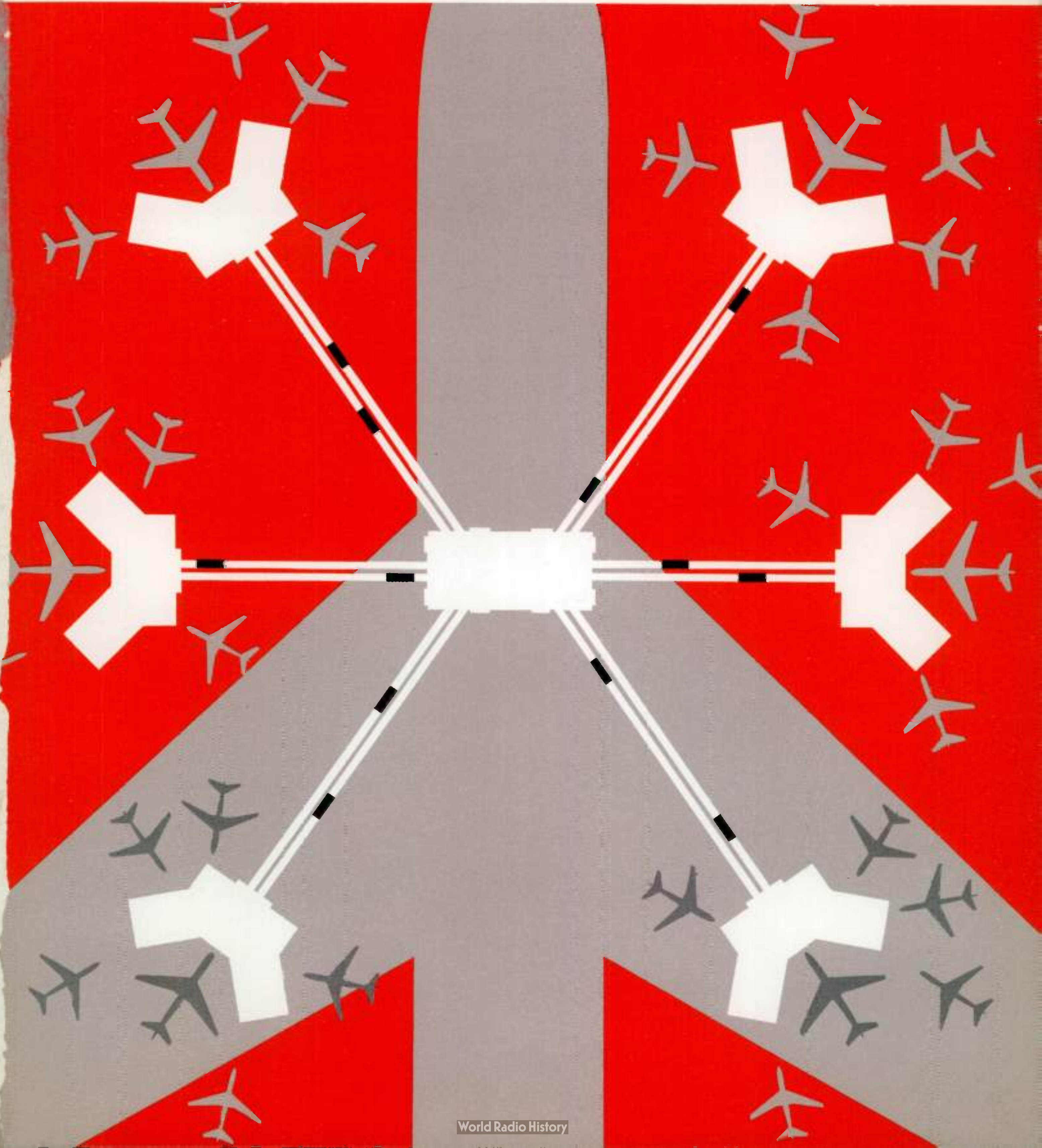
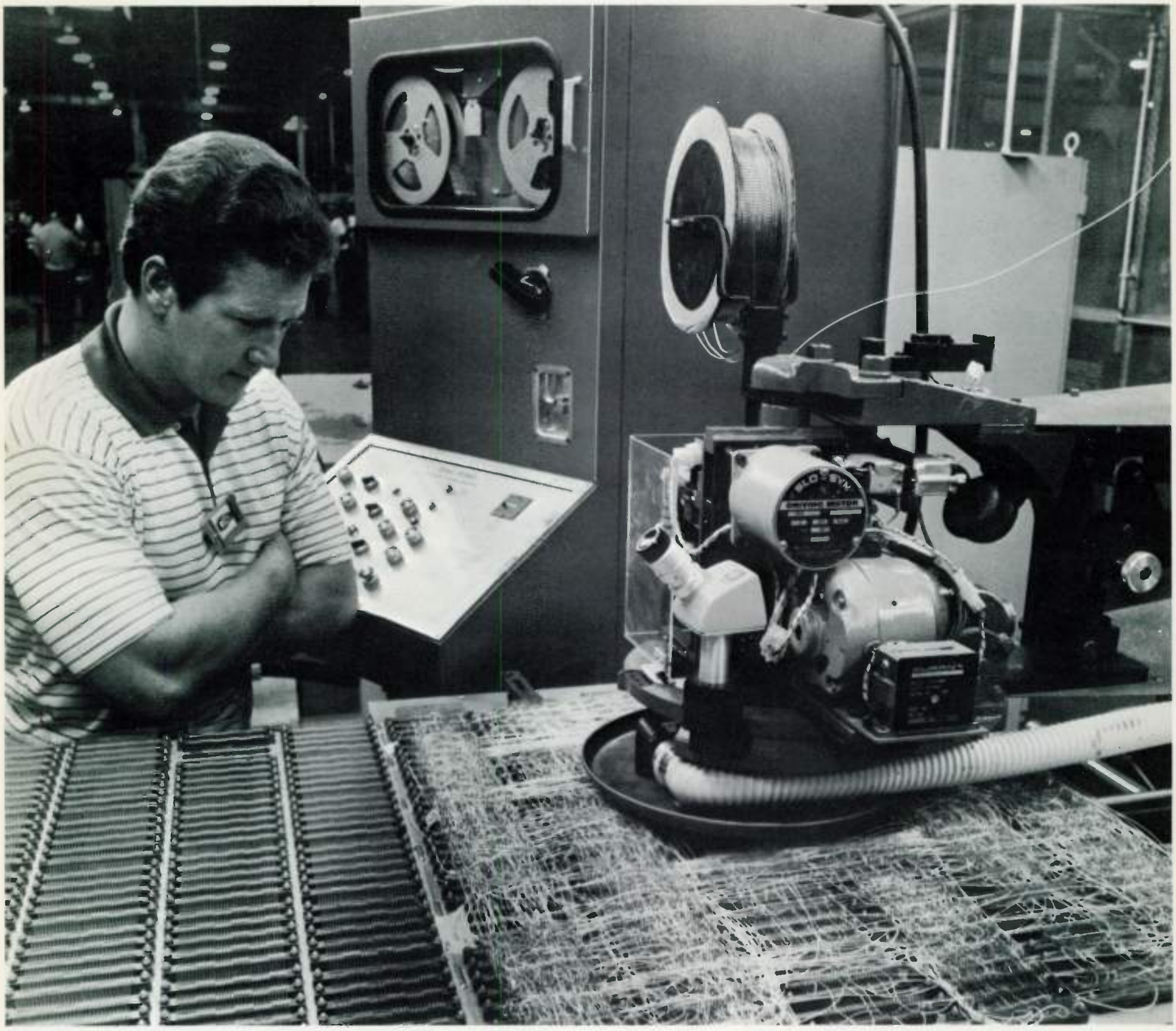
Westinghouse ENGINEER

January 1969





This tape-controlled wiring machine makes possible electronic panels with wiring density and complexity impossible to produce by hand. Such density in circuitry and wiring is increasingly important as one way of achieving compactness and light weight in complex electronic equipment.

The panel being wired here, for example, is part of a ground-based tactical radar system that has strict size and weight limits because it must be transportable by helicopter and truck. The panel has more than 200 circuit cards with thousands of integrated circuits and other electronic components, and thus thousands of individual wires and connections. In hand wiring such a sophisticated panel (and to an extent even in semiautomatic wiring), the error rate would reach a point where the panel simply could not be wired.

The machine, however, can wire such a panel in a matter of hours, controlled completely by a punched tape. Although it is a manufacturing tool, the wiring machine is also linked to the design engineering of the radar system through the tape: the tape is generated by computer-aided design techniques used by the Radar Systems Department at the Surface Division of the Westinghouse Defense and Space Center.

Westinghouse ENGINEER
January 1969, Volume 29, Number 1

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

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

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

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Cover design: The Landside/Airside building arrangement in the new passenger terminal at Tampa International Airport provides the pattern for artist Tom Ruddy's cover design. An article describing the passenger transfer system that makes the arrangement feasible, and eliminates the usual long walk for passengers, begins on page 9.

Integrated Process Control Rolls Steel More Efficiently

John W. Wallace

Glowing steel is about to enter the seven finishing stands of the new hot strip mill at Armco Steel Corporation's Middletown Works. It will come out the other end as a thin strip almost a mile long and traveling at nearly 40 miles an hour.

A new automation concept combines advanced computers with integration of control functions for more efficient and more effective control of modern rolling mills.

Today's continuous hot strip mills are vastly more complex and thus more costly than their recent predecessors, mainly because the steel industry's customers demand rolled products of ever higher quality and ever greater consistency in quality. And the industry has to fill that demand for consistent top-quality strip while meeting foreign and domestic competition, in which fractional differences in production costs can mean the difference between profit or loss and between gain or loss of business.

Economic realities, then, demand maximum return on the large investment in a modern hot strip mill. To achieve that end, management must make maximum use of the most modern automation systems.

John W. Wallace is Projects Manager, Rolling Mill Systems Group, Metals Industry Systems Department, Industrial Systems Division, Westinghouse Electric Corporation, Buffalo, New York.

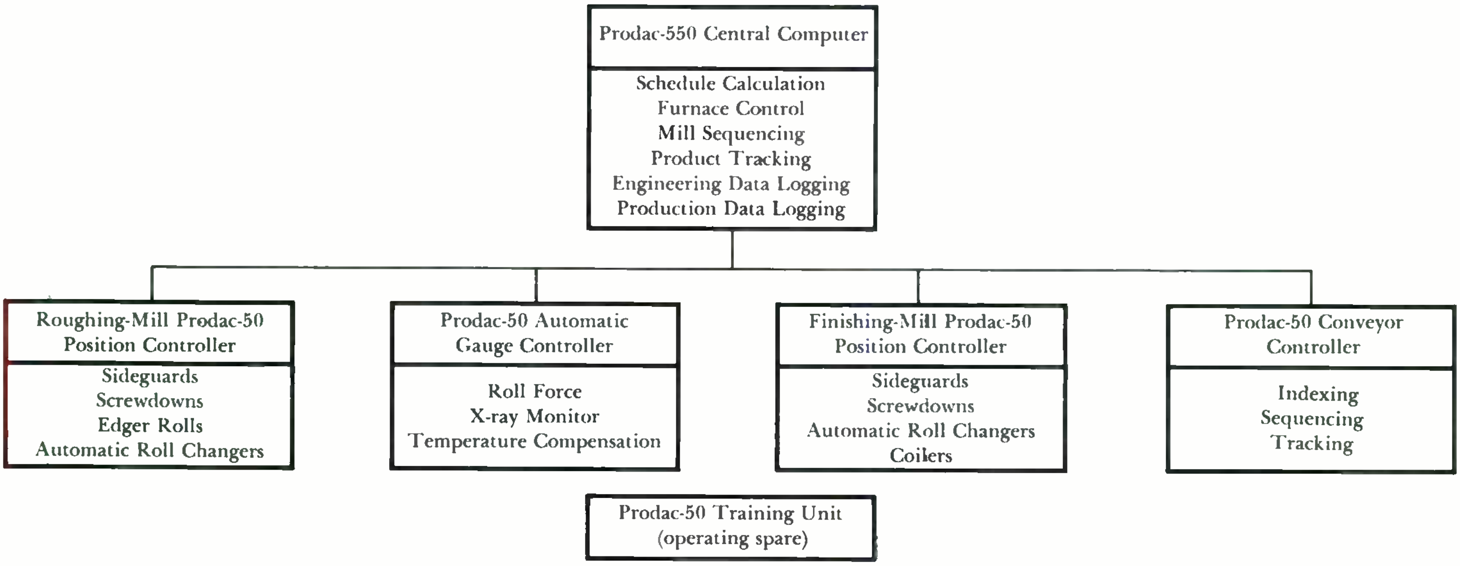
One of the most capable systems available today is integrated process control (IPC), a system that combines use of the most advanced engineering design concepts with integration of control functions into a homogeneous grouping at the control pulpit. IPC assists in making a higher quality product faster at maximum (but safe) utilization of the power equipment, automatically resulting in higher efficiency, lower operating costs, and minimum abuse to the mill. It also minimizes installation and startup costs and provides maximum versatility and flexibility.

The 86-inch hot strip mill recently started up by Armco Steel Corporation at Middletown, Ohio, illustrates the IPC concepts and capabilities. (See *Armco 86-Inch Hot Strip Mill*, page 5.) Its control system includes a Prodac-550 central control computer that calculates the data required to set up and operate the mill for each product order; the central computer then feeds the data to four smaller Prodac-50 subordinate control computers that set the mill drives accordingly (Fig. 1). The system controls the mill as a single entity beginning where slabs are placed on the furnace loading tables and ending after the completed coils arrive at the end of the coil conveyor system for shipment or storage.

Integrated Process Control

The nerve centers of any sophisticated hot strip mill control system are the control pulpits. In the IPC system for the Armco mill, the Prodac-50 controllers and associated centralized logic are combined within pulpit structures in close association with the operator stations there to provide a centralized logic and control system (Fig. 2). Sensing devices are located along the mill as required, and the central computer is in a computer office. Only the power and drive equipments are located in the motor room. All signal intelligence inputs and outputs operate into the centralized logic system, rather than into the conventional complex interconnecting network of interdependent control systems with its unnecessary duplication of functions and wiring.

IPC places management in much closer control of the entire operation than was previously possible, since management maintains the stored computer programs. And since the system automatically handles many of the functions previously



1—Integrated process control system for the new Armco hot strip mill operates the mill as a single entity, from slab heating furnaces to finished coil storage. Its Prodac-550 central computer calculates operating data to suit each product order. It sends the data to the four subordinate Prodac-50 controllers, which set the mill drives accordingly. A fifth Prodac-50 controller serves as a training unit.

performed manually, it allows fuller utilization of human capabilities and enables the operators to direct their attention to making high quality strip.

The system also provides accurate and up-to-date production information, and it continually monitors its own performance and can record various engineering data. Such information is useful as bases for innovations that further improve quality and performance.

Moreover, the IPC system operates the mill in a smooth, rhythmic, nonabusive manner, thus reducing maintenance and downtime and resulting directly in lower operating costs. Avoiding mechanical abuse of the mill also improves product quality by helping maintain the mill in the best possible condition.

Finally, the production capability of a mill with IPC can be expected to increase, for two main reasons. First, the main computer has the ability to determine rolling schedules that can roll the strip in the minimum time. Second, the system maintains that maximum performance continuously, thus utilizing the large investment effectively.

All of those factors help management achieve its goal of consistently producing the highest quality strip at the lowest possible cost.

Central Computer System

The Prodac-550 central computer system provides complete centralized automatic control of the process. That control includes integrated mill scheduling and automatic calculation and control of rolling schedules (in both roughing and finishing stands) to insure minimum peak horsepower demand, good rolling practice consistent with mill and drive capabilities, and control of gauge and width.

The automatic systems and programs provided include furnace charging, furnace temperature control, roughing mill setup and sequencing, finishing mill setup and sequencing, crop shear control, roughing mill and finishing mill schedule calculation, mill start (dry run of system), production data logging, engineering data logging, mill pacing, runout table spray control, runout table sequencing and slowdown, coiler control, manual intervention logging, mill fault logging, and determination of cause of delay.

The Prodac-550 process control computer is a high-speed solid-state digital machine specifically designed for effective on-line handling of perishable real-time data, urgent control activities, several concurrent programs, and off-line computations. It accomplishes those tasks in the proper order or priority and without complicating the programming of an individual function. The computer's speed and general organization suit it to process control applications, where decisions are based on data originating simultaneously at separate remote points and where control signals must be sent to various devices to control overall system operation.

Priority interrupt is provided by assigning priority levels to groups of programs. It permits concurrent processing of various unrelated real-time data, control of subsystems, and off-line scientific and data-processing computations. Priority interrupt is especially useful where programs of differing degrees of real-time importance are concurrently processed; programs requiring little real time, such as scientific or other off-line programs, are automatically interrupted to permit processing of control programs when required. Thus, priority interrupt allows full use of the computational capabilities of the computer by permitting common use by different functions without the possibility of interference.

The Prodac-550 computer system consists of a central processor and peripheral equipment connected by input-output channels. The input-output channels also can be used for intercomputer communication, allowing the machine to communicate directly with one or more other computers.

The input-output system can send information directly into, or take it directly out of, the core memory without interfering with the running program. The very fast core memory (two-microsecond cycle time) is time shared with the various channels and the arithmetic section. That arrangement allows many operations to be carried out concurrently and without interference; it is the key to the extreme power of the Prodac-550 systems in process control.

The computer's logic circuitry is modular, consisting of high-speed diode-coupled transistor NAND circuits mounted on plug-in cards. Wrapped-connection backpanel wiring provides trouble-free interconnection between the blocks into which the logic cards are plugged. Use of such modular logic, together with the small number of different card types, simplifies maintenance procedures and reduces the spare-parts stock required.

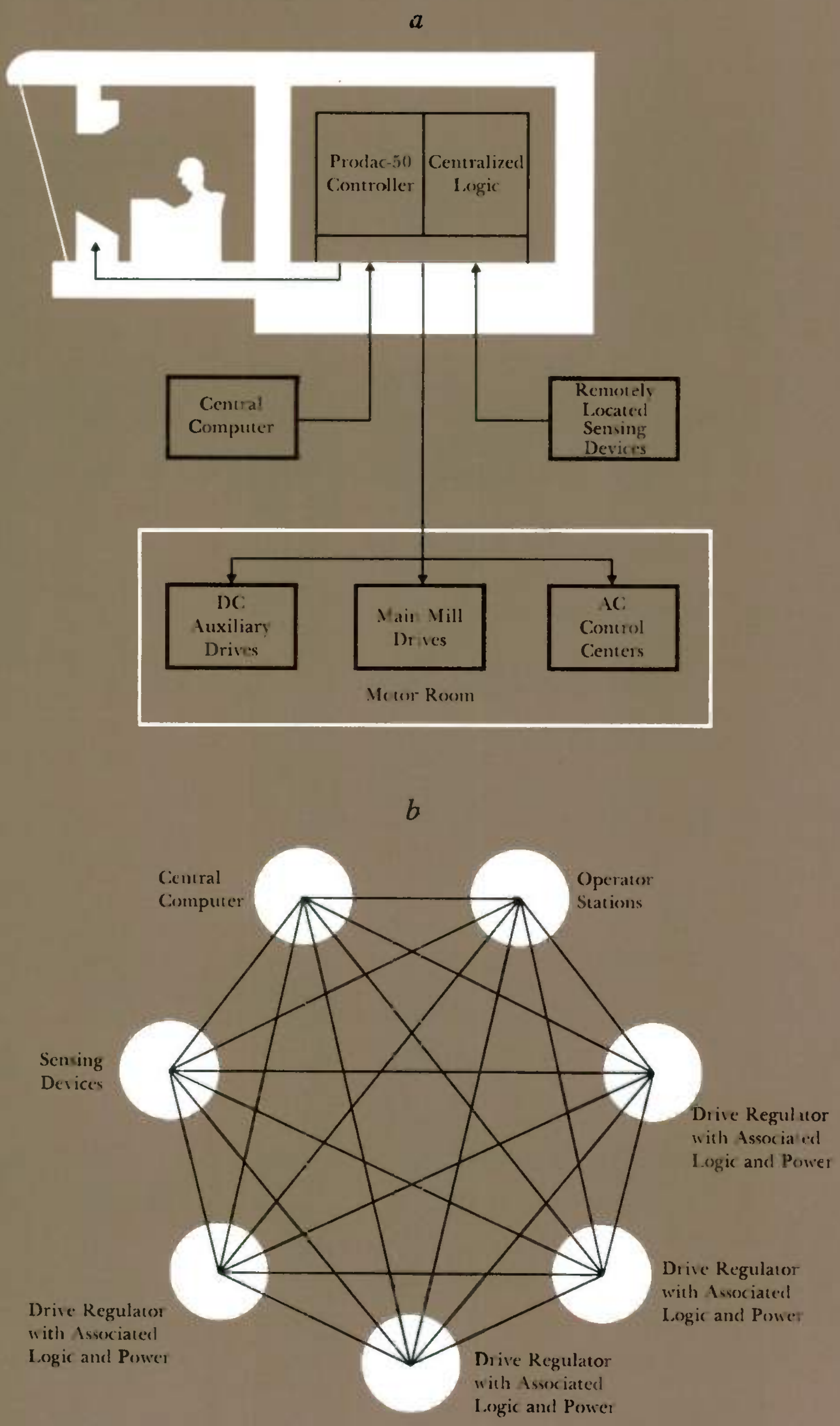
Subordinate Computer Systems

The Prodac-50 computer system was developed specifically for use as an industrial process controller, so a major design criterion was reliability. A controller must be "there" all the time, operating properly, or the process is down. And downtime in a hot strip mill may cost several thousand dollars a minute.

One of the key factors in the Prodac-50 system's proven reliability is a time-sharing mode of operation: using a single piece of hardware for multiple functions decreases the number of components and inherently tends to improve reliability. Another factor is the use of large circuit cards containing all register circuits associated with a single information bit, a design that lends itself to fast trouble isolation and correction.

Position Controllers—One of the first applications of the Prodac-50 computer control system was as an accurate position controller for the large number of position-controlled drives in hot strip mills. For the new Armco mill, two Prodac-50 units provide for 56 such drives. Each position-regulator channel positions its drive accurately on a command from a central-computer reference or from schedule-presetting dial switches at various operator stations. The position regulators also can be bypassed and the drives operated on direct manual control.

Time sharing enables each Prodac-50 position controller to control the position of as many as 20 mill drives simultaneously. The control system consists of the Prodac-50 main frame; input-output equipment for communication between



2—(*a*) The integrated process control system derives its name from the close physical and electrical relationship of each Prodac-50 controller with its associated centralized logic and with the operator station for that part of the mill. The arrangement eliminates much of the duplication of functions and complex wiring in the conventional manner of interconnecting interdependent control systems (*b*).

Armco 86-Inch Hot Strip Mill

The new mill recently started up at Middletown, Ohio, is the most powerful entirely static-powered mill in operation. Armco's initial production objective for the facility is more than three million ingot tons a year, and design capacity is more than twice that figure. To achieve such capacity, the mill rolls giant slabs through 13 main stands at speeds up to 40 miles an hour.

The mill's six roughing stands are driven by ac motors, and its seven finishing stands by double-armature dc machines. All individual table roll drives have permanent-magnet motors.

Spacious operator pulpits, all air conditioned, provide comfortable operating stations with maximum visibility of the process. Rooms for computer and centralized-logic control are located adjacent to the pulpits, unifying control locations for ease of adjustment and maintenance. Uniformity in all static-powered drives simplifies testing and maintenance.

Sensing devices for process automation include two X-ray thickness gauges, three width gauges, seven radiation pyrometers, 13 sets of load cells, 46 hot-metal detectors, and 58 cold-metal detectors.

This is the first mill with complete automatic gauge control by digital computer. The mill was operated under computer control from the very first coil.

Product Characteristics	*Min*	*Max*
Entering Slabs		
Thickness (in.)	5	10
Width (in.)	24	82
Length (ft.)	14	33
Weight (lb)	. .	88,000
Finished Coils		
Width (in.)	24	80
Gauge (in.)	0.050	0.500
Diameter (in. OD)	. .	78
Production Speed (ft/min)	1700	4000

Major Mill Components	*Horsepower*
Three Reheat Furnaces	. .
One Vertical Scalebreaker	1000
Six Roughing Mills	54,000
Five Vertical Edgers	4100
Seven Finishing Mills	73,000
Total Reduction Horsepower	132,100
Three Coilers	2250

the main frame and the positioned drive, the operator controls, and the central computer; an absolute position feedback encoder for each drive (mounted remotely from the mill); and input devices and displays in the operator stations.

Position feedback is absolute position from a rotary shaft encoder driven through a gear train by a selsyn receiver (Fig. 3). The receiver is driven from a selsyn transmitter coupled to the drive motor or mill part. The receiver-encoder assembly is supplied in a package, with several units in a single cabinet, as part of the Prodac-50 controller.

The Prodac-50 controller stores in memory the desired position reference for each drive. That reference is taken from either the central computer or the schedule-presetting switches, depending on the position of a mode-selector switch. The command signal from the central computer on automatic control, or from the push button on preset control, activates a program that compares the reference and actual position stored in memory and produces an output to the positioning drive reference circuit to so position the mill part that feedback equals reference. As the drive approaches zero-error position, it is slowed on a programmed basis. Where required, provision is made to always approach zero error from the same direction to compensate for backlash in the mechanical equipment. When the drive is properly positioned, zero error is indicated by a light on the operator's station.

The slowdown curves can be self-generated and changed by new instructions. That capability was used during startup, after the performance of the analog drive system was verified, by automatically developing optimum slowdown curves for the various positioned drives. First, the drive was accelerated to maximum speed and then stopped under the desired current limit setting. The Prodac-50 controller obtained readings of position versus time and thereby developed the maximum capability slowdown curve of the actual drive and load system.

Automatic Gauge Control—Automatic gauge control (AGC) is a vernier control system added to the drive control system of the finishing mill to compensate for output gauge variation. The mill is initially set as near as can be predicted by the central computer to run a given schedule and produce the proper gauge. The AGC system then takes over, while the strip is being rolled, to monitor and correct for any initial gauge error as well as for errors occurring during rolling.

The basic AGC system is coordinated with the other mill drive systems and with the central computer to insure a smoothly functioning system. It also operates in conjunction with the constant-tension-regulating interstand loopers. It maintains absolute gauge, within the practicable limits, throughout the length of each strip by correcting for the effects of temperature rundown from head end to tail end of each entering hot bar and of more abrupt changes such as skid marks.

The new Armco hot strip mill has the first complete system of automatic gauge control by digital computer. Its Prodac-50 controller simultaneously provides screwdown gauge control to all seven stands of the finishing mill (Fig. 4). Both roll-force and X-ray gauge systems are provided as in previous more conventional systems.

The AGC system includes automatic screw reset control to return the screws to the preset position at the end of a coil. An automatic looper position regulating system establishes and maintains loopers at the proper height. Other system components include load cells for obtaining roll-force signals, and an X-ray thickness gauge mounted after stand 7 to signal deviation from the desired gauge.

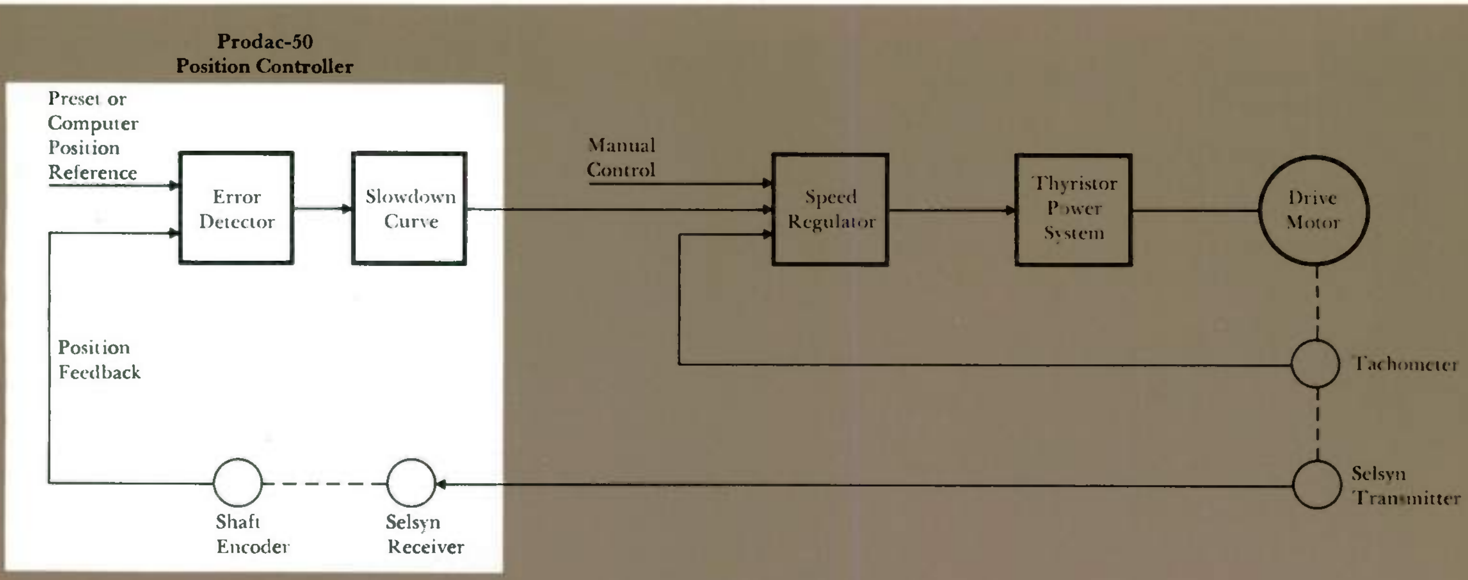
The AGC system includes two basic functions: the roll-force gauge control system on stands 1 through 7 corrects for gauge errors appearing at each stand, and the X-ray-gauge monitor system recalibrates the roll-force systems to bring the mill on gauge and hold it there. The functions are coordinated to perform the control action necessary for rolling on-gauge strip throughout the length of the coil. The AGC system can function independently of the central computer control, and it does not limit manual adjustments of mill drives.

The Prodac-50 AGC system has several programs, each with a unique function. A *scan program*, initiated as strip enters the mill, reads into the computer the various inputs used in the control system and repeatedly scans those signals while strip is in the mill. A *parameter program* supplies the various numerical constants required to determine the necessary control action. The *control program* actually provides the AGC control function, employing concepts used in conventional analog type AGC. It derives and provides the proper information for the *output program*, which then sends out the proper control signals to the various mill drives involved in AGC—screwdowns, loopers, and stand drive speed controls.

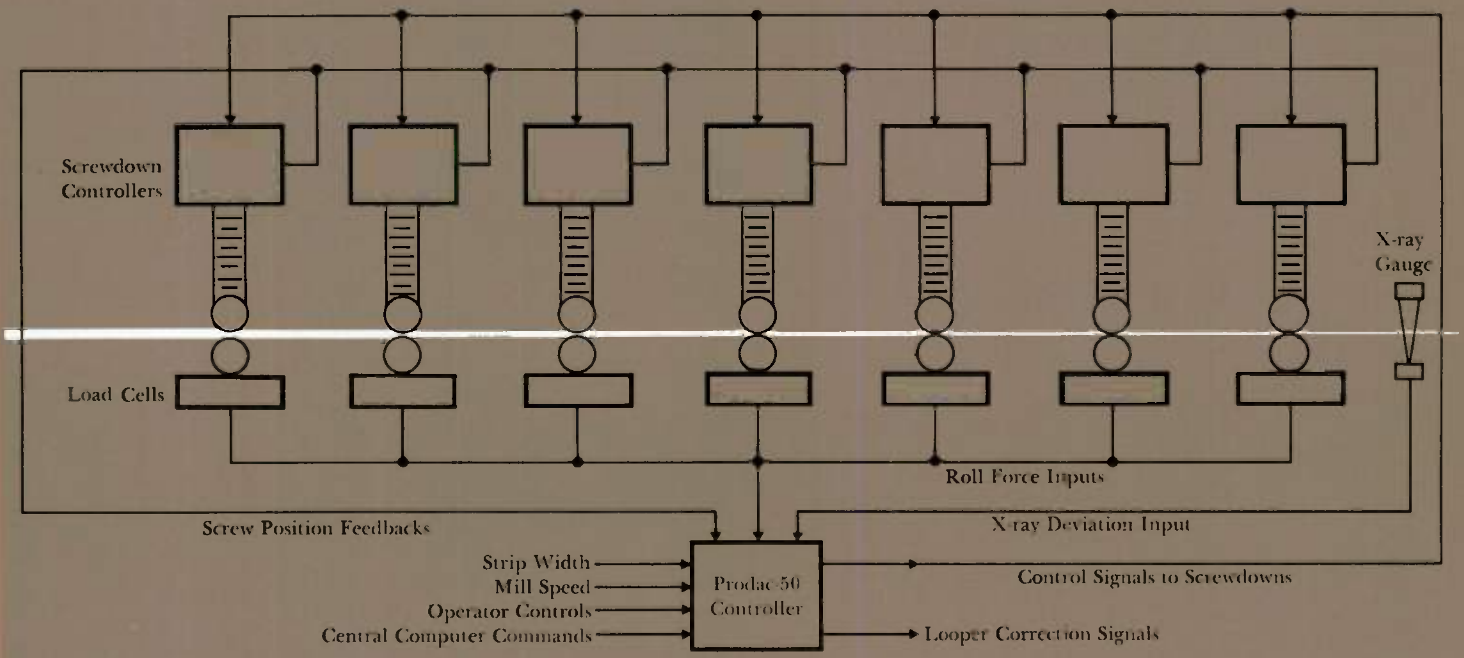
Conveyor Controller—An automatic conveyor system removes the coils of finished strip delivered by three coilers at the end of the finishing mill. It transfers the coils to storage or shipping locations.

A Prodac-50 industrial controller provides index positioning control of the conveyors and automatic sequencing and tracking of coils through the entire conveyor system. Pulse generators are coupled to the first three conveyors in the system (known as conveyors 1, 2, and 3) to synchronize the movements of those conveyors. Coils must be positioned accurately at the coiler end of the system, and the position maintained while transferring; when the coils reach the walking-beam transfer device some 200 feet down the line, they must still be centered to within half an inch to insure that they will not fall off the beam when some are shifted to a runout conveyor. Changes in chain and sprocket pitch caused by wear are easily compensated for by entering a new reference constant into the controller program.

Coils are always kept in the order in which they were removed from the coilers. Conveyors 1 and 2 are run in such a manner that the coil's position is accurately retained in the transfer from one to the other. The coil is transferred to conveyor 3 at the proper time so that its position is again accurately retained. As that conveyor is indexed, coils are accurately spaced as required for removal by the walking-beam transfer.



3—Typical position-controlled drive system is controlled by a position regulator channel in one of the Prodac-50 controllers. The position command can come either from the central computer or from schedule-presetting operator switches. Through time sharing, each controller can provide as many as 20 position regulator channels. Position feedback is through a rotary shaft encoder.



4—Automatic gauge control is a vernier control system added to the finishing-mill drive control system to compensate for strip gauge variation. The variations are sensed by load cells that monitor roll forces at each stand and by an X-ray thickness gauge at the output end. Signals from those sensing devices enable the Prodac-50 controller to calculate new instructions for the screwdown controllers to vary roll separation at each stand as required to keep gauge within tolerances for the entire length of the strip.

The coils are banded and weighed as they travel on conveyor 3, and then they are delivered to one of two runout conveyors. The runout conveyors are sequenced as slave conveyors to conveyor 3, so coil spacing is taken care of automatically. They operate on an indexing sequence until the leading edge of a coil actuates a sensor to stop the storage conveyor and cause a downender to downend the coil onto a storage conveyor that delivers it to the storage building.

Training Unit—A fifth Prodac-50 controller is installed in a training room that is part of the mill office complex. It contains a complete main frame and an assortment of peripheral hardware recommended as spare parts for the other Prodac-50 controllers. Armco programmers use it for classes conducted regularly for operating and maintenance personnel.

The training controller can also be used as a test unit by substituting modules and parts and testing them under operating conditions. The spare parts that make up the training unit are always being checked as the unit is used for training.

Conclusion

Integrated process control applied to the world's fastest and most powerful rolling mills provides the control capability required for maximum production and highest product uniformity in width, gauge, and metallurgical qualities. Such capability insures that these large mills become competitive immediately, and remain competitive, due to a higher degree of mill production capacity achieved earlier, reduction in managed costs per ton of steel produced, and higher mill production availability through reduced maintenance requirements.

