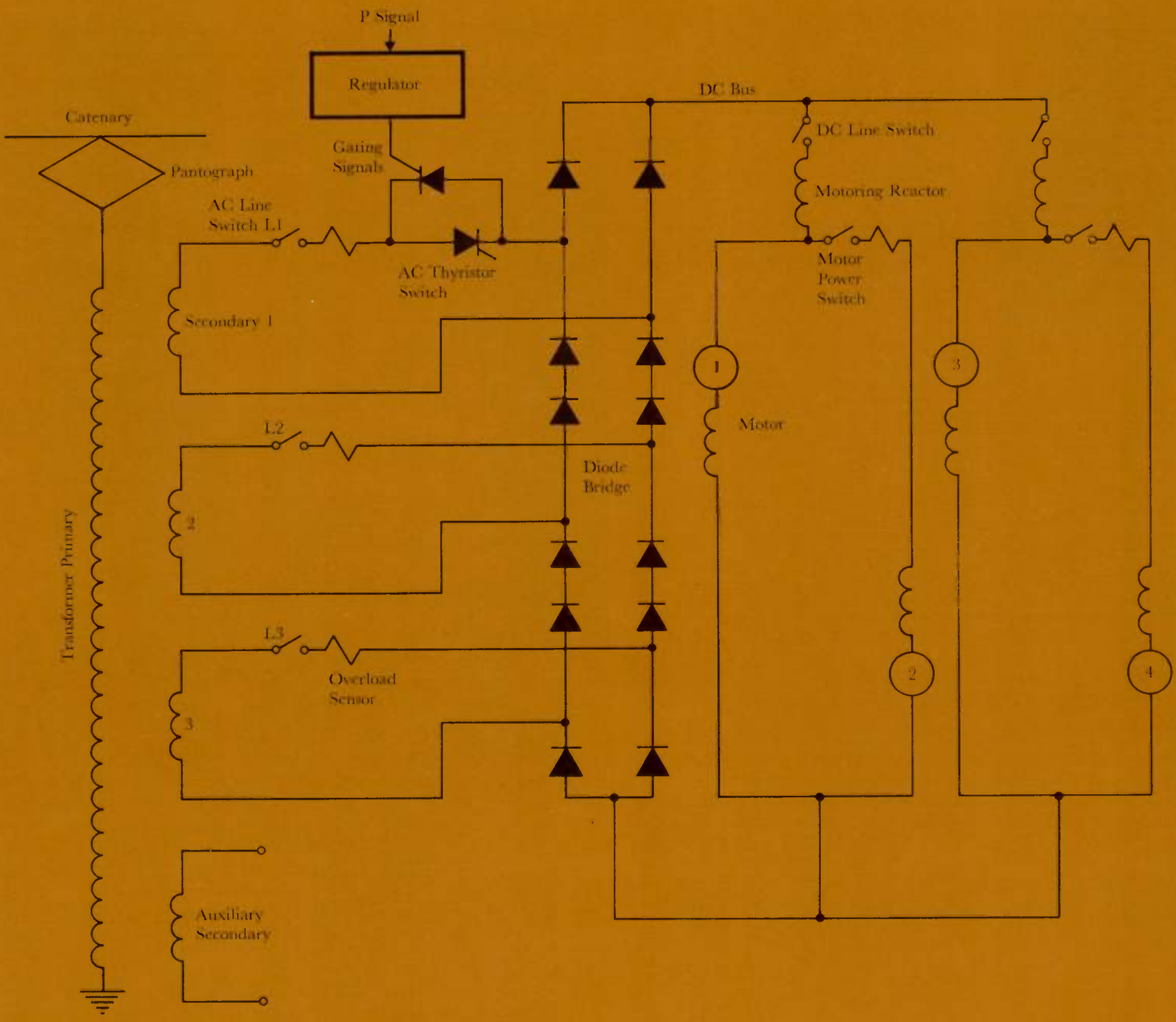
Mounted in each gear unit are inductive speed sensors, each of which provides a car speed signal proportional to the number of gear teeth passing a pickup. The signals are used for the speed maintaining circuit, the slip-slide circuit, the speedometer, and the cab signaling circuit, which monitors and supervises train speed with respect to allowable speed.

There are two dynamic braking circuits, one for each truck. Each includes the two motors of the truck.

A master controller is the prime interface between car control and operator (Fig. 2). Conventional controllers select only voltage levels and sometimes a few acceleration rates. The Metroliner master controller, however, allows the operator to do the following by means of a single handle: (1) select speeds up to 160 mi/h to which the cars automatically accelerate and at which they are kept by automatic

---

J. E. Moxie is Manager, Traction Projects, Transportation Division, Westinghouse Electric Corporation, Emeryville, California. B. J. Krings is Systems Engineer, BART Project, Transportation Division, Pittsburgh, Pennsylvania.



1—Simplified power circuit for the Metroliner propulsion system illustrates the three transformer secondaries that are switched in and out for speed changes. A phase-controlled ac thyristor switch also helps vary power and provides stepless transitions.

switching between power and brake, (2) select two fixed brake rates (1.4 and 2.0 mi/h/s), (3) manually select brake rates up to 2.0 mi/h/s, (4) automatically blend dynamic and air braking to maintain a fixed braking rate, (5) apply an emergency brake rate of 2.5 mi/h/s, and (6) select a low acceleration rate for switching by selecting a speed below 25 mi/h. The second handle seen in Fig. 2 is the reverser handle.

The master controller employs both digital and analog signals. The digital signals are obtained from cam switches and the analog signals from a potentiometer coupled to the handle. When the master controller handle is in the speed-maintaining mode, the potentiometer produces a signal proportional to the speed selected by the operator. When in the manual braking mode, the signal is proportional to the amount of braking selected.

If the control system malfunctions, the normal functions of the master controller can be cut out with a manual switch. The master controller then operates as a standard two-position device providing two levels of operating voltage.

Auxiliaries are powered by a motor alternator. The loads are primarily blower motors, air-brake compressor motor, air-conditioning compressor motors, transformer pump motor, battery and controls, and lighting.

System Operation

Speed Maintaining—Automatic speed maintaining is provided by a closed-loop speed control system. The two main requirements of the system are that the amount of tractive effort or braking effort being produced by each car must be approximately the same at any given time and that all cars in a train must be motoring or braking at the same time.

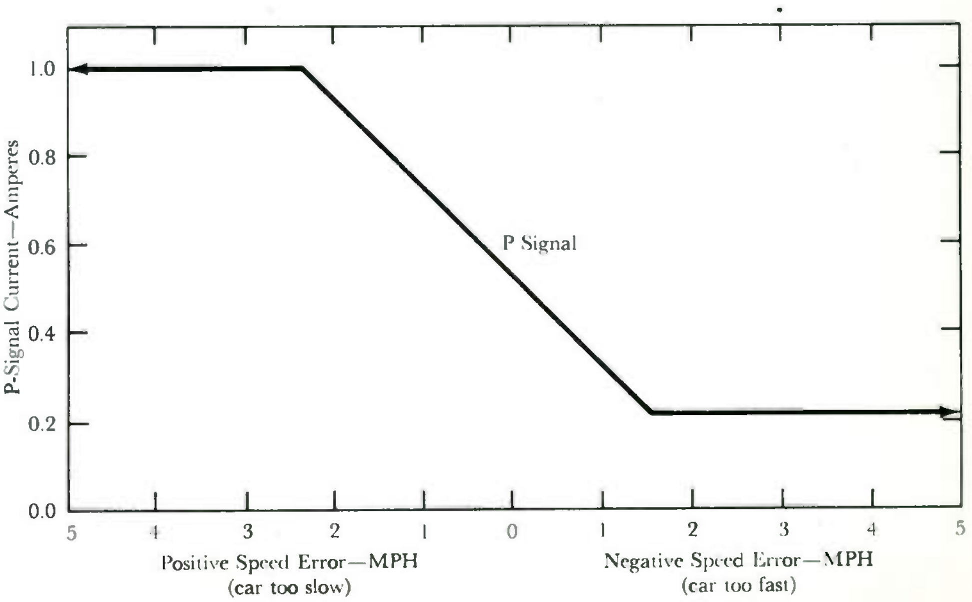
The first requirement is met by having all cars produce braking or tractive effort proportional to a trainlined current signal, which is generated on the head-end car by static circuitry and is known as the "P" signal. (The car selected to control the train does not have to be the head-end car, but, since it usually is, it is referred to in that way in this article.) The circuit is a constant current source for a given reference input, and hence the length of the trainline loop circuit due to the varying number of cars in a train has no effect on the current level.

The level of the P-signal current is variable from 0 to 1 ampere (Fig. 4). It is a function of a speed error signal derived by comparing a speed demand signal with the train speed.

The *speed demand* signal is a dc voltage

2—(*Top*) A master controller enables the operator to select the speed or the braking rate he wants. The control system then applies motor power, dynamic braking, or air braking as needed to accelerate, to maintain the selected speed, or to brake at the selected rate.

3—(*Above*) The high-speed rail cars are initially cutting Penn Central's scheduled travel time between New York and Washington by nearly an hour (to 2 hours and 59 minutes). When track improvements permit full use of the Metroliners' design speed of 160 mi/h, it should take only two hours.



4—(*Right*) For automatic speed maintaining, all cars produce braking or tractive effort proportional to a "P" signal transmitted from one of the cars. With no speed error, the signal current is 0.5 ampere. For positive speed error (speed demand greater than train speed), the signal varies linearly from 0.5 to 1.0 ampere. For negative speed error (speed demand less than train speed), it varies from 0.5 to 0.22 ampere.

signal generated by movement of a potentiometer wiper arm when the train operator sets the master controller to the desired speed level (Fig. 5).

The *speed* signal is a dc voltage signal that is a function of the average speed of three axles on the head-end car. The output of each of the three inductive speed sensors varies in amplitude and frequency in proportion to the speed of gear teeth passing its pickup, and static circuitry converts the variable frequency and voltage signal into a dc voltage that varies linearly with the frequency. Use of three speed signals in an averaging circuit minimizes the effect of slipping or sliding wheels.

The level of the P signal is measured on each car by a current transducer energized from a static 500-hertz square-wave generator. It then is converted to a voltage signal used as the reference input into the regulators that determine the amount of tractive or braking effort to be produced, as described later.