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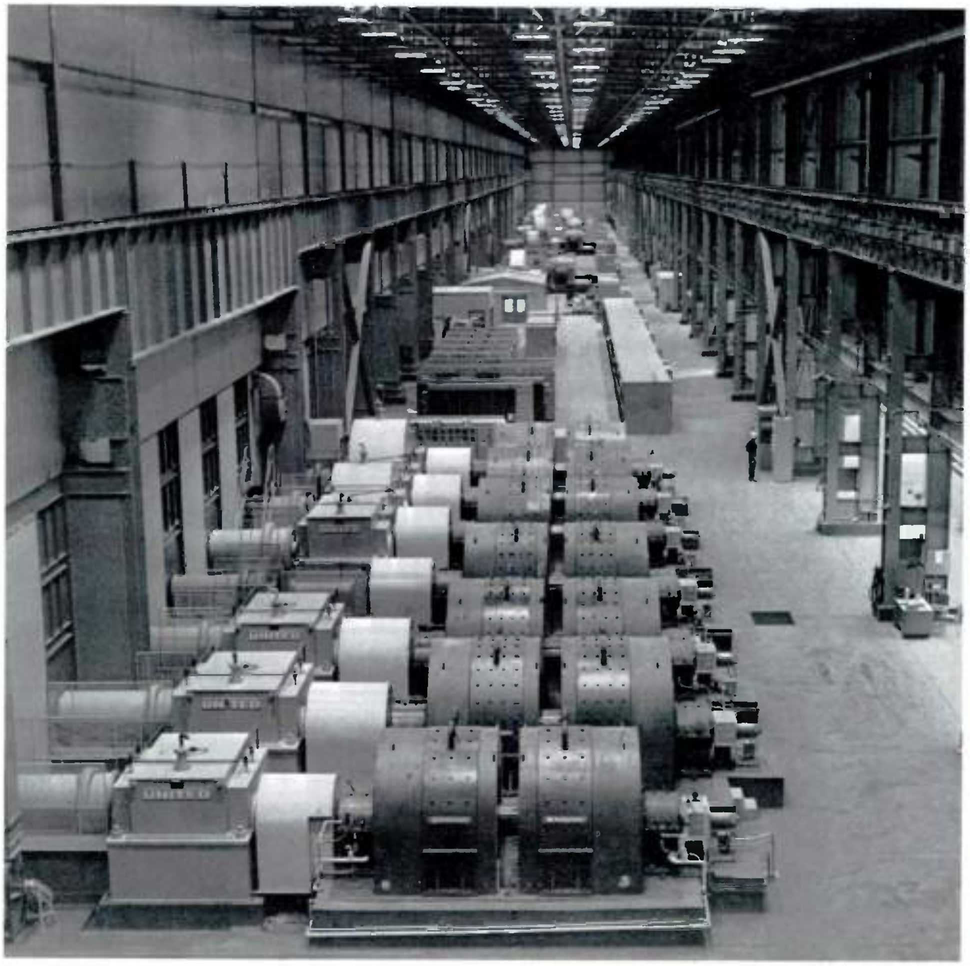


(*Top*)—Finishing-mill operator presides over the rolling operation in an air-conditioned pulpit. The mill operates on full computer control, but the operator can assume manual control whenever he wants to.

(*Bottom*)—Motor room houses the solid-state power control equipment and the 14 main drive motors for the rolling stands. Double-armature dc finishing-mill motors in the foreground are of two-bearing single-shaft design to provide a stiff drive.

Passenger Transfer System Will Take the Long Walk Out of Air Travel

E. E. Hogwood
R. B. Maguire

Automatic shuttle vehicles, running between the central air terminal building and outlying boarding and deplaning areas, will take much of the walking out of flying for people using the Tampa International Airport. Besides making travel more convenient, the system will improve traffic flow.

"Flight 670 is in the final boarding process at Gate 17. All aboard, please!" People who travel much by air often hear such an announcement while deplaning from a connecting flight at Gate 1 with perhaps a 2500-foot walk (or run) between it and Gate 17.

Most major airports have simply become or are becoming too large for convenient walking from automobile parking to passenger check-in to gates, or from one gate to another. To illustrate the problem, Table I shows walking distances for passengers within some major airports. And those distances are only from the terminal building entrance; they do not include the walk from the parking lot.

One reason for such expansion of airport terminals is the great growth of air travel, a growth that shows no sign of abating (Table II). The need to provide sufficient parking room for autos and planes; circulation space for taxis, limousines, and buses; and areas for baggage- and cargo-handling tend to make the air terminal ever larger and thus more inconvenient for passengers. Another reason is the growth in aircraft size (Table III). A DC-8, for example requires a lot of space, and even it will be dwarfed by some of the transports expected to be in use in a few years.

New Air Terminal Concept

The Hillsborough County (Florida) Aviation Authority started planning solutions to the problem of terminal sprawl in 1961 in anticipation of the need for a new terminal facility at the Tampa International Airport. The result is a plan for a terminal complex, to be opened late in 1970, that will include a new solution: the Landside/Airside concept and passenger transfer system described here.

The new design concept grew out of a study prepared by airport consultant Leigh Fisher. It is based on separation of such "Landside" functions as parking, baggage-handling, ticketing, and con-

*Table I. Walking Distances Within Some United States Airports (feet)**

Airport	Originating Passengers Minimum	Originating Passengers Maximum	Interline Passengers Maximum
Atlanta	630	1730	2680
Chicago O'Hare	580	1735	4720
Dallas Love Field	730	1650	1990
Dulles International	160	1170	1045
Los Angeles	836	1020	6640
Miami International	510	1120	3290
New York Kennedy	200	1130	7780
New York LaGuardia	455	1485	2525
Newark	530	1215	2015
Pittsburgh	296	720	1510
San Francisco	555	1300	3500
Tampa International (present)	210	1720	2710

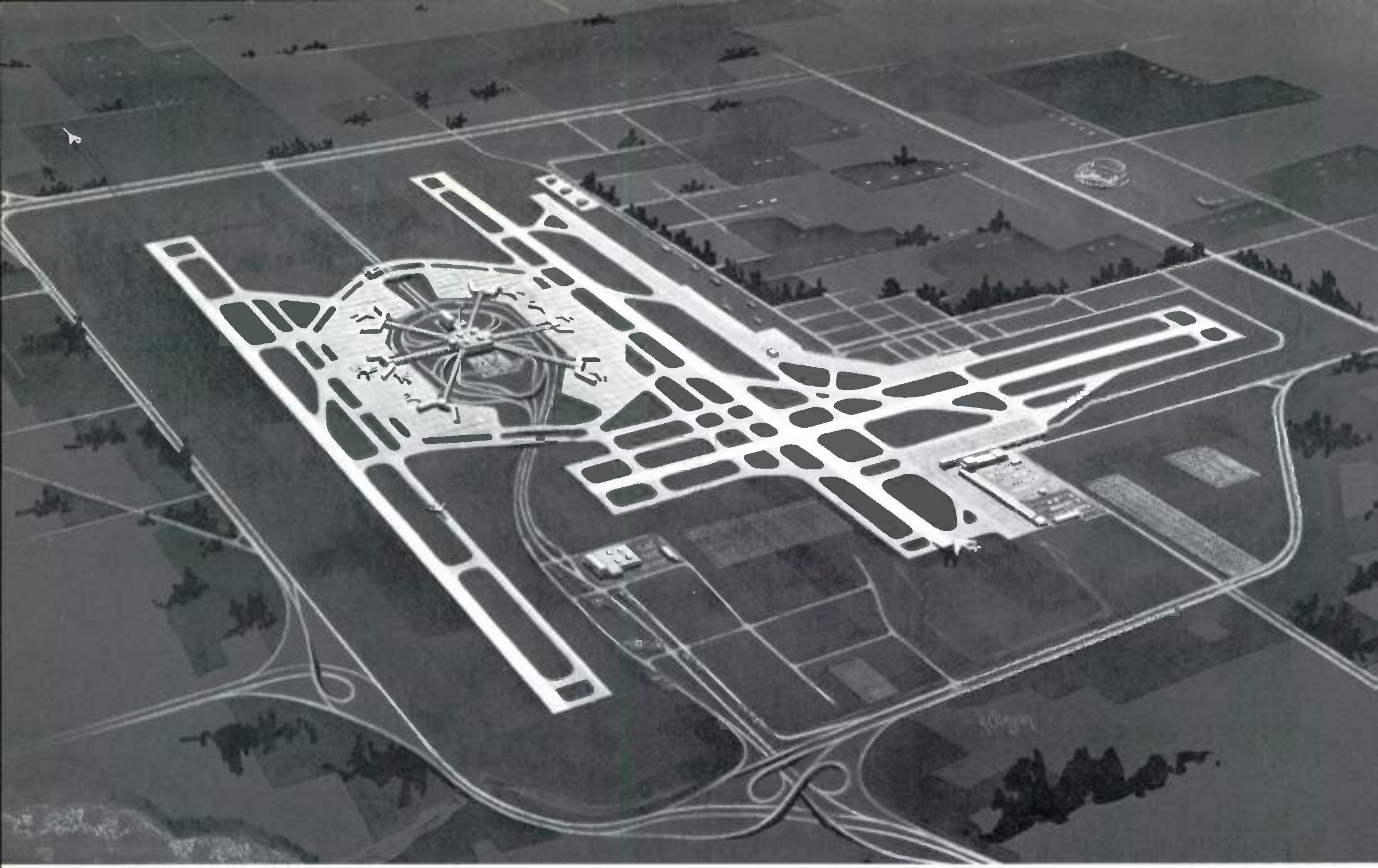
**Study of U.S. Airport Terminal Buildings as a Basis for Planning New Passenger Terminal Facilities at Tampa International Airport*, Leigh Fisher Associates, Inc., San Francisco, California, 1963.

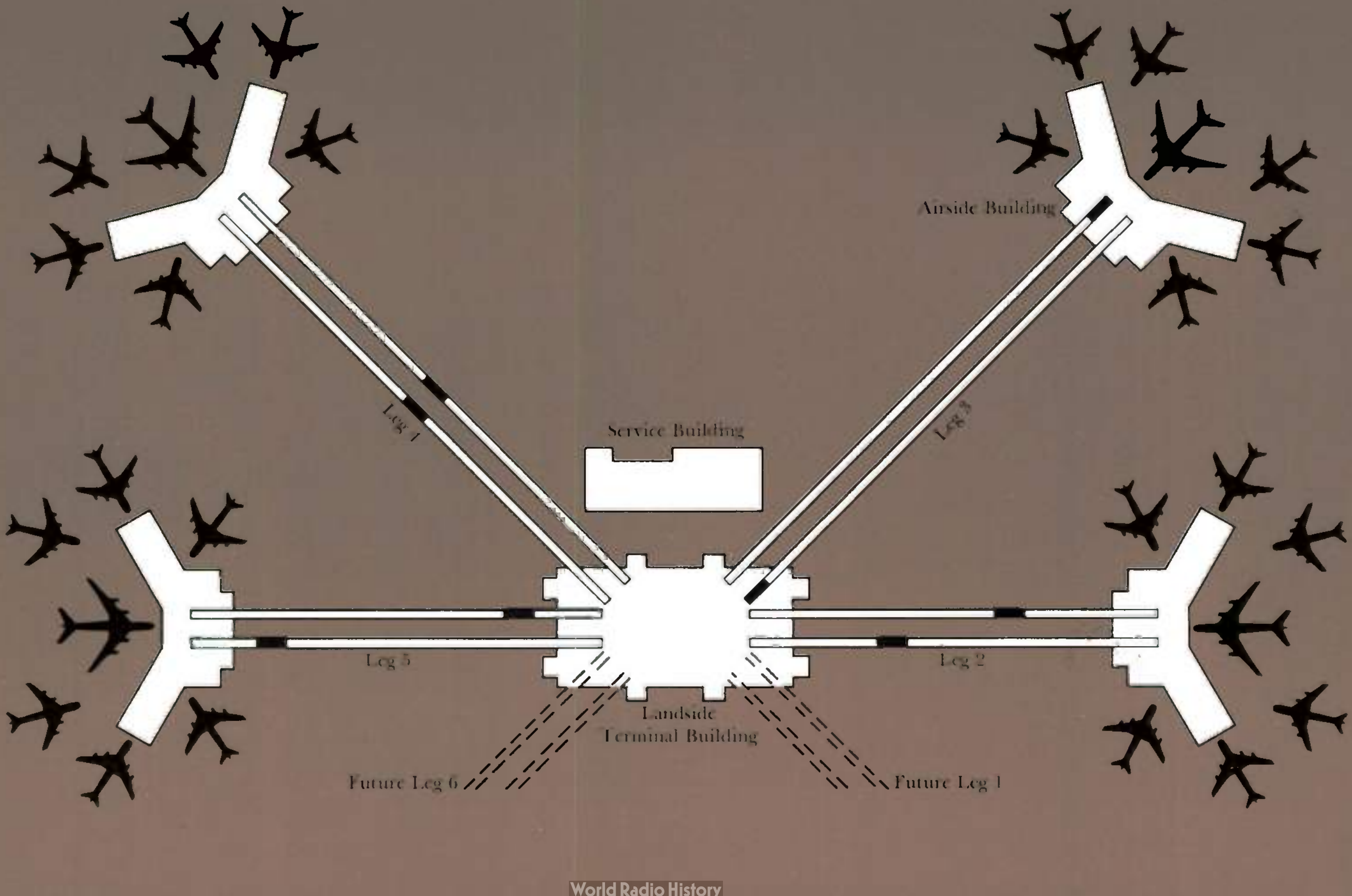
*Table II. Actual and Projected Activity for Some United States Airports**

Airport	Number of Passengers (thousands)** 1961	1965	1975	1980
Atlanta	1880	7110	23,800	40,000
Chicago O'Hare	9615	20,988	59,400	86,200
Dallas-Ft. Worth	3150	5942	19,368	33,000
Houston	2970	5200	15,200	26,400
Los Angeles	6947	12,579	57,500	63,600
Miami International	4116	6194	15,000	18,800
New York Kennedy	10,147	16,208	45,448	65,400
New York LaGuardia	3293	4750	21,000	32,600
Newark	2861	4868	14,000	19,600
Philadelphia	2180	3670	12,400	18,200
Pittsburgh	2260	3560	7859	10,240
San Francisco	5200	9800	31,600	44,200
Seattle-Tacoma	1620	2338	8400	14,200
Tampa International	987	1816	5500	8800

*Based on ATA Reports and *Aviation Demand and Airport Facility Requirement Forecasts for Large Air Transportation Hubs through 1980*, August 1967, Department of Transportation, FAA.
**Assumes total number of passengers is two times the number of boarding revenue passengers.

E. E. Hogwood is a Project Engineer, Transportation Division, Westinghouse Electric Corporation, Pittsburgh, Pennsylvania. R. B. Maguire is Assistant Director, Hillsborough County Aviation Authority, Tampa, Florida.




Airside Building
Leg 4
Leg 3
Service Building
Leg 5
Leg 2
Landside Terminal Building
Future Leg 6
Future Leg 1

cessions in the central building from such "Airside" functions as apron operations, gate check-in, and passenger holding. Separate facilities for the two types of function are connected by an automatic transportation system, called the passenger transfer system, that makes the concept feasible (Fig. 1).

The transfer system replaces the long walk in the terminal building with a brief comfortable ride between the Landside building and the outlying Airside buildings, and it shortens the walk from the parking area by centralizing parking facilities at Landside. Maximum walking distance for a passenger parking in the airport garage is about 700 feet—from his automobile seat to his airplane seat.

Passenger Transfer System

Each Airside building is connected to the Landside building by a separate system leg consisting of two elevated roadways 30 feet apart, each with a single vehicle shuttling between Landside and Airside. A walkway between the roadways is restricted to emergency use only; the transfer system is the only normal way that passengers can travel between the main terminal at Landside and the airplanes at Airside.

Since successful operation of the Landside/Airside concept depends on the automatic transfer system, several studies of passengers and requirements for handling them were first made by J. E. Greiner Company at Tampa and at John F. Kennedy International Airport to determine passenger flow requirements and other basic criteria. Also, Westinghouse and the Authority jointly conducted passenger flow studies at the Westinghouse Transit Expressway demonstration project at South Park (near Pittsburgh) and at the Tampa airport to determine vehicle configuration and size, minimum passenger space requirements, vehicle dwell time, and other criteria.

1—*(Top)* Artist's conception of the fully developed Tampa International Airport illustrates the idea of a central Landside terminal building, where passengers check in, surrounded by Airside buildings where they board and leave the aircraft. (All six Airsides are shown, although only four will be built initially.) *(Bottom)* Plan view of the terminal area. The Landside building is linked to each Airside by a leg of the automatic passenger transfer system, which will greatly reduce the distance passengers have to walk and also improve traffic flow.

The Authority had established the design criterion of 840 passengers and greeters to be moved in one direction by each transfer system leg during a 10-minute interval, or an average of 84 persons per minute. After considering single-door side-loaded vehicles, end-loaded vehicles, and other configurations, a four-door vehicle in which riders enter on one side and exit on the other was selected. It was determined that two vehicles per system leg could handle the 84 persons per minute. Each system leg can handle the passengers and expected greeters (one greeter for every two passengers) from the simultaneous arrival of four DC-8 aircraft.

The transfer system leg is designed to provide the one-direction flow rate of 84 persons per minute (5040 per hour) on a continuous basis. That flow rate is far in excess of Airside continuous requirements but is necessary to meet *peak* requirements, due to aircraft arrivals, for periods in excess of 10 minutes. Each car is designed to carry 100 passengers each trip, though maximum capability is 125 passengers for infrequent overloads as required. Running time is approximately 40 seconds, and the adjustable station dwell time is approximately 30 seconds; therefore, a car will be available about every 70 seconds to passengers in either building.

Vehicles—The vehicles are an adaptation of the Westinghouse Transit Expressway vehicle developed in the demonstration project for the Port Authority of Allegheny County at South Park.[1] They differ, especially in the control system, in being designed specifically for the operational requirements of a point-to-point shuttle system

Two eight-foot-wide doorways on each side of the car provide easy entrance and exit from the vehicle during the station dwell periods. Large windows completely around the vehicle let the passengers see the landscaping and architecture of the terminal area; they also assist in loading the cars quickly by attracting passengers to the sides and ends, and they allow passengers to see the arrival at the stations and prepare to exit.

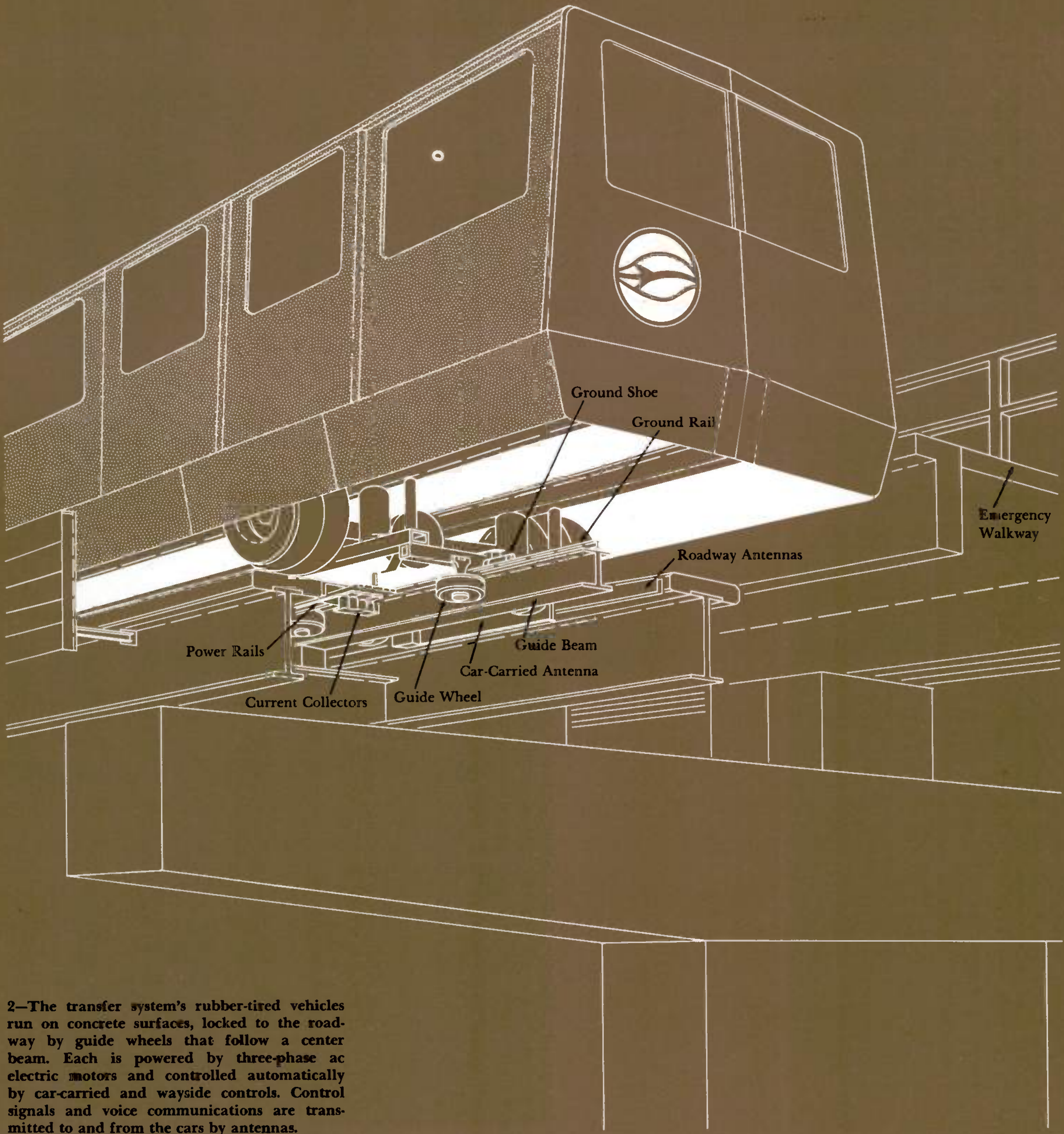
Passengers gather to board the transfer system at a central entrance lobby at each end of a system leg. The leg operates in automatic mode so long as passengers are detected entering the lobby and the vehicle by automatic sensors. The passengers enter either the "A" car or the "B" car, whichever comes into the lobby first.

The vehicles have mounting provisions for simple fold-down seats should the Authority later deem them necessary; however, because the ride is so brief, they will be equipped initially to handle standees only. Wheel chairs for elderly or infirm people are easily accommodated.

Each passenger, regardless of height, is provided a means of support to stabilize himself during the smooth 40-second ride to or from the Airside. When the vehicle arrives at the other station, passengers are directed by automatic announcements

Table III. Aircraft Passenger-Carrying Capability

Type	*Number of Passengers*
DC-3	21-26
DC-4	54-89
DC-6	60-70
DC-8	116-144
DC-861-3	200-251
B707-320	190
B707-323	132
B707-100	234
B720-023	112
B727-200	125
B727-23	93
B747	360-490
L-500 (C5A)	700-900
SST	250-300
Airbus	234
L1011	277-300



2—The transfer system's rubber-tired vehicles run on concrete surfaces, locked to the roadway by guide wheels that follow a center beam. Each is powered by three-phase ac electric motors and controlled automatically by car-carried and wayside controls. Control signals and voice communications are transmitted to and from the cars by antennas.

and signs to leave the car through the exit doors, which are opposite the entrance side. The car interior is made aesthetically pleasing by use of high-level fluorescent lighting, Micarta-finished walls, tinted glass, and carpeted floors. Its air is conditioned to meet the range of climatic conditions expected in Tampa.

An air bag and coil spring suspension system provides a smooth stable ride, with automatic floor leveling for smooth transition from station lobbies to vehicle as the load changes with passenger loading and unloading. Each end of the vehicle is designed for emergency impact with a hydraulic road-end buffer should the car overshoot the normal station stopping zone; the buffer is designed for controlled deceleration of the fully loaded vehicle from five miles per hour, although impact at higher velocity is possible without damage. Impact with the buffer will be a rare occurrence, since the car is equipped with a failsafe control system on board, a spring-applied failsafe emergency brake system, and a separate wayside system for detecting overspeed.

The vehicle is positively locked to a center I-shaped guide beam in the roadway structure by four pneumatic-tired guide wheels, with steel safety discs, on each axle (Fig. 2). The safety discs back up the guide-wheel tires in the event of tire deflation. The system is designed to withstand overturning moments imposed by hurricane winds up to 105 mph.

Power Distribution—Three-phase ac power for the vehicles is distributed through copper power rails mounted inside the concrete running surface on the side opposite the control communications antennas (Fig. 2). Nominal supply voltage is 480 volts supplied from the main power substation bus in the service building at 480/277 volts wye grounded. A fourth copper rail on top of the guide beam provides continuous car body ground for safety if passengers have to disembark to the emergency walkway. The roadway structure is grounded at each pier. Current is collected on the vehicle by two collectors mounted on the Landside-end axle; the redundancy divides current load on each collector and contributes to vehicle reliability.

The vehicle is propelled on eight pneumatic tires by two 100-hp dc series-wound traction motors, one driving each axle through a standard truck-type differential gear. A full-wave semiconverter thyristor power supply converts the ac power to controlled dc power, which is applied to the two motors for controlled acceleration. The converter provides an infinitely adjustable dc voltage for the motors and thus assures smooth fast response to the commands of the automatic train control equipment.

Roadway Structure—Main piers and substructure are of concrete poured in place on driven piles. Running surfaces are steel I-beam stringers with concrete surfaces poured in place; another I-beam stringer forms the guide beam between each pair of running surfaces (Fig. 2).

The emergency walkway consists of prestressed concrete structures spanning between piers. Space under it is reserved for a future baggage-handling system.

Station Doors—Each side of the vehicle will be separated from the entrance and exit lobbies by station platform doors, similar to elevator hatchway doors, that provide passenger safety and conserve conditioned air in the buildings. The station doors operate with the vehicle doors, and both sets have safety edges that stop and reopen them if they contact a passenger. Before cars are allowed to start, a photoelectric detector checks the space between station doors and vehicle doors to make sure passengers are clear.

The doors must operate quickly to maximize passenger flow, yet they must safely handle all segments of the public. (Tampa has a higher than average percentage of elderly and infirm passengers.) The controls are interlocked so that all doors on the two vehicles and at the Landside and Airside stations of a system leg must be closed and locked and all photoelectric detectors at doors clear before the vehicles on that leg can transfer in shuttle mode.

Wayside Control System—Vehicles are controlled by a system composed of wayside and car-carried controls. The system is significantly different from that used at South Park in that the wayside controls consist of hard-wired logic, with digital integrated circuits, instead of a digital computer. Each system leg has its own wayside control; the resulting ability to control each leg independently assures continued operation of the other Airsides should one complete leg become inoperative for short periods. Moreover, one car of each system leg can be taken out of service, during light load periods or for preventive maintenance, by the central dispatcher or by maintenance personnel. Scheduling preventive maintenance will keep the transfer system at a high level of availability

A dispatcher, who also has other airport communications responsibilities, monitors operation of the entire transfer system from a central communications console in the service building. He can place any vehicle in either automatic or manual mode. When both vehicles on a leg are in automatic mode, they operate as simple interlocked shuttles; that is, one transfers from Landside to Airside and the other from Airside to Landside on a fixed time cycle (which can be changed by the dispatcher by changing station dwell time). When a car is placed in manual mode, the other vehicle on that leg continues to operate in automatic mode.

Intelligence is centralized in the wayside controls and the central console for determining the operational mode and the sequence of logical events and commands (such as *go*, *stop*, *emergency stop*, *open doors*, *reverse power*, and *close doors*). The vehicles of each system leg are coupled to their wayside control by two-way audio-frequency communications through a parallel cable antenna running the length of the roadway (Fig. 3). Also, a transposed antenna on the edge of the last few hundred feet of roadway in each direction provides position intelligence to the car-carried controls for precise programmed stopping.

The transposed antenna is connected to its own transmitter for the final stop mode and is switched from one end to the other as the direction of the vehicle is changed. For safety, the vehicles are not allowed to leave the stations unless the proper direction signal is obtained on board and the "program stop" controls are energized.

Car-Carried Controls—The car-carried controls consist of receivers for the wayside-to-car control frequencies, transmitters to send control information from car to wayside, an automatic announcing system, an emergency voice communications system, a manual/monitor control panel for emergency and maintenance purposes, and propulsion and braking interface controls.

The wayside control sends a *go* command to the vehicle after all safety interlocks and power circuits are satisfied, and the car-carried controls automatically accelerate the vehicle under jerk-limited acceleration to maximum speed. Then the program-stop frequency is received by the car-carried controls to energize the propulsion and braking circuits that provide jerk-limited deceleration by a combination of dynamic and air braking. As the vehicle progresses toward the station, position information is fed to a car-carried program-stop computer that controls the vehicle to bring it to a programmed stop. The computer also sends a control signal to the air-brake controls to increase or decrease braking effort to maintain vehicle velocity within the allowed tolerance on the velocity-distance profile (Fig. 4).

When the car reaches the station zone, the deceleration rate is "flared out" to the final stop; that is, the brakes are partially released to provide as near a jerk-free stop as possible. When velocity reaches a preset minimum value, and the car's presence in the final stop zone is detected by an antenna on the station platform receiving a frequency transmitted from the car, the holding brake command is sent from the wayside to the car to make the final stop.

With the car positioned in the acceptable stop zone of ± 12 inches from "zero stop" position, a command is sent simul-

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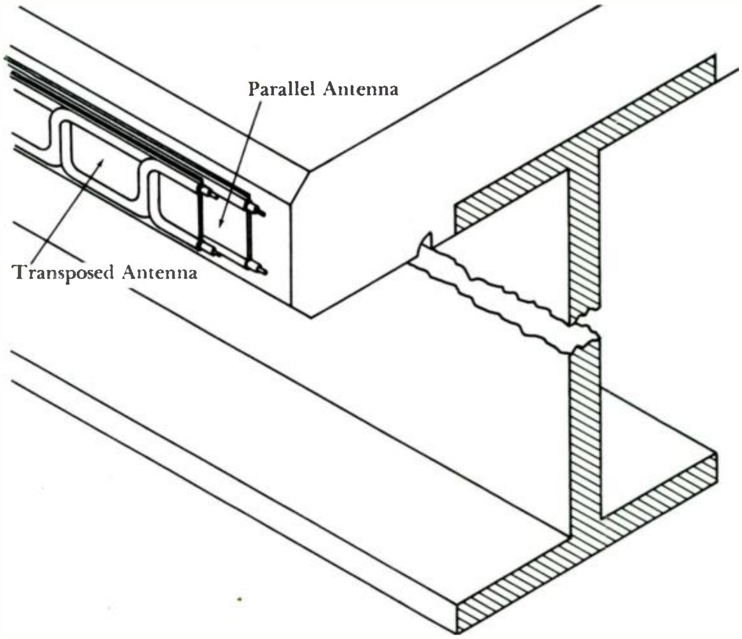

3—Control communications antennas on the roadways include a parallel antenna for command and alarm monitoring and a transposed antenna at the two ends of the roadway for precise vehicle stopping.

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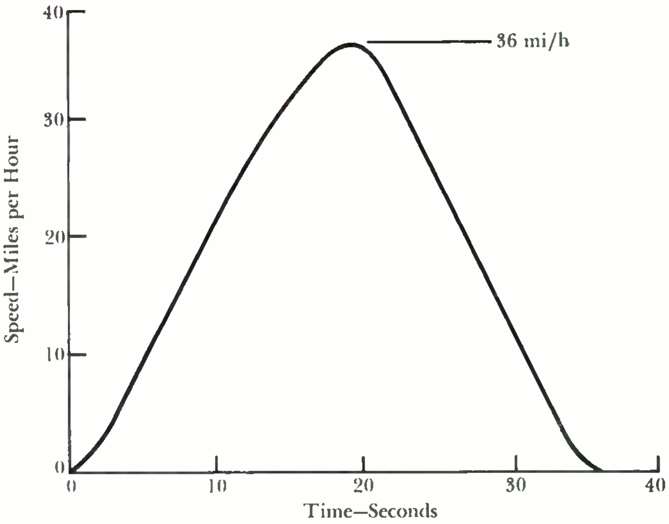

4—The control system accelerates each vehicle smoothly under jerk-limited control to about 36 miles per hour and then brakes it to a precise stop at the station.

taneously from the wayside control to car and lobby to open vehicle and station doors on the exit side of the car to allow passengers to leave. A short time later the entry doors are opened to allow boarding passengers to enter the car at the same time passengers are leaving it. Separation of entry and exit passengers contributes significantly to the passenger flow capacity of the vehicle and system.

Dwell time for the vehicles of a system leg is set into the system by the central communications dispatcher at the console. When the time has elapsed, the wayside control removes the *door open* signals, allowing vehicle and station doors to close. With doors closed, motors reversed, and all safety interlocks satisfied, the cars make the return shuttle trip to the opposite stations.

Manual Control—The cars are normally in automatic shuttle mode, but, for maintenance or emergency reasons, they can be operated manually by maintenance personnel on board. The central dispatcher places the selected car in the *manual* mode at the console. Only the exit doors of that car open (to unload passengers) when the cars complete the run to their respective stations; the car then reverts to "at rest" until a maintenance man boards it and places the car-carried controls into *manual* mode. The vehicle can then be operated manually from the manual/monitor panel at the end of the car. That panel also provides a means of quickly locating any difficulty.

When the maintenance checks are completed, the vehicle is located in one of the stations and returned to *automatic* operation on board the car by maintenance personnel and at the central console by the dispatcher. The system leg then reverts to normal automatic shuttle operation as soon as the cars are properly positioned, one in each station.

Braking System—Safely stopping the vehicle within the allowed tolerance at the station platforms required development of dependable control and braking systems. The criteria were met by use of reliable integrated circuits and vital relay logic circuits in the controls, failsafe design in controls and brake system, and air-applied friction brakes for service and emergency braking backed by a final overriding spring-applied emergency brake should all air on the car be lost or some unforeseen overspeed occur.

As an additional safety precaution, the air reservoir for the air brake system is divided into two tanks, one on each axle, with a main reservoir feeding the entire air system. Locating the reservoirs near the brake actuators also made brake response time much shorter than normal, permitting precise stops at the station doors.

Dynamic braking is employed at the top part of the speed-distance profile to brake the car from top speed to about 12 miles per hour. Then the air-applied friction brake makes the final precise stop. The difference between the dynamic braking effort obtained from the motors and the effort required to maintain the car on the proper speed-distance profile is provided by modulating the air brake to blend its braking effort smoothly with that of the dynamic brake.

Communications and Announcing—An emergency and maintenance voice communications station is part of the central console. It is a 450-MHz FM space radio system for communication between the dispatcher, passengers on any or all of the cars, transfer-system maintenance personnel at the airport, and the maintenance facilities. Each of the maintenance personnel will have a walkie-talkie unit when working in remote sections of the airport. Passengers can communicate with the central dispatcher by means of a handset on the vehicle.

Automatic announcements on board the cars are made by a tape recorder with programmed messages to announce arrival at Landside or Airside, baggage claim and ground transportation information, and warnings regarding door closing, emergencies, and so on. The automatic announcer is coordinated with graphic displays inside the vehicle to direct passengers to the correct baggage claim and ground transportation area and to inform them of the Airside station to which they are travelling and the airlines served by it. Graphics over the car doors on the entrance side will encourage passengers to exit through the opposite doors to maintain the flow-through pattern of passenger movement.

Maintenance

Westinghouse has a five-year full maintenance contract to keep the transfer system in peak operational condition. To achieve that condition, maintenance personnel will be on the site or on call 24 hours a day, seven days a week.

A maintenance facility is provided at each Airside for preventive maintenance of the two cars of each system leg while on the roadway structure. In addition, a central maintenance shop is provided in the airport service building for major repairs and storage of spares. The shop has an alarm monitor repeater and a voice communications repeater from the central communications console to keep maintenance personnel aware of the operational performance of the transfer system and alert them to any attention required while they are at the airport.

Conclusion

Consideration is overdue for the entire system problem of moving passengers from home to the airport, in the airport, and finally on their way by air. The problem demands the best attention of designers and planners.

The team of airport officials, consultants, engineers, and architects associated with Tampa International Airport has gone a long way toward providing an answer to the problem of terminal sprawl. By centralizing major functions either physically or by means of the passenger transfer system, they have given highest priority to the convenience, comfort, and safety of the passenger for the first time in airport planning. The necessity to traverse longer and longer distances on foot, so characteristic of major air terminals, has been eliminated at Tampa primarily by the passenger transfer system.

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Jet-Age Power Supply for Making Movies

W. E. Treese
R. W. Terry

Aircraft generation equipment provides a lightweight power supply system for an enterprising cinematographer's portable studio.

Fouad Said, a world-traveling cinematographer, conceived his all-purpose, single-unit "rolling studio" in 1961 and put the concept to its first test when he was on foreign location work for the television "I Spy" series. His custom-designed 16-foot panel truck carries the equivalent of 15 truckloads of conventional cinematic equipment—six cameras, complete sound facilities, automatic crane, lights, reflectors, camera stands, and an electric power system to operate all this equipment.

Said introduced a number of innovations in cinematic equipment and techniques to achieve this 15-to-1 reduction—small lightweight cameras, transistorized sound equipment, miniaturized quartz and xenon lights, lightweight camera dollies that operate on magnesium tracks, and a light compact power supply to name a few.

Lightweight aircraft generating equipment makes possible the compact power supply, reducing generator weight from the usual 2400 pounds of conventional ground equipment to 87 pounds each for two aircraft type generators. (The high power-to-weight ratio of aircraft equipment is achieved with high frequency and high operating speeds plus forced cooling.)

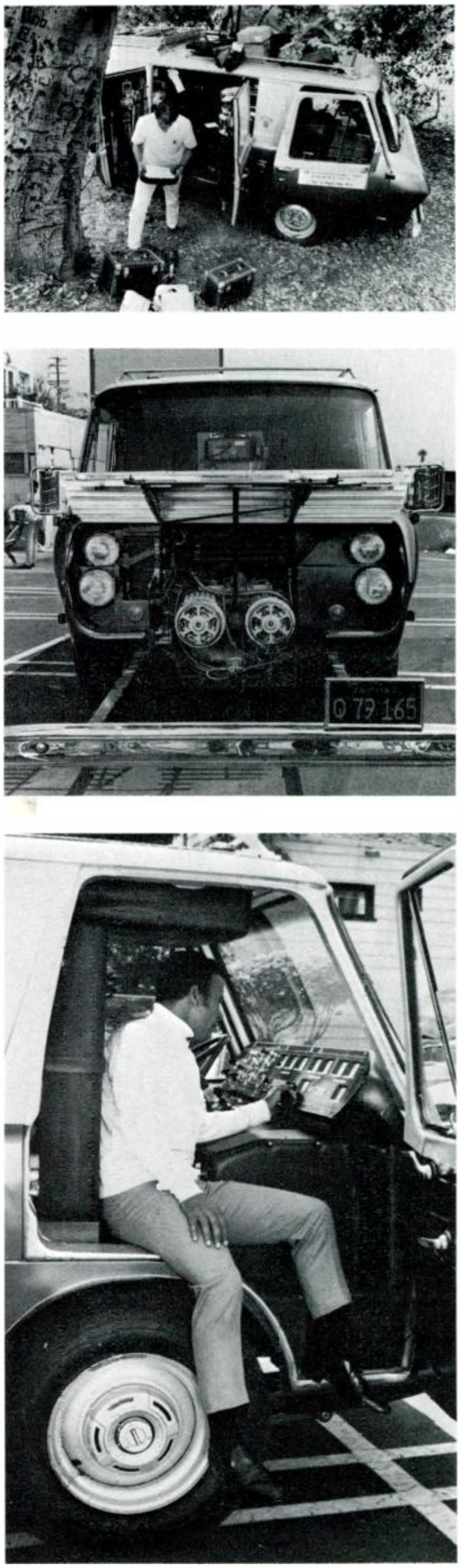
The two generators are driven from the truck engine through a 1:3 speed increaser (*diagram*). The speed increaser and generators are mounted forward of the truck engine, permitting the entire rear space in the vehicle to be used for carrying cinematic equipment.

The generators are similar to those used on 707 jet aircraft, except they have been specially wound to provide a lower-voltage, higher-current output. They are integrally excited and brushless. Each generator is normally rated at 40 kVA from sea level to altitudes in excess of 40,000 feet, but can deliver higher output on the ground because of more efficient cooling.

Generator output is rectified with two Westinghouse solid-state silicon rectifier bridges. The power supply can provide a continuous output of 750 amperes dc at 120/240 volts, three wire. Switching contactors are provided so that the generators can be operated singly for small loads, or together in parallel or series. Since load can normally be balanced, the three-wire system design allows the load to be carried on the outside conductors and only the unbalance on the center conductor, thereby minimizing total cable weight. (The two outside conductors are 0000 AWG and the middle conductor is 2 AWG.)

The power supply is presently limited to its 750-ampere output by engine capacity. However, with additional generator cooling and suitable increase in engine power, the generating equipment could produce 950 amperes output. (This has already been demonstrated while operating during cool ambient conditions.)

The electrohydraulic governor is a modified version of the Westinghouse prime-mover governor system (Type EFG). This governor has electrical frequency sensing in the control unit, which directs a hydraulic actuator that operates the engine throttle. The EFG governor is normally a fixed-frequency device, but, in this application, generator frequency is variable to permit the lowest possible engine speed for a given load (within the range of the generator system) and thereby minimize engine noise. An aircraft generator normally operates at 400 hertz, but in this application generator frequency may be varied from 375 to 525 hertz. After an operating speed (frequency) is selected on the basis of noise and power requirements, the governor automatically maintains the frequency



On location, this 16-foot "rolling studio" *(top)* carries compact cinematic equipment equivalent to 15 truckloads of conventional equipment. By mounting generating equipment forward of the engine *(center)*, the entire rear space of the truck can be used for cinematic equipment. Control and instrument panel for the generating equipment *(bottom)* is on the right-hand side of the dashboard.

W. E. Treese is Plant Manager, Aerospace Repair Plant, and R. W. Terry is an engineer, Aerospace Repair Plant, Westinghouse Electric Corporation, Compton, California.

within ±5 hertz of the selected frequency. A change in frequency indicates a load change, causing the governor to adjust engine throttle accordingly.

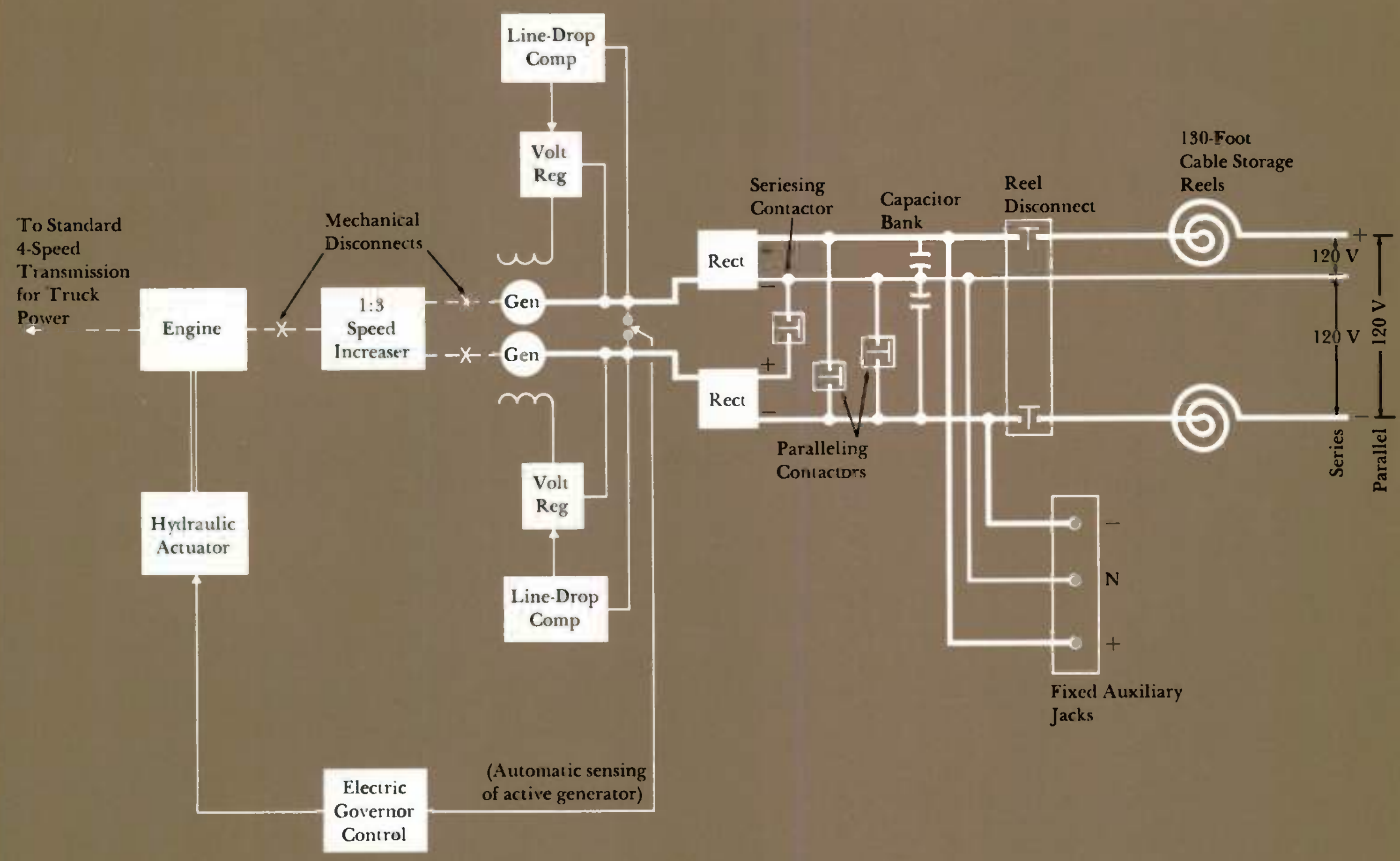
When used on location, the truck is parked some distance away from the cameras to keep engine noise away from microphones. To the 130-foot cable reels mounted in the vehicle, additional 100-foot lengths of cable can be added as required. Typical cable runs are about 400 feet. Thus, in addition to load variations, the length of cable run also varies from one setup to another, changing the line-voltage drop. To provide constant voltage at the load end of the cables irrespective of load or line length, a line-drop compensator circuit is used to raise the generator voltage to overcome line drop. A capacitor filter bank is also provided in the truck, electrically just ahead of the output jacks, to prevent arc lamps from emitting an audible whistle caused by the ac ripple.

The power rectifiers used are the latest exclusive Westinghouse CBE type (Compression Bonded Encapsulation) with double-sided cooling. This type of design was used to obtain the maximum power with minimum size and weight.

Because this application was for a mobile vehicle, it was necessary to use instruments that could maintain their accuracy under varying shock conditions. Therefore, Westinghouse taut-band-suspension (TBS) instruments were chosen.

Although lightweight cinematic equipment has been used in Europe for some time, Fouad Said's portable studio is a revolutionary step for domestic film producers. When Said had trouble convincing industry management that his single-unit truck could do the job, he promptly went into business for himself. He has completed five trucks that he rents on a daily basis, complete with equipment, driver, mechanic, and cameramen. These compact camera trucks can be quickly shipped by air to any location in the world. Thus, Fouad Said's new techniques make it possible to shoot television or motion pictures on locations that were either physically impossible or economically impractical to reach before.

Westinghouse ENGINEER **January 1969**



Versatile power supply arrangement provides frequency and voltage control for generators that can be operated singly, or together in parallel or in series.

A General-Purpose Onboard Satellite Computer

David K. Sloper
Jon S. Squire

A prototype stored-program computer has been built to demonstrate computational ability and reliability while meeting spacecraft requirements of small size and low power dissipation.

With the advent of relatively fast low-power integrated circuits and low-power memories, powerful yet compact computers can be built, and onboard satellite computers have become practicable. Of the several possible approaches to onboard computing systems, the stored-program general-purpose digital computer is particularly promising because it can be adapted to a large class of scientific spacecraft missions and thereby satisfy a wide range of present and future spacecraft needs.

Such a general-purpose satellite computer should provide an interrupt structure with programmable priority levels and graceful interrupt entry and exit. That structure accommodates a real-time environment and permits a reduction in spacecraft hardware because tasks can be time shared. Mission capability is increased by computer reprogrammability and high computational capacity.

To demonstrate the desirability of this general-purpose computer approach, a prototype Onboard Processor (OBP) has been built and delivered to NASA Goddard Space Flight Center for evaluation. In addition to its computational ability, the OBP has been designed to satisfy such spacecraft requirements as high reliability, low power dissipation, small size, and light weight.

Uses for an Onboard Computer

The onboard processor has been designed with sufficient capability to fulfill the basic needs of a scientific spacecraft: attitude control signal processing; command storage, decoding, and distribution; experiment data processing; and decision-making tasks.

For attitude-control signal processing, the onboard processor would effectively become an integral part of a closed-loop system in which error signals would be provided to the computer; the computer would determine body-to-inertial space transformations and feed corrections to the stabilization system. Attitude control computations can be highly involved for systems that require pointing accuracy and spacecraft slewing but can be readily solved with a general-purpose computer.

For command handling, the onboard processor would store telemetered command signals from the ground. These commands would be decoded and distributed in real time, or stored and distributed at a specified later time. A real-time clock would periodically interrupt the onboard processor at a frequency high enough to provide the necessary resolution for all time-dependent tasks, such as sampling experiment data at specific time intervals.

To provide efficient data handling, the onboard processor would sample all experiment and control inputs at a rate sufficient to give information about the highest signal frequencies of interest. The onboard processor can build an output buffer whose format is under program control so that data compression techniques can be used to reduce the amount of information that must be transmitted to ground.

Typical decision-making tasks might include the monitoring of status points; in the event of anomalies, decisive action would be initiated to put the spacecraft in a safe condition. For example, if low battery charge is sensed, the onboard processor could turn off low priority equipment; if strong radiation or thermal gradients are detected, the onboard processor could close protective shields. The wide variety of possible tasks that could be performed by a general purpose onboard computer is illustrated in Fig. 1. Actual task selection would be dictated by specific mission requirements.

Onboard Processor Organization

The onboard processor developed at the Aerospace Division is divided into three distinct module types: central processing unit, input/output unit, and memory. These three modules are interconnected with a busing network, as shown in Fig. 2. The busing network minimizes interface signaling between units and permits system modularity. As applications and requirements change, up to three central processing units, three input-output units, and eight memory units can be connected to the bus without changes to the basic individual modules. Such multiple-unit arrangements can be used to increase reliability, increase system capability, or both, depending on the application.

Central Processing Unit

The central processing unit (CPU) is a parallel digital computer, using two's complement arithmetic (Fig. 3). Data and instruction word size is 18 bits, which is sufficient to provide a convenient instruction format and to handle most data quantities. Instructions are stored along with data in the memory of the onboard processor. An instruction counter initiates transfer of an instruction from storage into the instruction register. While one instruction is being executed by the computer, the instruction counter is increased by one so that upon completion of the instruction, the processor automatically proceeds to the next.

Operating time is a compromise between high speed and low power requirements. For example, central processing unit add time is 6.25 microseconds; average multiply time is 45 microseconds; and average divide time is 90 microseconds. These times are longer than those of many airborne and ground-based computers because of the power limitations on spaceborne equipment. With these operating times, the CPU requires only 5 watts of operating power.

One of the more unusual features of the central processing unit is the use of a *scale register* for maintaining the binary point of binary numbers. The true value of a binary number is contained in the form $(n)\ 2^8$, where n is the fractional value of the number in the 18-bit *accumulator* and s is the value of the number contained in the 6-bit scale register. (To illustrate this concept with a decimal example, the decimal number 539,000 could have the form 0.539×10^6.) Thus, arithmetic operations on n in the accumulator provide the binary digits of a resultant product or

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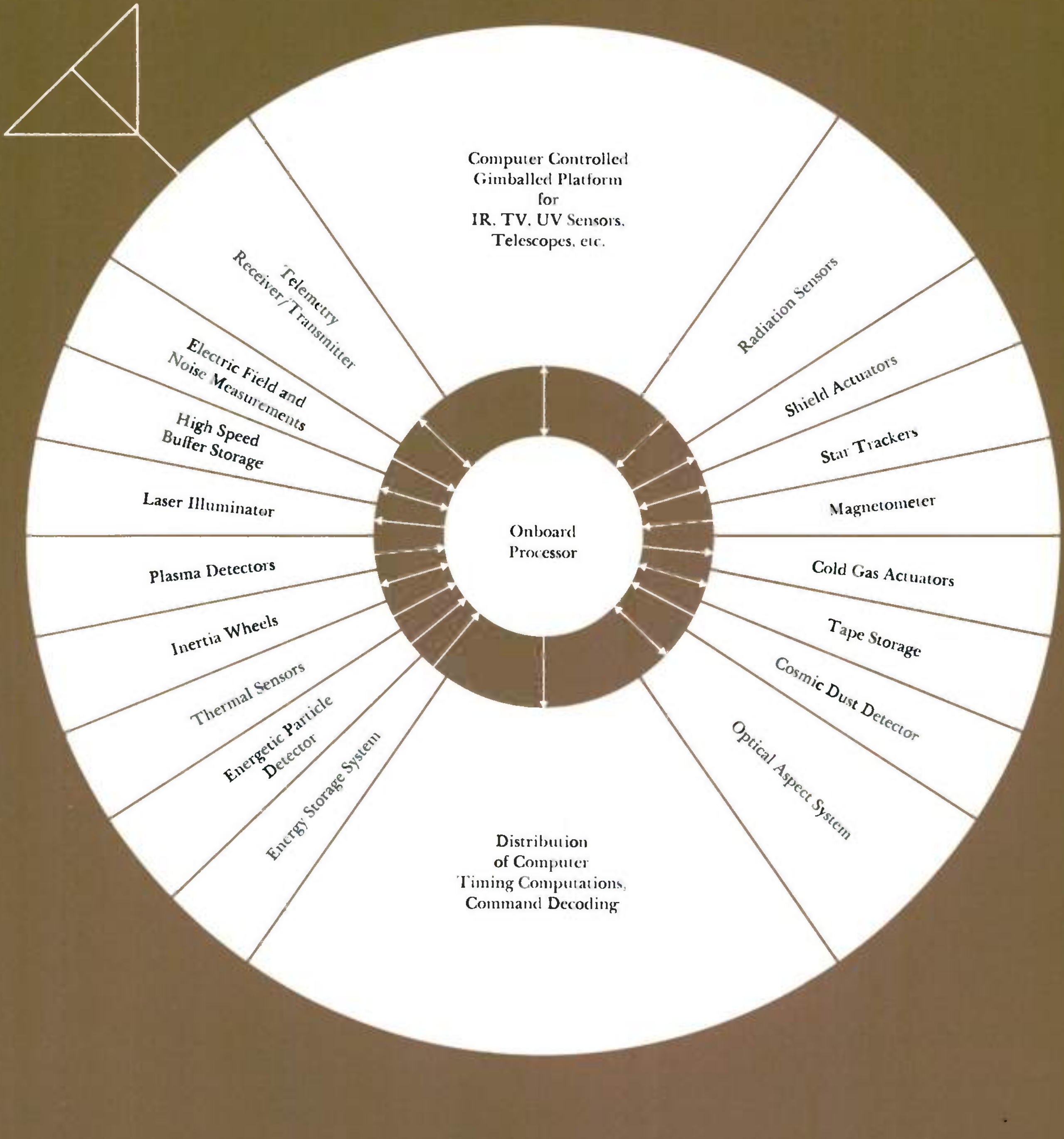
D. K. Sloper and J. S. Squire are design engineers at the Aerospace Division, Westinghouse Defense and Space Center, Baltimore, Maryland.



1—An onboard computer has a wide range of potential uses on scientific satellite missions.

quotient, and the binary point is maintained with *s* in the scale register; this is accomplished by automatically shifting the dividend before a divide and the product after a multiply.

The *arithmetic unit* of the OBP normally regards all numbers as fractional, i.e., the binary point is to the left of the digits. However, the scale register arrangement also permits the user to consider numbers as integer (binary point to the right) or mixed, just by setting the value of *s* in the scale register. Thus, standard fractional arithmetic is performed by setting the scale register to zero; standard integer arithmetic is accomplished by making the scale register equal to 17, which is equivalent to moving the binary point 17 places to the right (the 18th bit in the accummulator carries the sign). By use of the scale register the programmer may move the binary point so as to best suit his data. This eliminates the shifts required in a conventional fixed-point computer when computated results exceed computer word length.

The scale register has six bit positions, so it provides space for a sign bit and five binary bits (or a numerical range from 2^{-32} to 2^{+31}). The six-bit scale register is loaded into and stored from computer memory by program control.

A second unique feature of the central processing unit is its implementation of conditional program branching. Program branching can be initiated by a number of test instructions, such as comparing a value in the accumulator to a value in storage. A number of tests may be logically combined in series (ANDed, ORed, or complimented) to set a *decision register* and cause a program branch. There is no limit to the number of tests that may be combined, the results of which will cause or not cause a program branch.

To prevent one experimenter from accidentally destroying another's program, the central processing unit has the ability to limit the section of memory that may be altered by a given program. This is accomplished with an 18-bit *storage limit register*, which essentially reserves blocks in memory (each block containing 128 words) that can be written into under program control.

Input/Output Unit

To make the onboard processor applicable to a variety of scientific spacecraft programs, a general technique for data transfer between the input/output unit and the memory had to be developed. This technique consists of a system design that provides:

1) Data transfer that may be accomplished independent of program execution by substituting a data-transfer cycle for a program cycle, called a *cycle steal* mode;

2) Data transfer that may be completely under program control.

Thus, the input/output scheme is designed to accommodate any particular mission's individual and perhaps unique requirements with little or no effect on the CPU or memory unit design.

The *memory bus controller*, located in the input/output unit, synchronizes bus traffic and establishes the priority of memory system activity in event of simultaneous memory requests. Inputs to this controller are memory cycle requests from the input/output unit and from the central processing unit. Outputs of the controller are precise time-acknowledge pulses that allow the requesting unit to operate the memory and place an address and data word on the busing network.

The input/output unit is also capable of handling multilevel interrupts and appropriately signaling to the central processing unit. An interrupt causes the CPU to stop executing the present program and record program status at the time of interrupt. The computer executes the program called for by the interrupt, and returns to the original program when all levels of interrupt processing are satisfied. The *interrupt subsystem* stores and synchronizes external interrupts and provides priority logic to handle simultaneous interrupts.

There is an *interrupt lockout register* to provide the ability to lock out an unwanted or malfunctioning device. Interrupt priorities may be changed through software by temporarily locking out interrupts that are of lower priority.

Memory

For the flight model of the OBP, designers hope to use a plated-wire memory system. This memory would have low power consumption (less than 10 watts for a module of 8192 eighteen-bit words), and would be especially rugged because of its mechanical properties. However, since a commercial plated-wire memory system satisfying the OBP requirements is not readily available, the first OBP to fly on board a spacecraft will probably use a core memory.

A suitable core memory module will contain 4096 eighteen-bit words, weigh less than 7 pounds, and have a volume of less than 135 cubic inches. The memory will be random access. One module will consume a maximum power of 35 watts for a 100-percent duty cycle, but power switching techniques will be employed so that the actual power consumed will be dependent upon the duty cycle.

Although as many as eight memory modules may be used in the OBP, only the module being used will have power applied. Thus, the power consumed in the memory will be proportional to the frequency of memory access and not the number of memory units in the system.

Reliability

Reliability is being emphasized in the design of the onboard processor at both system and component levels. At the system level, modular organization permits redundant subsystem units to be added directly. As shown in Fig. 2, the address bus, input data bus, and output data bus make up a busing system that is the central tie point for all operating units and spare units. Spare units will not draw power unless activated. Both input and output data buses consist of two sets of 18 lines so that any worst-case single failure in the bus or memory will cause a loss of no more than 50 percent of memory capacity. Most single failures would be much less severe.

At the component level, a number of steps have been taken to assure maximum

2—The three basic components of the onboard processor are interconnected by a busing network to permit system modularity.

3—The central processing unit is a parallel digital computer with data and instruction word size of 18 bits.

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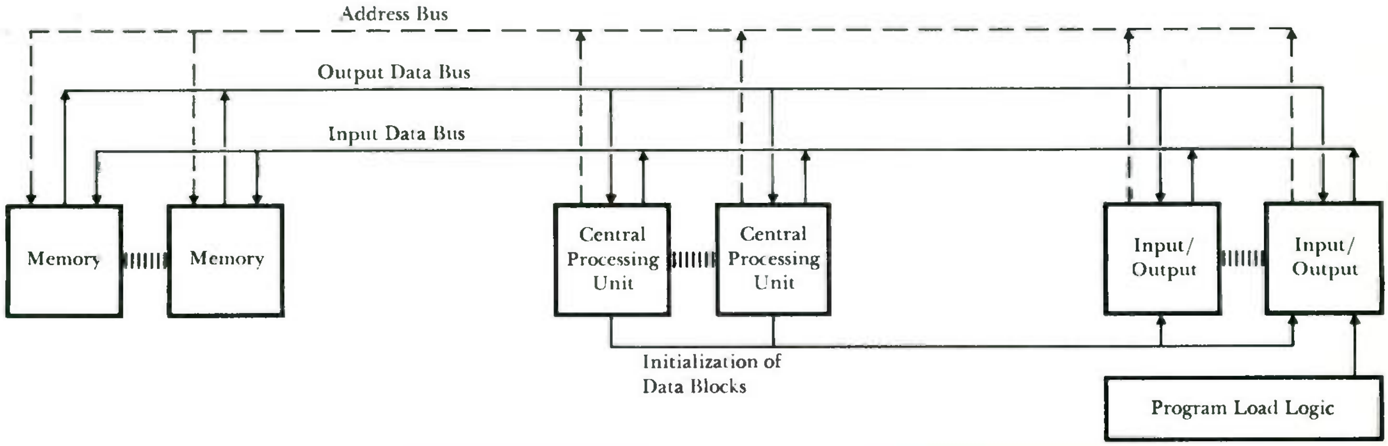

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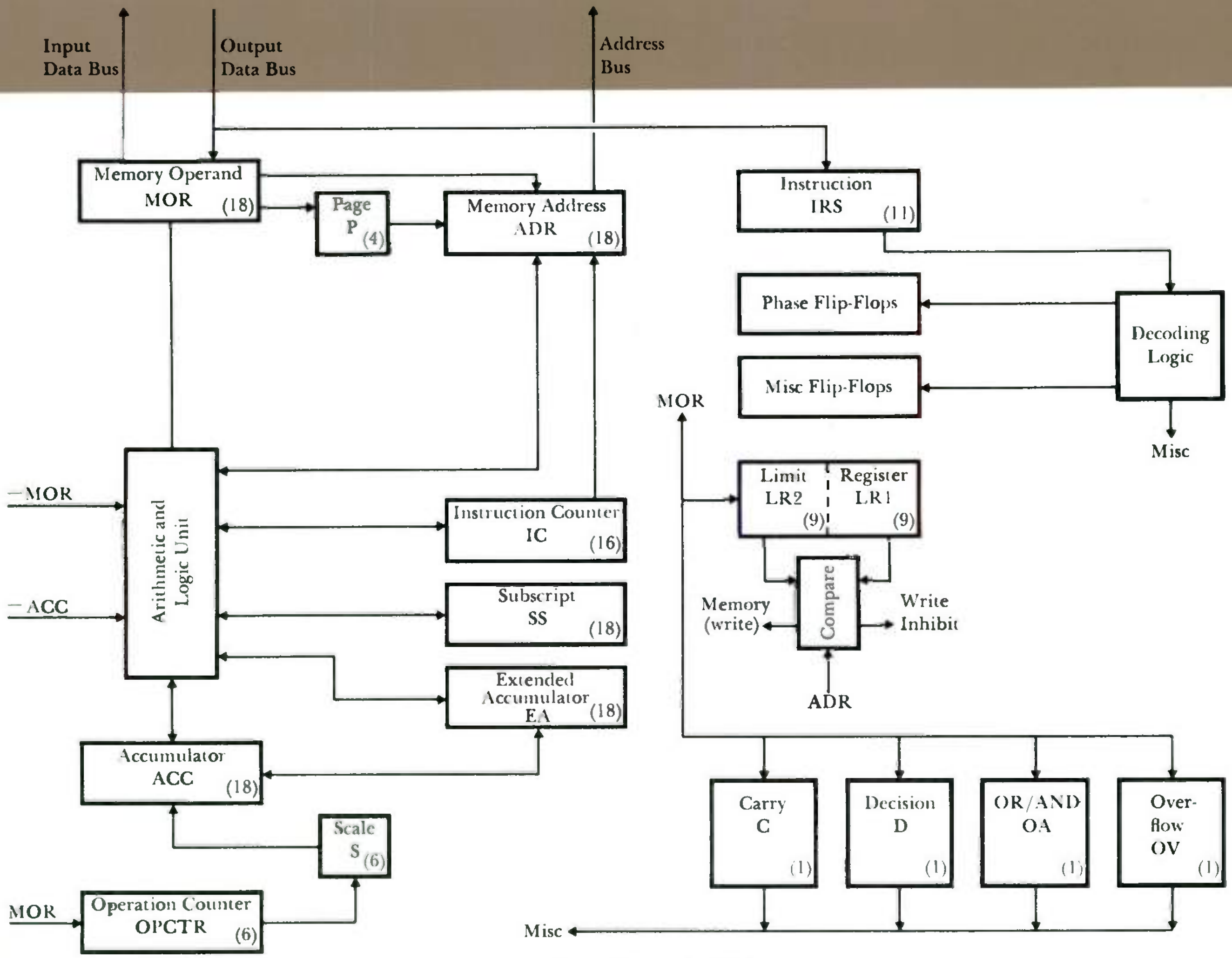


Central Processing Unit

reliability of all flight subsystems. Maximum use is made of monolithic integrated circuits. All circuit components will be operated well below rated values to minimize failures due to electrical stresses. Only tried and proven circuit techniques and components will be used. All active elements will be burned in to minimize drift due to aging and to detect early failures. Electrical connections will be minimized and all internal connections will be either welded or soldered. All the electronic subassemblies, including memory planes, will be encapsulated. And all fabrication will be performed in a clean room.

Repairability

Since the OBP will be inaccessable after launch, it is necessary that any repairs be effected either from the ground or automatically on board. Due to the added complexity required to automatically perform system repairs, it was decided that any repairs would be initiated by command from the ground.

To aid in this repair operation, a complete set of diagnostic programs has been prepared. These programs exercise each computer instruction in an ascending order of complexity. As output, the diagnostics prepare code words stating which portion of the system has failed and also which operation, or operations, in the sequence malfunctioned. These code words will be telemetered to the ground and analyzed to determine the cause of the malfunction.

After the cause of the malfunction has been determined, remedial action will be taken. This action could take one of two forms. In the case where no repair could be made, a new program could be sent to the spacecraft (by command). This program would be used to circumvent the failed portion of the computer and probably would have less capability than the original one.

In the case where repairs could be made, a control word would be sent via the command system to the spacecraft. This control word would switch in a redundant module and thereby allow the OBP to continue performing its full complement of computing tasks.

Software

The goal for software development is to make a powerful hardware system easy for the user to accurately program or reprogram. Since the experimenter can best specify the sensor data processing and the control requirements for his experiment on the spacecraft, he would prefer to communicate his instructions directly to the onboard computer rather than work through professional programmers. The experimenter will then know exactly what transformations have been performed on his raw data, and misunderstandings are avoided. To provide this capability, the necessary assembler programs and routines for ground computers have been developed so that experimenters and spacecraft engineers can use a simple form of English for describing their desired data processing and control instructions.

The executive control program and a number of utility processing routines will be placed in the onboard processor by professional programmers. This resident software prevents unplanned interference between the various control functions and experiments. It also performs satellite housekeeping functions so that the experimenters need only be concerned with their own experiment's data processing requirements.

To ensure the correctness of the software in the onboard processor, a *functional simulator* program for a ground-based computer has been provided. This functional simulator is a computer routine that may be given hypothetical sensor data along with the data processing instructions. The simulator will then process the sensor data and produce the exact results that the onboard processor would have developed for this sensor data. In this way, the control engineer or experimenter can determine whether he will obtain the desired quantity and quality of data processing in the time-shared environment of the satellite computer.

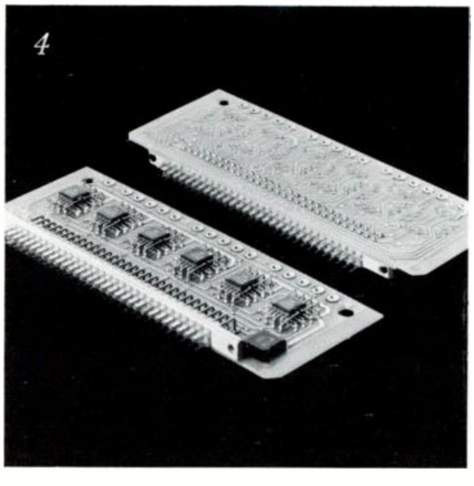
User Language—The programming language, a restricted form of grammatical English, simplifies user programming and provides the desirable feature of self-documentation (i.e., the program provides its own record). This facilitates program maintenance and modification.

Some typical examples of user programming language are:

IF PARTICLE COUNT IS GREATER THAN 200, THEN GO TO RADIATION PHASE. OTHERWISE GO TO PARTICLE COUNT COMPUTATION.

LET THE RMS-VALUE OF PARTICLE COUNT OVER SQUARE FEET YIELD RATE OF FLUX.

These instructions are punched on cards and processed with an assembler program, which translates the instructions into computer language for loading in the onboard computer. The programming language is free form, so that the user need not worry about aligning specific fields of the language to specific card columns. Text may be freely continued from one card to the next without any special indication. The user may create paragraphs and indent text for emphasis, just as he would write. Free use of standard English punctuation—periods, commas, exclamation points—is permitted. The double use of the hyphen, to form compound words and to continue a word across a line, has been preserved.



4—The basic element of the central processing unit is a pluggable printed circuit card, 1.2 by 4.4 inches. Integrated-circuit packages are stacked two high, with the top pack rotated 90 degrees with respect to the bottom pack.

5—Top and bottom views of the breadboard model of the CPU illustrate the high packaging density possible with printed-circuit cards plugged into a wired panel.

Breadboard System Developed

To prove certain design, circuit, and system techniques, a breadboard system of the central processing unit and the input/output unit has been constructed.

The approach selected takes advantage of recent developments in packaging techniques developed for airborne computer applications. The basic element in the breadboard design is a small pluggable printed circuit card (Fig. 4) on which a maximum of 12 flat-pack integrated circuits can be assembled.

The basic integrated circuits are low-power diode-transistor logic (LPDTL). These logic circuits are packaged in 14-lead ceramic flat packs, with power dissipation of less than two milliwatts per gate (50 percent duty cycle) and less than six milliwatts per flip-flop. These circuits have one of the lowest power-speed products (average power dissipated by a circuit times the propagation delay of signal through circuit) of any logic type presently available from stock.

The printed circuit cards plug into a wired panel. For the breadboard model of the central processing unit shown in Fig. 5, cards are racked in five rows, each row containing 30 cards on 0.30-inch centers with slotted card guides to hold the cards in place.

The small printed circuit cards are designed for general purpose use to minimize the number of card types required, permit a wide range of flexibility in design, and reduce the variety of spares required.

Preparing for a Flight Model

While the breadboard model of the central processing unit is being evaluated, designers are continuing to work on techniques for eventual use in a flight model. For example, system designs that would utilize internal redundance are being evaluated. It is expected that redundant systems with about 40 percent increase in hardware could provide an increase in mission reliability of 1000 percent.

On the component level, efforts are currently under way to achieve increased reliability through use of hybrid interconnection techniques. This technology places bare integrated-circuit chips directly on a ceramic substrate which contains metallized interconnects for forming more complete circuits from chip circuits. The chips and ceramic-substrate package is then sealed in a metal package. With this approach, mechanical interconnects can be reduced by a factor of five. These hybrid packages will be constructed and vigorously tested under environmental conditions to determine if they are suited for flight use.

Suitable software is also being prepared for eventual use in a flight model. Programmers are developing utility routines that would be needed during flight, such as fast Fourier transforms and trigonometric functions.

Westinghouse ENGINEER **January 1969**

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[2] Tharpe, H. M., and Sloper, D. K., "A Low-Power Computer to Improve Overall Spacecraft Performance," 19th Congress of the International Astronautical Federation, New York, N.Y. October 13-19, 1968, No. AT107.

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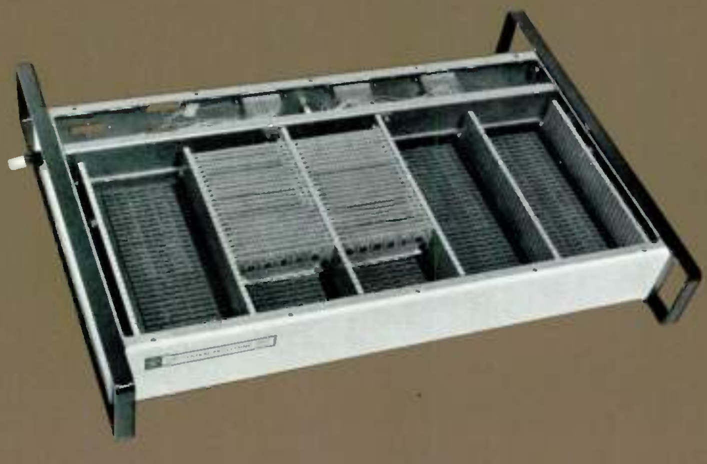

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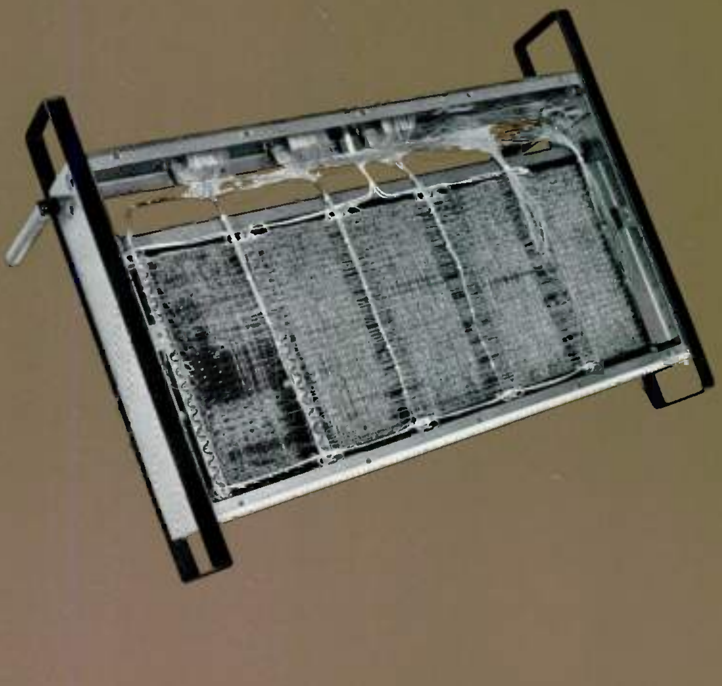

Vacuum Circuit Breaker for 15-kV Distribution Substations

Robert A. Few
S. John Cherry

The physical simplicity and reliability of vacuum interrupters provide inherent advantages for a new circuit breaker.

The advantage of arc interruption in vacuum—the opening contact gap recovers its dielectric strength almost instantaneously after a current zero with very little energy dissipation—makes a vacuum interrupter ideally suited to ac circuit breaker application. Recent developments in materials and manufacturing techniques have made possible a vacuum interrupter that is technically and economically competitive with conventional methods of arc interruption. As a result of this development, a vacuum circuit breaker (144V250) has been developed to provide fault protection for 15-kV substation applications.

The breaker is equipped with three vacuum interrupters, each rated 600 amperes continuous and 12,000-ampere interrupting duty. The vacuum interrupters are mechanically linked to interrupt temporary and permanent faults simultaneously on three phases through a shunt trip mechanism. The breaker can also be electrically operated from a remote location or tripped manually.

Speed of interruption, reduced maintenance, and increased life are the greatest advantages of the vacuum breaker. The vacuum interrupter can consistently clear a current after one-half cycle of arcing, so that when relay and solenoid operating time is included, the circuit breaker will clear a fault in 2.5 cycles or less, regardless of fault type. Contacts cannot oxidize, making the interrupter a maintenance-free device. Other advantages include reduced chance of fire or explosion and reduced ground shock during interruption. The physical simplicity of the vacuum interrupter makes possible a small interrupting device that requires no auxiliary equipment such as compressors or arc chutes, and can be operated with a simple actuating mechanism.