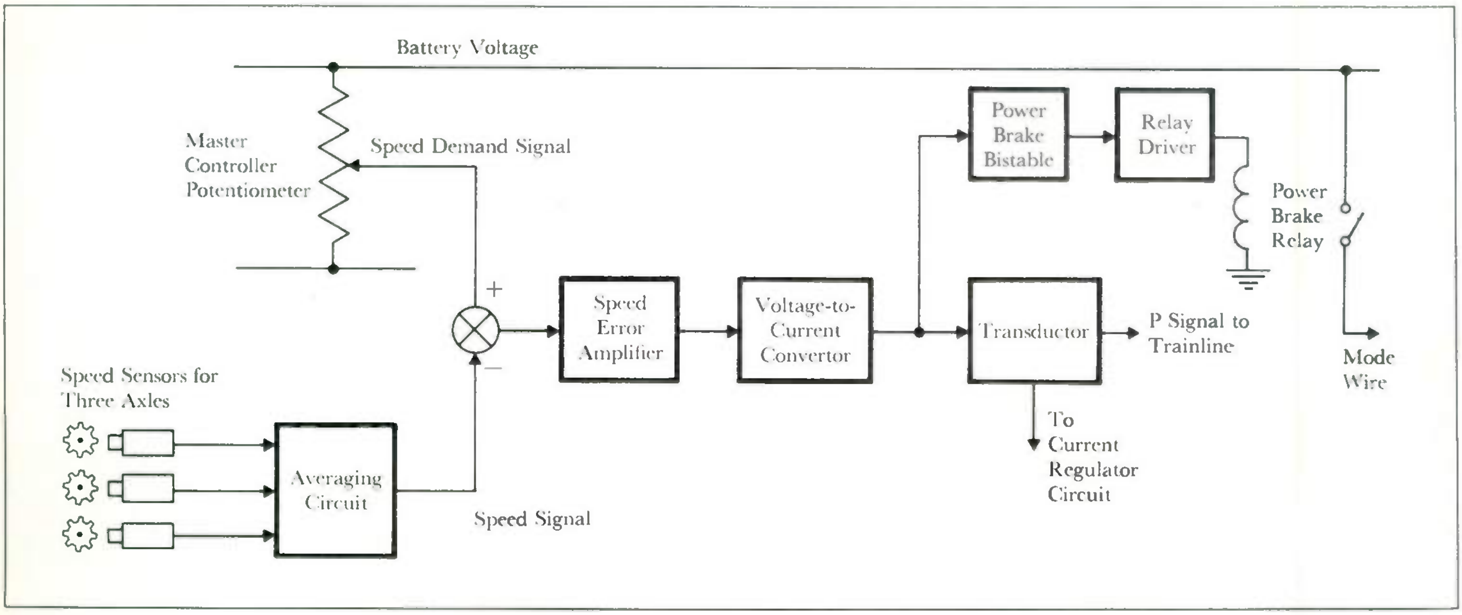
The second main requirement of the speed-maintaining system is avoidance of the intolerable situation of some cars being in power while the other cars are in braking. To meet it, a "mode wire" is energized when motoring is required and de-energized when braking is required.

In the speed-maintaining equipment on the head-end car, the level of the P signal is used to control a static bistable and relay driver circuit (Fig. 5). At 0.6 ampere on an increasing P signal, the relay driver energizes a power-brake relay. A normally open contact on the relay then energizes the mode wire, and all cars in the train set up the motoring connection. At 0.4 ampere on a decreasing P signal, the relay driver de-energizes the relay to de-energize the mode wire and break the motoring connections. Opening of the motoring switches automatically picks up the switches required for dynamic braking.

The static circuits for speed maintaining are part of a panel mounted under the console in the operator's cab. Each car has a panel, but only on the head-end car is the circuitry connected to the trainline P-signal loop and the mode wire. Thus, control from any other car is impossible.

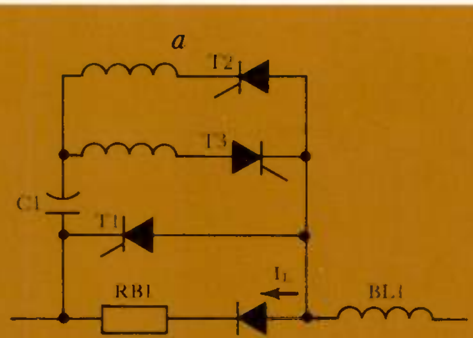
Motoring—Although the mode wire initiates the motoring connections on all cars, a number of permissive interlocks on each car have to be in order before the connections can be completed. The doors must be closed, the motor alternators must be running, air for motor and semiconductor ventilation must be available, and air-brake cylinder pressure must be zero. To complete the motoring circuit, ac line switch *L1*, the dc line switches, and the motor power switches are closed initially (Fig. 1).

Then the regulator is released, and, with the P signal as reference, the phase-controlled ac thyristor switch raises dc bus voltage to the motors so as to maintain the requested current as train speed and motor CEMF increase. When the maximum voltage from secondary No. 1 is reached, secondary No. 2 is energized by the closing of line switch *L2*. The firing position of the ac thyristor switch returns to the maximum delay position and then again advances to hold current

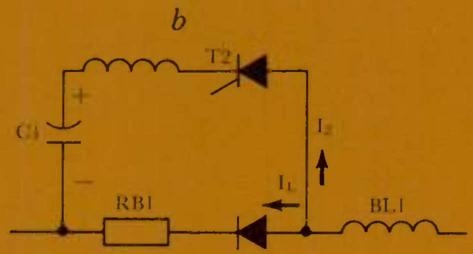


5—P-signal current level is a function of a speed error signal derived by comparing train speed with a speed demand signal from the master controller. It is sent by a trainline from the car on which it is generated to the other cars in the train, where it serves as the reference input for the motoring and braking regulators. Additional circuitry derives a mode signal from the P signal; transmitted to the other cars by a mode wire, the mode signal keeps all cars in the train either motoring or braking at the same time.

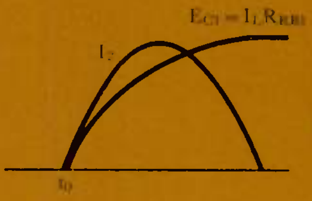
Dynamic Braking Chopper

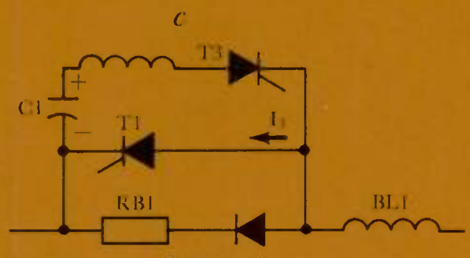


Simplified Braking Chopper Diagram

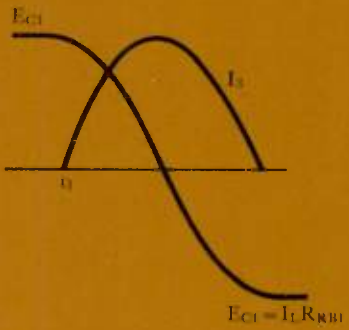


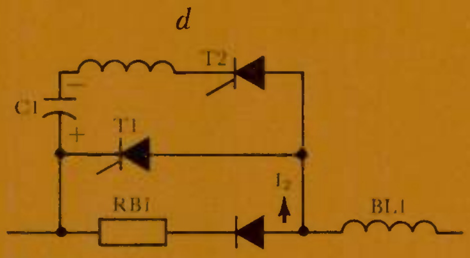
Operation, T2 Turned On



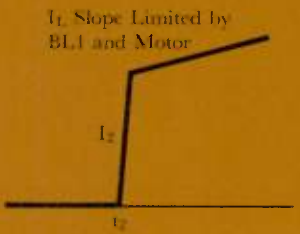


Transient After T1 and T3 Turn On





T1 Only Turned On

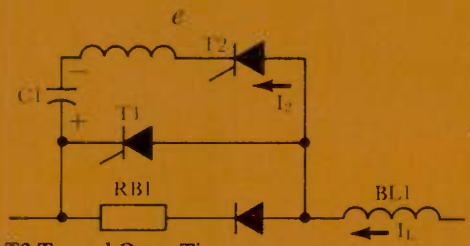


Before the chopper is activated, the braking switches must close, thereby establishing the dynamic braking loop. As a result, a load current I_L flows (Fig. *a*). The chopper operates as follows:

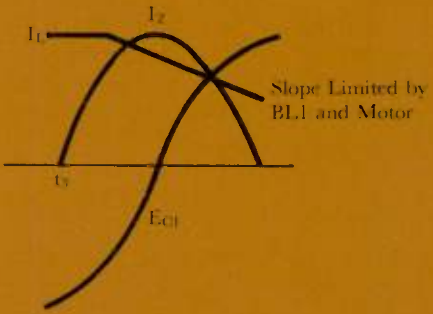
1) Action: Charge turn-off capacitor *C1* before chopper action.
Initiated by: Gating thyristor *T2*.
Transient result: I_2 flows as in Fig. *b*.
C1 charged to $+ I_L R_{RB1}$. *T2* shuts off when I_2 reverses.

2) Action: Turn on chopper to increase I_L.
Initiated by: Gating thyristors *T1* and *T3*.
Transient result: I_3 flows as in Fig. *c*. Charge on *C1* reversed. Current through resistor diverted through *T1*. I_L increases as in Fig. *d*.

3) Action: Turn off chopper to decrease I_L.
Initiated by: Gating thyristor *T2*.
Transient result: Reversed *C1* voltage shuts off *T1*. I_2 flows as in Fig. *e*. Charge on *C1* reversed. *T2* shuts off when I_2 reverses. I_L decreases as in Fig. *e*.



T2 Turned On at Time t3



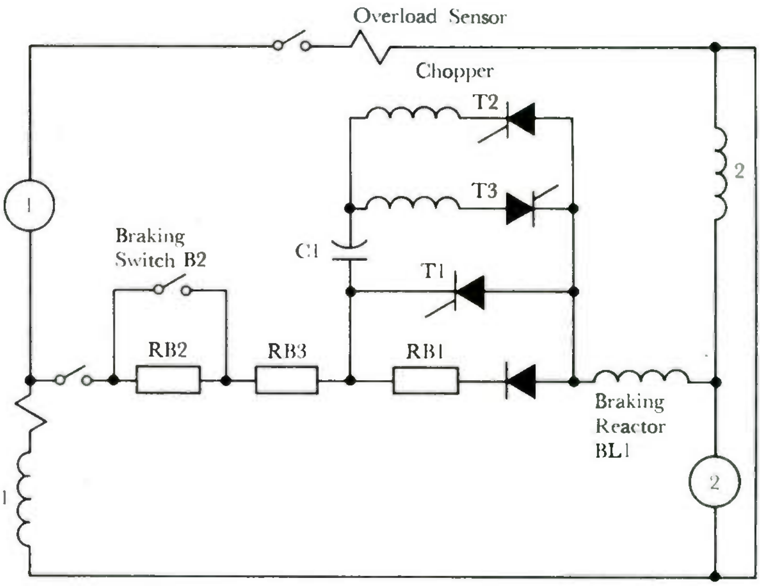
constant as motor speed increases. The same process is repeated with line switch *L3*. Maximum obtainable voltage is achieved when *L2* and *L3* are closed and the ac thyristor switch circuit is in the minimum-delay firing position.

Because of the large acceleration current that had to be controlled, thyristors were paralleled in each leg of the ac switch. This required special precautions to avoid problems due to improper division of current between devices. To minimize temperature effects on current division, the thyristor heat-sink assemblies are brazed to bus bars, providing a common heat sink that remains at a relatively constant temperature throughout its length. A continuous "daisy chain" reactor assembly and a small resistor in series with each thyristor also help force equal current division.

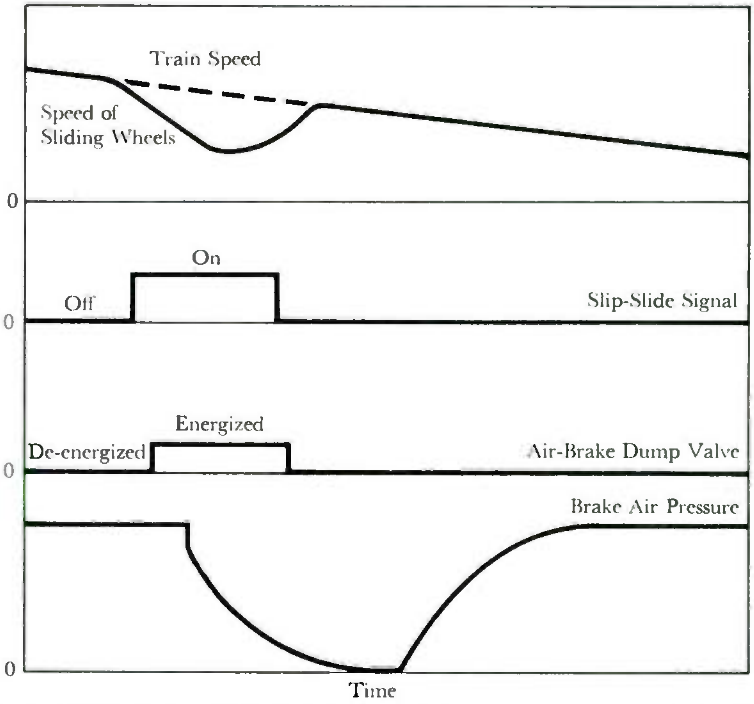
Brake Blending—Another first on the Metroliners is the use of an automatically blended air and dynamic braking system. Performance has been convincing enough that, at Penn Central's request, the blended braking system was used for deadman and overspeed emergency stops rather than the straight air-brake emergency stop as originally specified.

The blended air and dynamic braking system is controlled by the trainlined P signal from the speed-maintaining system. The signal is read by both the dynamic braking control equipment and the electropneumatic brake equipment. An indication of the total dynamic braking effort being produced is transmitted to the electropneumatic brake system, and the amount of supplementary air braking needed is determined and applied. For stops at the normal rate of 1.4 mi/h/s, the dynamic braking system produces the major portion of the braking effort down to a speed where the braking begins to fade out. Automatic blending then adds additional air braking to compensate for the fadeout.

Dynamic Braking—The dynamic braking system employs a static resistance chopper to regulate the braking effort produced in each motor. The system has two circuits, one for the forward truck and one for the rear truck (Fig. 6). Use of separate braking loops for the two



6—Dynamic braking system has two duplicate circuits, one for the forward truck with motors 1 and 2 (shown here) and one for the rear truck with motors 3 and 4. A thyristor-controlled resistance chopper regulates the braking effort produced in each motor.



7—A slip-slide system takes corrective action when it determines that a pair of wheels is sliding (as in this example) or slipping. To correct sliding, it produces a signal that turns off the dynamic braking and energizes dump valves to release the air brakes. When wheel speed begins to catch up with train speed, the system reapplies braking effort.

trucks minimizes the number of devices required to switch from power to brake.

The load resistance in each loop consists partly of the *RB1* resistor controlled by the chopper. (See *Dynamic Braking Chopper*, page 147.) In addition, a resistor (*RB3*) is connected in the braking loop without provision for shorting it out; it is the permanent brake resistor that establishes the dynamic braking fadeout curve. Another resistor (*RB2*) can be shorted out by closing switch *B2* to extend the speed range over which the basic resistance chopper can regulate current.

The braking current regulator is a ripple control regulator. Whenever dynamic braking current drops below a value set by the reference input to the regulator (derived from the P-signal current level), the regulator generates a gating pulse to the *T1* and *T3* thyristors. As a result of *T1* being on, the dynamic braking current increases. Whenever the current rises approximately 100 amperes above the current at turn-on, the regulator turns off the chopper by generating a pulse to turn on *T2*. This combined action produces an average current equal to the reference input plus half the 100-ampere ripple current.

In addition to the static regulator circuits, some other static interlocking functions are required for proper chopper operation. They are:

1) The chopper is not given a signal to turn on or off until the braking loop is complete, i.e., the braking switches are closed.

2) When the main circuit is complete, the chopper is first turned off to assure that the capacitor *C1* is charged before the chopper is turned on.

3) A specific period of time is allowed between an *off* pulse and an *on* pulse. This is necessary to prevent the chopper from being turned on before capacitor *C1* is charged to a voltage that will back-bias the *T1* thyristor the next time an *off* pulse is required.

4) The chopper is turned off periodically whenever the dynamic braking current is below the reference setting and the current is building up slowly to the reference setting. This is necessary to assure that *C1* stays charged to the proper value of voltage to effect a successful turn-off of *T1* when required by the regulator.

The control for the dynamic braking choppers is all solid-state, with operational amplifiers of the discrete-component type used throughout. Some of the interlocking functions are performed by transistors, and the gate-pulse generators are also transistor circuits.

Slip-Slide System—The basic function of the slip-slide system is, first, to detect that a pair of wheels is slipping (running faster than the wheel speed equivalent to train speed) or sliding (running slower than the wheel speed equivalent to train speed). Then it must take corrective action to reduce the tractive or braking effort being applied to the axle so as to permit the wheels to regain the speed equivalent to train speed. Once they have done so, the system must permit the tractive or braking effort to be reapplied.

A speed signal is developed for each axle by inductive speed sensors of the same type used in the speed-maintaining system. (They are separate pickups to avoid interaction with the speed-maintaining system.) A dc voltage proportional to the frequency of the output of the speed sensor is developed, and a derivative of this voltage is used to trigger the slip-slide system. When the derivative voltage exceeds a value equivalent to wheel acceleration or deceleration of 8 mi/h/s, an output from the system picks up a relay to initiate action that reduces the tractive or braking effort until the slip or slide is eliminated.

Once slipping or sliding has been eliminated, the wheels should return to a speed equivalent to train speed. In the Metroliner system, the assumption is made that the return to speed will be at the rate of 8 mi/h/s or greater; therefore, a speed derivative with a sign opposite to the sign of the derivative signal that initiated the reduction in tractive or braking effort is used to reset the system, eliminate the system output, drop out the relay, and thus re-establish braking or tractive effort.

As an example, consider a sliding pair of wheels (Fig. 7). When wheel deceleration exceeds 8 mi/h/s, the negative derivative of the speed signal produces a system output that picks up a relay. The relay turns off the resistance chopper and energizes dump valves that release the air brakes. With no braking applied, the sliding wheels should speed up to train speed at a rate exceeding 8 mi/h/s. The speed derivative signal is now positive, and the slip-slide system output is reset to zero. The relay drops out and permits the braking circuit to return to the output necessary to maintain the braking effort requested by the P signal.

For slipping wheels, the logic involved is reversed. The system output and relay pickup occur on a positive derivative signal, while the system and relay dropout occur on a negative derivative signal.

The slip-slide system recognizes that, for some conditions, the assumption that an equivalent wheel deceleration always follows a wheel slip acceleration or vice versa may not be valid. A time-out circuit is provided, with timing initiated when a system output occurs. If the opposite-sign derivative does not occur before the end of three seconds, the system is reset and the relay dropped out by the timing circuit. The relay dropout then permits tractive or braking effort to be re-established.

Conclusion

Considering the advances in propulsion and braking control involved, there have been few problems with the equipment in service. The cars have been putting on mileage at the rate of 22,500 miles per month, four times that of previous equipment. Their smooth acceleration and high speed capability have contributed greatly to their favorable acceptance by passengers.

Airborne Test Computer Facilitates Radar Maintenance

F. C. Rushing
W. F. Brown

Westinghouse AWG-10 radars can be checked out in flight by computer for possible faults. A built-in test computer uses 105-mm tape for combined storage of the computer program and visible alphanumeric information. The compact tape transport with a block reader and optical readout is mounted in the cockpit of the aircraft.

Computerized checkout of airborne electronic equipment is a natural adjunct to the ever increasing sophistication of modern avionics. This technique permits a "built-in test" during flight, and it automates the technician's job by searching the system for functional trouble during routine maintenance. When trouble occurs, computerized checkout quickly locates the problem and informs the radar operator or the technician. Computer-supervised test systems will find economic justification for many complex systems in the future.

Selector Test Programmer

In the application to be described, a computer, called a *Selector Test Programmer*, has been developed for (and is currently in production as part of) the AWG-10 radar system used on F4J aircraft.

The Selector Test Programmer is a compact assembly of electronic circuitry, with a storage tape memory, and a tape transport with a block reader for extracting information from the tape. Two sizes of programmers have been built, one with 1000 readouts on the tape, and the other with 3000 readouts. The 1000-readout model is designed for airborne use; the 3000-readout model can make a more thorough search for system faults and is intended for repair-base use to supplement, where necessary, the indications given by the airborne model.

The large number of readouts required indicates the need for computerization to supplement the technician's efforts in maintaining radar equipment. Computerized testing provides a major contribution to the efficient and economical use of complicated electronic gear, especially when aircraft are widely dispersed over the entire world. Equally valuable, the radar operator can check his equipment in flight—checkouts at the start of a mission, during, or at the end can provide much needed information on the status of radar equipment.

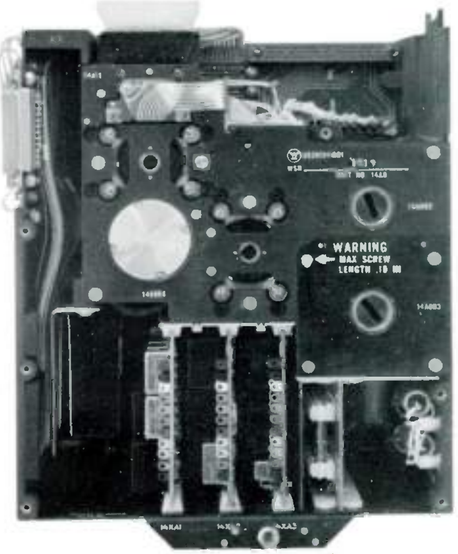
Tape Transport and Block Reader

The Selector Test Programmer is mounted in the cockpit beside the operator so that he can conveniently see the alphanumeric readout, which informs him of the condition of his equipment. The programmer is a compact assembly with dimensions of only 9 × 7.7 × 8.75 inches (Fig. 1). The tape transport and block reader are contained in the programmer. The tape transport, being airborne, is of necessity compact and light in weight. The tape transport with side plate removed is shown in Fig. 2.