Vacuum Interrupters

The construction of a vacuum interrupter is shown in Fig. 1. The interrupter (WL-23223) is basically a pair of contacts enclosed in a vacuum-tight bottle. When the contacts separate, the arc vaporizes the contact faces forming a charged vapor, but because of the extremely rapid dispersion of vapor in vacuum, there is little or no charged medium in which to reestablish the arc after current zero.

The moving contact rod is sealed to the bottle through a flexible metal bellows, which allows contact movement without disrupting the vacuum seal. A bellows shield protects the bellows from the arc.

The mating stationary contact is attached to the metal end plate at the other end of the bottle. Both metal end plates are hermetically sealed to a ceramic insulating envelope with a ceramic Kovar seal. The ceramic used for the envelope is a dense material designed to prevent gas diffusion from the atmosphere. A 10^{-7} torr vacuum or better is maintained within the bottle.

A metal envelope surrounds the contacts, forming an arc chamber which provides a condensing surface for collecting vaporized contact material produced by arc interruption. This condensation also performs a "getting" action, so that the interrupter self cleans.

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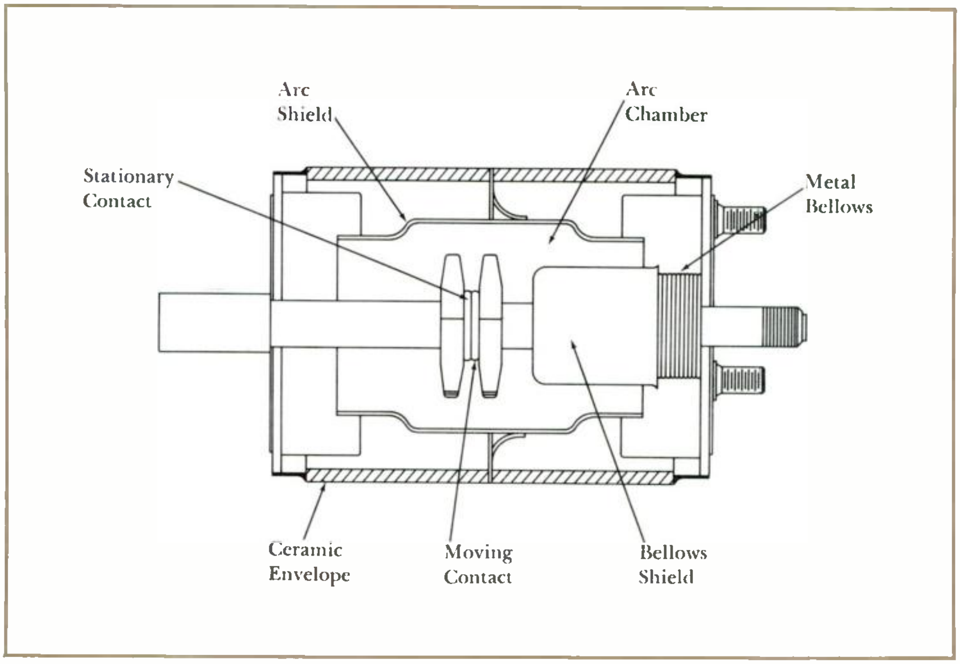
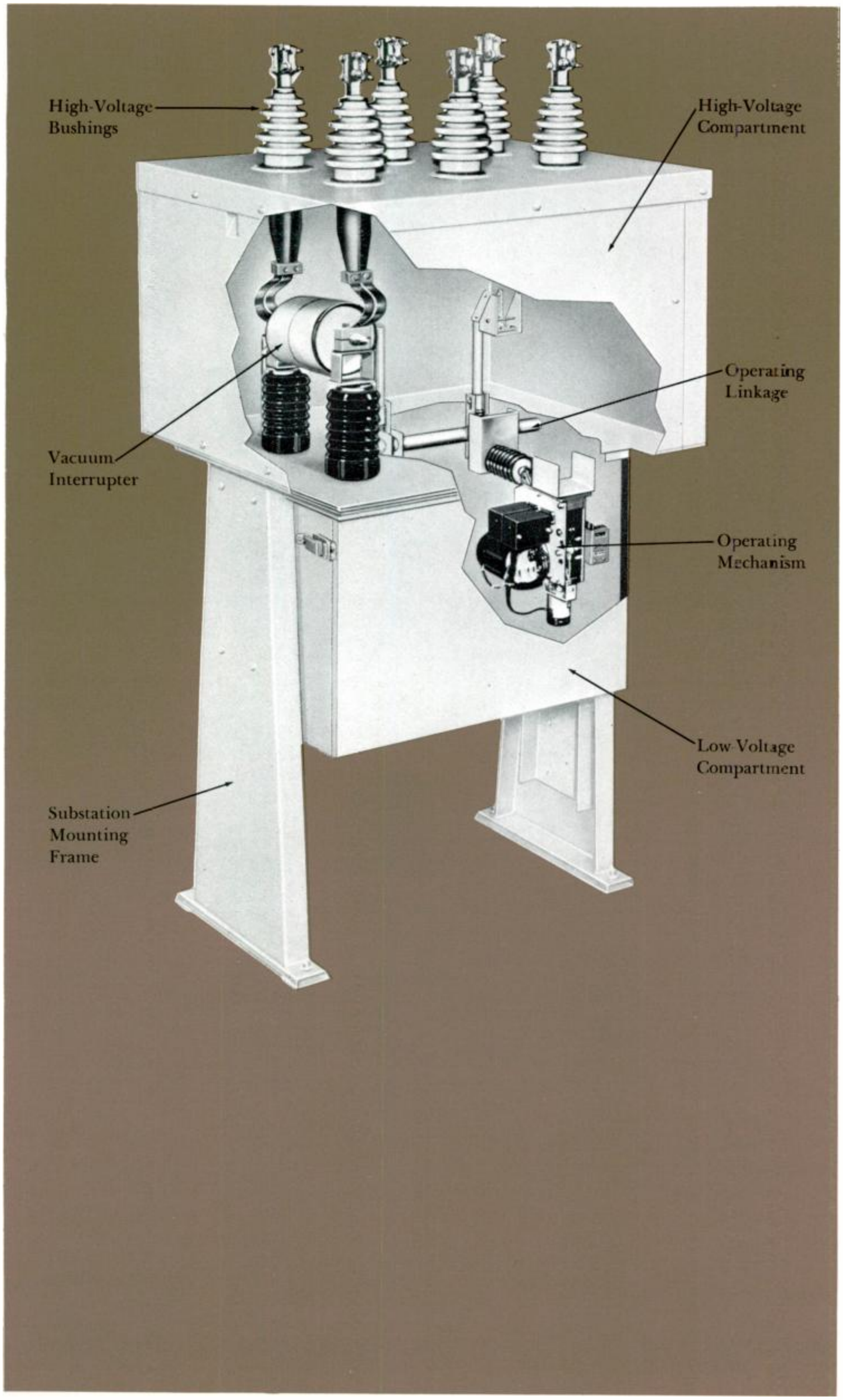


1—The vacuum interrupter (WL-23223) is designed for 15.5-kV circuit breaker service. The interrupter is rated at 600 amperes rms continuous current and is capable of interrupting up to 12,000 amperes rms.

The interrupter consists of two contacts enclosed in a vacuum bottle. A metal bellows permits movement of contact rod but maintains vacuum. The contacts are only 0.5 inch apart when open, a spacing made possible by the vacuum environment. The vacuum bottle has an outside diameter of about 6 inches and the ceramic body is about 8½ inches long.



Since vacuum must be excellent for a vacuum interrupter to function properly, both initially and throughout operation, all interrupter parts are thoroughly degassed during manufacture and processing. Contacts are freed from trapped gas that might contaminate the vacuum by vaporization during arcing. The latest techniques for purifying and degassing materials are used. A ceramic rather than glass envelope permits the bottle to be subjected to high temperature during evacuation to improve degassing.

Circuit Breaker Construction

The breaker cabinet consists of a high voltage compartment that contains the vacuum interrupters, bushings, and bushing current transformers, and a low-voltage compartment that contains the operating mechanism and control functions.

The high voltage compartment is fabricated from heavy gauge steel, and is electrically isolated from the low-voltage compartment. A mounting frame supports the cabinet. The frame is bolted to the high-voltage compartment and is adjustable from 95 inches to 119 inches (Fig. 2).

The high-voltage entrance bushings are constructed in two parts—an extra creep 15-kV porcelain weather shed is potted to a molded epoxy entrance bushing. The molded epoxy bushing provides high strength and extremely low radio-frequency noise level. A solid copper rod is molded into the epoxy bushing and connects the high voltage terminals to the vacuum interrupters.

The vacuum interrupters are mounted directly to the high-voltage compartment floor by six station post insulators and are mechanically isolated from the high voltage bushings. This method of mounting prevents the mechanical forces of the operating mechanism from being transmitted to the entrance bushings and allows complete assembly and adjustment before the high-voltage cabinet is put in place.

2—Vacuum circuit breaker uses three vacuum interrupters, mechanically linked for three-phase operation.

The low-voltage compartment contains the operating mechanism and breaker control equipment. The operating mechanism is motor closed, spring opened, and electrically and mechanically trip free. Mechanical energy, either motor-closing or spring-stored trip energy, is transmitted by the operating mechanism to an operating shaft. The rotational motion of the operating shaft is translated through insulating operating arms and bell cranks to the moving contact rods of the vacuum interrupters.

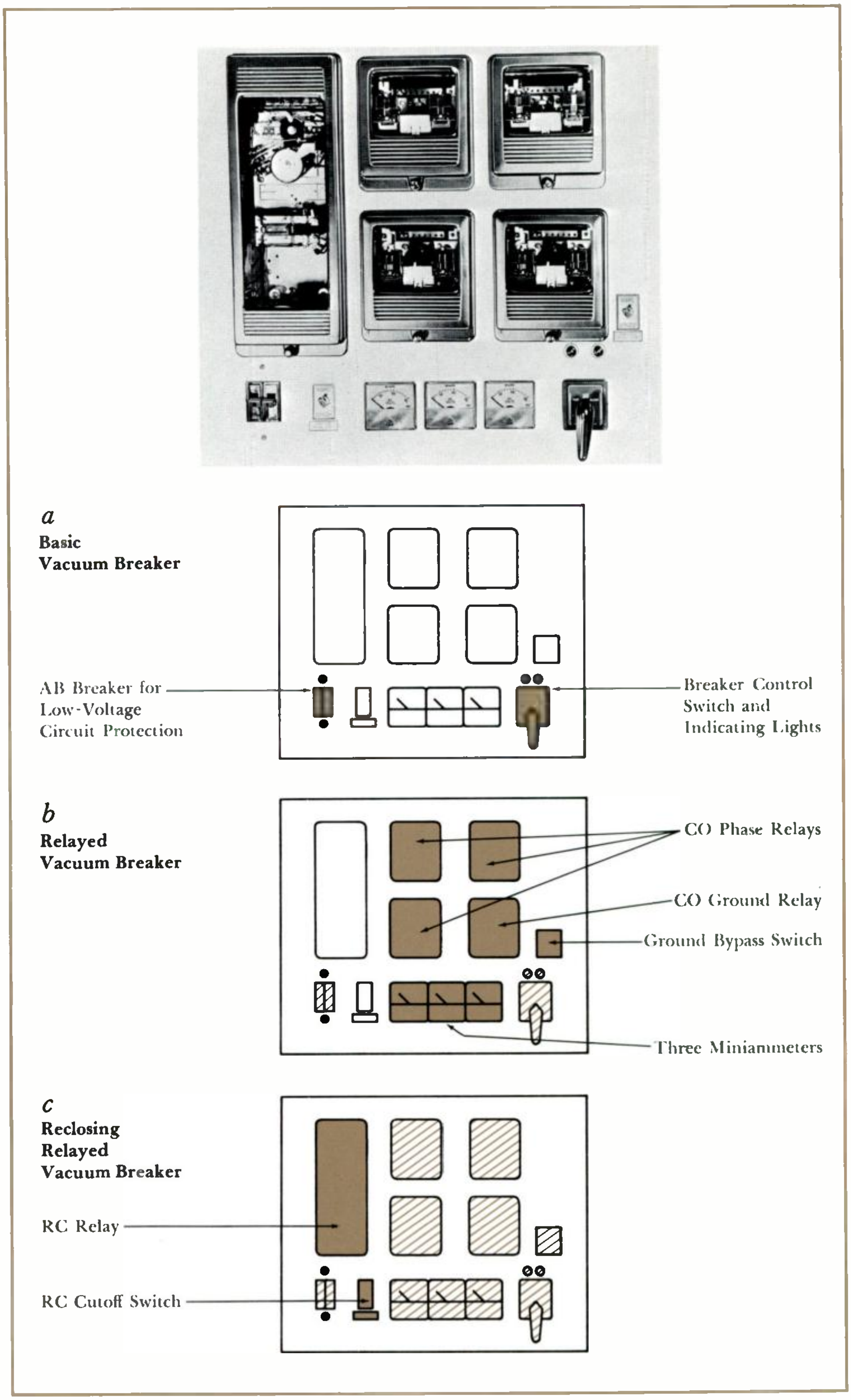
Vacuum interrupter contact pressure is maintained by springs integral to the operating arms to provide overtravel for the mechanism, which assures consistent contact pressure during the life of the interrupter. The entire device is a short throw, high-energy linkage system designed for rapid operation.

An operations counter, contact position indicator, auxiliary switches, and shunt trip solenoid are attached to the operating mechanism.

Breaker Control

Three-phase overcurrent monitoring and protection may be provided by the addition of suitable induction disc relays. A variety of time-delay curves are available for coordination with both primary and feeder devices. An over-current relay for ground fault protection can also be provided as an optional accessory.

Automatic reclosing to restore service automatically after fault clearance is accomplished by adding a reclosing relay, which can be programmed to operate the breaker in the desired sequence of instantaneous and time-delay trip and reclosing operations to clear temporary faults.



3—A hinged control panel is provided inside weather-proof door of low-voltage compartment. It can accommodate three basic control arrangements: The basic vacuum breaker control (*a*) consists of a breaker control switch, indicating lights, and an AB breaker for low-voltage control-circuit protection. For a relay control (*b*), CO phase relays, CO ground relay, and three miniammeters are added. The addition of an RC relay and an RC cut-off switch (*c*) provides reclosing relayed control.

Baseboard Heater Designed for Easy Installation and Clean Operation

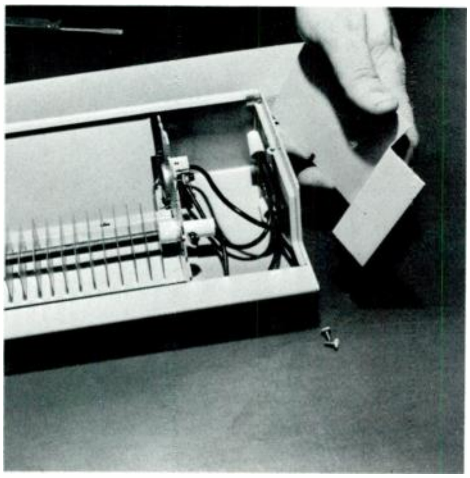
A new line of baseboard electric heaters has been engineered with the installer as well as the user in mind: even the box the heater arrives in is functional. The box has a tear tape for easy opening without staple-stabbed fingers. Once open, it serves as a convenient platform to rest the heater on in front of the wall for wiring. When the heater has been mounted and wired, the box can be slipped over again to serve as a cover while the rest of the room is being plastered and painted.

Installation is made easy by a snap-off cover, large wiring boxes located at both ends of the heater, knockouts in the back, bottom, and side of each wiring box, and prepunched mounting holes. The heater was designed and is built by the Westinghouse Bryant Division.

For the user, clean operation was a major design consideration. The problem of wall streaking is greatly reduced by providing a wide lip (three inches out from the wall) and a flow pattern that funnels air out and away from the wall. In addition, a flexible sealing strip running the full length of the back molds itself to irregularities in the wall to prevent air currents from carrying dirt up between heater and wall.

The heater has a fail-safe overheat sensor that runs the entire length of the interior. The wide upper lip is set at an angle that makes it almost impossible to drop anything into the heater from above—at the same time hiding the inner parts. The body of the heater was designed to support inquisitive children who find it convenient to climb on to peer out of windows or to reach some otherwise inaccessible object; it easily carries a 50-pound load at its center (the weakest point).

The heater comes in lengths of two, three, four, five, six, eight, and ten feet, with heating elements in two densities: 188 watts per foot and 250 watts per foot. Accessories include a built-in thermostat, night light, corner pieces, duplex receptacle section, grilles, blank sections, and an air conditioning receptacle with summer and winter settings.



Baseboard heater has wiring box at each end so it can be wired from either right or left. Cover snaps off for cleaning.

Huge Fans Will Comfort-Control Traffic Tunnel Under Mountain

Twenty-four large centrifugal fans will be installed this summer to provide fresh smoke-free air for motorists traveling through the Big Walker Mountain tunnel on Interstate 77 in Virginia. The tunnel under the 3400-foot mountain will be 4229 feet long. Scheduled for completion by mid-1970, it will consist of two double-lane roadways.

A fan house will be located at each end, with each house ventilating half of the tunnel. Twelve of the fans will be 108¾ inches in diameter and will require 200-hp motors each; the rest will be 98 inches in diameter and operate with 50-hp motors. The smaller fans will exhaust air while the larger ones will bring it in.

The intake fans will supply air to the tunnel via a fresh-air duct above the roadbed connected to small flues that run down the side of the tunnel to introduce air at bumper height. Air will be exhausted through grilles in the roof by drawing it through an exhaust duct in the ceiling to the fan house and out.

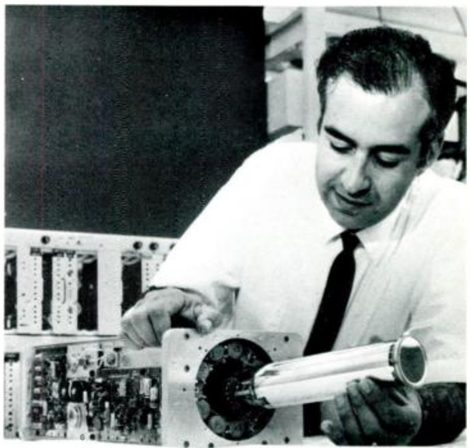
Normally, only 16 of the 24 fans will be needed to keep the tunnel air changing; the others are for standby use. When operating at peak load, the eight exhaust fans will handle a total of 1,824,000 cubic feet per minute and the eight intake fans 1,829,800 cubic feet per minute. The fans were designed and built at the Westinghouse Sturtevant Division.

Document Storage System Employs Video Tape

An electronic system for instant automated document filing and retrieving can store several million documents on two-inch-wide magnetic video tape, like a television program recorded for later viewing. Each document is recorded by a camera-scanner onto the tape, and the documents are arranged alphabetically, numerically, or chronologically. Seven 14-inch reels of tape can store records that ordinarily would require 150 four-drawer filing cabinets.

Unlike microfilm, whose purpose is primarily archive storage, the Videofile Information System developed by Ampex Corporation is intended for day-to-day filing and reference. Time required for electronic delivery of a document is typically 30 seconds.

The heart of the system is a two-inch television image tube in the high-resolution cameras used. The vidicon WX-



Document storage system is based on a two-inch video tube that produces high-quality images for tape storage.

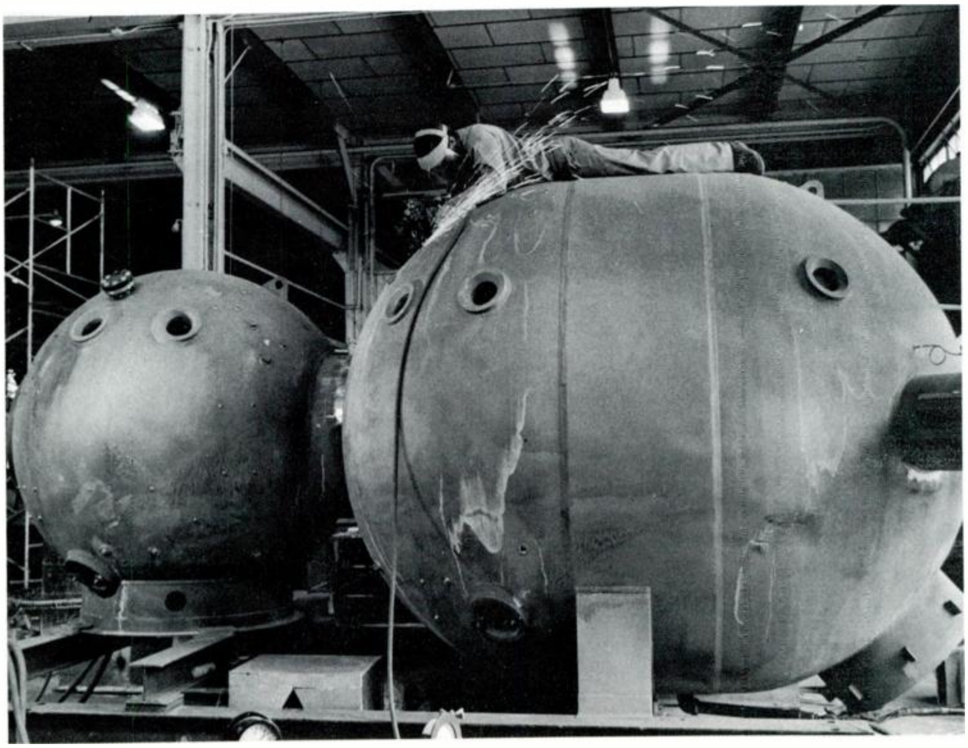
5140 tube, developed by the Westinghouse Electronic Tube Division, produces an image of near photographic clarity.

Deep-Diving Research Facility Nears Completion

One of the key laboratories at the Westinghouse Ocean Research and Engineering Center—the man-rated pressure facility—is nearing completion. When finished, the pressure-chamber complex will be used by life-support engineers and scientists to study diving physiology and equipment and also to train divers. Its maximum pressure capability will be equivalent to that produced by 1500 feet of water, about 700 psi.

The facility will include the pressure chambers and supporting equipment such as breathing-gas tanks and handling systems, compression equipment, instrumentation, and laboratory and office space. Its three chambers can be pressurized independently. The entry chamber, a sphere about six feet in diameter, will be connected by pressure-tight hatches to a second chamber about nine feet in diameter and eleven feet long. Divers and researchers will be able to live in the second chamber for extended periods, a required capability for prolonged-submergence diving research. (However, the chamber complex will also be used for study of the more economical shallow-water diving techniques.) The third chamber is about nine feet in diameter and ten feet long; it will be positioned below and toward the end of the second chamber. Those two will also be linked by pressure-tight hatches, and the lower chamber will be partly filled with water.

Among the research programs planned for the new pressure facility are experiments in prolonged-submergence diving to depths of 1000 feet or more. The experiments will provide the basis for diving tables and techniques for working dives to be made with the Westinghouse Underseas Division's Cachalot-850 saturation diving system. Divers using that system will live under pressure for a week or two weeks, "commuting" to working depth in pairs on a shift basis from a surface pressure chamber by means of a submersible pressure chamber. More than two years' experience with an existing Cachalot system designed for depths to 600 feet has encouraged Westinghouse engineers to expect divers to be able to work proficiently at depths to 850 feet.



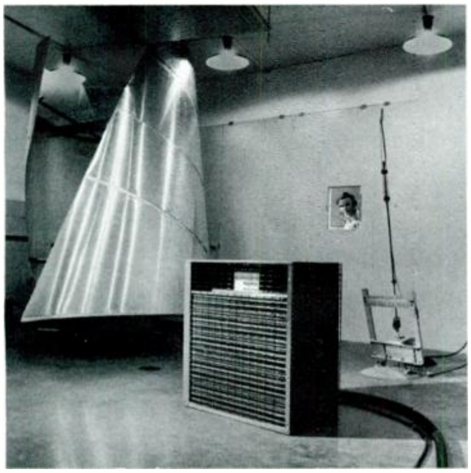
Two of the three pressure chambers for a new deep-diving research facility receive finishing touches. The smaller one is the entry chamber of the three-chamber complex; it is connected to the main chamber by an airtight hatch. The third chamber will be connected to the main one at another airtight hatch seen in the lower right corner of the photo.

Acoustic Test Room Controls Sound Mixing

One type of "sound room" used to test mechanical equipment for acoustical noise is designed to be reverberant by a standard amount (within the tolerances established by ASHRAE Standard 36-62). The reverberation produces mixing that permits the sound spectrum to be scanned accurately with a minimum of microphone positions in the room. However, a hazard with such mixing is that if the sound waves mix in certain ways (determined by the size of the room), certain frequencies are intensified while others are reduced at a given point.

To insure that the sound mixes properly, engineers at the Westinghouse Central Residential Air Conditioning Division use a room with an unusual rotating vane (see photograph). The vane prevents development of standing sound waves by breaking up wave patterns that tend to form, in effect producing a much larger room.

The microphone in the sound room changes sound-wave pressures into electrical signals measured in the equipment room as "sound pressure level." From calibrations of the equipment and room, the sound pressure measurement can be converted into "sound power level," the measure on which the reference standards on noise are based.



Sound room set up to test an air-conditioning unit for noise. The vane at left breaks up sound waves for more accurate measurement.

The sound room not only measures sound that is heard but also frequencies that are too low or too high to be audible. It is used for testing air-conditioning equipment for "noise pollution" according to standard ratings, checking for defective parts, and developing new equipment designs.

Plutonium-Bearing Reactor Fuels Being Developed for Nuclear Plants

Approximately 100 nuclear power plants are expected to go into operation in the United States during the next decade, and, while the plants will use enriched uranium as their basic fuel, each will produce significant quantities of fissionable plutonium as a by-product of uranium fission. Reprocessing the used fuel will result in accumulation of a huge plutonium inventory, which could approach a billion dollars in value. To make use of that valuable inventory, the Westinghouse Atomic Fuel Division has opened a Plutonium Fuels Development Laboratory for developing the technology needed to manufacture plutonium fuel elements for today's nuclear generating plants.

The Laboratory will carry out programs aimed at enabling the Division to design and fabricate plutonium fuel elements with the same degree of confidence attained in uranium fabrication. While learning how best to work with plutonium fuel, the people there will also be learning how best to design a commercial-scale plutonium fuel fabrication plant. The Division expects to begin that plant design in mid-1970 and to complete the design in about a year or a year and a half.

Fuel rods assembled in the Laboratory will consist of about 5 percent plutonium and 95 percent uranium. The initial assignment will be production of 720 plutonium-bearing rods, which will be shipped to an operating nuclear plant and inserted in the core during a scheduled refueling. Performance of the fuel assemblies, and post-irradiation testing programs at the Laboratory, are expected to bring continued refinement of the plutonium fuel fabrication technology to the point where the Division can build the full-scale fabricating facility.

Plutonium Fuels Development Laboratory includes this totally enclosed high-temperature electric sintering furnace. Semiautomatic transfer equipment will move trays of compressed plutonium-uranium pellets through furnace.

Pressing Out Defects Alters Material Properties

A method devised to press out the holes left by missing atoms in the atomic structures of certain defect-laden alloys and compounds may result in a new class of materials. The "ironing" is done at pressures ranging from half a million to a million and a half pounds per square inch and at temperatures between 1500 and 3000 degrees F, and it is followed by rapid cooling. The effect is permanent unless the material is again heated.

Experimenters at the Westinghouse Research Laboratories apply the pressure with a tetrahedral anvil press. All or only some of the holes can be eliminated from a specimen, depending on the degree of property change sought. Properties that can be changed include electrical resistance, elasticity, aging, working characteristics, and magnetic qualities.

One of the materials investigated is titanium monoxide, which has 15 percent of the possible sites for titanium and oxygen atoms unfilled in the natural state. After processing in the press, density had increased 15 percent. When the material's superconducting critical temperature was measured it was found to be 4.14 degrees above absolute zero F—an increase of 2.88 degrees from the normal value. With extremely low temperatures difficult to achieve and maintain, any process that can produce such a rise in a superconducting critical temperature is considered significant.

The technique has two other possible applications considered significant by the Westinghouse scientists. First, eliminating atomic vacancies would simplify experimental study of such fundamental properties as molecular bonding in defect-laden materials. Second, tables relating numbers of vacancies to pressure applied could provide a method of precisely measuring force exerted by high-pressure high-temperature presses.

Unscrambler Improves Communications in Helium-Oxygen Atmospheres

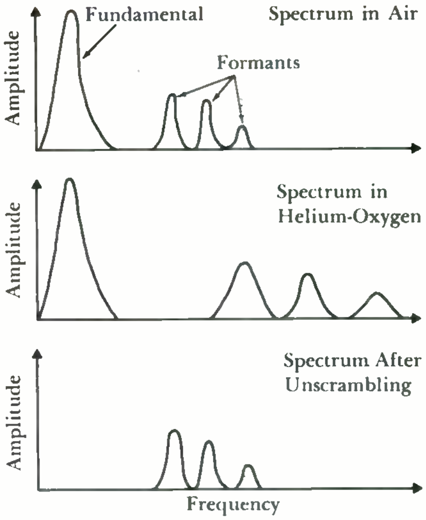
Helium-oxygen breathing mixtures are essential for all types of diving below the 200-foot depth to avoid nitrogen narcosis (the "rapture of the deep") and oxygen toxicity, a poisoning caused by too much oxygen under pressure. Unfortunately, a helium-oxygen atmosphere distorts speech, so deep divers until recently have had to remain content with marginal voice communications with the surface.

Now, however, the Helium Speech Unscrambler, developed at the Westinghouse Ocean Research and Engineering Center, effectively eliminates the voice communications problem. An Unscrambler of the type shown in Fig. 1, originally developed for the Office of Naval Research, has been installed in the command station for Sealab III, the latest in the U.S. Navy's underwater laboratories.

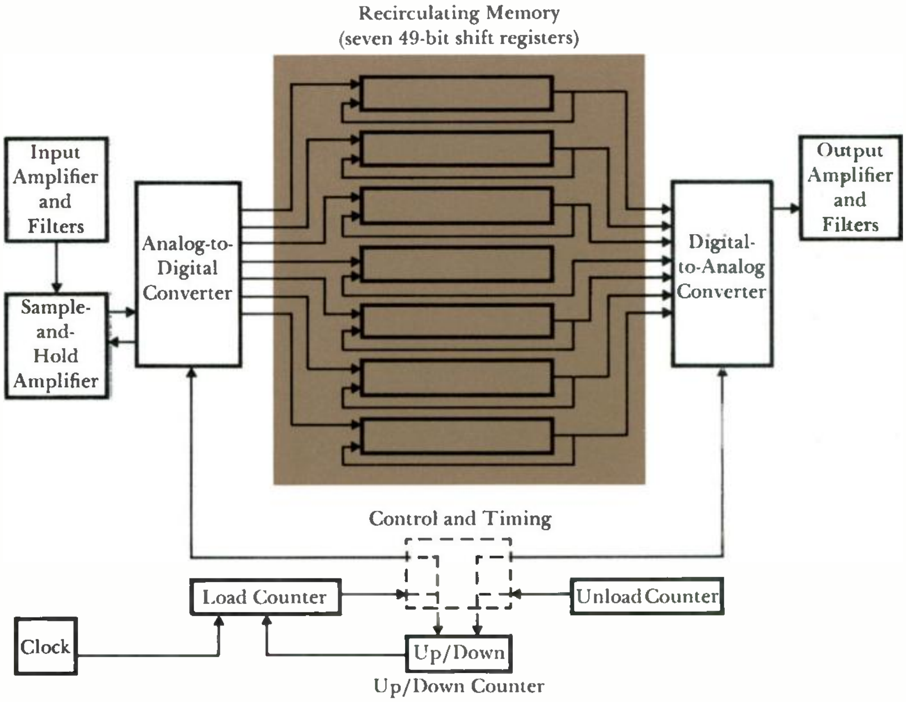
Fundamental frequency components in human voices are essentially the same in helium-oxygen atmospheres as in air. However, all formants (the frequency-related characteristics of speech sounds—similar to harmonics) are shifted upward in a way that can be approximated by a constant multiplication factor. The Unscrambler operates by loading the helium speech into a digital storage system and then removing it (with amplitude information preserved) at a slower rate than that at which it was loaded; the difference between loading and unloading rates provides the downward shift in frequency required to make the speech intelligible (Fig. 2). The process is directly analogous to playing a tape recording of helium speech at a speed slower than its recording speed.

However, since speech is stored at a rate higher than the rate at which it is removed, the storage fills up periodically. When that occurs, further input must be inhibited until the storage is emptied. (Otherwise, samples of the speech in storage would be destroyed by having more recent samples written into the same space.) The Unscrambler, then, shifts the frequency of helium speech down to normal levels until its memory is filled; then its input is interrupted until

1—Model Digital-1 Helium Speech Unscrambler built and tested for the Office of Naval Research for use in the Sealab III command station. A manual mode allows the load and unload rates to be finely adjusted by thumbwheel switches.



2—Unscrambler operation is illustrated by comparing frequency spectrums for a word spoken in air, in helium-oxygen atmosphere, and after unscrambling. The Unscrambler filters out the fundamental frequency and shifts the formants back down.



3—Major components of the Helium Speech Unscrambler. An incoming speech sample is converted to a digital word so that its frequency can be shifted downward as it leaves the recirculating memory for conversion to intelligible speech.

the memory empties and operation can resume. No significant portion of the speech is lost, because the interruption time is only 5 to 10 milliseconds, while basic speech components (vowels, consonants, and syllables) require from 30 to several hundred milliseconds.

The Helium Speech Unscrambler is basically a frequency divider of helium speech (Fig. 3). The incoming speech signal is brought to proper strength and its fundamental frequency removed by the input amplifier and filters before it reaches the sample-and-hold amplifier. A convert command pulse, generated by the load counter and applied to the analog-to-digital converter, initiates a conversion cycle during which a sample of the incoming signal is converted to a seven-bit digital word. An enable pulse is generated by the load counter before the convert command to transfer the previously converted sample to the recirculating memory.

The memory consists of seven 49-bit shift registers operating at a 2-MHz clock rate. A strobe pulse, generated by the unload counter, is applied to the digital-to-analog converter to transfer the digital word from the memory to a storage register in the converter to produce an analog signal. At time intervals determined by the load and unload counters, operating according to the setting of the frequency shift switch, digital words are transferred into and out of the recirculating memory.

An up/down counter monitors the loading and unloading of digital words in the memory. The load counter registers an *up* count for each load pulse, and the unload counter registers a *down* count for each unload pulse. When a count of 49 is reached, the input to the load counter is inhibited for a period of 49 unload pulses during which the memory is cleared. When the up/down counter reaches state zero, the inhibit to the load counter is removed and the loading and unloading operation resumes.

Much smaller unscramblers than the one in the photograph could be made by using solid-state components, so future models could be carried on the belts of untethered divers—instead of in the mother craft—for efficient radio intercommunication. (Tethered divers can communicate with each other and the surface by their connecting transmission lines, permitting the unscrambler to be centrally located.)

The Helium Speech Unscrambler is thus applicable to all deep-submergence uses, including diving systems and vehicles. It is, in fact, useful wherever helium-oxygen atmospheres are employed, regardless of pressure. For example, manned space vehicle applications are foreseen.

One final application being tested concerns normal, not helium, speech. Frequency division compresses the transmission bandwidth and thus reduces the required bandwidth of the transmitter, resulting in use of significantly less transmitter power for equivalent distances.

Products for Industry

Base rate controller (WRC-1) is an accurate digital device that provides demand control information. The information can be used to initiate control operations of various types of external interface equipment (such as motor-driven rheostats, tap changers, circuit breakers, and warning lights) to add or drop load so that high load factors can be maintained without exceeding contractual demand limits. The controller generates its own base pulse rate and compares it with the demand pulse rate from the utility billing meter. When demand rate approaches the preset base rate, control circuits signal the external interface equipment to take action. *Westinghouse Meter Division, P.O. Box 9533, Raleigh, North Carolina 27603.*

Detachable instruments are taut-band-suspension devices (Types EA-251 and EX-251) for convenient and economical monitoring of ac or dc electric power at the point of use. Main use is on drive motors where motor loading depends on conditions controlled by an operator; the instrument reading enables the operator to optimize conditions. The instruments plug into standard watthour meter sockets that can be sealed off when not in use. The ac units can handle about 35 times normal current and the dc instruments about 150 times, on a momentary basis, without damage. *Westinghouse Relay-Instrument Division, 95 Orange Street, Newark, New Jersey 07101.*

Data reader camera system includes an electronic camera that converts optical images to precise electrical signals that represent the image data in digital form. Scanning commands can be supplied by any digital computer or by the small specially programmed computer available as an option. The optional unit directs the camera's scan and also delivers the output for storage or processing by other data-reduction equipment. Applications include medical electronics, natural-resource exploration, topographic imagery, astronomical photography, and automated reduction of photographic data and chart records. *Westinghouse Astroelectronics Laboratory, P.O. Box 245, Newbury Park, California 91320.*

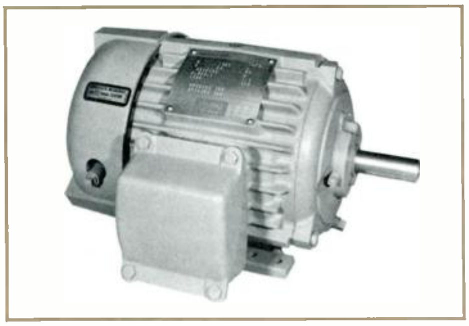
Packaged computer room that includes everything but the computer is custom-engineered in modules to fit the user's needs. The package can include design of the room and manufacture and installation of all components—raised floor, partitions, ceiling, air conditioning, lighting, even light switches and cover plates. Its air-conditioning system has precise automatic controls for temperature regulation (plus or minus two degrees) and

Packaged Computer Room

humidity regulation (plus or minus five percent). Filters maintain cleanliness. *Westinghouse Architectural Systems Department, 4300 36th Street, Grand Rapids, Michigan 49508.*

140T-frame induction motors of cast-iron construction meet the need for rerate corrosion-proof ac motors in ½- to 2-hp range. Essentially all exposed parts of the Life-Line T totally enclosed fan-cooled motors are of cast iron for reliable rust-free operation in dirty and corrosive industrial atmospheres. AGMA flange required for gearmotors is a standard option, permitting combination with Moduline cast-iron gear units. Other options include C-flange and D-flange, either footless or foot mounted. *Westinghouse Medium AC Motor and Gearing Division, 4454 Genesee Street, P.O. Box 225, Buffalo, New York 14240.*

Portable welding control and wire drive facilitates high-quality gas-shielded welding at hard-to-reach locations up to 100 feet away from an arc-welding power source. The SA-210 ToteM-Pak control and drive weighs 39 pounds when fully loaded with a ten-pound spool of welding wire. It is designed for use with an air-cooled torch and a constant-voltage dc welding power supply. Wire speed stays constant with load changes, and the speed settings range up to 700 inches per minute. *Westinghouse Welding Department, P.O. Box 300, Sykesville, Maryland 21784.*



140T-Frame Induction Motor

Portable Welding Control

Load-break bushing for use on distribution system equipment is made of cast epoxy and is completely shatterproof, with no possibility of the material fracturing or ejecting pieces. The non-vented bushing is interchangeable with elbow connectors supplied by various manufacturers. It includes a metal collar for welding to the transformer tank, and provision also is made for mounting with a gasket and internal flange. Contacts can be removed and cleaned or replaced. The bushing is rated as a 200-ampere load-break device and can be closed in on a 10,000-ampere fault. *Westinghouse Distribution Transformer Division, Sharpsville Avenue, Sharon Pennsylvania 16146.*

Periguard intrusion detection system protects such installations as industrial plants, warehouses, research facilities, unattended power and pumping stations, private homes, and swimming pools. Pressure changes in the earth caused by the intruder are registered by a pair of buried liquid-filled sensor hoses, which may extend up to 750 feet. The hoses transmit a signal to a control location, where an alarm is initiated on a system panel layout visually, audibly, or both. Electronic cancelling prevents false alarms from pressure changes caused by ground conditions, temperature cycles, seismic disturbances, or other general ground movements. *Westinghouse Specialty Electronics Division, P.O. Box 8606, Pittsburgh, Pennsylvania 15221.*

Test stands for aircraft generators and constant-speed drives have thyristor power supplies and transistor speed regulators for improved speed control, reliability, efficiency, and response. No motor-generator sets are required. Speed range is 0 to 12,000 r/min, there are no starting transients, and maintenance costs are reduced. Stands include drive assembly, power supply and speed control assembly, 40- to 120-kVA load bank, metering console, and oil supply for constant-speed drives and oil-cooled generators. Ratings are from 55 to 200 hp for testing generator and constant-speed drive packages with outputs to 120 kVA. *Westinghouse Aerospace Electrical Division, P.O. Box 989, Lima, Ohio 45802.*

New Literature

Application of Balancing Transformers to Spot Networks is a 12-page booklet (B-9458) that presents problem-solution information on the large electrical demands placed on local substations by "megaplazas"—the big multistore shopping complexes being built in large numbers. Topics discussed and illustrated include standard protector-and-relay and balancing-transformer application, network systems requiring balancing transformers and special relays, balancing-transformer fundamentals and analysis techniques, and system analysis procedure and application rules. Example problems are presented, as well as curves to determine if balancing coils can be used to allow network operation from feeders supplying other loads. *Westinghouse Power Transformer Division, 469 Sharpsville Avenue, Sharon, Pennsylvania 16146.*

Precision Heating for Quality Steel is an 18-page booklet on induction heating applications in the steel industry. The applications section includes diagrams and photographs of heating installations for bar-stock processing, continuous casting, strip processing, and pipe manufacturing. Another section contains cost, time, and efficiency estimating guides. Also included are short summaries of the uses of induction heating in the steel industry and its application advantages. *Westinghouse Industrial Electronics Department, 2519 Wilkens Avenue, Baltimore, Maryland 21203.*

About the Authors

John W. Wallace is Projects Manager, Rolling Mill Systems Group, Metals Industry Systems Department, Industrial Systems Division. The projects group that he heads is responsible for engineering and designing electrical drive systems for hot and cold rolling mills.

Wallace has been involved in feedback systems analysis, systems and design engineering, negotiation work, proposal writing, and project handling for the metals industries ever since he joined Westinghouse on the graduate student training program in 1951. Developments he has been responsible for or contributed to include various feedback control systems, mill automatic control, automatic gauge control, a looper control system, use of computers in control, and analog computer studies.

Wallace served as an electronics technician on Navy destroyers in World War II and the Korean War, and he graduated from Case Institute of Technology with a BSEE in 1951. His first permanent Westinghouse assignment was to the former Systems Control Division in Buffalo. He was transferred to the Industry Engineering Department at East Pittsburgh in 1961 and then back to Buffalo in 1964 when the Industrial Systems Division was formed. He was appointed to his present position in January 1967.

E. E. Hogwood graduated from the University of Texas in 1952 with a BSEE degree, and he has since taken graduate work at the University of Pittsburgh. He joined Westinghouse on the graduate student training program and was assigned to the former Industry Engineering Department. Projects he worked on there include electrification of oil drilling rigs, remote control of pipeline pumping stations, and oil well automation. He also coauthored, with J. K. Howell, the book *Electrified Oil Production* published by *Oil and Gas Journal* in 1962.

Hogwood was transferred to the Transportation Division in 1964. As assistant project engineer for the Bay Area Rapid Transit Demonstration test track program, he contributed to development of a train control system for the tests. Since then he has been responsible for development of the Tampa International Airport passenger transfer system and for other airport passenger transfer systems now in negotiation.

R. B. Maguire joined the Hillsborough County Aviation Authority in 1965 as coordinator of the engineering, architectural, and other technical effort for the new Tampa International Airport terminal and for other Authority projects. He is Assistant Director (Engineering) of the Authority.

Maguire is a registered professional engineer in Florida. He graduated from Loyola College, Baltimore, in 1936 with an A.B. degree. Before joining the Hillsborough County Aviation Authority, Maguire worked on various airport, bridge, and highway projects as an inspector, resident engineer, designer, and project manager.

W. E. Treese graduated from Tri State College with a BSEE in 1954 and joined Westinghouse on the engineering and service (E & S) training program. His first assignment as an E & S Engineer was field testing large steam turbine generators. He then moved to the Aerospace Electrical Division as a field service engineer to work on aircraft generation equipment. He was made a supervisor in the Westinghouse Aerospace Repair Plant at Compton, California, in 1959 and is presently Plant Manager.

Robert W. Terry, who collaborates with Treese in describing the movie power supply system in this issue, is a graduate of the University of Nebraska (BSEE, 1958). He came with Westinghouse on the graduate student training program and was assigned to the aircraft generator design section in the Aerospace Electrical Division. There he worked on the electrical design of a wide variety of ac and dc electrical power supply generators for special applications. He transferred to the Compton Aerospace Repair Plant in late 1967. As Plant Engineer, he performs engineering duties associated with design, maintenance, repair, and test of a large variety of airborne electrical power system components and their support equipment.

David K. Sloper and **Jon Stuart Squire** have been coauthoring aerospace computer developments at the Aerospace Division for several years, with Sloper concentrating on hardware and Squire working on software. Thus, their coauthored article on the general-purpose space computer in this issue is a natural extension of their everyday work.

Sloper graduated from Dartmouth College with an AB degree in 1960 and continued at the Thayer School of Engineering to obtain his MS degree in 1961. He then came to Westinghouse, and, after the graduate student training program, began working on logical design for aerospace computers. He moved to hardware design in 1962 when he began work on the SOLOMON breadboard model, an experimental computer design that utilized the principles of parallel processing. Sloper next performed study, research, and design work on associative memory systems. He conducted complete logical design of a serial general-purpose computer and a high-speed aerospace computer, both of which are now in operative systems. He next worked on the design of a torpedo guidance computer, a fire-control computer, and, most recently, the general-purpose spacecraft computer described in this issue.

Sloper is a registered professional engineer in the state of Maryland.

Squire is a graduate of the University of Michigan, with a BSEE (1960), an MSEE (1962), and an MS in Mathematics (1963). While he was working for his master's degrees, he served as an instructor in the Department of Mathematics at Michigan and also worked for the University of Michigan Research Institute. There he developed a number of translator programs and worked on the machine organization of a multiple-processor computer.

Squire joined the Westinghouse Aerospace Division in 1963 to work on the preliminary design of the SOLOMON software, the same computer for which Sloper was developing hardware. He has since worked on numerical techniques for other advanced computers and on compiler programs for NELIAC and FORTRAN languages. He directed the software development for several special-purpose computers and for the general-purpose computer described in this issue.

S. John Cherry and **Robert A. Few** represent the Westinghouse divisions responsible for development of the new vacuum circuit breaker described in this issue.

Cherry is with the Electronic Tube Division and is manager of vacuum interrupter engineering, where the new interrupter was developed. He is a graduate of Newark College of Engineering with a BSEE (1936). Upon completing the Westinghouse graduate student training program, he moved to the Lamp Division in 1937 to work on power tubes. When the Electronic Tube Division was established in 1951, he was a section engineering manager in the power tube factory and moved along with the section to the new plant in Elmira. He has since served in a number of management positions—manager of quality control, manager of special-purpose manufacturing and engineering, manager of image and storage tube manufacturing and engineering and, presently, manager of vacuum interrupter engineering.

R. A. Few joined Westinghouse in 1949 after obtaining his BME from Clemson College. After the graduate student training program, he joined the Aviation Gas Turbine Division in Philadelphia as a design engineer in the mechanical design section. When the division moved to Kansas City in 1955, he moved with the division. He served as a supervising engineer in the mechanical design section and in the preliminary design and development section, contributing to the design of the J40 and J46 turbojet engines.

Few joined the Distribution Apparatus Division in 1960 as a design engineer in the recloser and switch engineering section. He is presently manager of the overcurrent protective equipment engineering section, responsible for development of reclosers, sectionalizers, switches, fuse cutouts, and the vacuum breaker described in this issue.

A leaktight glove box is used for grinding nuclear fuel materials at the new Westinghouse Plutonium Fuels Development Laboratory. The facility will speed development of techniques for using plutonium in fuel elements for present-day nuclear power plants. For more information about it, see page 29.

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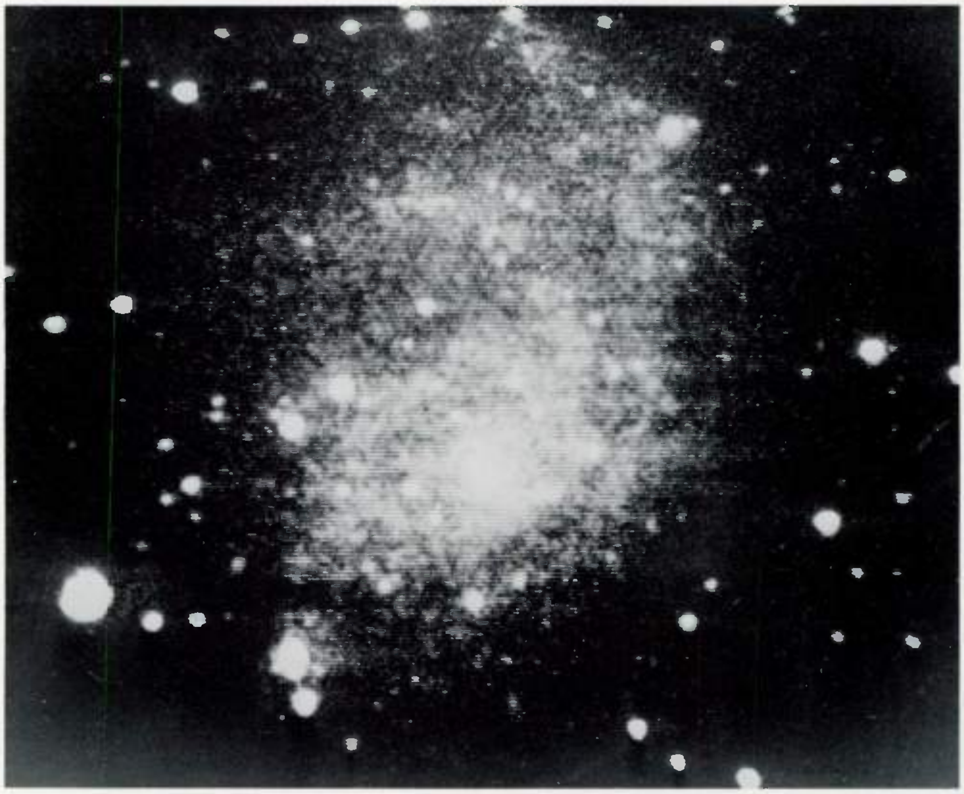
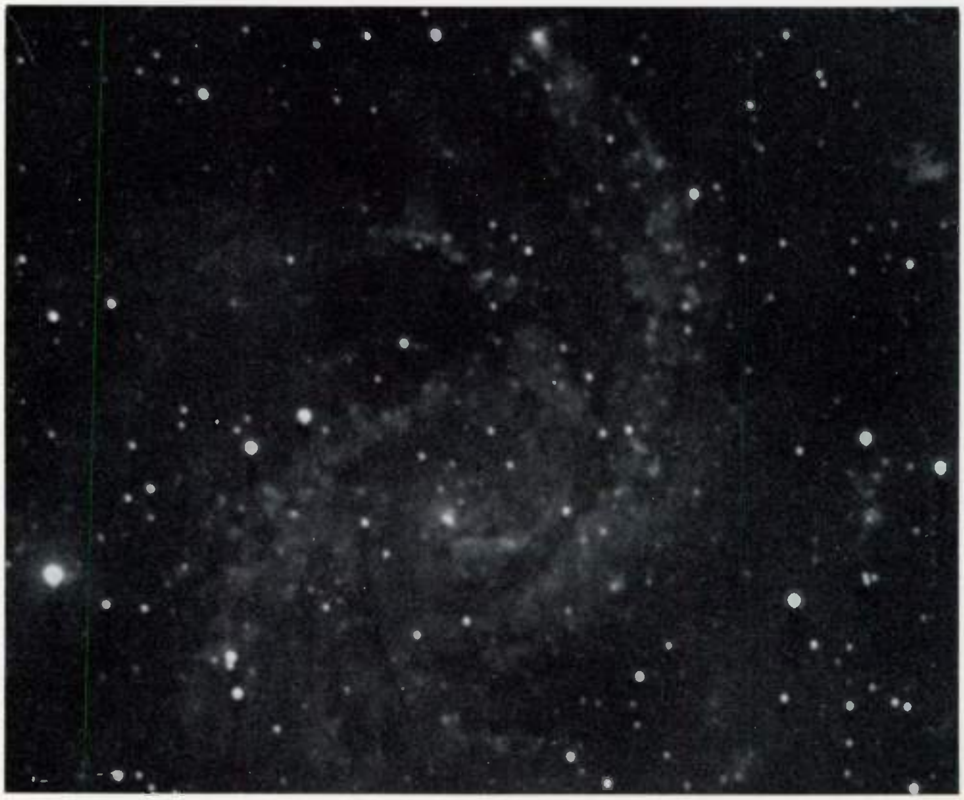
The top picture, clearly showing the large galaxy NGC-6946, was made in two seconds with a telescope and low-light-level television equipment. The bottom picture of the same area of sky was made by the conventional procedure of exposing a photographic plate directly through the telescope; it barely shows the same galaxy after an exposure of an hour and a half. Both pictures were made with the 36-inch telescope at the McDonald Observatory of the University of Texas. The television equipment, consisting of an electrostatic image intensifier coupled to an SEC camera, is being developed by Westinghouse engineers to speed surveys of the heavens. Another application of SEC image tubes in astronomy is described on page 63.





Westinghouse ENGINEER
March 1969, Volume 29, Number 2

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

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

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

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Deepstar; Prodac.

Cover design: A conveyor table, consisting of many rollers powered by individual permanent-magnet dc motors operating in unison, feeds steel to the rolling mill represented in Tom Ruddy's cover design. Permanent-magnet motors and their varied uses are discussed in the article beginning on page 46.

Probability Calculation of Generation Reserves

C. J. Baldwin

System planners have used probability methods extensively over the last ten years to solve their long-range generation planning problems. The most recent computerized approaches use continuous probability distributions of peak load and available capacity, rather than discrete values, to determine adequacy of generation reserves.

The application of probability methods to the long-range generation planning problem is most important to electric utilities committing large units for service with long lead times. Generation reserves at any given instant are affected by two chance or random events—forced outages of generator units on the system, and system load. Thus, generation reserve can never be predicted *exactly* for any specific time in the future. However, with appropriate probability techniques, utility planners can determine the system generation capacity required to provide reasonable assurance of maintaining a satisfactory generation reserve.

Forced outages of generator units are generally chance events. They occur for a variety of reasons in the steam generator, auxiliaries, prime movers, and the generator itself. Outages for any particular unit may be considered a sequence of random occurrences, which can be represented by a probability distribution. Analysis of historical data provides the basis for the probability representation of existing generating units. Forced outage predictions for new units must be engineering estimates of future performance.

Utility loads are random fluctuations about some mean system load, another probability distribution. With probability mathematics, the forced-outage and load probability distributions can be combined to determine the probability of not having sufficient generation reserves.

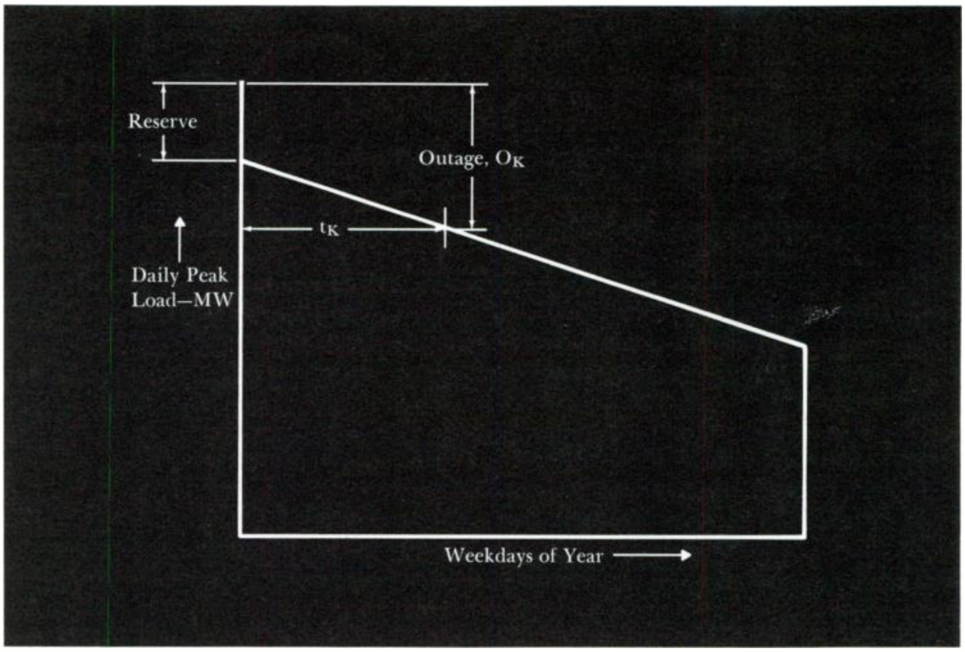
When long-term load forecasts of system planners are used for the calculation, *installed* reserve requirements are found from the probability combinations. If short-term forecasts of system operators and probabilities of their forecast error are used, *operating* reserves are determined. These two types of reserves are calculated for distinctly different purposes: The former indicates necessary generation purchases and installation schedules; the latter determines the required number of units to operate from a given complement of available units.

Probability Methods Using Discrete Values

The earliest application of probability mathematics to the generation reserve problem used the binomial expansion (see *The Binomial Expansion*). This technique provides a table of outage probabilities for discrete values of generation outage capacity, similar to Table IV. These outage probabilities are combined with a graphical expression of load variability, in the form of a daily peak duration curve (Fig. 1), to produce the so-called loss-of-load probability.[1]

Loss-of-Load Probability—The daily peak duration curve of Fig. 1 gives the number of weekdays of the year that the daily peak load will reach a certain value. The contribution to system loss-of-load probability (in days per year) for each outage of a particular magnitude (O_k in Table IV) is the probability of that outage (p_k) multiplied by the number of days (t_k) for which there will be a loss of load. The probabilities for all the various outage magnitudes (for the days of a given year) are summed to obtain a yearly loss-of-load probability. The binomial expansion is sometimes done on a monthly basis also, to account for the variations due to units scheduled out on maintenance. For large systems, however, a monthly binomial expansion increases computing time substantially and still allows only an approximate model of maintenance because it does not allow for maintenance periods shorter than one month.

Another fundamental shortcoming of the loss-of-load probability method is that it does not take into account the *uncertainty* of the forecasted annual peak in Fig. 1. The more accurate loss-of-load probability (P_i) is the summation of the expectancies of all deviations from forecast peak multiplied by the loss-of-load probability associated with each deviation: *Loss-of-Load Probability* = Σ (*Proba-*



1—Daily peak duration curve gives the number of weekdays of the year that daily peak will reach or exceed a certain value.

C. J. Baldwin is Manager of Development, Advanced Systems Technology, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania.

The Binomial Expansion

The binomial expansion is one of the fundamental probability-generating functions used in probability mathematics. Applied to the generator outage problem, it uses the forced outage rate (p) for the units of a group (the probability of the existence of an outage on each unit) to predict the probability of any simultaneous combination of unit outages in the group.

The probability that a unit outage exists or does not exist must be unity. Thus, if the outage rate is p, then the probability that an outage does not exist must be $1-p=q$. For an n-unit group, each unit in the group having identical p and q probabilities, the probabilities for all possible combinations of unit outages are given by the binomial expansion,

$$(q+p)^n = q^n + nq^{n-1}p + n(n-1)q^{n-2}p^2 + \ldots$$
$$\ldots + \frac{n!}{r!(n-r)!}q^{n-r}p^r \ldots + p^n$$

where r is the number of machines out of service at one time due to forced outages. Thus, the probability of exactly r outages is given by the $(r+1)$th term of the expansion,

$$\frac{n!}{r!\,(n-r)!}q^{n-r}p^r$$

which is the binomial probability function.

To illustrate the application of the binomial expansion, consider a hypothetical system consisting of four 20-MW units, each with an outage rate of 2 percent, and three 30-MW units, each with an outage rate of 2 percent. Considering first the group of four 20-MW units, $p = 0.02$, $q = 0.98$, $n = 4$, $r_1 = 0, 1, 2, 3$ and 4, the binomial expansion yields the outage probabilities,

$$\begin{aligned}(0.98 + 0.02)^4 = 0.922368 &+ 0.075296\\ &+ 0.002304 + 0.000032\\ &+ 0.00000016,\end{aligned}$$

which are tabulated in Table I.

Similarly, the binomial expansion for the three 30-MW units gives the outage probabilities listed in Table II.

To determine the probabilities of combinations of 20-MW and 30-MW units being out simultaneously, the probabilities from Tables I and II must be combined in matrix form, as shown in Table III. For example, an outage of 0 MW on the system can only be obtained when both r_1 and $r_2 = 0$, so that the probability of a 0 MW system outage is $0.941192 \times 0.922368 = 0.868125$. Similar calculations are used to determine probabilities for other combinations of unit outages, as listed in Table III.

If system outages are considered in terms of megawatt capacity rather than specific units, there will be instances in which more than one combination of unit outages can produce the same total megawatt outage. For example, an outage of 60 MW can result from two 30-MW unit outages, or from three 20-MW unit outages. Therefore, the probability of obtaining a 60-MW outage must be the sum of the probabilities of the possible combinations; thus, from Table III, the probability of a 60-MW outage is: 0.000030 + 0.001085 = 0.001115. The probabilities (p_k) of specific capacity outages are listed in Table IV.

For each step of outage capacity, the sum of the probabilities for all possible outages occurring must equal 1.0. Thus, the probability of an outage of 0 MW *or more* is a certainty and is therefore equal to 1.0. The probability of an outage of 20 MW or more will be the same as for 0 MW less the probability of an outage exactly equal to 0 MW. (The probability of an outage of 20 MW or more is also equal to the sum of all individual probabilities of outages equal to 20 MW and above.) In this way, the cumulative probability values (P_k) tabulated in Table IV were derived.

Table I. Outage Probabilities for 20-MW Units

Number of Units Out (r_1)	*Outage Capacity—MW*	*Probability of Outage*
0	0	0.922368
1	20	0.075296
2	40	0.002304
3	60	0.000032
4	80	Negligible

Table II. Outage Probabilities for 30-MW Units

Number of Units Out (r_2)	*Outage Capacity—MW*	*Probability of Outage*
0	0	0.941192
1	30	0.057624
2	60	0.001176
3	90	0.000008

Table III. Outage Probabilities for Combinations of 20- and 30-MW Units

		Three 30-MW Units			
	$r_1 \backslash r_2$	*0*	*1*	*2*	*3*
	0	0.868125	0.053150	0.001085	0.000007
Four 20-MW Units	1	0.070868	0.004339	0.000089	..
	2	0.002168	0.000133	0.000003	..
	3	0.000030	0.000002	..	..
	4	..	..	..	..

Table IV. Probabilities for Capacity Outages with 20- and 30-MW Units

Outage—MW O_k	*Probability of an Outage Exactly Equal to* O_k p_k	*Probability of an Outage Equal to* O_k *or More* P_k
0	0.868125	1.000000
20	0.070868	0.131875
30	0.053150	0.061007
40	0.002168	0.007857
50	0.004339	0.005689
60	0.001115	0.001350
70	0.000133	0.000235
80	0.000089	0.000102
90	0.000002	0.000013
100	0.000003	0.000011
110	..	0.000008
120	..	..

bility of Deviation)×*(Loss-of-Load Probability)*.

Outage probability is commonly expressed in years per day as either a monthly risk or an annual risk: *Monthly Risk (Years/Day)* $=1/12\ P_i$, *for Month i; Annual Risk (Years/Day)* $=1/(P_1+P_2+\ldots+P_{12})$, where P_i is the expected number of days in month i in which system peak load cannot be met. P_i can also be defined as the sum of the daily probabilities in month i of having zero installed reserve margin or less.

Note that annual risk is the average of all the monthly risks. The utility planner who bases his expansion plans on an annual risk of load loss should be careful that most of his annual risk is not being accumulated over a relatively small part of the year, perhaps the month or two during which his annual peak occurs. If this should be the case, a generation reserve planned on the basis of yearly risk could be in real trouble during the annual peak period.

Loss-of-Energy Probability, the expected per-unit energy curtailment, is an alternate measure of reliability. The method is similar to the loss-of-load technique except that the outage area under the load duration curve is calculated for each outage condition. This area times the probability of the outage, divided by the total area under the load duration curve, gives the energy curtailment on a per-unit basis. The various outage conditions are summed to get the expected per-unit energy curtailment on either a monthly or yearly basis.

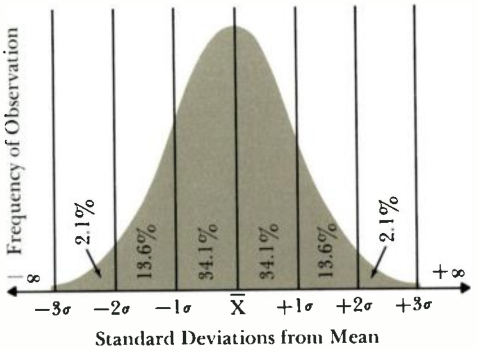
Frequency and Duration of Outage is another method of expressing system reliability. The average expected frequency and duration of all possible forced outage conditions for the power system are determined. Unlike the loss-of-load method, where the probability of a particular outage *capacity* was found, this method separates the different ways that an outage can occur. For example, an outage of 60 megawatts can be obtained by loss of either three 20-MW units or two 30-MW units, which have outage probabilities of 0.000030 and 0.001085, respectively. Knowing this and the average down time for these unit sizes, the frequency of the outage occurring in a particular way is

$$D_r = P_r\left[\frac{r}{t} - \frac{(n-r)}{(1-p)T}\right]$$

where D_r is the outage frequency (times/year), P_r is the probability the outage will occur in a particular way, r is the number of units out, n is the total number of units, t is the average outage duration, T is the average interval between outages, and p is the average forced outage rate corrected for unit exposure by multiplying the unit forced outage rate by the fraction of the year the unit is in service.

The frequencies for the different ways a particular outage occurs are summed to get a total frequency of occurrence for that outage. After calculations have been made for all the different outage possibilities, the frequency of a capacity outage equal to or exceeding a specified amount can be found. Then the average duration of an outage of X or more megawatts is the probability of an outage of X or more megawatts divided by its frequency of occurrence. The interval between outages of X megawatts or more is merely the reciprocal of the frequency.

Knowing the annual peak, the installed capacity, and the capacity on maintenance during the month that the annual peak occurs, it is possible to plot annual peak load versus the duration of and interval between outages equal to or exceeding the effective reserve. If the calculation is terminated here, it does not allow for uncertainty of the load forecast nor variability of the daily loads.



2—The normal distribution curve is based on one of the fundamental concepts of probability. This concept contains two principal postulates: (1) A variable (x) has a tendency to cluster about a center, or *mean* value ($\bar{x}$); and (2) individual readings will differ from the mean in a random but predictable pattern.

The amount by which the data differs from the mean value is expressed in terms of *standard deviation* (σ), which is the root mean square of the individual deviations from the mean, or:

$$\sigma = \sqrt{\frac{\Sigma\,(x_i - \bar{x})^2}{n}}$$

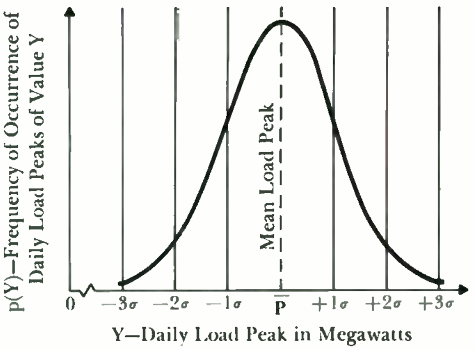
where x_i is each individual reading and n is the number of readings.

The standard deviation provides an indication of the dispersion (randomness) of data. If it is large in proportion to the mean value, the data varies widely; if small, dispersion is small, and a larger proportion of the data is near the mean value.

The standard deviation is an extremely useful means for analyzing data. For example, for a normal distribution, the probability of obtaining any particular range of deviations can readily be determined by expressing this range in terms of standard deviation units, and then comparing the area under the curve in this range to the total area under the curve (100 percent). For example, the probability of obtaining readings between plus two and plus three standard deviations is 2.1 percent.

Continuous Probability Distributions

To overcome the disadvantages of the older methods—no allowance for uncertainty of the peak load forecast nor realistic maintenance schedules—Monte Carlo simulation of discrete events was tried in the early days of digital computers.[2,3] While detail and accuracy were very satisfying, calculating time was not. However, the approach led to the development of a continuous probability distribution to represent loss of load. The more recent approaches in the application of probability mathematics to the reserve capacity problem differ from the



3—Daily peak loads can be described by a normal distribution curve.

Table V. Partial Table of First Order Statistic

Observations	*Mean Value of Highest Order Statistic*
5	1.16
10	1.54
15	1.74
18	1.82
19	1.84
20	1.87
21	1.89
22	1.91
23	1.93
25	1.97
30	2.04
40	2.16
50	2.25

Table VI. Effect of Load Truncation on Risk

Truncation Point in Standard Deviations Above Mean	*Years/Day Load Loss Risk*
13.0	6.06
5.0	6.06
4.5	6.06
4.0	6.08
3.5	6.16
3.0	6.45
2.5	7.66
2.0	9.29
1.5	12.1
1.0	18.0

earlier methods primarily in that they use continuous probability distributions of peak load and available capacity, rather than discrete values, and convolve these distribution curves mathematically to get a generation reserve margin distribution. The computation is fast because formulas can be used to accomplish the convolution. The most important advantages of the continuous variable approach are that it allows load peaks beyond the observed or forecasted peak to have a probability of occurrence, and thereby represents the actual situation more accurately, and it is fast enough to allow detailed unit maintenance planning on an equal-risk basis.

Load Distribution—The continuous variable method assumes that system load distribution is normal so that it can be described in terms of a *mean* daily load peak and a standard deviation (sigma) of load from this peak (Fig. 2). The mean and standard deviation values are characteristic of the load level and load variation in a certain month for a particular utility system or pool. Other months have distributions with other means and sigmas, depending on seasonal variations in level and fluctuation characteristics. Thus, the continuous variable method permits monthly loads to be described by just two numbers rather than cumbersome "daily peak load variation curves." Furthermore, the sigmas can be put in per unit of the mean so that certain generalities can be observed. For example, means and sigmas can be projected for future years by averaging or trending. As more systems are analyzed, means and sigmas appear to be predictable seasonally and geographically, at least within a range.

With normal distribution, daily load peaks can be viewed for a month as being say 21 (workdays of a month) draws from a large population having an underlying distribution whose properties can be estimated. The average of the 21 daily peaks provides a *sample estimate* of the underlying distribution mean. One of the 21 loads will be the largest of the group, representing the peak for the month. However, the calculation of load-loss probability must include the probabilities of having all possible loads from the normal distribution, which means including the probability of having load peaks higher than the one observed in the 21-day sample. The statistical relationship between the highest peak of the sample and the mean and sigma of the underlying distribution is given by the equation: *Estimated Value of Peak* = *Distribution Mean* + (*Distribution Sigma*) × (*First Order Statistic*), where the first order statistic is a constant determined by the number of draws in the group. This constant reflects the fact that the more draws in the group, the more chance for a higher observation. A partial listing of the first order statistic is shown in Table V. Using the first order statistic for a 21-day month from the table, the above equation says that if the distribution mean and sigma are known for the month, the best estimate of the peak is 1.89 sigma above the mean. Or, if the monthly peak is forecast, the best estimate of the mean of the daily peaks for the month is 1.89 sigma below the forecasted peak.

In computing probability of load loss with normal load distribution, a higher probability is obtained than when one assumes that the load distribution is truncated at the forecasted peak, which, for the monthly forecast, is only 1.89 sigma above the mean. A number of engineers (but rarely mathematicians) will argue that utility loads are in fact not normal because load can never exceed connected load, which certainly is not infinite. They argue that the load distribution should be truncated at connected load. The argument is valid, but the important question is the effect of truncation on risk, which is illustrated in Table VI. The table uses an exact binomial expansion for outages, which is then convolved with a normal load distribution with truncations at various sigmas above the mean load peak. For a 21-day month, the estimated value of the monthly peak is 1.89 sigma. If the load is truncated there (as in Fig. 1) rather than carried out to 3 or 4 sigmas, the years per day load-loss risk is optimistically biased by 50 or 60 percent. However, truncation beyond three or four sigmas (which is certainly much less than connected load) is seen to have little further effect on risk. Hence, the conclusion is that truncation at any reasonable value is equivalent to using the full-tailed distribution.

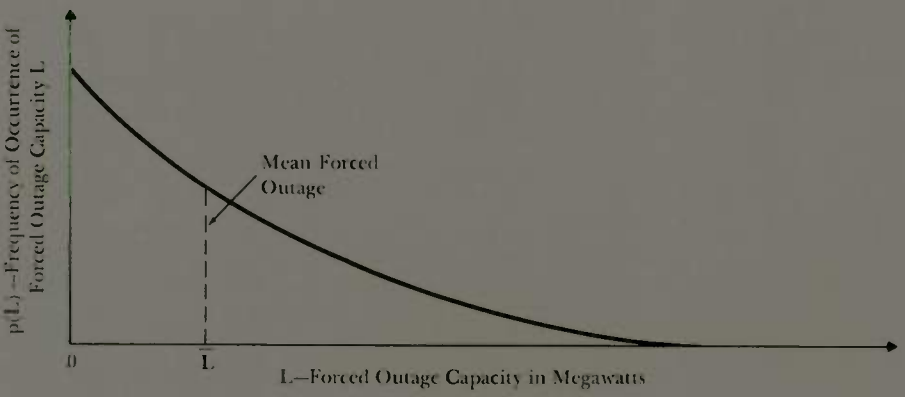
A monthly load model based on normal distribution can be constructed for a power system as shown in Fig. 3. The daily weekday load peaks are used in groups corresponding to the separate months of the year. Long-term trends of annual peaks, seasonal factors, and the order statistics are used to establish the mean of the daily peaks, $\overline{P}$, and the standard deviation, σ_1.