The tape is standard 105-mm photographic film, sprocketed along both edges. The airborne test programmer carries 100 feet of tape, enough for 1000 discrete readout positions. The tape is stored on spools (Fig. 3) and moved through the transport in steps, 0.94 inch per step. The test program is read from the tape during the dwell period between steps by a compact array of light sensors that detect light through the coded array of transparent windows in the tape. The tape can have windows for any one or any combination of the 7 × 22 array of sensors (Fig. 4) in the sensor pack.

When a fault is sensed during checkout, the tape is stopped. The alphanumeric printing on the tape positioned in the readout gap is magnified with fiber optics (shown as the protrusion from the top of the sensor pack) so that the operator can read the printed message directly from the tape.

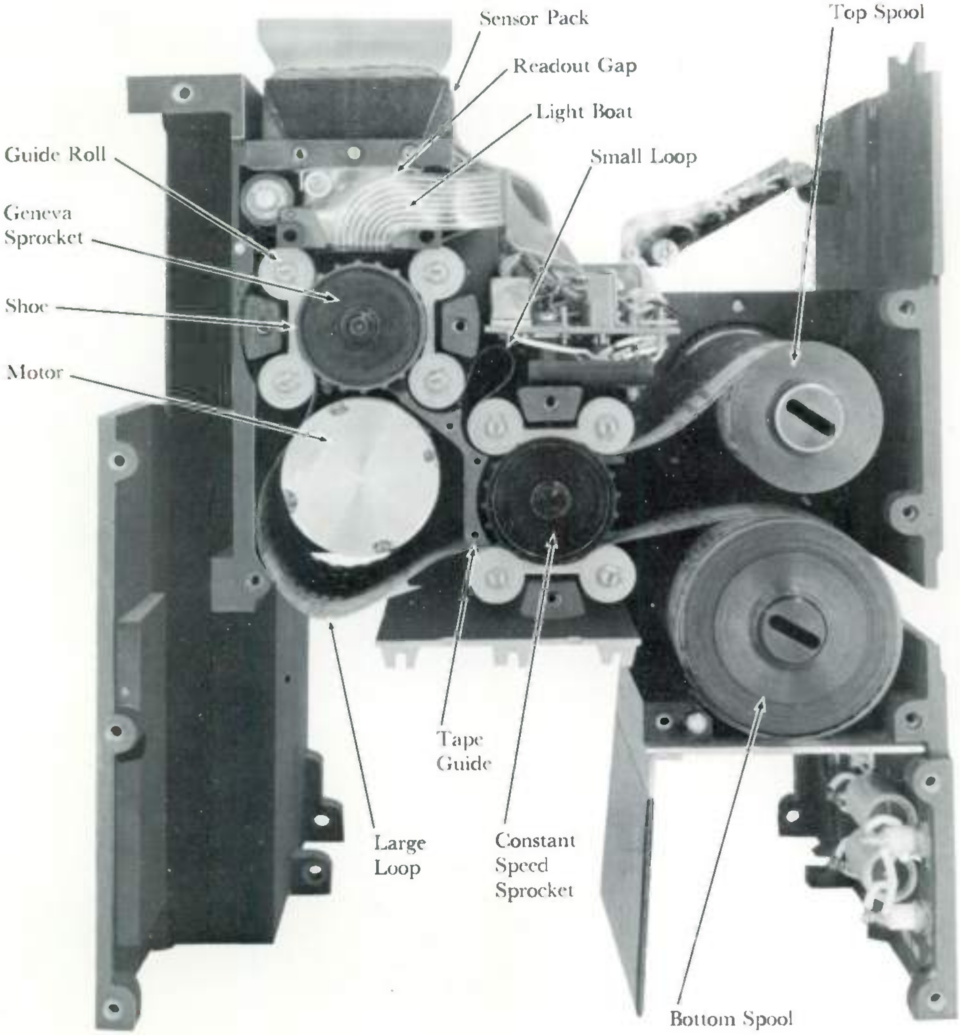
The tape is stepped through the readout gap with a geneva drive, providing an intermittent motion of 10 frames per second. The takeup sprocket rotates at a constant speed, and two loops serve the conventional requirement of accommodating the difference in movement between the constant-speed and the step-



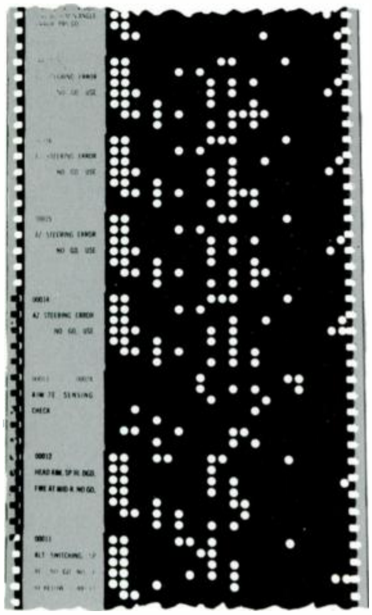
1—The Selector Test Programmer contains the tape transport, block reader, and electronic circuitry. The complete assembly is 9 × 7.7 × 8.75 inches.

2—Tape transport with side panel removed shows the mechanical arrangement. A geneva wheel (not shown) drives the upper sprocket at 10 frames per second. The lower sprocket is driven at constant speed. The tape can be rapidly started, stopped, or reversed upon command.

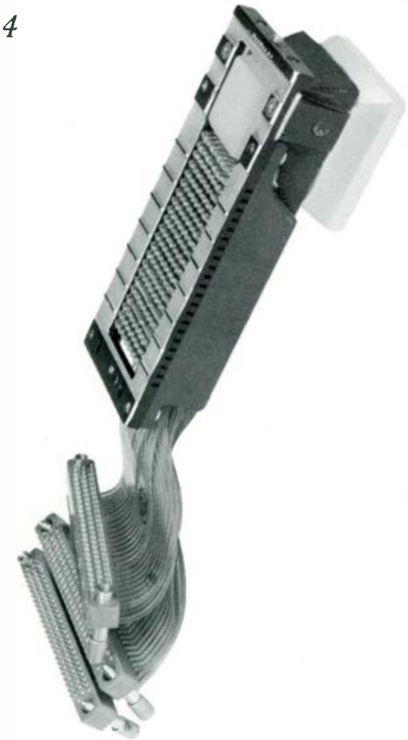
F. C. Rushing and W. F. Brown are with the Electronic Systems Division, Westinghouse Defense and Space Center, Baltimore, Maryland.


Sensor Pack
Top Spool
Readout Gap
Light Boat
Guide Roll
Small Loop
Geneva Sprocket
Shoe
Motor
Tape Guide
Large Loop
Constant Speed Sprocket
Bottom Spool

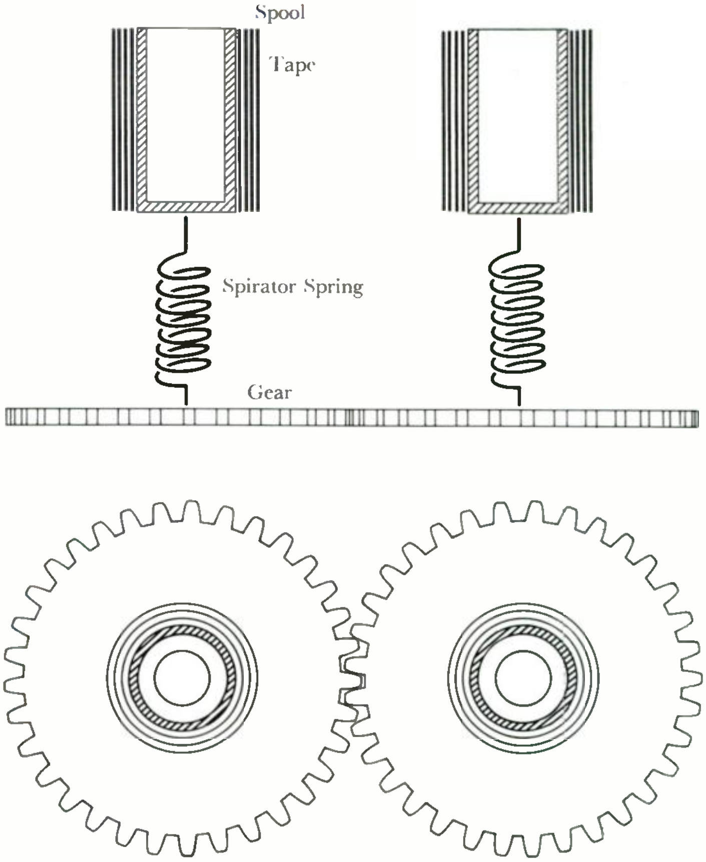
3



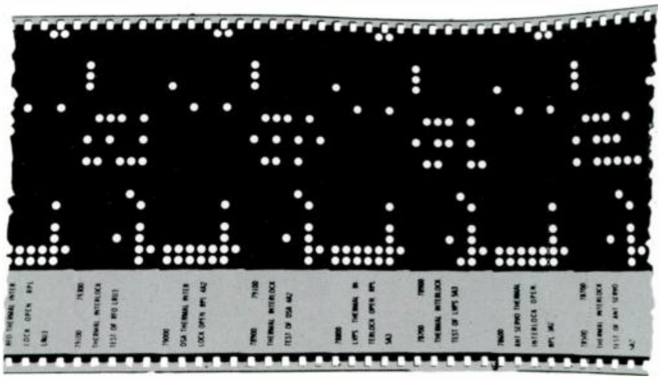
4



5



6



ping sprockets. In this case, the requirements of compactness and of fitting into a given space have led to unnatural paths for the loops, and special guiding with shoes and tape guides is required.

The tape is driven in either direction through the transport, requiring each spool to pay out or to take up as required. To accommodate rapid starting, stopping, and reversing, the spools must keep the tape compactly wound and reasonably taut and give minimum reaction to quick starts. The spools are constantly torqued by clock-like mainsprings, producing a "window shade" type of tension. To maximize their effectiveness, the ends of the mainsprings are linked to each other through gears, shown schematically in Fig. 5. As tape is pulled from one spool, it tends to wind up that spool's spring, but part of its windup is transmitted by gears to the other spool's spring which is taking up tape and tending to unwind its own spring. In this way, the springs can be used with greater efficiency, contributing to needed compactness.