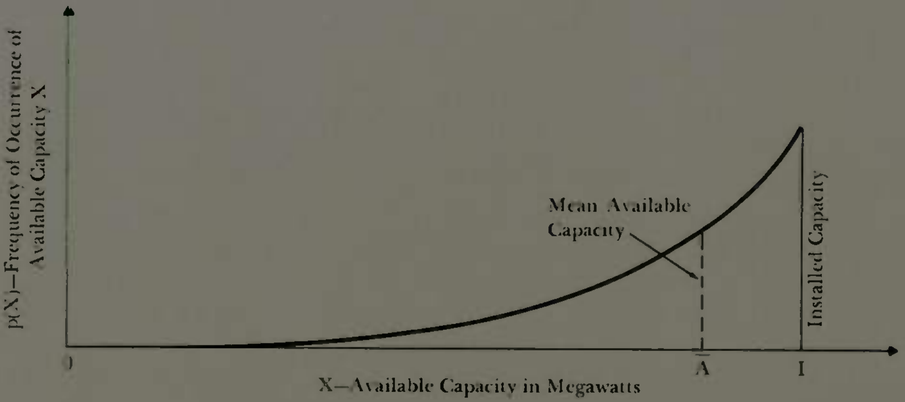
Available Capacity Distribution—The probabilities of capacity outages, developed for discrete values by the binomial expansion, may be plotted as a continuous function as shown in Fig. 4. The mean forced outage ($\overline{L}$) is equal to $\Sigma p_i c_i$, where p_i is the forced outage existence rate for the ith unit and c_i is the megawatt capacity of the ith unit. The area under the curve represents probability and is unity. The standard deviation for the curve is

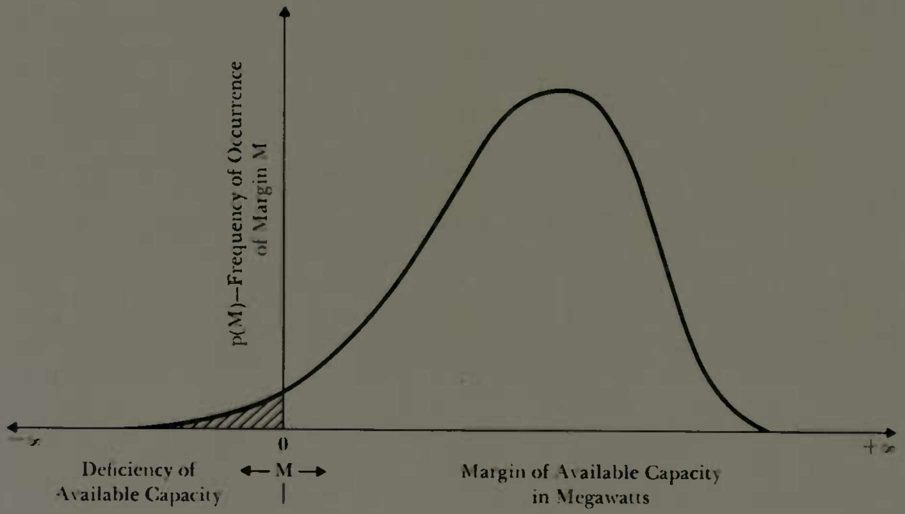
$$\sigma_2 = \sqrt{\Sigma p_i\,(1-p_i)\,c_i^2}.$$

The available capacity (X) is equal to the installed capacity (I) minus the forced outage capacity (L), or $X=I-L$, and can be plotted as the curve shown in Fig. 5. The mean available capacity ($\overline{A}$) is equal to the available capacity minus the mean forced outage ($\overline{A}=\overline{X}-\overline{L}$).

Margin Distribution—The margin of available capacity (M) is the available







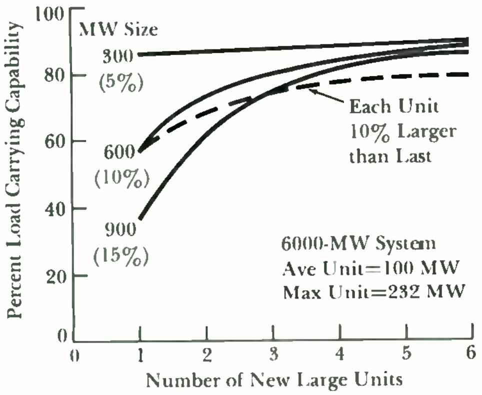
4—(*Top*) Probability of loss of capacity, developed for discrete values, can be plotted as a continuous function.

5—(*Center*) Available capacity curve is found by subtracting forced outage capacity (Fig. 4) from the installed capacity.

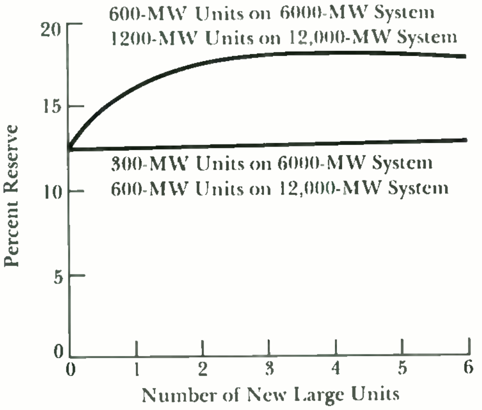
6—(*Bottom*) The margin of available capacity is found by convolving load and outage distributions (Figs. 3 and 5) with probability mathematics. The probability of zero margin or less is the area under the margin curve from − ∞ to 0, i.e.,

$$\int_{-\infty}^{0} p(M)\, dM.$$

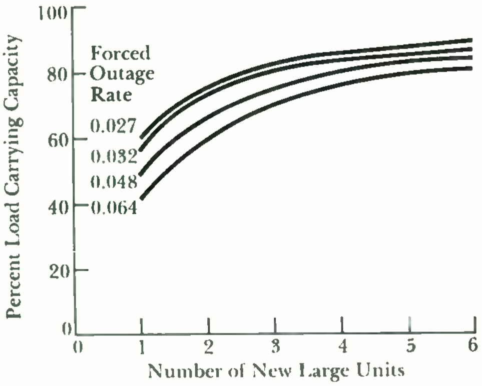
System planners must decide what probability value is sufficient to provide reasonable assurance of maintaining satisfactory service.



7—Load-serving capability as a percentage of the unit's rating for each of six subsequent larger new units installed on a sample system.



8—Percent installed reserve required for the total system as additional new large units are added in several sizes.



9—Load-serving capability as a function of forced outage rate of successive large 600-MW units installed on a 6000-MW sample system.

capacity less the load peak ($M=X-Y$). Thus, the load and outage distributions can be convolved with probability mathematics to get margin distribution, shown in Fig. 6. The mean of the margin curve ($\overline{M}$) will be the mean available capacity ($\overline{A}$) minus the mean peak load ($\overline{P}$), or $\overline{M}=\overline{A}-\overline{P}$. The standard deviation of the margin curve is the square root of the sum of the squares of the standard deviations for the outage and load distributions:

$$\sigma=\sqrt{\sigma_1^2+\sigma_2^2}.$$

Appropriate mathematical methods account for the nonnormality of the margin curve. The probability of negative margin, the shaded area in Fig. 6, is the probability that there will be a deficiency of available capacity to meet the peak load.

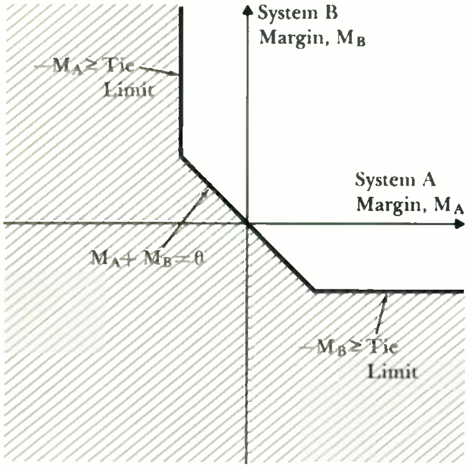
Load-Carrying Capability—An Application for Probability Calculation

One obvious source of economic savings on installed costs is the use of larger plants. However, the decrease in first cost of large plants is counterbalanced by the increased reserve requirement on any given system as unit size is increased; i.e., more capacity must be installed to maintain a given service quality because there are "more eggs in one basket." Another way to look at it is that if an unusually large unit were applied to an otherwise homogeneous system, a large part of its capacity must be assigned to reserve rather than peak load-carrying capability. When a second large unit of the same size is installed, less of its capacity must be assigned to reserve than was required for the first unit. This is in part because there is less probability of having two large units out at the same time. Similarly, a third large unit has even more of its capacity available to carry peak load.

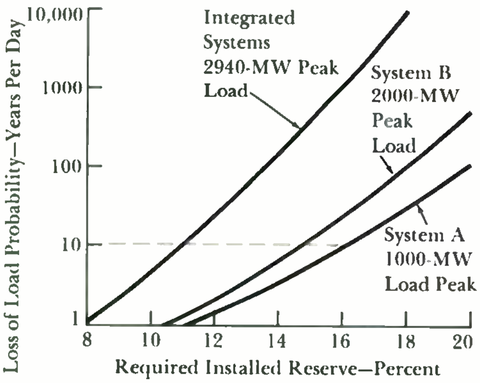
Probability calculations can show how much of a unit's capability must be assigned to reserve when it is applied to any specific system. The amount depends upon the new unit's forced outage rate, existing unit sizes and outage rates, and the fluctuating characteristics of the system peaks. Calculations have been made for a number of typical systems, and Fig. 7 shows some curves of the load-serving capability of the first six large new units applied to a hypothetical 6000-MW system with an average installed unit size of 100 MW, a maximum unit size of 232 MW, and with relatively low outage rates and no allowance for peak load forecast error. The three solid curves show the load-serving capability of 300-, 600-, and 900-MW units, respectively. Expressed in percent of total installed capacity, these are 5-, 10-, and 15-percent units. Note that the first 10-percent unit has 43 percent of its capacity assigned to reserve, leaving only 57 percent available to carry growth in peak load. However, when there are two of these units on the system, the second has only 27 percent of its capacity assigned to reserve. Of course, the first unit is still caring for the largest single hazard. One might argue that part of the improvement in load-carrying capability is caused by the fact that the relative unit size is decreasing as the system grows and a 600-MW size is retained. However, the same general effect is seen if the unit size is allowed to increase along with the system growth. The dashed curve is for all 10-percent units; that is, the first unit is 600 MW, the second 660 MW, etc.

As successive 300-MW (5 percent) units are added, there is only a small increase in their load-serving capability. This is because the system reserve is already sized large enough to take care of nearly this big a hazard. Consequently, only the required reserve percentage for the total system, or about 12.5 percent, must be assigned to reserve on each new 300-MW unit.

Pooling offers a way to enjoy the lower installed costs of large plants without suffering as much penalty in load-carrying capability. The percent reserve requirements for a sequence of 300-MW, 5-percent units and 600-MW, 10-percent units applied to the same 6000-MW system is shown in Fig. 8. While 600 MW represents 10 percent of this system, it represents only 5 percent of a 12,000-MW system (also shown in Fig. 8). Thus, if the 600-MW unit were applied to the 12,000-MW system, it would enjoy exactly the same high load-carrying capability that



10—The improved margin for the integration of two systems with tie limitations is indicated by the unshaded area outside the upper right-hand quadrant.



11—Reserve savings from pooling of two utility power systems as a function of service quality maintained.

the 300-MW unit has on the 6000-MW system. Similarly, the 600-MW curve on the 6000-MW system applied to a 1200-MW unit on the 12,000-MW system. These statements assume no increase in forced outage rate with increase in size. If forced outage rate increases with size, as many believe it does, there would be some loss in load-carrying capability and greater reserves required. The amount is demonstrated in Fig. 9 for 600-MW units on the 6000-MW system. However, the fact remains that a large unit's load-serving capacity can be greatly improved by scaling up system size.

The discussion so far has dealt with reliability calculations for a single company or single completely integrated pool. As large pools become an operational reality, a logical consideration is the economy to be realized by further coordinated planning and operation among neighboring pools. This step introduces the problem of pool-to-pool studies. An additional question of importance in these studies is how much interconnecting transmission capacity is required to effectively pool the two pools. Probability techniques have been extended to permit the solution of this problem. The load and capacity distributions of each pool must be included. Probability calculations are made for each pool, recognizing the margin situation in both. The improved margin for the integration of two systems with tie limitations is illustrated in Fig. 10. The shaded area indicates negative margin for the integrated pools with tie limits. If systems *A* and *B* were not interconnected, all but the upper right-hand quadrant would represent negative margin.

In pool-to-pool calculations, tie capacity is permitted to have different ratings for export and import as might be caused by transmission limitations within each pool. Limits may be imposed on the amount of tie built to represent physical or contractual limitations. Finally, load correlation, the degree to which daily peak fluctuations occur simultaneously in the two pools, must be accurately included. A high degree of load correlation has an adverse effect on the risk. For example, when pool *A* needs tie help because a heat wave has driven up the cooling load, it might be that pool *B* is unable to supply reserve generation because the same weather has had a similar effect on its load.

The reserve savings that can result when full advantage is taken of ties between systems or pools is illustrated in Fig. 11. At ten years per day risk, the required reserve drops from 15 and 16 percent of individual peaks to 11 percent of the coincident peak, while service quality remains at the same level.

Conclusion

This discussion has dealt with several methods of applying probability mathematics to the calculation of generation reserve requirements. The binomial expansion requires analysis of discrete variables to which several measures of reliability, such as loss of load, loss of energy, and frequency-duration may be applied. However, the more recent representation of system load and available capacity by continuous functions has several advantages over the discrete-variable methods. The familiar loss-of-load probability index as a service quality criterion can be retained, but computation is faster and can be readily adapted to a variety of planning problems such as maintenance planning, tie representation, and pooling.

The evolutionary trend in the application of probability methods to generation planning has not yet run its course. The need for more sophisticated long-range plans and the availability of larger and more powerful digital computers have set the stage for significant advances in all phases of power system reliability analysis.

Westinghouse ENGINEER **March 1969**

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AC Power Provides Flexible Maneuvering for Deep-Submergence Rescue Vehicle

Robert C. Fear
Robert R. Madison
Joseph M. Urish

The U.S. Navy's Deep Submergence Rescue Vehicle will require precise positioning capability for its missions. Battery-powered ac systems for propulsion, maneuvering, and hydraulic equipment provide that capability.

When the first Deep Submergence Rescue Vehicle (DSRV) is completed this year, the U.S. Navy will have a rescue vessel able to reach disabled submarines at depths to 3500 feet. Carried to the vicinity by a "mother" submarine, the DSRV will maneuver under its own power to locate the disabled submarine and attach itself to the escape hatch; then it will rescue 24 men in each trip to the mother submarine. When not needed for rescue duty, the vessel will be used for scientific tasks such as ocean floor mapping with sonar.

Because speed is essential in rescue operations, the DSRV must be small and light enough to be carried by jet transport to any place in the world. At the same time, its pressure hull and external systems must be strong enough to withstand the crushing water pressure of the ocean depths, which reaches 2250 psi at 5000 feet, the eventual operating depth of the DSRV.

The DSRV also needs precise navigating and maneuvering capability to enable it to locate and mate with the disabled submarine quickly. Requirements are considerably more demanding than those of conventional submarines, because in a rescue operation the vehicle's position must be controlled within inches despite strong water currents and low vehicle speed (which makes conventional controls sluggish or ineffective).

The Navy has incorporated a navigation system that can be used either as an accurate dead-reckoning system or, with sonar, as a precise navigation system referenced to the sea floor. For carrying out the required maneuvers, the Westinghouse Aerospace Electrical Division has designed and supplied systems for propulsion, maneuvering, and hydraulic power. The engineering principles of the systems are extensions of those successfully applied in the deep-submergence research vehicle *Deepstar 4000*.

General Description

The DSRV propulsion and maneuvering system is composed of one 15-horsepower main propulsion drive system, four 7½-hp thruster drive systems, and two 7½-hp hydraulic-pump drive systems. The propulsion drive system powers a six-foot propeller at the rear of the vehicle, and each thruster drive powers one of the maneuvering propellers oriented laterally and vertically at the front and rear of the vehicle. The hydraulic-pump drives provide hydraulic pressure to actuate various controls and pump systems. Each drive system consists of a solid-state controller and an ac motor unit (see Table I).

For rapid travel to rescue depth, the propulsion system can be made to deliver 20 hp instead of 15 hp by increasing the controller output frequency 10 percent (to 66 hertz). Such operation imposes thermal overloads in the controller, so it is restricted to 10 out of every 30 minutes.

The controllers operate over an input voltage range of 100 to 140 volts dc from the vehicle batteries. Each is enclosed in a spherical pressure vessel, allowing its components to operate in a controlled environment.

Propulsion and thruster motor units include gearboxes. The units are filled with fluid and pressure-compensated to allow for changes in fluid volume with external water pressure and changing temperature. The hydraulic-pump drive motors operate submerged in the vehicle's hydraulic fluid, and they do not have gearboxes. All motors are designed to operate in ambient pressures up to 2250 psi.

Motor, gearing, and controller are connected into a complete propulsion or thruster system as shown in Fig. 1. A contactor at the battery bus, remotely operated from the crew compartment, opens and closes the battery input circuit. Control signals from equipment in the crew compartment adjust controller output frequency and phase sequence to control motor speed and direction of rotation.

The hydraulic-pump drive systems are controlled simply by on-off switches, since neither adjustable speed nor reversibility is required.

Controllers and motors are constructed for continuous operation at seawater temperatures between 28 and 85 degrees F. The systems can be operated in air for five-minute checkout periods. When not operating, the systems can be exposed to continuous temperatures of −40 to 160 degrees F with no detrimental effect.

The equipment is built to withstand shocks that may occur during shipping, installation, launch, or operation in rough seas (wave slap up to 1000 pounds per square foot). Motors and controllers are designed for 10-year life and 2000 submergence cycles.

Table I. Main Characteristics of DSRV Drive Systems

Characteristic	*Propulsion System*	*Thruster Systems*	*Hydraulic-Pump Systems*
Weight of Motor Unit and Controller in Air (lb)	508*	279*	247
Displacement (ft^3)	3.94	2.5	2.1**
Efficiency at Full Load (%)	60	60	70
Rating (shp)	15***	7.5	7.5
Output Speed (r/min)	2 to 90***	12 to 590	3450
Motor Reversing Time (full speed in one direction to 90% speed in reverse direction) (sec)	3.5	3.5	Not reversible

*Includes coolant fluid in motor and gearing unit.
**Controller only. Motor is immersed in fluid of hydraulic system.
***Operable at 98 r/min and 20 shp for limited periods.

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Controllers

Electrical Design—Each controller consists of a static dc-to-ac three-phase adjustable-frequency inverter. (See Fig. 1 and Table II.) The inverter employs front-end commutation (bridge commutating action accomplished at the dc input) and digital control to convert dc input power to three-phase variable-frequency output power. Six heavy-duty thyristors are connected in a standard three-phase inverter bridge that does not require interphase transformers or reactors to supply power suitable for a polyphase induction motor. Proven solid-state digital control circuitry provides wave-form and frequency control to prevent motor saturation under various conditions of load and battery voltage.

The thruster and main propulsion controllers are regulated from the operator's panel, which provides signals for *start*, *stop*, *rotational direction*, and *speed*. The *start* function applies power to the controller in such a way as to insure that commutating conditions and control logic pulses have been established. Motor speed is regulated by frequency control through a feedback loop, and rotational direction is determined by control of phase rotation. Signals from the motor actuate indicators of speed and direction of rotation in the crew compartment.

The controller is started by closing the battery contactor; opening the contactor shuts down the controller and resets it for the next start. An overtemperature or overload condition clamps the thyristor firing circuits off, reducing current into the controller. An indicator light alerts the operator to either condition, and he must reset by commanding zero speed and then returning the speed control to the desired setting.

Control circuits are composed of solid-state digital elements. Two feedback signals from the inverter output control the output wave form. The first signal is a measure of the volt-seconds per cycle of the output wave form, and the second is the dc line current into the output bridge. The first signal controls the output voltage to maintain constant volts per cycle or a controlled volts-per-cycle increase applied to the motor as frequency is decreased. The second signal provides an adjustable current limit to protect the motor and controller components.

For overload protection, the current feedback loop provides a signal to a clock module that limits the peak dc line current to a value the commutating circuit can reliably accommodate. This protection controls the peak currents that occur during motor starting, plug reversing, or locked-rotor conditions.

Controller components were selected for high reliability. The calculated mean time before failure for the prototype controller is more than 10,000 hours. Recommended maintenance involves only periodic replacement of filter capacitors and commutating capacitors. The logic control circuits consist of five printed circuit boards, all of which have plug-in connectors for ease of replacement. All other components are readily accessible and can be removed with ordinary hand tools.

Mechanical Design—The major design objectives were to protect the controller components from the high water pressures encountered at operating depths, to provide sufficient cooling to limit component temperatures to conservative levels, and to make the electrical components easily accessible for maintenance. Those objectives have been achieved by mounting all components and modular assemblies on an aluminum-alloy base plate, then sandwiching the plate between two hemispherical heads (Figs. 2 and 3). The base plate acts as a heat sink through which component losses are conducted out to the edge, which is exposed to seawater. (This mounting arrangement is used successfully in the five-kW controller for *Deepstar 4000.*)

The hemispherical heads are clamped against the base plate and sealed by O-rings. The interior is maintained at essentially sea-level pressure, so water pressure at operating depths forces each head against the sealing surface to effect a leak-free seal.

The pressure heads are of aluminum alloy, with walls 0.592 and 0.520 inch thick for the two sizes (20- and 17-inch

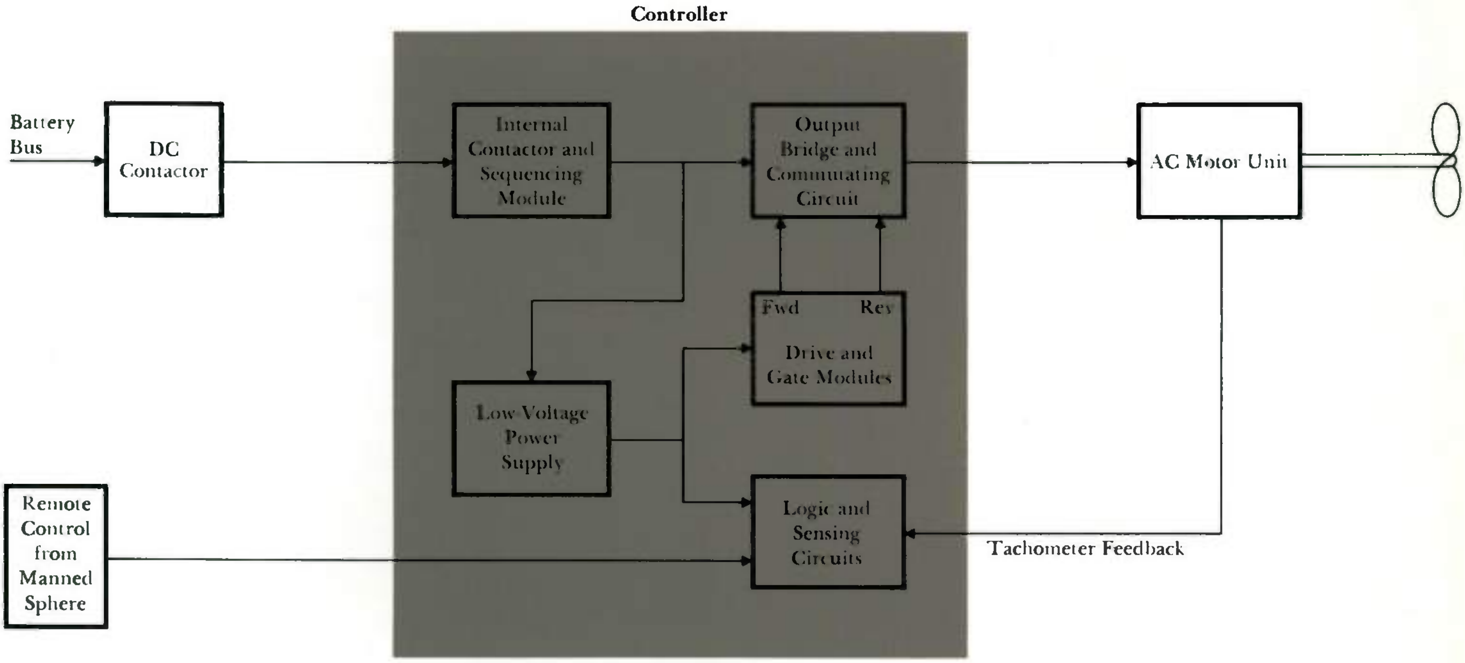
Table II. Controller Characteristics

Characteristic	*Propulsion Controller*	*Thruster and Hydraulic-Pump Controllers*
Input Voltage (V dc)	100 to 140	100 to 140
Output Voltage, Line to Line (V ac, rms at 60 Hz)	82	82
Frequency (Hz)	0 to 60*	0 to 67**
Efficiency at Full Load (%)	90	90
Life Expectancy (years)	10***	10***
Size, OD (in., major/minor)	24.0/21.9	21.3/19.3
Weight in Air (lb)	270	189

*Frequency is 66 hertz at 20 shp.
**Hydraulic-pump controllers provide 60 Hz only.
***Ten-year life is achieved by periodic replacement schedule. Electrolytic filter capacitors and commutating capacitors will be the major components concerned.

1—Deep Submergence Rescue Vehicle (DSRV) propulsion system converts battery power into adjustable-speed motor output. The controller is essentially an inverter that supplies adjustable-frequency ac power to the squirrel-cage motor. System indicators and controls are located inside the crew compartment. The systems for the vessel's four thrusters are similar to the propulsion system, though of lower rating; those for the two hydraulic-pump drives have similar controllers and motors but need no gearing nor provision for controlling motor speed and rotational direction.

***Right*—Artist's concept of the DSRV being built by Lockheed Missiles and Space Company. The vehicle is shown mating to the restraining guide wires and "piggyback" berth on its mother submarine. A large propeller at the aft end provides propulsion, and smaller propellers in vertical and horizontal thruster ports at bow and stern provide maneuvering thrust.**


Controller
Battery Bus
DC Contactor
Internal Contactor and Sequencing Module
Output Bridge and Commutating Circuit
AC Motor Unit
Fwd
Rev
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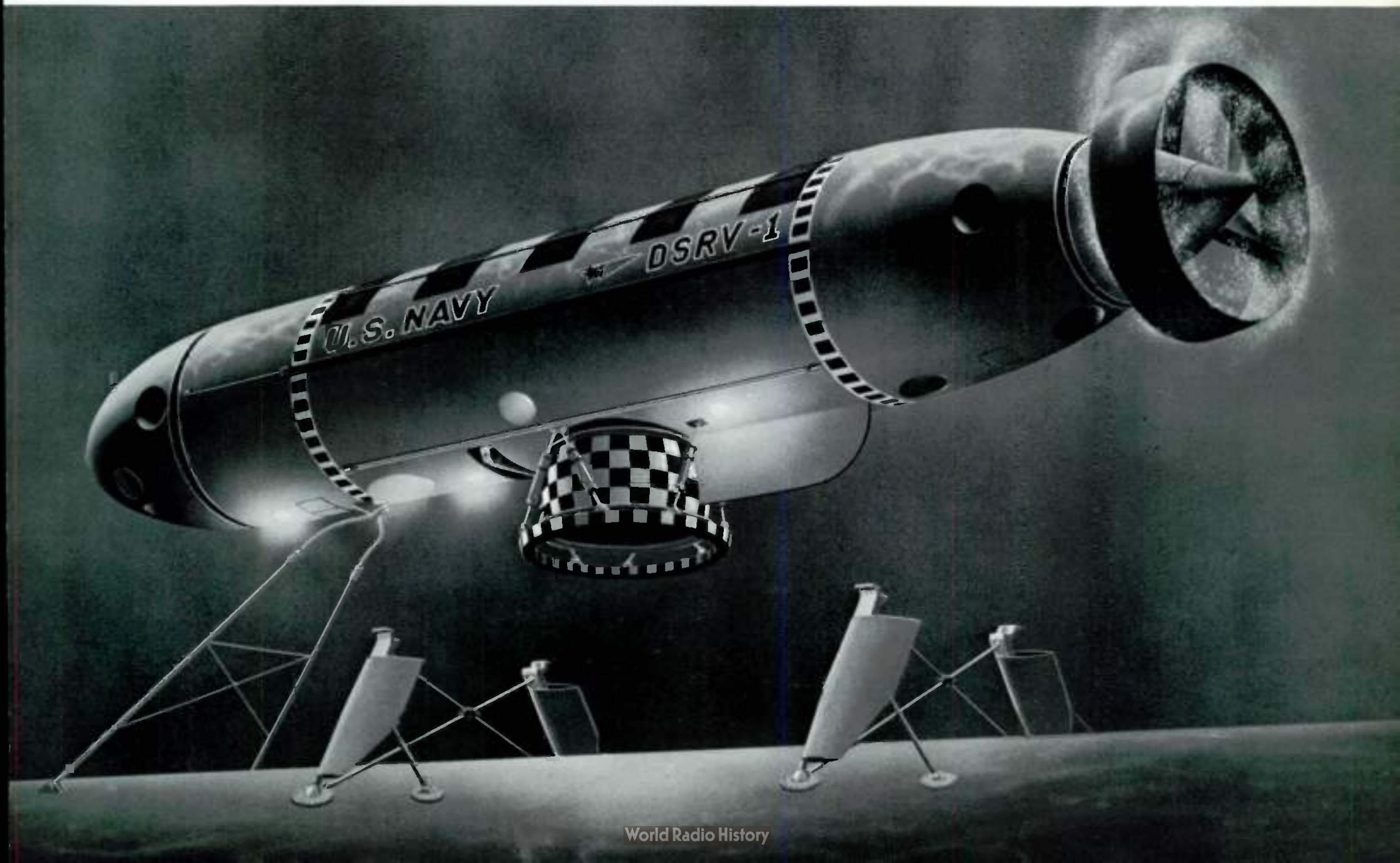
Low Voltage Power Supply
Logic and Sensing Circuits
Tachometer Feedback
Remote Control from Manned Sphere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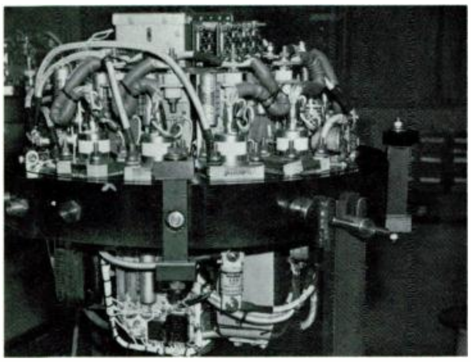

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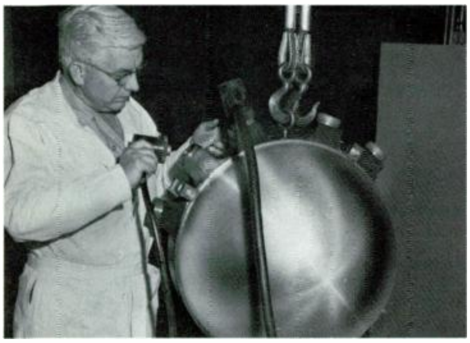

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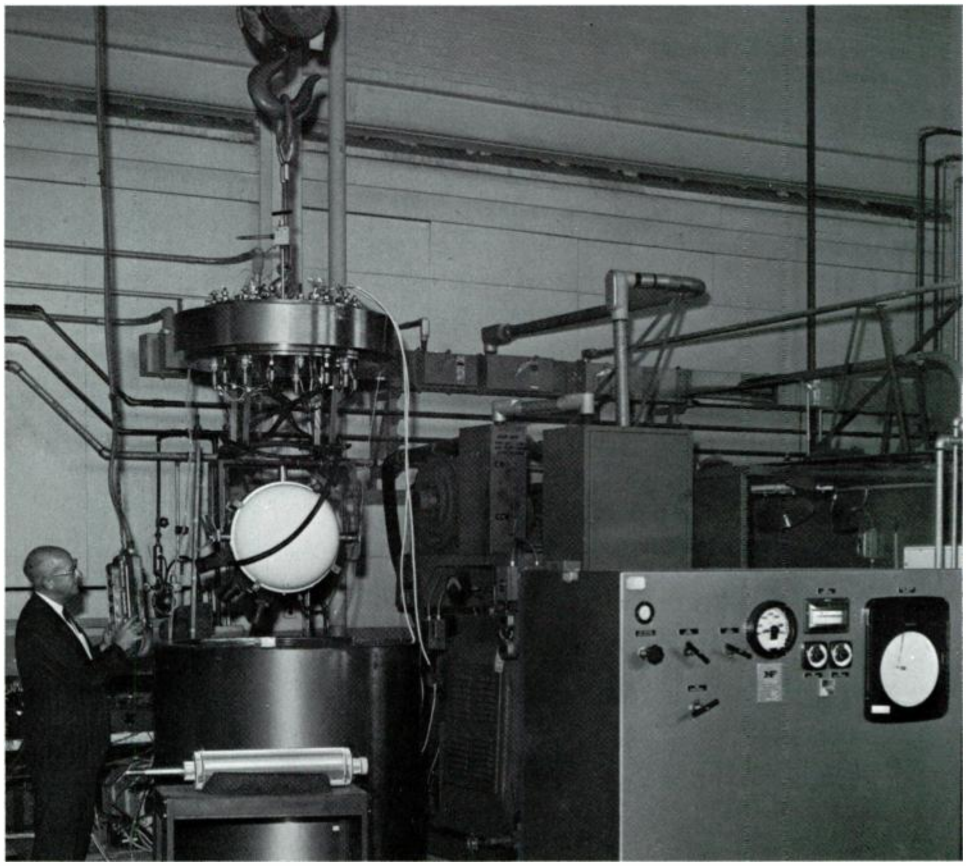


2—Thruster controller (with covers removed) has components mounted on a base plate that serves as a heat sink.

3—Propulsion controller shown with covers installed. Covers are hemispherical pressure vessels that protect the controller components from the great pressure at operating depths. The technician is installing electrical cables before a pressure test.

4—Thruster motor unit (shown here) and propulsion motor unit are similar except that the latter is larger. The units consist of a motor and reduction gearing enclosed in a housing, which is filled with a coolant fluid pressure-compensated to allow for changing outside water pressure and for thermal expansion. Thruster motor top speed of 3450 r/min is reduced by the gearing to 590 r/min shaft speed

5—Controller mounted on the cover of the Aerospace Electrical Division's pressure test chamber is about to be lowered into the chamber. (A thruster motor is on the cart in the foreground.) The chamber is filled with salt water; a pressure of 13,500 psi can be attained in 30 minutes pumping time. The test chamber is three feet in inside diameter by six feet in inside length. The cover has sixteen 200-ampere electrical power penetrations and 24 thermocouple penetrations. Motor units as well as controllers have been operated in the facility under pressures exceeding the service operating pressures.

inside diameter, respectively). This construction minimizes vessel weight and size, for buoyancy and ease of transporting, while retaining adequate strength. The vessels are designed for operation at 2250 psi, and they withstand a collapse-test pressure of 3500 psi (pressures equivalent, respectively, to 5000- and 7800-foot depth).

Cable Connections

Water-tight connectors are used at the cable entrances of controllers and motors; they are designed for operating pressures up to 13,500 psi. The molded cable assemblies will be blocked to seawater entrance at both ends.

Propulsion Motor Unit

The motor and its speed-reducing gear train are enclosed by an aluminum housing. (See Fig. 4 and Table III.) It is filled with a synthetic organic fluid for cooling and exclusion of seawater; the fluid is retained by a face-type rotating shaft seal.

Electrical Design—The two-pole ac squirrel-cage induction motor operates at 3450 r/min with a 15-hp propeller load on a 60-hertz electrical input. Synchronous speed is 3600 r/min with 60-hertz input and 120 r/min with 2-hertz input.

The motor is designed for 82 volts line to line at 60 hertz. Stator windings are delta connected to match the inverter and provide the best system efficiency; the delta connection also allows use of a smaller wire size with more turns per coil than a "Y" connection, resulting in a more compact winding for the chosen voltage rating.

Stator winding wire is insulated with an enamel thickness of two mils per side, providing compactness, good heat transfer from the wire to the surrounding oil, and protection for a limited time from direct seawater immersion. Stator slot cells are a laminate 10 mils thick. The wound stator is vacuum-impregnated in varnish to maintain winding rigidity when subjected to vibration and to provide additional protection against short-time exposure to seawater. This insulation system was subjected to short-time cyclic static pressure tests in fresh water at 20,000 psi without detectable degradation. It has also been operated successfully in an engineering feasibility model tested to 13,500-psi pressure at the Aerospace Electrical Division test facility; the fluid fill was diluted 10 percent with salt water for a 50-hour test period.

Mechanical Design—The motor is mounted in the aluminum housing with clearance over the stator frame to provide room for circulation of the coolant fluid and to equalize fluid pressures on both ends of the rotor. Sleeve bearings support the rotor.

The planetary gearing style was selected for light weight, high capacity, reliability, and high efficiency. Helical gears are manufactured with precision shaping equipment for accurate involute profile and spacing. The high-speed sun gear is made from carburized SAE 8620 material and is integral with the motor shaft. Planetary gears are through-hardened SAE 4140 material and are mounted on hard steel journals operating in replaceable bushings in a ductile-iron carrier. The internal ring gear is made of SAE 4140 through-hardened material and is mounted on a ductile-iron web to the output shaft, which is supported by tapered roller bearings to withstand propeller thrust and wave slap.

Effects of Seal Leakage—A small quantity of seawater can be absorbed by the cooling fluid. Additional water over that which can be absorbed does not form a thick "mayonnaise" emulsion as it does with some hydrocarbon fluids. Partial or total replacement of the fluid by seawater would increase fluid density and viscosity, resulting in greater fluid friction losses; however, the unit would operate for a period exceeding mission time.

Rotor and stator assemblies would not be affected by short-term saltwater ingestion, though longer exposure would cause corrosion. The effect of seawater on the primary conductor insulation would be to increase electrical leakage eventually; electrical components might have to be replaced. The remaining components would be salvageable, except for the component that permitted the gross entrance of seawater.

Other Motor Units

General construction of the thruster motor units is the same as that of the propulsion unit. (See Fig. 4 and Table III.) The motor shaft is machined with a gear on one end for driving the propeller gearing of the thruster unit and with a spline on the other end for driving the hydraulic pump; thus, rotors are interchangeable. The pump motor units have no reduction gearing.

Conclusion

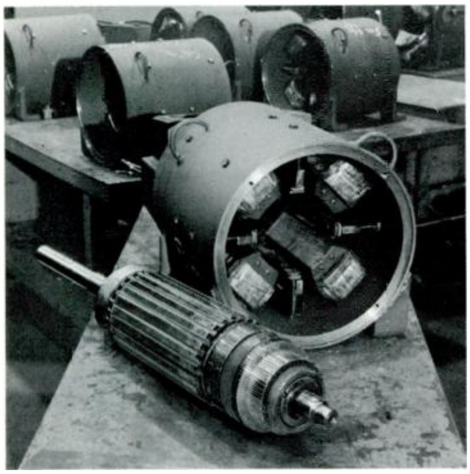
The DSRV will give the U.S. Navy the capability for worldwide rapid submarine rescue. System requirements to achieve that capability are even more demanding than those of conventional submarines: besides the requirement for small size to permit air transport to the point of need, the DSRV demands precise maneuvering and propulsion control for locating a disabled submarine and mating with its escape hatch. The advanced solid-state control systems and the compact motor and gear units help meet both requirements.