The main drive motor assembly (Fig. 2) contains an induction motor with reduction gears, about 40:1, a clutch, and a brake. The drive assembly is required to start, stop, or plug reverse on command during the time that the geneva drive has the tape in the dwell position; at full drive speed, this dwell time is only 0.05 second. The estimated life requirements are as high as one million starts, stops, and plug reversals. The clutch, brake, and gearmotor have been designed to meet these requirements.

3—The coded computer program and alphanumeric information describing each readout is stored on tape made from standard 105-mm photographic film.

4—The tape is "read" with a sensor pack consisting of a 7 × 22 array of light sensors and visual readout optics.

5—The Spirator spool drive uses gearing to transmit torque between spool tension springs so that tape tension stays relatively constant as spools turn.

6—Photographic tape is silane-glutaraldehide treated to resist moisture. This section of tape shows no deterioration after 15 days in water.

The sensor pack (Fig. 4) is an accurately positioned array of 154 light sensors combined with magnifying fiber optics for alphanumeric viewing. The tape passes between the sensor pack and a light boat that uniformly floods the area with light. Transparent windows in the tape allow light to fall on selected sensors. Combinations of windows in each readout step provide intelligence for the system.

Tape Treatment

For the airborne application, severe environmental requirements have been imposed. The most severe problems are humidity and moisture, which cause untreated photographic type tape to degrade and become sticky. Extreme humidity results in standing water on all the internal parts including the exposed tape. This problem has been overcome by using a silane-glutaraldehide treatment of the tape. The piece of tape shown in Fig. 6 had been soaked for 15 days in water, and no degradation is visible.

Standard 105-mm photographic film is used to make the tape. Special tape production equipment has been made to expose the master and to make copies. The photosensitive film is exposed to the coded light window arrays simultaneously with the alphanumeric material for each readout in sequence. Positional accuracy of the windows is held to within ±0.003 inch from an edge and lengthwise from the edge of an associated sprocket hole. Copying from the film masters is done with a special adaptation of a conventional film tape copier that provides greater accuracy. The master and copy are held to within ±0.002 inch of each other from one edge and from associated sprocket holes. The film accuracy together with accurate positioning of each sensor in the sensor array and the capability of the transport to accurately position the film in its dwell position for readout permit the sensors to be spaced only 0.125 inch apart so that the entire 7 × 22 sensor array can be placed within a 0.97 × 2.84-inch rectangle.

Built-in Testing

The success of the Selector Test Programmer system in airborne applications suggests areas for growth in directions of greater, as well as lesser, sophistication. Meeting the rigorous requirements of airborne space and environmental conditions has been a major first step for the tape transport and block reader arrangement. The simplicity of its mechanized alphanumeric readout compared with that of a completely solid-state system is a definite advantage. In addition to its more extensive application for aerospace, the tape system also has attractive characteristics for ground-based installations such as communications and tracking stations, processing lines, power generating systems, and equipment testing.

Multistation Test System Allows Thorough Testing of a Wide Variety of Electronic Subassemblies

Neville E. Jacobs

Data transmission lines of the RIFCA test system reach out from a central controller to remote test stations in the various manufacturing departments. Tape-programmed control makes thorough testing feasible even on subassemblies that are produced in small volume, and it greatly speeds testing.

The rapidly changing technology of industrial control has necessarily increased the variety of control subassemblies manufactured and has accelerated the frequency with which they are introduced. Thorough testing of these diverse subassemblies is particularly important because the full performance of the final system can only be realized if each subassembly performs all of its functions satisfactorily.

Subassemblies are the building blocks that go into such diverse control *systems* as those for automated steel mills, paper mills, giant shovels, automatic warehouses, numerically controlled machine tools, and production lines. Each subassembly generally consists of 50 to 500 components and performs a specific function, such as signal amplifying or pulse counting. A number of subassemblies are connected into a system that performs the operation the customer requests, such as speed control of the rolls in a steel mill or positioning of a machine-tool table.

Until a few years ago, most control subassemblies produced at the Industrial Systems Division had been tested successfully with either automatic test equipment built for each job or, for short runs, with multipurpose consoles operated manually. However, automatic custom-built test equipment was complex, expensive, inflexible, required long lead times, and was becoming hard to justify because of the progressively shorter life cycle of control products. Manual test equipment was slow and so added unnecessary cost to products and lengthened delivery time. Experiments with tape-controlled test equipment showed that the elaborate programming required made it uneconomical because a substantial part of the control business is in systems with a large number of subassemblies, only a few of which are of the same type (often less than ten of a kind).

Accordingly, custom-built automatic test equipment was reevaluated to see if cost and lead time could be reduced. The main findings were that the basic test circuitry must indeed continue to be specialized and rigid, owing to the unique characteristics of the highly specialized units being tested, but that much associated hardware (such as stepping switches and annunciators) was being repeated in different forms on all pieces of test equipment. Those items represented a substantial portion of the cost of the equipment, and their repetition implied an absence of standardization in design and test procedure. Thus, standardization was an area for potential improvements.

The Philosophy

The first need was for a new test philosophy that could be applied uniformly both by the Division's design engineers and by its shop personnel on all four widely separated and diverse test floors. Then the system to implement the philosophy could be selected on criteria that would minimize the investment in hardware (excluding the initial cost of the system), software, and lead time for each new job.

The philosophy that was adopted was strikingly simple:

1) All "standard" functions should be part of the system;
2) All "special" functions should be put through custom-built "black boxes" whose purpose would be to convert special functions to standard functions;
3) All standard functions should be transmittable over long lines between a central controller, where they would be generated and evaluated, and remote test stations where the black boxes and units under test would be located;
4) Self-programming should be practiced wherever possible.

Standard functions would include step switching, step numbering, establishment of tolerances, annunciating and message readout, dc and ac measurements, ohm measurements, power supply, and time delays.

Special functions could be wave-shape analysis, counting, frequency generation, phase angle measurements, pulse width measurements, and so on.

The System

A test system incorporating the philosophy was designed to the exact requirements by the Industrial Systems Division and the Electronic Systems Support Division. The latter also built the system's central controller, while the Industrial Systems Division supplied the test power supplies and satellite stations (Fig. 1). The system was completed and installed last October. Known as RIFCA (for Rapid Integrated Factory Circuit Analyzer), it has reduced test times, increased test throughput, and improved product reliability as shown by marked reduction in the number of failures in subsequent systems testing.

The RIFCA central controller (generally referred to as RIFCA central) generates and evaluates the standard functions, and units under test are hooked up to it at remote stations (Fig. 2). The system serves a manufacturing area of about two acres, has test stations up to 400 feet from RIFCA central, and required about 80 miles of wire to install.

One of the two types of remote stations used in the system is referred to as a satellite station and is used for testing printed-circuit boards and small modules. The other type is a peripheral station that can be used for testing a complete system or for rechecking any subassembly that shows unusual behavior on final system test.

RIFCA central is housed in an air-conditioned room. Two operators are generally on hand, one to control the system and one to work on new programs and make tape changes.

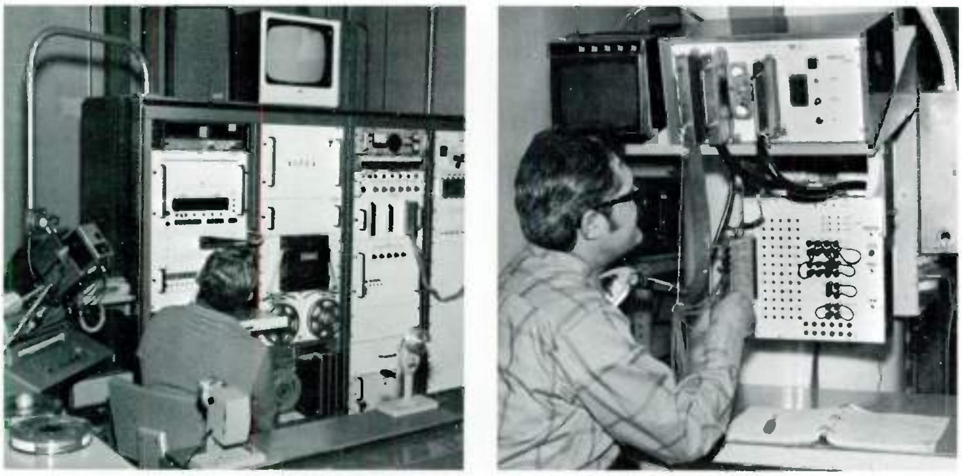
The console operator at RIFCA central loads tapes into the tape readers, assigns the station that is to go on line, and sets up the necessary front panel controls. He has 16 test and programming options to choose from, and he selects them with

---

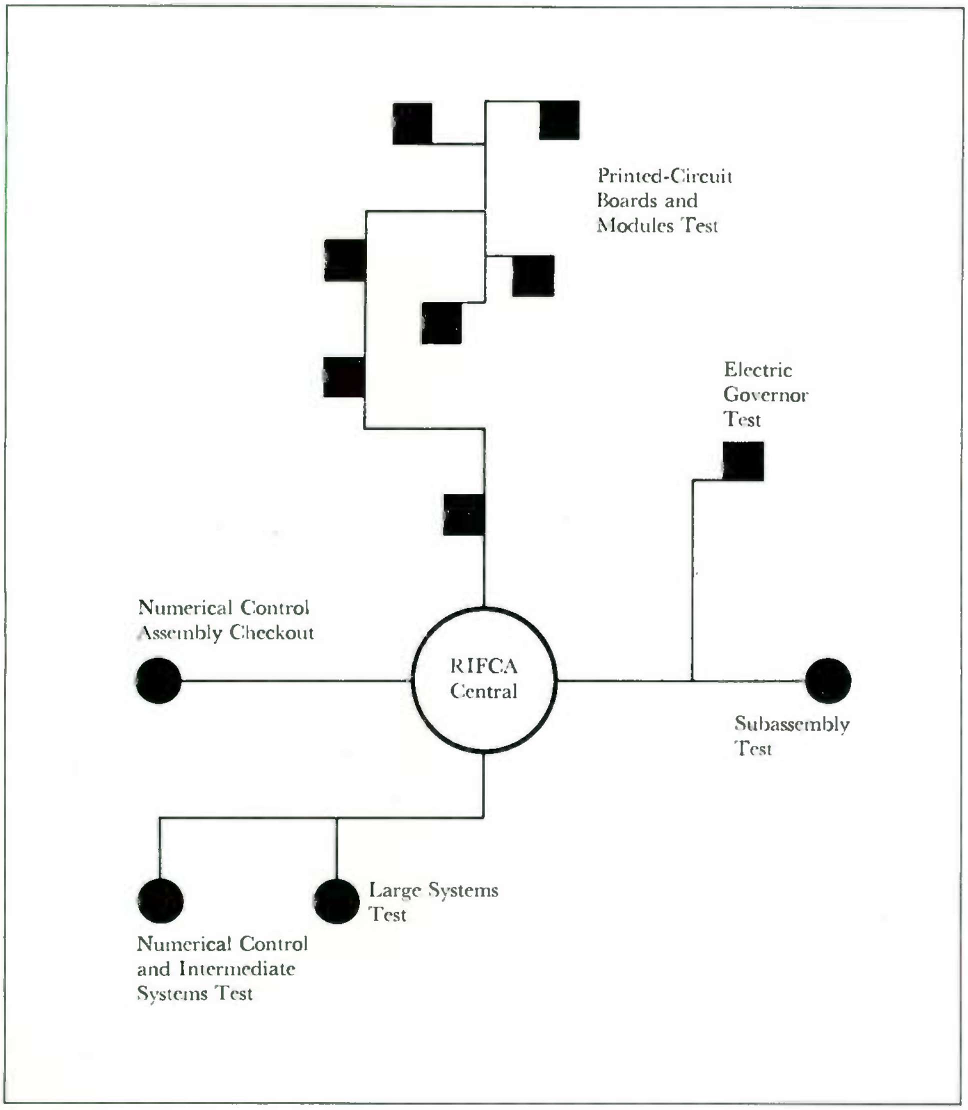
Neville E. Jacobs is Manager, Quality Control and Test, Industrial Systems Division, Westinghouse Electric Corporation, Buffalo, New York.

pushbuttons and toggle switches. Periodically, he checks the television monitor, which shows teletype data transmitted to each remote station to tell the tester there what he must do and to indicate the defects detected. He also talks with the testers at each station by means of a pushbutton switching panel. When he switches a tester on line at a remote station, he may also choose to turn control of the system over to the station, thereby enabling him to ignore its operation during actual test and concentrate on the next job at hand.

Meanwhile, the second RIFCA central operator may be working on an off-line teletype making self-programming tapes. In the self-programming mode, new programs are generated by hooking a "known good unit" to a test station on the system and directing RIFCA to scan it. (The known good unit is generally a laboratory prototype that has been thoroughly tested manually.) The scan instructions are sometimes put into the controller by keyboard but more often are entered on punched tape through a tape reader. RIFCA processes the instructions, sets up the power supplies, makes leakage,



1—(*Top*) The RIFCA system is a testing network consisting of a central controller (known as RIFCA central) and remote test stations in manufacturing areas. RIFCA central is shown in the first photograph, making a test tape in the self-programming mode. A "scan" tape is carried on the two center reels, and the new test tape is being wound onto the lower reel; the "known good unit" being scanned is at a remote station. Teletype and television camera are at left, television monitor and speakers at top, and microphone and station-select panel near the operator's head. In the other photograph, a printed-circuit board for a numerical machine-tool control is tested at a satellite station. The television monitor shows the tester instructions and test data being printed out at RIFCA central, and the microphone enables him to communicate with the operator there. The manual breakers on the shelf permit him to interrupt all power to his station until he is ready to test.



2—(*Left*) The two general types of test station used at the Industrial System Division, satellite and peripheral, are indicated respectively by squares and circles in this schematic representation of the manufacturing and test area.

RIFCA System Characteristics and Capabilities

RIFCA Central	
Maximum number of test connections	100,000
Present number of test connections	1560
Number of tests that can be performed	Unlimited
System isolation	100 megohms at 2500 volts
Leakage detector low limit	100 kilohms to 50 megohms
Maximum hipot voltage	1500 volts
Continuity detector upper limit	5 to 1000 ohms
Ohms measurement range	1 ohm to 10 megohms
Number of independent test power supplies	10 (6 with remote sense leads for especially accurate voltage regulation)
Range of test power supplies	Up to ± 50 volts dc; up to 440 volts ac, 3 phase
Number of test points allowing both input test power and output signals	60
Volts measuring range, dc	0.01 to 1000 volts
Volts measuring range, ac	0.001 to 1000 volts
Test rate	7 tests per second
Programmable time delay range	0.01 second to 9 seconds
Programmable tolerances	1) Greater than; less than. 2) Percentage differences above and below nominal or self-programmed value. Tolerances available: 1, 3, 5, 10, 30 percent of nominal value and 1 percent of full range for each range. During self-programming, independent tolerances can be set up for ohms and voltage measurements.
Remote Stations	
Number of satellite stations	8
Number of test connections on each station	60 for input-output signals plus option to use 100 more for output signals only
Number of peripheral stations	4
Number of test connections on each station	60 for input-output signals plus option to use 1500 more for output signals only
Communications at all remote stations	Two-way audio to RIFCA central; TV showing teletype output; signal light showing progress of test; remote control of *Stop, Go,* and *Reset*
Self-Programming Capability	
Modes available	All test modes (leakage, continuity, resistance, voltage)
Signal level for solid-state circuitry	5 volts 5 milliamperes maximum
Signal level for relay circuit checking	5 volts 1 ampere maximum
Diode testing	Programmable polarity reversal
Ranges	Self-ranging with option to use fixed ranges for higher test speeds

continuity, resistance, and voltage measurements on the known good unit, sets tolerances, and commands the tape punch to make a test tape that is then used to test subsequent units. The scan tapes, or self-programming tapes as they are generally called, are based on engineering test specifications and are prepared either by computer or by the operator on the off-line teletype.

RIFCA in Operation

A tester at a remote station connects a unit to be tested to his station. He reads test specifications from the drawing and sets up any required jumpers or black boxes. When ready to test, he presses the *Request* button, calls RIFCA central, tells the operator the style number of the job he wants tested, and awaits the signal light to proceed. The RIFCA central operator inserts the requested test tape into the tape reader, enabling the station that requested it to tie in to the controller by electrically releasing a latch blocking his circuit breaker. (Other testers can continue hooking up their jobs to their test stations, but the system is interlocked so that, for the brief duration of the test, they are blocked from connecting electrically to the controller until the first tester is through.)

When the signal light comes on and the latch is removed, the tester (who is now on line) manually closes his two multipin circuit breakers and is ready for testing. He presses the *Proceed* button and observes the television monitor for verification of the correct tape number, for instructions, and for reject data if any. He records any reject data printed out as the test proceeds. The tester can stop the test if he desires, and he can repeat tests that he finds questionable or repeat tests when he has been instructed to make adjustments to components.

On completion of the test, the tester opens his breakers (instantly releasing the system), unhooks the unit from the test station, and either stamps the unit if it is good or investigates the reject printed out and writes a repair tag. Then he gets on with the next job.

The basic characteristics of the system and the range of tests that can be performed are listed in the accompanying table. Other significant features follow.

Versatility—Rapidly changing technology requires that RIFCA have ample integrated-circuit logic and isolation capability to perform any combination of analog and digital tests in any sequence and on units of any size. It is a combination solid-state and relay system. The system is modular and can be readily expanded, without major interruptions, by plugging in additional test modules that can be built when needed.

Ease and Speed of Operation—The whole test operation can be handled safely by production testers. Although some RIFCA-central operators have received fairly extensive training courses, most normal test routines are now handled by regular shop test personnel. Thus, any qualified tester can handle any job immediately, irrespective of its complexity or of his familiarity with it. The result is that jobs for which a test-program tape exists can be tested, troubleshot, and repaired much faster than before.

Test rate is seven tests a second, which, while not as fast as that obtainable with all-solid-state low-voltage switching, is satisfactory for most of the Industrial Systems Division's applications and very much faster than the equipment used previously. The fast test rate makes actual test times generally far less than hook-up times, enabling the system to service all test stations without need for time sharing. As a result, system complexity is minimized and reliability maximized. Moreover, off-line stations can be connected in complete safety because each tester manually interrupts all power at his own station and can visually assure himself that breakers are open or closed. The simple configuration also eliminates crosstalk and electrical noise and thus was a major factor in holding system start-up time to just three weeks.

Environmental Testing—Tests can be run at temperatures up to 160 degrees F to simulate extreme conditions in the field.

Message Readout—Messages in the program print out on the RIFCA-central teletype, where they are viewed by the television camera and transmitted to all stations. The messages can instruct the tester to add jumpers, throw switches, adjust potentiometers, read instruments, and so on.

Reject data is printed out only when a test step fails. It gives the identity of each test point, the nominal value of the measurement and its tolerance, the actual value recorded, and whether it is above or below the acceptable tolerance band. The step number and defect diagnosis, when included in the test specifications, are printed out immediately after the test step that failed. This diagnosis can be displayed in any form and at any length.

Though the printout data is quite detailed, it is given only for test steps that fail. Consequently, less than one percent of the information on the test tape is typed by the teletype during an average test sequence, and that is all that is presented on the television screen for the tester to analyze. Two copies of the test report are made for documentation.

Interface Capability—RIFCA can operate from or into any computer having ASCII code, either directly or through a telephone line. The self-programming tapes are normally obtained off line from a batch-process computer, but the time-sharing services of an on-line computer have been used experimentally to explore special fault analysis techniques that could be applied to more sophisticated systems testing.

Dependability—RIFCA has 364 printed-circuit boards using integrated circuits, two high-speed tape readers, a tape punch, a teletype, and video and audio circuitry, yet all of that equipment must run continuously 16 hours a day and be always available for immediate testing of rush jobs. To insure that system failure rate would be low enough to cause no operating problems, the design team used reliability prediction techniques to study component stress and long-term reliability. It also established levels of redundancy for a number of the weaker items. Plug-in components and assemblies were used wherever possible to speed replacement, self-checking tapes were developed to enable RIFCA to troubleshoot itself, and the cabinet and panels were laid out to insure fast repair or replacement of a failed component.

As a result, predicted mean time between failures was five times better than would normally be expected for equipment of similar complexity. Throughout the months of two-shift operation since last October, not a day's production has been lost. Total lost time due to equipment failure has not exceeded two percent of available time.

Present and Future Benefits

RIFCA has been used routinely up to now to test digital printed-circuit boards for numerical and computerized machine-tool controls, digital printed-circuit boards for Prodac II position regulators, and analog modules for motor speed control. Tests that previously took up to two hours are being routinely performed in less than three minutes of machine time, and the incidence of failure in subsequent complete-system testing has dropped dramatically.

Self-programming tapes are being made by a central data-processing computer, and then test tapes are made and the units tested within two to three days as compared with an average of almost a month before. Jobs requiring construction of harnesses and black boxes need additional time, but it is now measured in weeks rather than months as previously.