Table III. Motor-Unit Characteristics

Characteristic	*Propulsion Drive*	*Thruster Drives*	*Hydraulic-Pump Drive*
Motor Power Factor at Full Load	0.9 lag	0.9 lag	0.9 lag
Weight in Air (lb)	238*	90*	58
Displacement (in.^{3})	1870	670	227
Overall Length (in.)	52.75	30.2	15.75
Mounting Flange Diameter (in.)	16.0	No flange	6.750
Motor Diameter (in.)	7.5	6.0	5.250

*Includes coolant fluid.

The Modern Permanent-Magnet DC Motor



1—Permanent-magnet motors in integral-horsepower sizes have Alnico magnets for the main poles. (The smaller poles are wound commutation poles.) Windings around the main poles are for magnetizing and demagnetizing the permanent magnets.

Recent improvements in magnet materials have given permanent-magnet motors high capability and new application flexibility.

Permanent-magnet dc motors differ fundamentally from wound-field dc motors in that current need be supplied only to the armature, while wound-field motors require current for both the armature and the field windings. That difference in design influences both motor performance and overall cost.

Elimination of field excitation, for example, increases efficiency, simplifies control, and reduces maintenance requirements. It also reduces installation costs by reducing the amount of wiring needed. Speed drift caused by temperature change is much less than with wound-field motors, and overload torque per ampere is higher. Moreover, the low armature inertia of the Westinghouse permanent-magnet dc motors reduces the amount of power required for acceleration and provides the faster response speed that has become so useful in many modern industrial drive systems.

The first permanent-magnet motors in integral-horsepower sizes were made by designing the magnets to suit existing motors, so the magnet size was limited by existing armature and frame dimensions; as a result, the motors operated at lower than desired flux levels and had low peak torque capability. Changing the approach by designing the motor to suit the permanent magnet resulted in the present Westinghouse high-performance motors.

The earlier permanent-magnet motors in integral-horsepower sizes also were severely hampered by the low energy level of the magnets then available; the flux level that could be obtained was not high enough to allow the motor to compete economically with conventional wound-field dc motors for general applications. Joint development work with various suppliers of Alnico permanent magnets improved the energy level until, by 1960, it became possible to build permanent-magnet motors to compete economically with wound-field motors for many applications. And since then, the energy level of the magnets has been increased more than 25 percent, so the present motors work at higher air gap flux densities than do wound-field motors.

Design of Permanent-Magnet Motors

In the permanent-magnet motor, each main pole is an Alnico magnet that produces the motor's flux (Fig. 1). Although ceramic magnets cost much less than Alnico magnets and are used in fractional-horsepower motors, they can produce only a third of the flux that Alnico magnets produce. Integral-horsepower permanent-magnet motors need high flux levels to compete with wound-field motors, so Alnico magnets are used.

Normal temperature, vibration, or aging do not cause an Alnico permanent-magnet motor to lose flux. The flux output of the magnets does not change with temperature until the magnet reaches 300 degrees C, and that is more than double the maximum permissible temperature for Class B insulation. Heavy and repeated shocks do not cause the permanent magnets to lose flux; mechanical failure would result before any loss in flux were detected. As for aging, a magnet supplier has estimated that the Alnico magnet will lose less than one-half of one percent of its flux level in two thousand years.

However, the permanent-magnet main poles do lose flux if the motor is loaded beyond its design limit. The loss in flux gives the motor new electrical characteristics, such as higher speeds and less torque per ampere. Flux loss from overloads can be calculated the same as other motor characteristics. (See *Calculating Motor Flux*, page 48.) Once a motor loses flux from a given overload, it does not lose additional flux until the motor is overloaded beyond its previous maximum overload. The amount of flux the motor loses from an overload varies with the motor design and magnitude of overload. Once a motor loses flux, it can only be brought back to the original flux level by re-energizing the magnets, but that is

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James C. Wachob is a product design engineer and John C. Erlandson a design engineer in the computer section, Large AC/DC Motor Division, Westinghouse Electric Corporation, Buffalo, New York.

done simply by energizing the motor's excitation coil for two seconds.

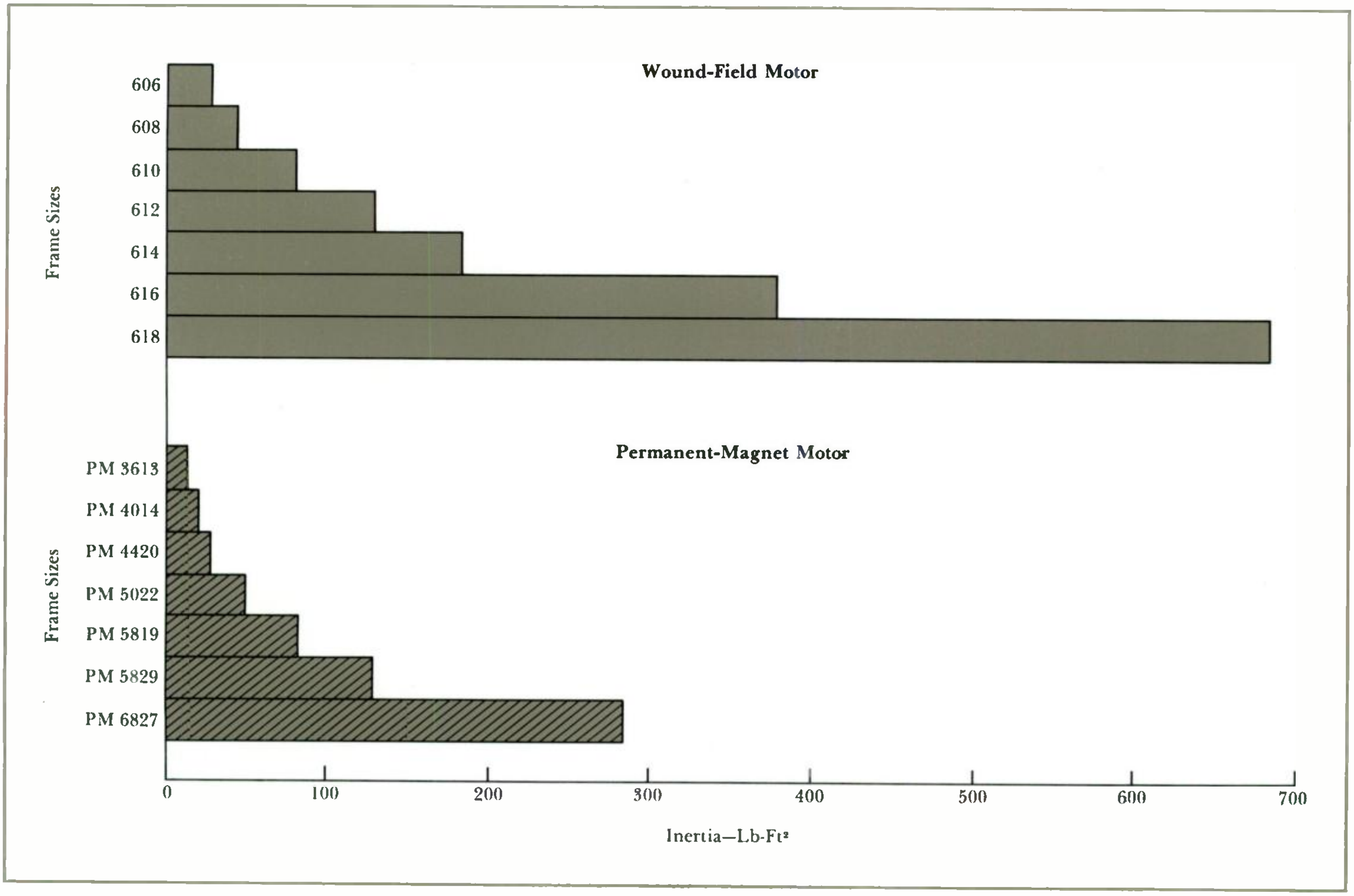
The only other known way in which a permanent-magnet motor has lost flux is when a strong magnet, such as the electromagnets used on overhead electric cranes, touches the motor frame. The flux from the electromagnet may saturate the frame and cause a loss in motor flux level.

All Westinghouse permanent-magnet motors are so designed that they will not lose flux until they reach their commutation limits at base speed, which means they have high overload capability without loss in flux. That capability is achieved by making the permanent-magnet main poles radially longer than equivalent wound-field poles. Since it is desirable to retain standard mounting dimensions, the use of large poles requires the armature diameter to be smaller than that of equivalent wound-field armatures. However, permanent-magnet motor armatures must have the same volume (D^2L) as the equivalent wound-field armatures to produce equivalent overload peak torques, so permanent-magnet motors usually have long armature cores. Ratio of armature length to armature diameter varies between 2 to 1 and 4 to 1, while in wound-field motors the ratio varies between ½ and 1½ to 1. The small diameter results in one of the lowest-inertia motor lines in industry (Fig. 2).

Standard dc motor design practices are used for permanent-magnet motors. Extreme care must be given to all portions of the magnetic circuit because, if any portion of the circuit saturates prematurely during overloads, the saturation can cause a premature loss in flux. The procedure used to calculate the motor's flux is described in *Calculating Motor Flux*, page 48.

Commutation problems are similar to those of any dc motor. Most permanent-magnet motors require conventional wound-field commutation poles to commutate successfully.

Before development of computer design programs, the engineer had to de-



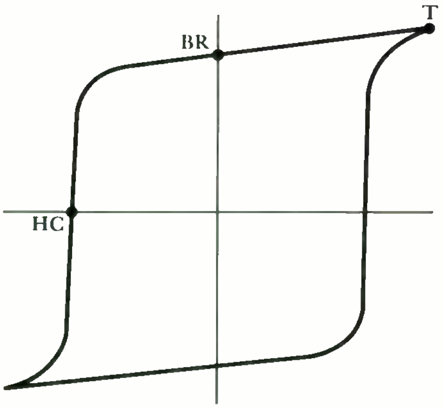
2—Armature inertia is much lower in permanent-magnet motors than in equivalent wound-field motors, providing faster speed response. The difference results from the higher main poles of the permanent-magnet motor and the consequent smaller armature diameter. The comparison here is between AISE 600 MC motors and equivalent Westinghouse permanent-magnet motors.

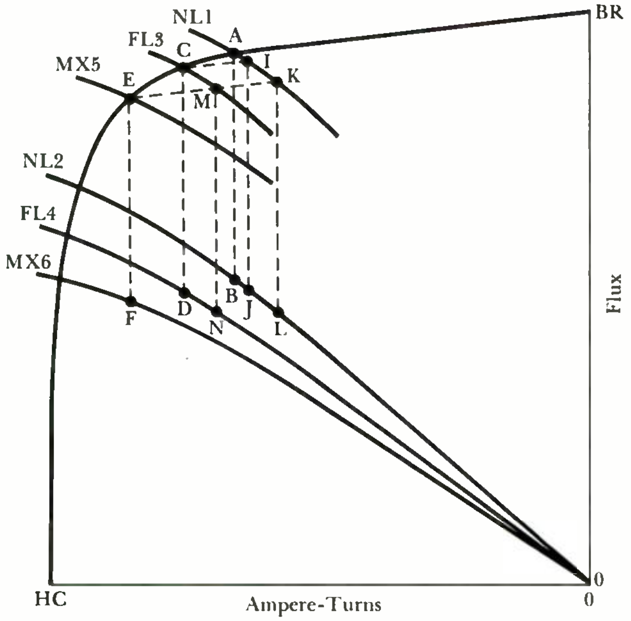
Calculating Motor Flux

A typical hysteresis curve for Alnico magnetic material is shown below. In motor design, only the demagnetizing portion of the curve (the second quadrant) is used; that portion and the saturation curves for the magnetic circuit in the motor are shown at bottom right.

The magnet is magnetized by applying a large magnetizing force to the excitation winding on the main poles, saturating the magnet to point *T*. When the force is removed, the flux follows the curve from point *T* to the intersection of the no-load saturation curve *NL1*, point *A*. The curves *NL1*, *FL3*, and *MX5* are the saturation curves for the flux through the magnetic main poles. The curves *NL2*, *FL4*, and *MX6* are the saturation curves for the actual useful flux passing across the airgap. When the motor is operating at the no-load point *A*, the no-load airgap flux is at point *B*. When a load is applied causing the demagnetizing curve *FL3*, the flux follows the curve to point *C* and the motor operates with an armature airgap flux point *D*. If the load is now removed, the flux follows a new minor hysteresis curve to point *I*. If points *A* and *I* are projected to the curve *NL2*, giving points *B* and *J*, the difference in flux between *B* and *J* is the no-load flux loss from no load to full load. When a maximum overload is applied causing the demagnetizing curve *MX5*, the flux follows the magnet curve to point *E*. If the load is removed, the flux follows a new hysteresis to point *K*. If point *K* is projected to the curve *NL2*, point *L*, the difference in flux between *B* and *L* is the loss in no-load flux from no load to maximum overload.

The loss in flux caused by the overload condition forces the motor to operate at a full-load flux point *N* instead of flux point *D*, resulting in the motor running faster. Any time the maximum overload condition exists, the loss in flux cannot be recovered until the magnet is fully magnetized by the excitation coils.





sign motors manually to meet customer specifications. It was a time-consuming task involving selection of parts from drawings and documents and then making detailed calculations to predict motor performance, so the manual method limited the number of designs an engineer could examine and seldom produced the optimum economical design.

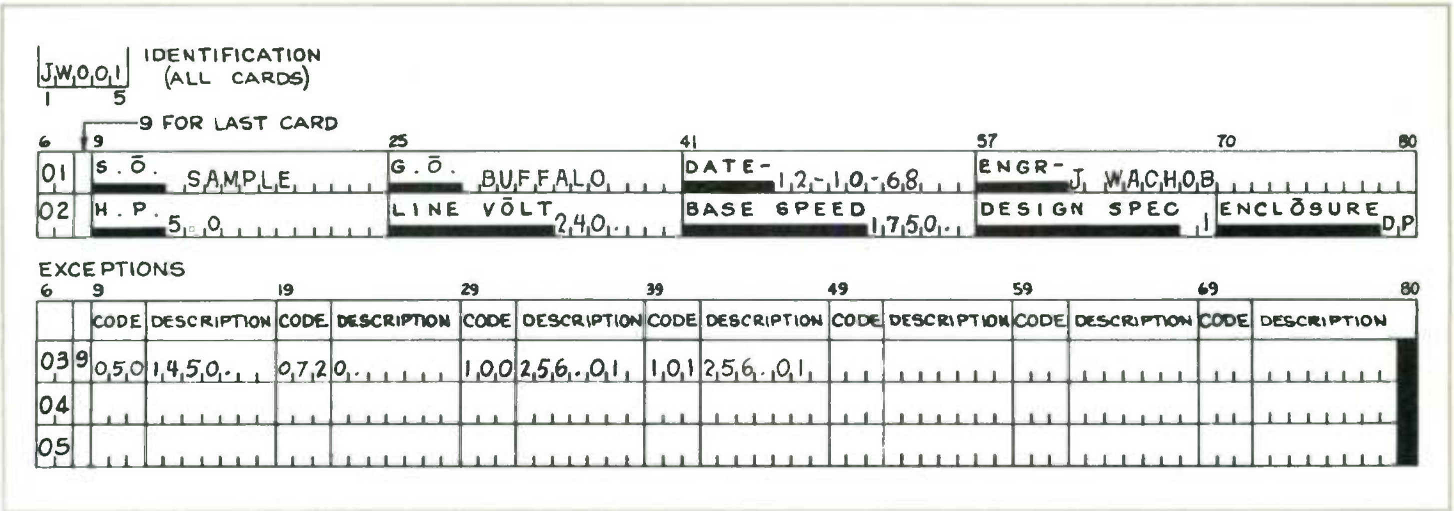
Now, however, motor designs to meet customer specifications are selected by a computer program that gives the engineer the capability of examining a large number of designs before selecting the best one. The program logic is based on selection of a design that uses standard parts, so it gives the most economical design and helps reduce delivery time.

The computer program requires only a minimum amount of input information. The engineer specifies customer requirements such as horsepower, line volts, speed, and maximum overload condition on a simple input form (Fig. 3). The computer program selects a set of standard parts, calculates the performance of the motor, and compares that performance with customer specifications. If the design does not meet customer requirements, a new set of parts is selected from a table in the computer program, and performance is calculated and compared with specifications. Selecting, calculating, and comparing continue until a satisfactory design is found or the range of standard parts is exhausted. A satisfactory design using standard parts is usually found, but, if not, then special parts are used.

The computer output consists of the complete input, design limits, specifications, electrical parts selected, and detailed performance for each design (Fig. 4). The performance calculations predict operating speeds, torque, horsepower,

3—*(Top right)* The computer program used to design motors accurately to customer specifications requires only simple input. It selects parts that give desired rating and performance.

***Right*—Table roll drive, as in this steel mill, applies the permanent-magnet motor's advantages of low installation and operating costs, reliability, performance, and low maintenance requirements.**



JW001 IDENTIFICATION (ALL CARDS)
1 5

9 FOR LAST CARD

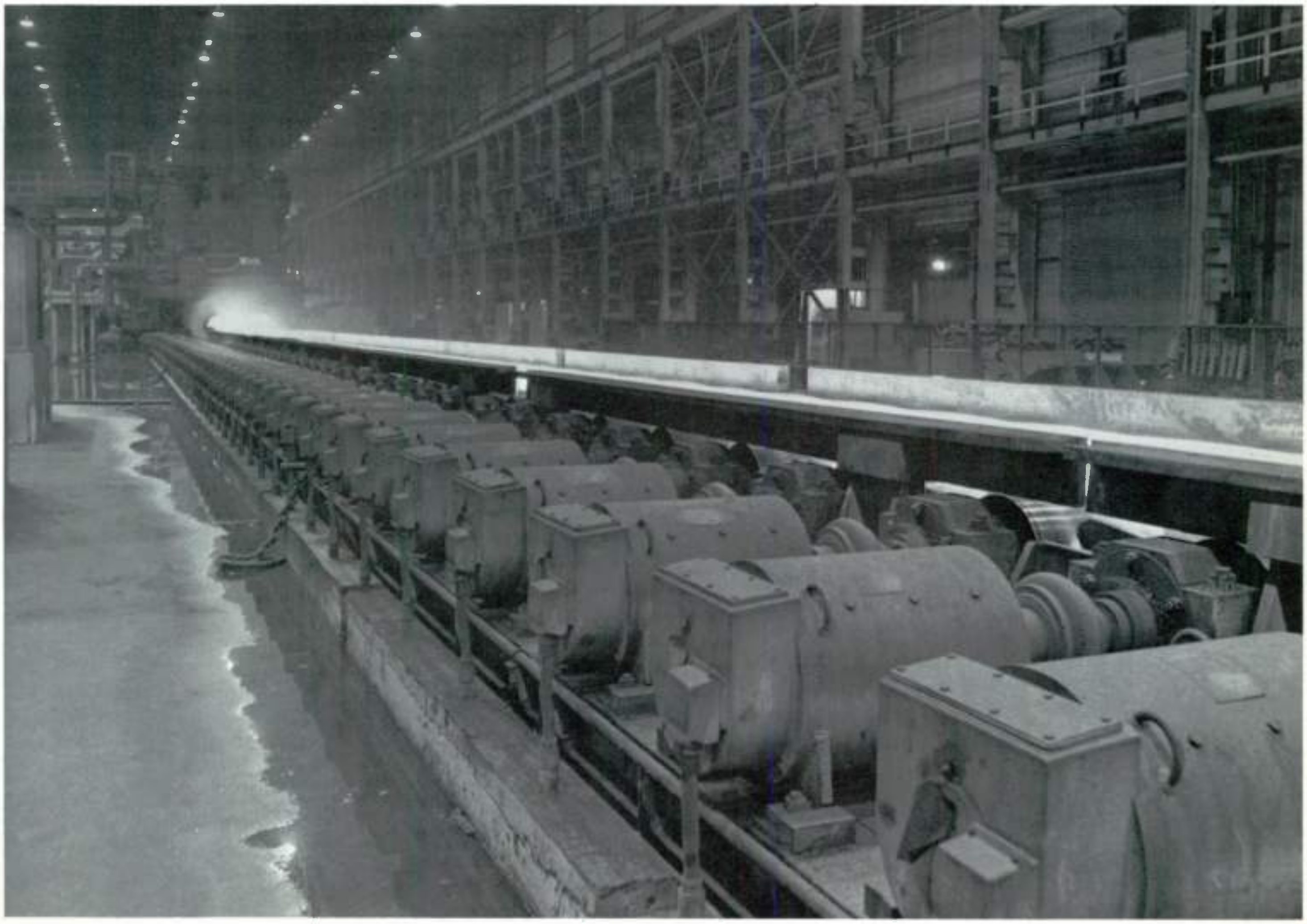
6 9 25 41 57 70 80

01		S.Ō. SAMPLE	G.Ō. BUFFALO	DATE- 12-10-68	ENGR- J WACHOB	
02		H.P. 5 0	LINE VŌLT 240.	BASE SPEED 1750.	DESIGN SPEC 1	ENCLŌSURE DP

EXCEPTIONS

6 9 19 29 39 49 59 69 80

		CODE	DESCRIPTION	CODE	DESCRIPTION	CODE	DESCRIPTION	CODE	DESCRIPTION	CODE	DESCRIPTION	CODE	DESCRIPTION	CODE	DESCRIPTION
03	9	050	1450.	072	0.	100	256.01	101	256.01						
04															
05															



efficiency, commutating ability, and heat dissipating ability at various horsepower loads. From the computer output, the engineer selects the best design to meet customer requirements.

For economy, each frame size has one magnet, one pole design, and one airgap. To obtain the desired motor speed, the designer must vary the armature. (For a wound-field dc motor, not only can the armature be varied to obtain the desired speed but the flux level also can be varied by changing field coils and airgaps.)

All magnets used have been fully tested by the supplier to insure that they have the proper energy level. Testing coupled with an optimized magnetic circuit permits all the motors of a given design to approach ±2 percent of the average speed of the design, a very important feature for applications where the motors run in parallel.

More than 80 percent of the permanent-magnet motors shipped in the past five years operate on thyristor power supplies (TPS), and the permanent-magnet motor faces the same potential difficulties as wound-field motors in regard to additional heating and commutation problems.* Its construction gives the permanent-magnet motor a higher inherent inductance than equivalent wound-field motors; because of that increased inductance and because the permanent-magnet motor has no field-weakening speed range, commutation has not been a problem with permanent-magnet motors used on TPS.

However, ripple current peaks coming from a TPS can cause premature demagnetization. For example, a permanent-magnet motor may be overloaded to 900 percent of its totally enclosed nonventilated (TENV) rating with less than ½ percent loss in flux, while on a TPS the same motor may only be able to be overloaded to 750 percent before ½ percent loss in flux. The additional amount of flux the motor will lose on a TPS is difficult to calculate because the current ripple is a function of the total control and motor circuit, but tests have indicated that peak overloads must be reduced approximately 20 percent on semiconverter TPS and 10 percent on full-converter TPS.

An excitation coil, which is similar to a wound-field motor's shunt field coil, is used in a permanent-magnet motor to either magnetize or demagnetize the magnets. When the motor is assembled, the magnets are not energized because Alnico magnets lose most of their flux when not enclosed in a magnetic circuit. After the motor is assembled, the excitation coil is connected cumulatively to a dc power supply for two seconds to energize the magnets. The values of current and voltage required to fully energize the magnets is stamped on the motor's nameplate.

To dismantle the motor easily, the magnets should be demagnetized. The same coil is used again except now it is connected differential. The current value required to demagnetize the magnets (approximately ¼ of the current needed to energize them) and the corresponding voltage value are stamped on the motor's nameplate.

Advantages

Performance—The new permanent-magnet motor has approximately 10 to 15 percent more overload torque per ampere than does the equivalent TENV shunt-wound dc motor. In fact, the overload torque capability is very similar to that of a compound dc motor, with the torque output nearly linear to line current. The saturated design and the patented pole face design that keeps the loss in flux from overloads to a minimum are the main reasons for this high capability in overload torque per ampere.

The permanent-magnet motor has a flat speed regulation the same as shunt dc motors, but a major advantage of the Westinghouse permanent-magnet motors is that they are stable (no rise in speed with increase in load) out to maximum overloads for all sizes. The saturated design and the pole face design are the main reasons for the motor's stability. Standard shunt motors normally require series fields to be stable to full load on 75 hp and larger.

Since the flux produced by the magnet is not a function of temperature (below 300 degrees C), the only element in the permanent-magnet motor that varies with temperature is the armature circuit resistance. The change in armature circuit resistance from cold (just started) to operating temperature causes only a 1 to 2 percent change in the motor speed. Standard wound-field motors normally have a 15 to 20 percent change in speed from cold to operating temperature.

Reliability—With the elimination of the motor's field coil, the reliability of the motor is improved. And since field power is not required, field control components such as resistors, failure relays, and power supplies are not necessary; elimination of all those components greatly improves the total reliability of the system and reduces total maintenance requirements.

Installation Cost—When large numbers of motors are used, large savings can result from the elimination of field control hardware, field power supplies, and wiring; often, the elimination of control hardware alone offsets the additional cost of the permanent-magnet motor. Permanent-magnet motors have higher continuous TENV horsepower ratings than do equivalent wound-field motors, so for many duty-cycle applications they do not require external ventilation. That factor often amounts to substantial installation savings.

Efficiency—Permanent-magnet motors have 10 to 15 percent higher efficiency than equivalent wound-field motors. For battery operated applications, the result is longer service between battery charges; when large numbers of motors are used together, the higher efficiency cuts operating cost by a substantial amount.

Safety—Motor flux is produced by permanent magnets and, therefore, is independent of external power supplies. Permanent-magnet motors do not overspeed from an open field coil, since the

4—The computer output repeats the input and then gives the limits, specifications, parts selected, and calculated performance for the design. The engineer can have several design computations made and select the best one.

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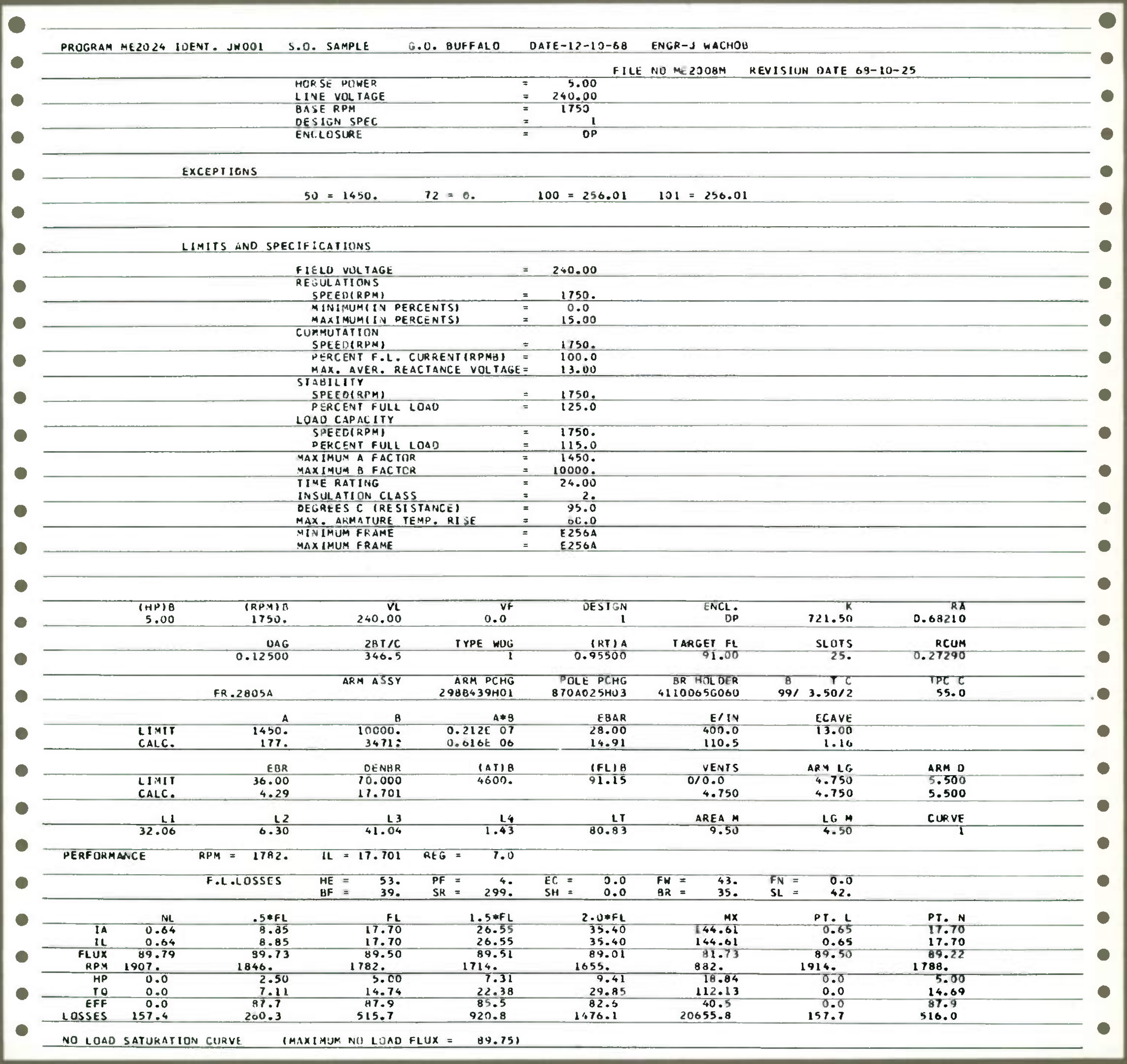
*V. E. Vrana, "The DC Motor and the Thyristor Power Supply," *Westinghouse ENGINEER*, July 1967, pp. 98-104.



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 PROGRAM ME2024 IDENT. JW001   S.O. SAMPLE     G.O. BUFFALO    DATE-12-10-68    ENGR-J WACHOB

                                                                      FILE NO ME2008M   REVISION DATE 69-10-25
                                  HORSE POWER                  =      5.00
                                  LINE VOLTAGE                 =    240.00
                                  BASE RPM                     =     1750
                                  DESIGN SPEC                  =        1
                                  ENCLOSURE                    =       OP


                    EXCEPTIONS

                                   50 = 1450.      72 = 0.        100 = 256.01     101 = 256.01



                    LIMITS AND SPECIFICATIONS

                                  FIELD VOLTAGE                =    240.00
                                  REGULATIONS
                                    SPEED(RPM)                 =     1750.
                                    MINIMUM(IN PERCENTS)       =      0.0
                                    MAXIMUM(IN PERCENTS)       =     15.00
                                  COMMUTATION
                                    SPEED(RPM)                 =     1750.
                                    PERCENT F.L. CURRENT(RPMB) =     100.0
                                    MAX. AVER. REACTANCE VOLTAGE=    13.00
                                  STABILITY
                                    SPEED(RPM)                 =     1750.
                                    PERCENT FULL LOAD          =     125.0
                                  LOAD CAPACITY
                                    SPEED(RPM)                 =     1750.
                                    PERCENT FULL LOAD          =     115.0
                                  MAXIMUM A FACTOR             =     1450.
                                  MAXIMUM B FACTOR             =    10000.
                                  TIME RATING                  =     24.00
                                  INSULATION CLASS             =        2.
                                  DEGREES C (RESISTANCE)       =      95.0
                                  MAX. ARMATURE TEMP. RISE     =      60.0
                                  MINIMUM FRAME                =     E256A
                                  MAXIMUM FRAME                =     E256A



            (HP)B        (RPM)B            VL            VF        DESIGN         ENCL.            K            RA
             5.00         1750.        240.00           0.0             1            DP       721.50       0.68210

                            DAG         2BT/C     TYPE WDG         (RT)A     TARGET FL        SLOTS          RCUM
                        0.12500         346.5            1       0.95500         91.00          25.       0.27290

                                     ARM ASSY     ARM PCHG     POLE PCHG     BR HOLDER     B      T C         TPC C
                      FR.2805A                  2988439H01    870A025H03    4110065G060    99/ 3.50/2          55.0

                              A             B          A*B          EBAR          E/IN        ECAVE
            LIMIT         1450.        10000.   0.212E 07         28.00         400.0        13.00
            CALC.          177.        34712   0.616E 06          14.91         110.5         1.16

                            EBR         DENBR        (AT)B         (FL)B         VENTS       ARM LG         ARM D
            LIMIT         36.00        70.000        4600.         91.15       0/0.0          4.750         5.500
            CALC.          4.29        17.701                                      4.750        4.750         5.500

               L1            L2            L3           L4            LT        AREA M         LG M         CURVE
            32.06          6.30         41.04         1.43         80.83          9.50          4.50             1

 PERFORMANCE       RPM =   1782.    IL  = 17.701    REG =      7.0

                      F.L.LOSSES     HE =     53.    PF =      4.    EC =      0.0    FW =     43.    FN =     0.0
                                     BF =     39.    SR =    299.    SH =      0.0    BR =     35.    SL =     42.

               NL          .5*FL            FL        1.5*FL        2.0*FL            MX        PT. L         PT. N
       IA    0.64           8.85         17.70         26.55         35.40        144.61          0.65         17.70
       IL    0.64           8.85         17.70         26.55         35.40        144.61          0.65         17.70
     FLUX   89.79          89.73         89.50         89.51         89.01         81.73         89.50         89.22
      RPM  1907.          1846.         1782.         1714.         1655.          882.         1914.         1788.
       HP    0.0            2.50          5.00          7.31          9.41         18.84          0.0           5.00
       TQ    0.0            7.11         14.74         22.38         29.85        112.13          0.0          14.69
      EFF    0.0           87.7          87.9          85.5          82.6           40.5           0.0          87.9
   LOSSES  157.4          260.3         515.7         920.8        1476.1        20655.8         157.7         516.0

 NO LOAD SATURATION CURVE      (MAXIMUM NO LOAD FLUX =     89.75)
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flux from the magnet is always present. Also, dynamic braking can easily be added so that the motor can be stopped when the external power supply is entirely lost.

Two-Wire Systems—Many drive systems such as those on cranes have always used series dc motors to eliminate the need for a third wire. For most applications, however, a flat speed-torque characteristic is desirable, and permanent-magnet motors provide that characteristic.

Low Inertia—The low inertia of the Westinghouse permanent-magnet motor armature permits quick response.

Disadvantages

No Field Weakening—Permanent-magnet motors only operate at one field strength; they cannot be used when speed change by field weakening is required.

Cost—A given rating in a permanent-magnet motor normally costs more than the same rating in a wound-field motor because of the cost of Alnico magnets. (Very little is saved by the elimination of the field coil, since permanent-magnet motors have excitation coils.) For many applications, however, the reduction of installation cost due to elimination of field power and control may offset the higher cost of the motor and actually result in a lower total cost.

Demagnetization—As noted earlier, a permanent-magnet motor loses flux when overloaded beyond its design capability. Each frame size has a maximum overload torque it can produce before there is any loss in flux. That peak torque does not vary with the type of ventilation of the motor; it is a function of the sizing of the permanent magnets and the commutation ability of the motor. For continuous-nonventilated-rated motors, peak torque is in the range of 5 to 10 times the continuous torque. For one-hour-rated motors and continuous-force-ventilated motors, peak torque is in the range of 2½ to 3½ times the rated torque. When thyristor power supplies are used, current ripple causes an additional reduction of the motor's maximum overload torque. Demagnetization from overloads is not normally a problem for a continuous-nonventilated-rated motor. With either short-time-rated or force-ventilated permanent-magnet motors, especially when used with a TPS, the maximum overload torque the motor must produce without demagnetization is often what sizes it.

Unfortunately, there are a few applications that abuse dc motors to the point where flashovers are common. For those applications, demagnetization can be a problem and therefore permanent-magnet motors are not recommended.

Applications

Although the permanent-magnet motor was originally designed for the steel industry, it is now commonly used in practically all industries. Seldom are permanent-magnet motors used just to eliminate the field coils and excitation; they are used when their advantages provide the user with economy and superior performance.

Cost difference between small permanent-magnet motors and small wound-field motors is slight, while the difference for larger motors is considerable. The reason is that the larger motors require larger proportional pounds of magnet compared to the total pounds of the motor (to keep from losing flux during overloads) than do the smaller motors. The magnet cost of the larger permanent-magnet motors may be as high as half the total cost of the motor. It is this higher cost of the larger permanent-magnet motors that has limited the number of them applied.

The largest size built to date by Westinghouse is 400 hp. It is being used to drive an ingot buggy in a steel mill; the additional cost was justified by savings in installation and operation cost and by improved safety.

Following is a general classification of applications in which permanent-magnet motors have been applied:

Large-Quantity Applications—The table roll drive is an example of this type. Each motor usually drives a single roll, with as many as a thousand motors used in one installation. The advantages are lowest first cost for the total system, lowest operating cost, improved overall reliability, reduced maintenance, and improved motor performance.

Duty Cycles—In many applications such as screwdowns, loopers, arc-furnace drives, and press-feed drives, the motor is required to work at full field continuously while the average torque output produced is very low. Since a permanent-magnet motor is always operated at full field without any field heating, the low average torque output required of the motor, coupled with a higher continuous TENV capability, allows use of a smaller motor, enclosed frame instead of open frame, or complete elimination of external cooling.

Many of these applications have a motor driving the load through a large gear reducer. Often the reflected inertia from the load back through the gear reducer is small compared to the motor's inertia, so the motor's inertia is the major load during acceleration. Since a Westinghouse permanent-magnet motor normally has half the inertia of the wound-field motor, it therefore has faster response and outperforms the wound-field motor.