The Industrial Systems Division's test department is working on three advanced RIFCA applications: faster programming so that more products can be RIFCA-tested economically, even when they are one of a kind; total-system testing; and portable telephone stations that would enable users of the Division's control equipment to test and repair troublesome modules at their own locations. When those development projects are completed, RIFCA and its tape making will become fully integrated into the Division's order development system and will be testing much more of its products.

Battery-Powered Vehicles Find More Applications

Widespread use of battery-powered electric vehicles in place of vehicles powered by internal-combustion engines could go far in reducing air pollution, but they will not be generally competitive in other performance characteristics until better batteries are devised. In the meanwhile, however, some users are taking advantage of battery-powered vehicles' pollution-free operation by applying them in areas where they *are* competitive. Examples of such areas are indoors, as in manufacturing plants and warehouses, and congested city areas.

Changeover from gasoline- to electric-powered tugs by Alfred M. Lewis, Inc., a California-based food distributor, provided much less noise and much cleaner air in the warehouses, increased the productivity of order fillers, and reduced maintenance costs by about 75 percent. Each tug pulls up to 5000 pounds (four to six four-wheel carts). Average battery life under normal operating conditions is from 18 to 24 months. When not in use, tugs are plugged into 50-ampere chargers for 8 to 10 hours; after charging, they can operate up to 12 hours. The tugs were made by the Westinghouse Electric Vehicle Department.

Warehouse operation with the gasoline tugs required 16 to 20 man-hours a day for maintenance; now maintenance takes only five man-hours a day. The tugs are serviced by two employes, who check for proper water level in the batteries and perform additional maintenance, such as brake adjustment, as needed.

A new product of the Electric Vehicle Department is an electric passenger bus designed to carry up to 18 passengers. Typical uses include transportation within industrial complexes, shopping centers, college campuses, and other activity centers where people otherwise would have to walk long distances and where fume-free operation is especially advantageous. One of the first applications was by a manufacturing company in the Los Angeles area to carry employes, visitors, and customers around the office and production facilities. The bus is capable of operating for eight hours straight, making more than 500 stops and starts. Typical speeds are 6½ miles an hour loaded and 9 empty.

The bus is 14 feet long, 5½ feet wide, and 7½ feet high. Power for the four-horsepower dc series-wound motor is provided by 12 six-volt batteries; two other batteries power accessories. The six doors for entrance to and exit from the side-facing seats are removable for warm-weather use. Total weight is 3000 pounds, of which 1000 pounds is battery weight.

Electric bus carries up to 18 passengers. Intended for use in high-density areas, such as shopping centers or industrial complexes, the electric vehicle produces no air pollution and practically no noise. Twelve 6-volt batteries power a 4-horsepower motor and enable the vehicle to operate for eight hours.

AEC Assigns Liquid-Metal Breeder Reactor Responsibilities

The U. S. Atomic Energy Commission has awarded a five-year contract to WADCO Corporation to manage its liquid-metal fast breeder reactor development and technology programs at the Pacific Northwest Laboratory, Hanford, Washington. (WADCO is a wholly owned subsidiary of Westinghouse Electric Corporation.) The programs include design, construction, and operation of the Fast Flux Test Facility, which will be used for testing fuels and other materials under fast-reactor conditions.

Another program is operation of a new High Temperature Sodium Facility scheduled for completion in 1972. That facility will be used for engineering development in support of the liquid-metal fast breeder reactor concept, especially studies of the effects of high-temperature sodium on reactor components and structural materials.

Materials Test Loop Completes 10,000-Hour Run

An important milestone was reached when one of the Westinghouse Advanced Reactors Division's materials test loops completed a 10,000-hour run with flowing sodium under simulated liquid metal fast breeder reactor (LMFBR) conditions.

In fact, ten test runs have been completed to date and represent an accumulated operational time of over 40,000 hours. The most recent test, which lasted 10,000 hours, showed that the corrosion rates are acceptably low, even at elevated temperatures of 1325 degrees F, provided the oxide impurity level is kept low.

The testing program on the materials test loops for the LMFBR program is approximately 70 percent complete. Additional test runs are underway to complete the planned test matrix.

Many of the developmental facilities at the Westinghouse Waltz Mill Site near Pittsburgh, Pennsylvania, were built to help solve problems like:

How fast will Type 316 stainless steel piping corrode when liquid sodium is circulated through it at a flow rate of 20 feet per second, at a temperature of 1325 degrees F?

How much carbon is transferred from one section of piping to another section at different temperatures?

What effects does hot sodium liquid have on valves, pumps, tanks, and loops?

How is a system designed to handle and compensate for all of the expected temperatures, pressures, and other materials requirements in a fail-safe manner?

The materials test loops approximate the conditions of the LMFBR system and consist of two types of loops. One loop has a hot section of Type 316 stainless steel, and a cold section of Type 304 stainless steel. This loop simulates the cladding of fuel elements and the primary sodium loop passing through the intermediate heat exchanger. The other test loop has a hot section of Type 304 stainless steel and a cold section of Incoloy-800. This loop simulates the secondary sodium loop passing through the intermediate heat exchanger and the steam generator.

Test specimens are introduced into either the hot or cold test legs during operation by mating an inert-gas dry box to flanges welded to valved expansion tanks located over the test sections. When a test run is completed, the entire loop is dismantled for metallurgical examination, and additional in-line samples are recovered for analysis.

Oxygen Regeneration System to Recycle Astronaut's Breath

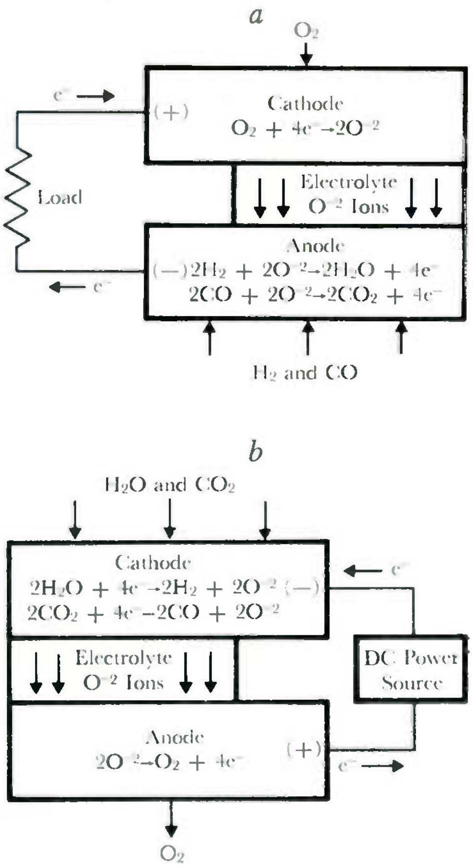
So far, men in space have been supplied with oxygen carried along in liquid form from earth. However, as space missions become 100 days or longer, a means of regenerating oxygen from a crew's own respiration products will become more economical in terms of total weight than a stored oxygen supply. Such a regeneration system is being developed by the Westinghouse Research Laboratories under the sponsorship of the National Aeronautics and Space Administration.

The system is based on the solid-electrolyte fuel cell developed at the Laboratories, although its operation is the reverse of the fuel cell's operation. A fuel cell uses gaseous reactants to produce electricity and products of combustion, while the oxygen regeneration system uses electricity to produce oxygen from combustion products. (For spacecraft application, the "combustion products" are water and carbon dioxide exhaled by the crew.)

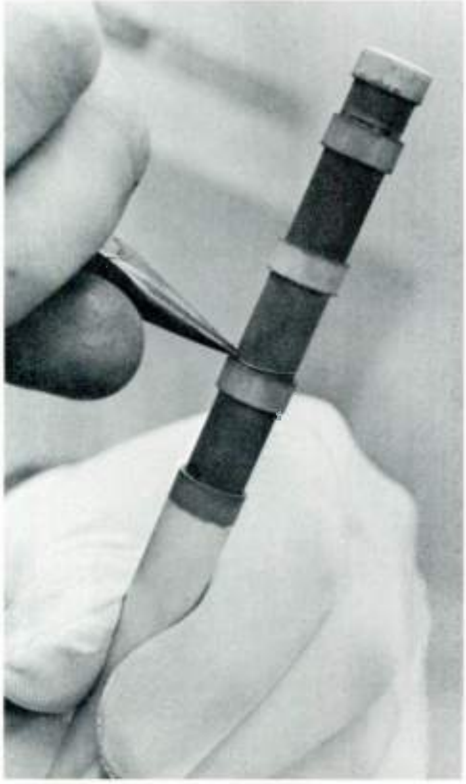
The Westinghouse fuel cell consists basically of a solid electrolyte sandwiched between two porous electrodes. (See diagram.) At any temperature, oxygen molecules and oxygen ions are in equilibrium at the cathode: $O_2 + 4e^- \rightleftarrows 2O^{-2}$. At the operating temperature of about 900 degrees C, however, the electrolyte provides a good path for oxygen ions while preventing flow of electrons, molecules, or other ions.

To generate electricity, oxygen is supplied at the cathode of the fuel cell, and fuel (hydrogen and carbon monoxide in this example) is supplied at the anode. The oxygen ions migrate through the electrolyte, leaving a deficiency of electrons in the cathode. At the anode, the ions react with the fuel gases to form water vapor and carbon dioxide. As these reactions occur, the ions relinquish their extra electrons, creating a surplus of electrons at the anode. If the two electrodes are connected through a load, electrons flow from the anode, through the load, to the cathode and thus produce useful electricity.

For oxygen regeneration, the input gases (water vapor and carbon dioxide) are fed to the cathode of the electrolysis cell. Since the oxygen as contained in those compounds is at a relatively low energy level, electrons are provided from a dc power source to dissociate the



The oxygen-regeneration electrolysis cell is similar in construction to a solid electrolyte fuel cell, each consisting essentially of a solid electrolyte between two porous electrodes. The cells are opposites in function, however, as the fuel cell (*a*) reacts fuel gases with oxygen to produce electric power, while the electrolysis cell (*b*) consumes electric power to produce oxygen from the input gases. For the fuel cell, hydrogen and carbon monoxide are the fuels used in this comparison to illustrate the reverse nature of the two processes. For the electrolyis cell, water and carbon dioxide from the breath are the inputs, and oxygen is the desired output.



***Photo*—Series-connected stacks of solid-electrolyte cells are the main elements in the oxygen regeneration system. Each tubular cell fits into the adjacent cell for electrical interconnection and also to provide a channel for gas flow. As many as 8 stacks of 20 cells each might be used in the electrolysis battery of a regeneration system.**

carbon dioxide and water vapor into carbon monoxide and hydrogen, producing high-energy oxygen ions in both reactions. The heated electrolyte again allows passage of oxygen ions only; as the ions flow into the anode, they give up their extra electrons and combine to emerge as oxygen molecules.

Electrolysis batteries consist of several stacks of interconnected cells. (See photograph.) Water and carbon dioxide flow around the outside of the hollow stacks and react on the outer walls (cathode), and the oxygen produced emerges from the inner walls (anode).

The system being developed at the Research Laboratories first concentrates carbon dioxide and water from the cabin atmosphere and then passes them to the electrolysis battery, where the chemical reactions take place. The hydrogen formed is drawn from the battery by vacuum through palladium membranes, which allow it to pass while blocking other gases. The other by-product, carbon monoxide, is broken down chemically to carbon.

About 1.7 volts at 159 amperes is required to sustain a reaction rate in the battery that produces 2 pounds of oxygen a day, the approximate amount needed for human respiration. A system presently being designed to regenerate oxygen for four men on a 100-day space mission will weigh about 120 pounds and require about 1200 watts of power for continuous operation.

The solid-electrolyte system was chosen by Westinghouse for spacecraft development for several reasons. It can decompose both water and carbon dioxide into oxygen that requires no further purification, and it can deliver the oxygen at almost any desired temperature and pressure. The batteries are light and compact, and their power requirements are relatively small. As the electrolyte is a stable solid and the reactants are gases, the lack of gravitation in space will have no effect on the process. Since the construction is basically the same as that of a fuel cell, with a few adjustments the electrolysis battery could be operated as a fuel cell for emergency power.

Thin-film cells are being investigated as a way of improving battery performance. They have cathode, electrolyte, and anode layers in a paper-thin band wound around a support tube. One tube supports many such bands for effective series interconnection. Since the electrolyte layer is only 0.0004 to 0.0016 inch thick, compared with about 0.015 inch in the conventional cell, electrical resistance is significantly reduced; that factor could lower battery weight, decrease power requirements, and lower the operating temperature. Although thin-film cells have been built successfully, considerable development work is still required to incorporate them into a practical oxygen regeneration battery.

Products for Industry

Adjustable-speed dc drive with controlled regeneration for reversing applications is a solid-state unit assembled in a standardized package. Ratings are from 5 to 40 horsepower, suiting it for machine tools, paper winders, dyeing machines, test stands, and other applications requiring controlled regeneration. Standard option kits add special features such as jog, tester panel, dynamic braking, and field control; special options are available to customize the unit. The Regenerative 22-1000 Thyristor Drive has a three-phase half-wave double-converter power supply with six SCR's, three for each direction. Controlled regeneration gives control in all four quadrants of the motor speed/torque characteristic; it provides controlled stops for accurate positioning, and fast reversals for such machine operations as tapping. *Westinghouse Industrial Systems Division, 4454 Genesee Street, Box 225, Buffalo, New York 14240.*

Mini-Degreaser

Mini-Degreaser is a compact ultrasonic vapor degreaser that uses chlorinated solvents for quick and thorough cleaning of small parts. A 750-watt heater with automatic thermostatic control produces the vapor zone above a 1.5-gallon tank, and a solid-state 200- or 300-watt Magnatrak ultrasonic generator feeds the Magnapak magnetostrictive transducer. The entire cleaning unit measures 17 by 13 by 25 inches high. A recirculating and filter system for removing particulate matter in the ultrasonic sump is optional. *Westinghouse Industrial Equipment Division, Box 300, Route 32, Sykesville, Maryland 21784.*

Silicon-carbide thermistor is a p-n junction device that has an exponential decrease in impedance as temperature increases. It can sense temperature changes from cryogenic to maximum operating level of 1000 degrees C with extreme accuracy. The thermistor can be used with leads for conventional installation or with sliprings for installation on rotating equipment. *Westinghouse Astronuclear Laboratory, P.O. Box 10864, Pittsburgh, Pennsylvania 15236.*

New Literature

Guide to Outdoor Lighting Design is a 70-page booklet (B-9684) giving basic design criteria for most outdoor lighting. Part one deals with standard applications, illustrates each, and presents tables of recommended equipment for the desired illumination. Part two lists and illustrates types of equipment, with individual specifications and applications. There is also a section describing floodlight design. *Westinghouse Outdoor Lighting Department, P.O. Drawer 5817, Cleveland, Ohio 44101.*

About the Authors

Richard E. Kane graduated from the University of Wyoming with a BSEE degree in 1950. He came to Westinghouse in 1951 to work in the Switchgear Division on air-blast circuit breakers. After several positions there, he moved in 1964 to the Special Development Section of the Power Circuit Breaker Division and later that year became Supervisory Engineer. In 1968, Kane assumed his present position of Manager, Special Products Development Section. His main contributions have been in development of compressed-air, SF_6, and SFV circuit breakers.

Charles F. Cromer received a BSEE from Missouri School of Mines in 1949 and an MSEE in 1951. He joined Westinghouse on the graduate student training program in 1951 and worked in the Power Apparatus group on development of rectifiers, lightning arresters, switchgear, and power circuit breakers. Cromer has recently been made a Fellow Engineer at the PCB Division, and his major responsibilities have been design, development, and testing of interrupters for oil, air-blast, EHV SF_6, and SFV circuit breakers.

William H. Fischer received a BSME in 1950 and an MSME in 1958 from the University of Pittsburgh. His first assignment after joining Westinghouse on the graduate student training program in 1951 was in the Materials Engineering Department. Fischer's subsequent responsibilities have been in the Power Circuit Breaker Division in development of mechanical and electrical systems for advanced circuit interrupters using air, SF_6, and vacuum techniques. He currently heads an engineering team in the Special Products Development Section for the development of 115-kV through 230-kV SFV circuit breakers.

Zeno Neri received a BSEE in 1947 from West Virginia University and an MSEE from the University of Pittsburgh in 1951. He joined the Switchgear Division of Westinghouse in 1947 to work on the design and application of capacitors, potential devices, and line traps. Neri transferred to the Power Circuit Breaker Division in 1958, and is presently a Fellow Engineer, Special Products Development Section, specializing in insulation systems and high-voltage testing.

John L. Patrick earned his BSEE degree at Wayne State University in 1958. He joined the Chrysler Corporation Missile Division as a quality control engineer, and the following year he moved to the Bendix Industrial Controls Division to work in design, development, and application of machine-tool controls.

Patrick joined Westinghouse at the Defense and Space Center, Aerospace Division, in 1963. There he helped develop drafting, electronic packaging, and manufacturing techniques. Patrick transferred to the Industrial Systems Division in 1965 as Engineering Manager, Numerical Control Product Group; in 1968, he was made Manager of that group. He directed development of the control system described in his article.

Joseph E. Moxie graduated from Brown University in 1946 with a BSEE degree, and he has since done graduate work at the University of Pittsburgh. He joined Westinghouse on the graduate student training program and went to work in the Transportation Engineering motor design section, where he contributed to the development of high-performance high-speed traction motors, auxiliary rotating machines, and epoxy insulation systems. He was appointed manager of the section in 1961.

Moxie was made Project Engineer in the Transportation Division for the Northeast Corridor Metroliner propulsion and control system in 1966, and Project Manager the following year. Since then he has served as Project Manager for the propulsion and control systems for the New Jersey State Highway Department's Jersey Arrows, the new MBTA (Boston) rapid-transit cars, and the Bay Area Rapid Transit cars. He became Manager, Traction Projects, in 1969.

B. J. Krings joined Westinghouse on the graduate student training program after graduating from Penn State University in 1942 with a BSEE degree. His first work assignment was in design and development of transportation control. In 1954, he moved to the Bettis Atomic Power Laboratory as an apparatus engineer in nuclear plant instrumentation and control.

Krings transferred to the Plant Apparatus Department in 1959 as Supervisory Engineer of a group working on nuclear instrumentation and steam-generator water level control. He then moved to the Research Laboratories to work in the Electric Power Systems group, mainly on development of thyristor circuits for elevators. Krings has been in the Transportation Division since 1965. His first responsibility there was design and development of the propulsion and dynamic-braking equipment for the Metroliner rail cars. He is now Systems Engineer for the BART project.

Frank C. Rushing came to Westinghouse in 1928 on the graduate student program from the University of Texas with a BSME. He attended the mechanical design school and obtained his MSME degree from the University of Pittsburgh. After a year of industrial motor design, he was awarded the Lamme Memorial Scholarship in 1931 and given a leave of absence to study electric machine design at Techniche Hochscule zu Charlottenburg, Germany.

Rushing returned to the Westinghouse Research Laboratories to work on specialized machine design and development. Among his accomplishments were high-speed motors for the unbalanced rotors used in rayon spinning, dynamic balancing machines, and vibration instruments. He led the development of an ultra-high-speed centrifuge for uranium isotope separation. In 1945, Rushing was appointed Engineering Manager of the Motor Division.

Rushing was asked to join the Defense and Space Center in 1964 to put his talent for machine design and development to work on the increasingly complex mechanical and electromechanical problems of defense and space equipment. He has led or assisted with such varied developments as satellite attitude control by gravity gradient, nutators for electro-optical rocket guidance and radar antennas, motors for underseas and deep space, electronic countermeasures, scanners for satellites, gimbaled optics, and large space-erectable antennas and reflectors.

William F. Brown is a Senior Engineer at the Electronic Systems Division (formerly the Aerospace Division). He graduated from Johns Hopkins University in 1956 with a BSME degree, and he joined Westinghouse in 1963 to work in the mechanical design and development department of the Aerospace Division. Before coming to Westinghouse, Brown had worked for Bendix Corporation and the Glenn L. Martin Company. Major programs Brown has worked on at Westinghouse include the Gemini SSE (Special Support Equipment), the AWG-10 selector test programmer, and the Digital AWG-10 program (now known as the AWG-14). He was the lead mechanical engineer on the latter two.

Neville E. Jacobs was born in Argentina but went to high school in England and later attended Jesus College, Oxford University, where he graduated with a BA degree in engineering in 1954. He joined S.I.A.M. di Tella Ltda., a Westinghouse licensee in Argentina, to work as chief of the refrigeration development laboratory and then in quality control management. He also received his MA degree in engineering. In 1962, he left the company for private consulting in market research and acoustics.

Jacobs joined Westinghouse in 1963 as a manufacturing engineer in the Industrial Systems Division. He was made Superintendent of Quality Control in 1965, and in 1966 he started planning the RIFCA test system. Jacobs is now Manager, Quality Control and Test. He has quality-control responsibility for all the Division's products, and he also is responsible for design and maintenance of its test equipment as well as for maintenance and calibration of all instruments used throughout the Westinghouse Buffalo location.

Westinghouse ENGINEER
Westinghouse Electric Corporation
Westinghouse Building
Gateway Center
Pittsburgh, Pennsylvania 15222

Address Correction Requested
Return Postage Guaranteed

Launch tube for Poseidon missile. (Information on contents page.)