Battery-Operated Traction—Permanent-magnet motors are used as traction motors on vehicles that have the gear ratio set for maximum load at top speed (e.g., personnel carriers and mine tractors). The high efficiency gives 15 to 20 percent longer battery life between charges. Additional advantages are high overload torque per ampere, flat speed regulation that keeps the vehicle from overspeeding, and ease of dynamic braking. Moreover, permanent-magnet motors can regenerate power to the battery.

Two-Wire Systems—Because of their flat speed-torque characteristic, many permanent-magnet motors are being used in place of series motors for such two-wire applications as cranes, coil tong drives, and hydraulic pumps.

Conclusion

Many thousands of permanent-magnet motors have been built and used in varied applications. Although most have been used in the steel industry, the number of other applications will continue to increase as industry becomes aware of the motors' unique characteristics.

Control Computer Can Ease Process Startup

G. S. Rambo
Vester S. Buxton

Imaginative use of the process control computer while the process is being installed and started up can reduce the time and expense required for startup far below what has been considered normal. An example is the recent startup of the new Armco hot strip mill.

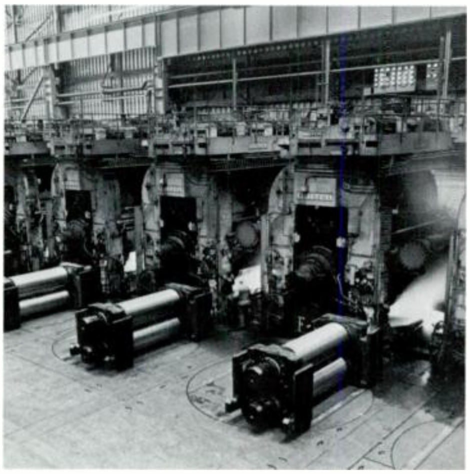
Although digital process control computers are purchased primarily for their long-term benefits in *operating* the process, using them to help *start up* the process can yield significant additional savings. That capability was demonstrated recently at Armco Steel Corporation's new hot strip mill at Middletown, Ohio, where startup and production were accomplished in a smoother manner and shorter time than could normally be expected, resulting in savings of millions of dollars in break-in costs. The manner in which the process control computers were integrated into, and utilized in, the overall startup plan was a major factor in the startup.

Using the computer to verify and calibrate the operation of the many subsystems to which it is connected is, then, an extremely useful and powerful tool during startup. However, it requires adequate planning and scheduling and a computer hardware and software package whose factory and on-site operation has been proved by combination testing.

Total Planning

The first step in applying a computer control system is to analyze the *total* job, with particular emphasis on the computer—the piece of equipment that will eventually manipulate almost all of the conventional equipment purchased. When the purchase of the computer is made on a sound economic basis and with all personnel understanding its short- and long-term benefits, the system can enable the user to reach levels of quality operation unobtainable only a few years ago.

Initially, the user must plan a coordinated functional system and win unequivocal commitment to that system from all departments, especially the operating portions of the organization. Then operating personnel must be thoroughly trained in the use of the computer.



Top—**Hot rolling complex at Armco Steel Corporation, Middletown, Ohio, includes the most automated hot strip mill in the world, with five computers to control it from start to finish. The shorter leg of the "L" houses soaking pits where ingots are heated; the steel then goes through a slab mill and roughing and finishing mills. The mill was started up with the aid of its control computers.**

Bottom—**Finishing train at the Armco mill reduces incoming steel bars to thin strip. The mill operates on full computer control, although operators can assume manual control when desired. The automatic roll changers beside the mill stands change work rolls quickly when they become worn.**

Operator acceptance can be enhanced during installation by a common-sense approach. For example, the computer should always be installed and started up simultaneously with the more conventional controls. Then a few problems with the computer are not highlighted and overemphasized, because every part of the system has its problems during shakedown. In such an environment, the operator gains confidence in the computer (or, more correctly, does not lose confidence). The successes of the computer are a part of those of all the control equipment, so the operator tends to treat the computer as just another of his tools.

Full production demands on the process should be deferred for a time to allow all contributing parties to experiment with and tune the control system. Such an approach permits greater familiarization with the operating system and its capabilities—a prerequisite to optimum performance.

The Armco startup plan included a detailed "line-of-balance" schedule that showed the interfaces between control elements, electrical drives, wiring, and construction. The startup schedule was coordinated with Armco and each separate activity tied to a key event. Since the coordinated schedule allowed the progress of each activity to be measured relative to every other activity, all control elements were available when needed. Thus, as each event was reached, the proper resources were there to accomplish the next activity.

Startup moved smoothly, and even delays did not disturb the pattern. As a result, the first attempts to roll steel in the roughing mill were successful, as were the first attempts to roll from one end of the mill to the other.

Computer in Startup

Among the many advantages that can be gained by intelligent and imaginative use of the computer during startup, a prime example is tuning a rolling mill's po-

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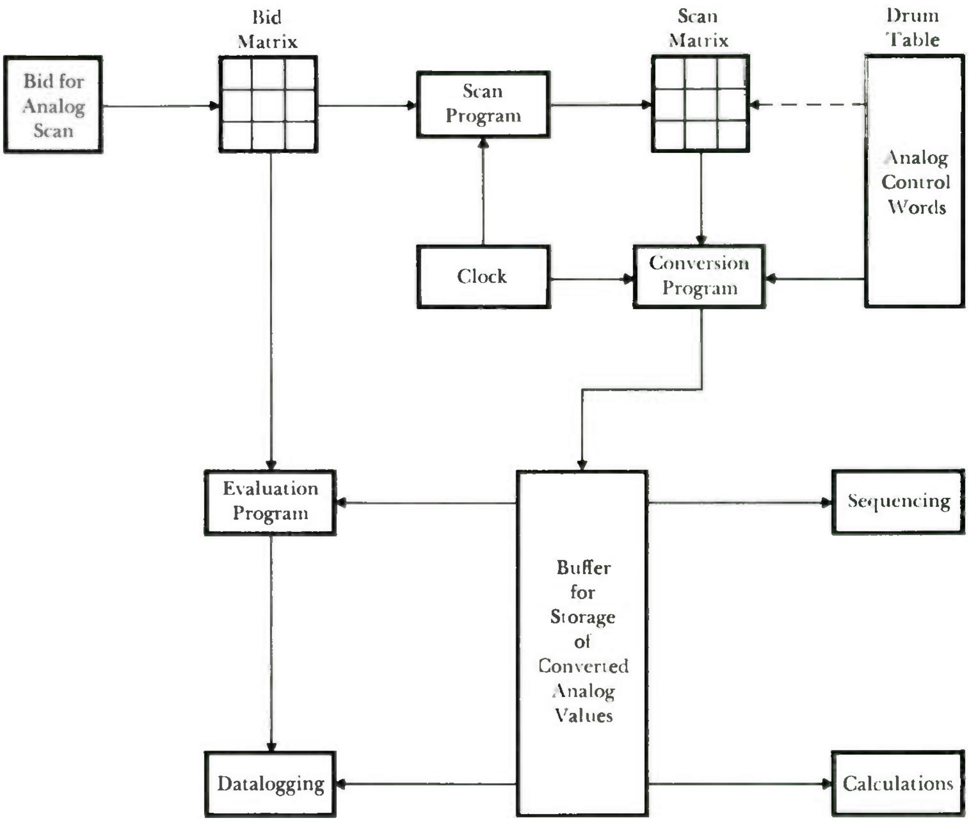
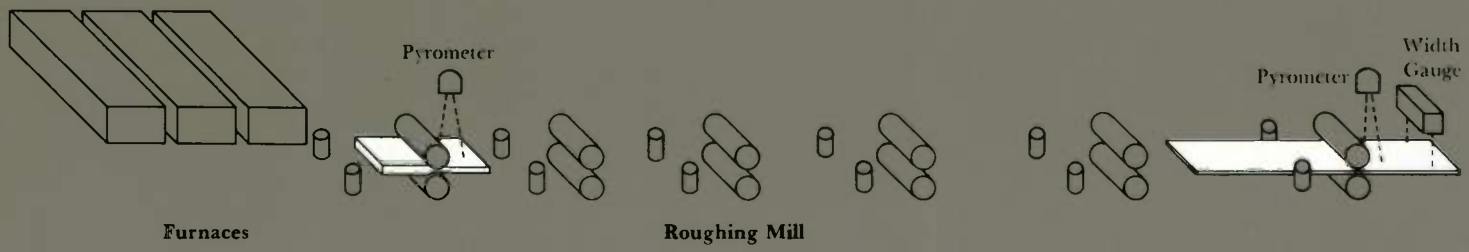
sitioning subsystem to compensate for friction and other mechanical restrictions. Rolling requires accurate positioning of screwdowns (for thickness reduction), edgers (for width control), and sideguards (for control of material position on the tables). The position regulating system in a Prodac 50 process control computer has a self-tuning feature that allows the computer to run the positioning drives at top speed and then stop them under maximum braking torque (current limit) at the exact point desired without overshooting or creeping.

By observing the time it takes to traverse a specific distance for a particular control voltage, the computer automatically constructs a slowdown table that establishes the relationship between distance from target and drive speed for each positioning drive. Knowing the length of travel remaining, the computer determines the maximum operating speed for each point that yields a no-overshoot stop at the target reference. The positioning drives are then controlled in accordance with the slowdown tables for optimum response and accuracy.

An adaptive positioning control feature (not on the Armco mill) has been used to optimize positioning performance of other mills, where operation of the electrical-mechanical positioning system is not consistently predictable. With adaptive control, the computer continually observes actual performance. If the stopping



1—Information flow in the analog programs of a process control computer. Such programs can be used by the computer before process startup to verify and calibrate the process's electrical subsystems.



2—The Armco hot strip mill is represented here in greatly simplified form. It was started up one area at a time, beginning with the roughing mill, after the subsystems had been verified.

characteristics change, due to friction changes for example, the computer automatically corrects its slowdown table to compensate for the changes in the electrical-mechanical system.

Other electrical subsystems can also be calibrated and verified by the computer through the analog programs. An example is calibration of the temperature sensors in a furnace. The computer first checks polarity by reading the voltage at an analog input. Since negative temperature is not valid, a wiring error can thereby be discovered. Next, the computer converts the analog input voltage to temperature by the manufacturer's recommended conversion technique, giving a value in engineering units for the temperature being measured by the sensor. It is then a simple matter, by using alternate sensor systems, to adjust the sensor to provide the proper voltage level in accordance with the computer's analysis.

Operation of the analog input program is diagrammed in Fig. 1. The scan program is initiated at predetermined intervals (controlled by the computer clock), with the drum table correlating selection of the inputs that represent the desired variables. The conversion program translates the voltage received into proper engineering units and stores it in the buffer until the data is used for evaluation or logging purposes. The data in the buffer is available to all control programs in the software system. Because closed-loop control depends on the feedback values, use of the computer program to calibrate sensors initially assists the overall startup.

Another example is calibration of the subsystem that controls the speed of the motor-driven tables used to move steel from one point in the process to another. As the steel passes through a mill stand, entry speed is less than exit speed because thickness is being reduced and mass flow must be constant. (The condition is similar to that of fluid flowing through a constriction in a pipe.) Therefore, entry table speed must be "draft-compensated" by an amount depending on the draft (amount of reduction) taken. The computer controls speed by setting a reference to the table. During startup, the computer can be used to observe speed feedbacks and indicate deviations from speed reference settings. The information can then be used to calibrate the draft-compensation settings.

Moreover, the computer can read and log the results of thousands of inputs to verify operation of thumbwheels, pushbuttons, pushlights, displays, and other contact communication devices.

Thus, effective use of the computer as a central information point can measurably reduce the time necessary to pinpoint errors in auxiliary control subsystems. The computer acts as a central debugging device for verifying the operation of all connected system components.

After the subsystems have been verified, the mill startup is approached functionally by processing areas. At Armco, the first area started was the roughing mill (Fig. 2). Programs were included in the computer to simulate the actual presence of steel, and the total control system was checked in this dry-run mode. Thus, the computer verified the operation of all main roughing-mill systems without endangering any mill equipment.

Conclusion

The decision to purchase process control computers will continue to be made on the basis of long-term benefits. However, computers have proved that their effective use in putting a major process on line can yield important additional economic benefits. Conversely, lack of proper planning for their use can result in unnecessary delays for the user and cost overrun for the computer supplier.

The Armco installation is one of several hot strip mill applications where initial operation was sufficiently satisfactory to permit reduction of pilot operation time in favor of starting production. Two slab mills, a variety of process lines, and several steel-making facilities have also demonstrated the validity of this installation approach. Less realistic approaches too often result in dissatisfaction without a clear understanding of the reason for failure to achieve the desired goals.

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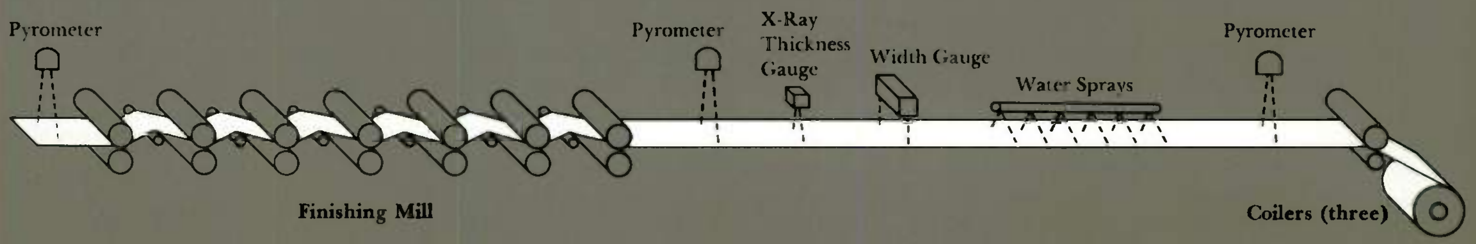

Fundamentals of Pulse Doppler Radar

L. P. Goetz

Pulse doppler radars provide the search and track functions for today's aircraft and missile systems. Use of the doppler effect separates moving targets from regions of high background clutter.

Modern doppler radars, particularly those used in today's high-speed aircraft and missile systems, have advanced several technological generations from the first doppler radars that were developed during World War II. Those early versions were ground-based radars, designed to avoid the great amount of ground clutter (reflection from land or sea surface) that results when ground or ship radars search the sky at low elevations to pick up distant aircraft. By utilizing the doppler effect, radar reflection from an oncoming aircraft is shifted sufficiently in frequency to permit the radar receiver to receive the target return signal at frequencies removed from the ground clutter return.

Today's radars for high-speed aircraft and missiles also use the doppler effect to separate moving target returns from regions of high background clutter. However, missile and aircraft applications require one major design innovation from the earlier versions of doppler radar. Since transmitting and receiving antennas cannot be physically separated far enough to provide the necessary signal isolation between transmitter and receiver, it is necessary to alternate the transmit and receive cycles. Radars of this class use a single antenna, time-shared between transmitter and receiver, so they are called *pulse doppler radars.*

A typical pulse doppler application for missiles is the final guidance phase of target acquisition. For example, a ground-based interceptor missile is guided from ground to the target's vicinity and elevation, where the pulse doppler radar is then activated for the terminal guidance phase. The high relative speed between missile and target provides sufficient doppler shift to separate the target return from background clutter.

In aircraft applications, a typical pulse doppler radar is used in a *search* mode to hunt for moving targets. Upon target acquisition, the radar switches to a *track* mode to guide the aircraft to the target.

Doppler Shift

Doppler radars operate by detecting the doppler shift introduced by a target that has a radial velocity component with respect to the radar. All modern doppler radars detect the amount of frequency shift rather than the actual frequency of the return signal. The equation for doppler shift can be written:

$$f_d = \frac{103\ V}{\lambda}$$

where f_d is the frequency shift in hertz, V is the radial velocity of the target (relative to the receiver) in knots, and λ is the operating wavelength of the radar in centimeters. Thus, for a doppler radar operating in the three centimeter wavelength region (X band), the doppler shift is about 34 hertz per knot of relative radial velocity.

A typical pulse doppler transmission is the pulsed carrier wave shown in Fig. 1. The carrier wavelength is usually in the centimeter range (3-30 GHz). From the doppler equation, it can be seen that the frequency shift produced by a typical moving target is relatively small compared with the carrier frequency. For example, if a Mach 2 aircraft and a Mach 2 target are closing on each other, the closing velocity is about 2700 knots. At 34 hertz per knot, the doppler shift is only 92 kHz. Thus, to accurately separate the doppler frequency from the high carrier frequency, extremely stable transmitter and receiver oscillators are required. Typically, a stable reference source is used for radio frequency generation, and a fixed offset from this frequency is used to determine the amount of doppler shift. This technique simplifies the stable oscillator design, and the tolerable short term stability.

Pulse repetition rate—The minimum pulse repetition frequency (PRF) is set by the anticipated doppler frequency. One criterion for selecting PRF is Nyquist's sampling theorem, which specifies that a necessary condition for reconstructing a wave form is that the sampling frequency be at least twice the frequency of the wave form being sampled so that the information will not be ambiguous. For the example given, PRF must be at least twice the maximum anticipated doppler frequency (92 kHz), or about 200 kHz.

Frequency Spectrum of Pulse Doppler Signals

A transmitted carrier chopped at a continuous PRF can be shown by Fourier analysis to consist of frequency components that form a grouping of spectral lines about the carrier frequency. The interrelationships between carrier frequency (f_0), pulse repetition period ($T = 1/PRF$), and pulse period (τ) for a chopped carrier are shown in Fig. 2.

The spectrum of the returned signal is essentially the same as the transmitted signal except that each spectral line is shifted by the amount of the doppler frequency (f_d). The magnitude of the doppler shift is the measure of relative velocity between radar set and target. If this shift could be measured directly, it would provide within itself all the information on the target measurable on a frequency basis. However, since it is not practical to measure doppler shift directly, the received signal is heterodyned to an intermediate frequency and detection then removes the intermediate frequency component to provide a detected frequency spectrum (Fig. 3) from which the desired doppler information can be derived.

Since the desired doppler information is contained in the frequency distribution associated with each PRF spectral line, signal filtering limits the bandwidth actually selected for detection to a portion of the spectrum associated with a single spectral line. Signal heterodyning produces a doppler signal both above and below each PRF spectral line (i.e., $f_0 + f_d$ and $f_0 - f_d$), so doppler shift (f_d) must not be allowed to exceed one half the PRF or the doppler signals from adjacent PRF spectral lines will overlap, making it impossible to resolve doppler frequency. Thus, the maximum doppler shift that can be detected unambiguously is limited by the PRF, $f_{d_{max}} \geq PRF/2$.

This, in effect, is the pulse doppler

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version of the application of the Nyquist sampling theorem.

Clutter Spectrum

Clutter in a radar set is the reflection of nontarget objects from either the main beam or the antenna side lobes. In aircraft pulse doppler radar, clutter originates from the three sources illustrated in Fig. 4. Main beam clutter is the backscatter from ground when the main beam dips below the horizon; it is relatively strong because of the strength of the main beam. Side-lobe clutter comes from the antenna side lobes striking the ground at various angles, and it produces doppler shifts both above and below the transmitted carrier frequency. Side-lobe clutter has a range of doppler frequencies corresponding to twice the ground velocity of the aircraft. At any particular instant, one of the side lobes is looking straight down at the earth and returns a signal with zero doppler shift. This altitude line occurs in all airborne radars.

The distribution of the clutter spectrum about each spectral line in the return signal is shown in Fig. 5. Depending on the size of the nontarget object, its bearing, and its relative velocity and range, its reflection may obscure a desired target. The basic problem is to arrange the parameters of the radar set such that clutter is minimized in the frequency region where targets are expected. Thus, to appear in a clutter-free region, an approaching target must have a closing velocity such that its doppler shift is greater than the closing clutter to the right of the spectral lines in Fig. 5. However, closing velocity cannot be too great or its doppler shift will run into the open-

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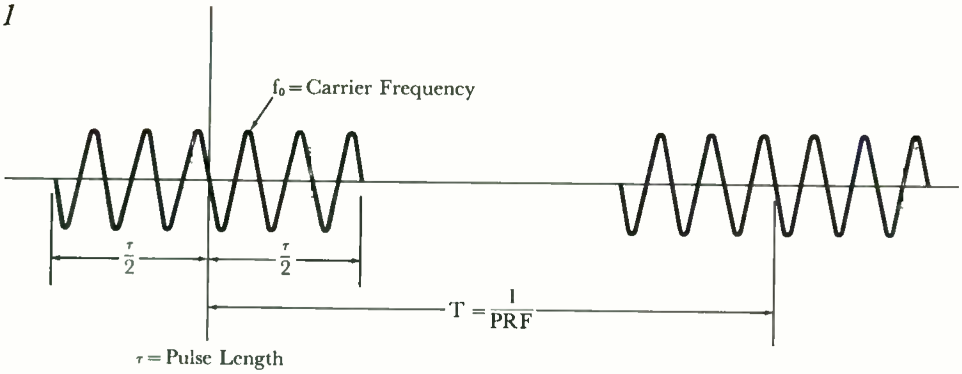
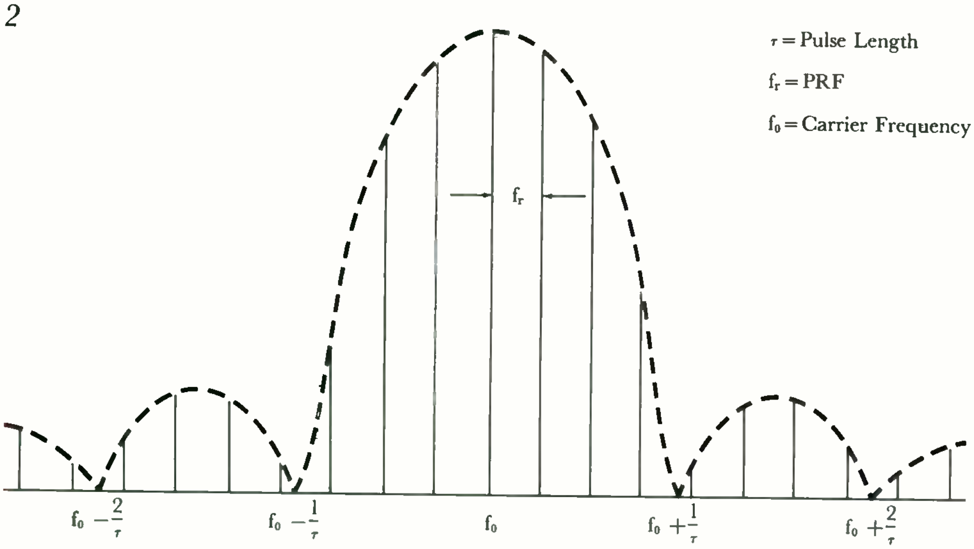


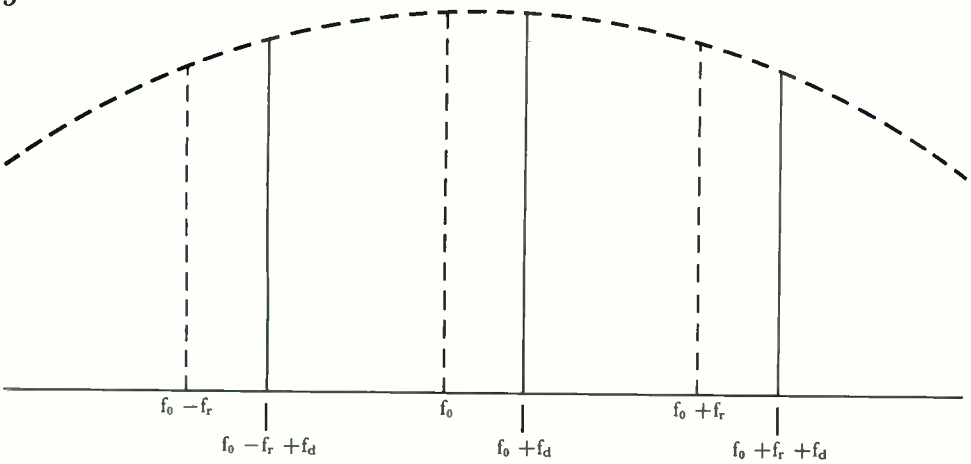
1—Pulse doppler transmission is a pulsed sine wave.

2



2—Frequency spectrum for pulsed sine wave is a grouping of spectral lines above and below carrier frequency (f_0) encompassed by an envelope whose shape is determined by the shape of the transmitted pulse.

3



3—Spectral lines of detected signal spectrum are shifted above or below return signal spectral positions by doppler frequency (f_d), depending on whether the target has a closing or opening velocity.

ing clutter of the neighboring spectral line. Since the spectral lines are separated in frequency in direct proportion to the PRF, the PRF determines the range of closing target velocities that can be handled unambiguously by the radar. The range of opening target velocities that can be detected is similarly limited.

The effect of each of the various types of clutter for different target headings is shown in Fig. 6. An aircraft with a scanning antenna is flying in the direction shown. Two targets are indicated, one directly ahead of the aircraft and one at an azimuth angle of 45 degrees. Each target is located at the center of circles that represent ratios of target ground velocity to interceptor ground velocity. A target vector showing velocity ratio and direction is drawn from the center of each target position. The tip of the vector shows whether the target is clear or obscured by clutter.

The two target vectors illustrated in Fig. 6 show the targets to be outside the clutter region. If both targets were traveling opposite to the directions indicated, the target straight ahead would be obscured by opening side-lobe clutter, but the target on the 45-degree bearing would be clear of opening clutter because of its higher velocity.

Range Resolution

In pulse doppler radar, as in conventional pulsed radar, range to the target is proportional to the time interval between a transmitted pulse and its return echo. However, the high pulse repetition frequency that must be employed with pulse doppler radars causes many time-around echos and corresponding ambiguities in range information.

Several techniques can be used to resolve such ambiguities. One typical ranging system uses multiple PRFs. The principle of the multiple-PRF system can be described by considering the two-PRF system, illustrated in Fig. 7. The basic ranging frequency sets the maximum unambiguous range that can be measured. Two higher frequencies are then derived from this basic frequency by multiplying by two integers. In the example shown, the integers are 3 and 4. Target returns

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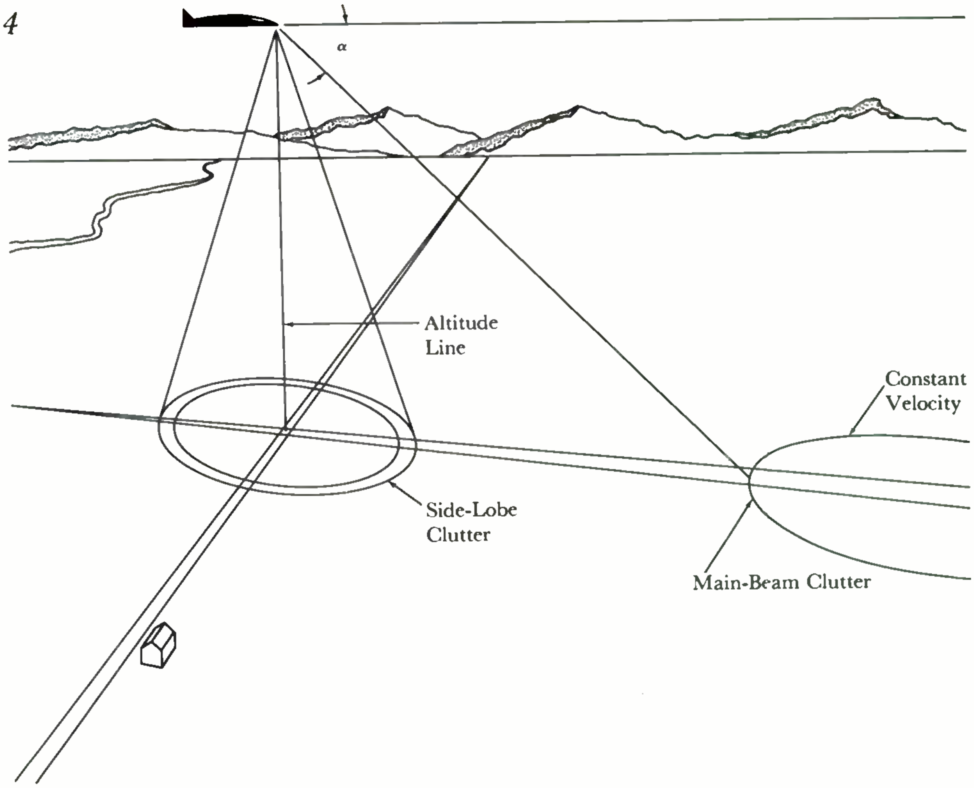

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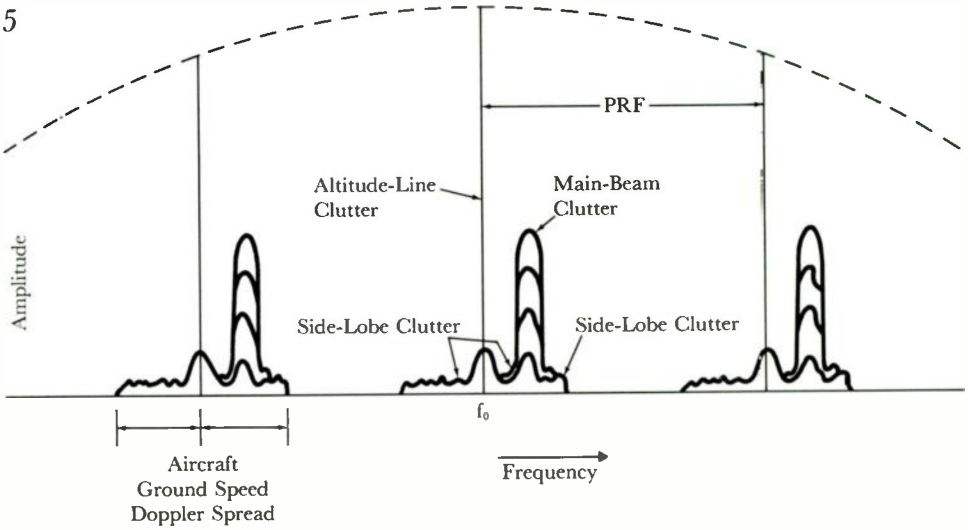

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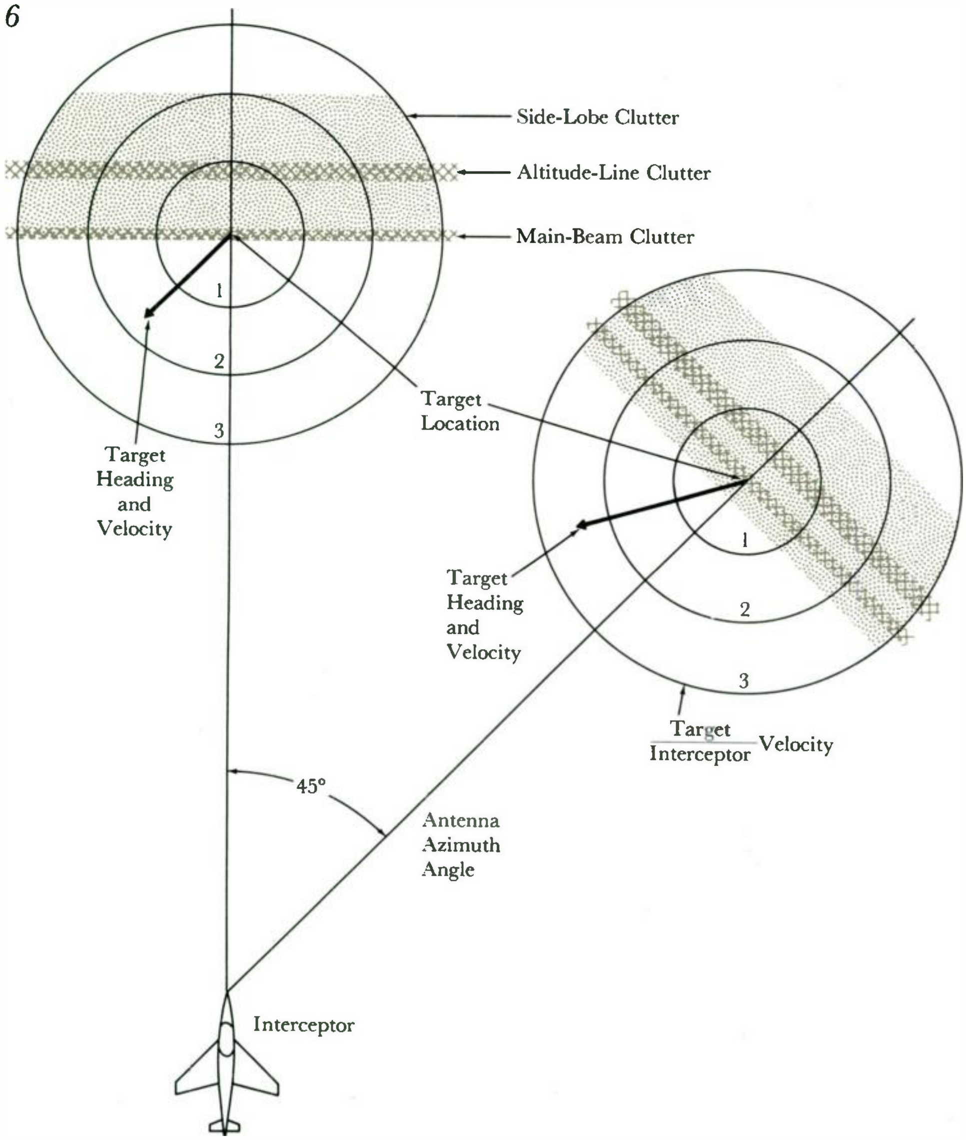


4—Clutter in an airborne pulse doppler radar is generated by reflections from main beam and side lobes.

5—Typical distribution of clutter around each spectral line in an airborne, nose-mounted pulse doppler radar.

6—Clutter and target vector diagram illustrates whether target will be clear or obscured by clutter.

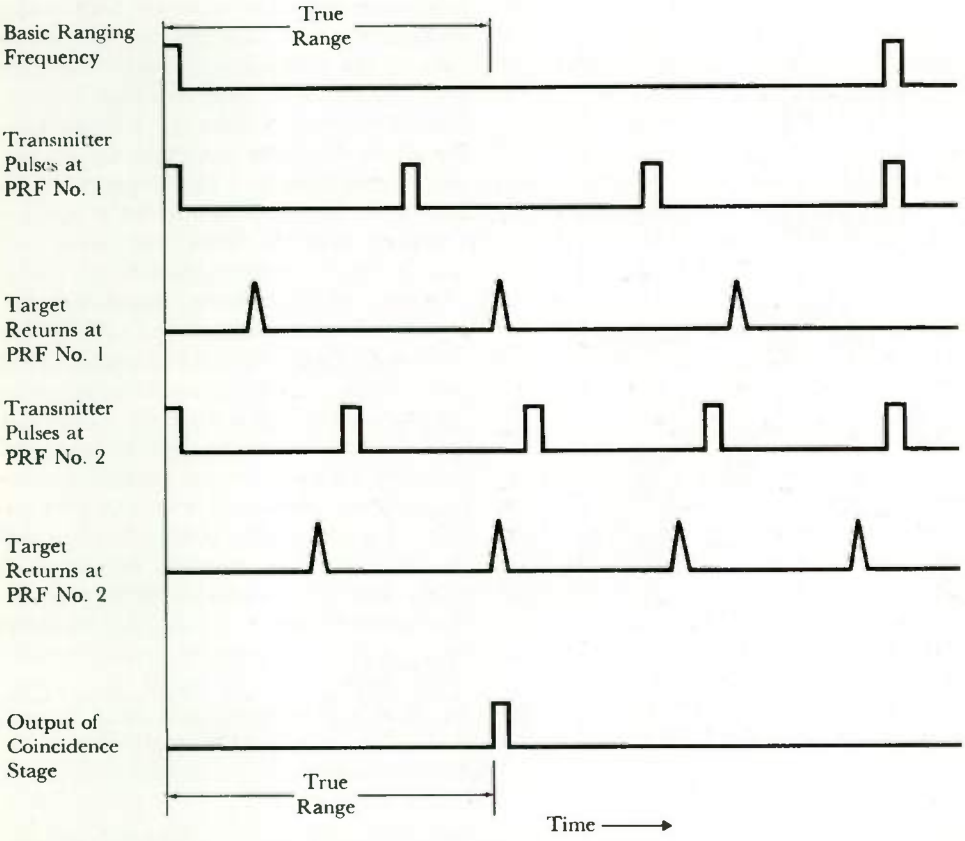
produced by each of these PRFs are ambiguous, but these returns will coincide at the true target range. Thus the radar transmits alternately at each PRF, and stores the returns for comparison. Return coincidence gives true range.

This multiple-PRF technique can be extended to a number of PRFs, but, in practice, a two- or three-PRF system can usually resolve the range problem.

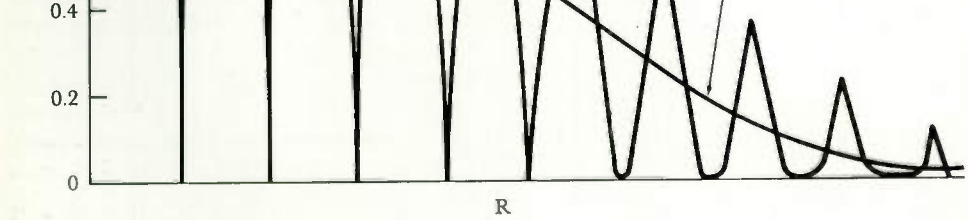
Target eclipsing—Range calculation for a pulse doppler radar is similar to the range calculation of other types of pulse radar with one exception, and that is eclipsing of the target reflection by the transmit cycle. Because many transmit pulses occur between the transmission of a particular pulse and the return of its echo, it is quite possible for all or part of the echo to return during a transmission pulse, causing the target to be "eclipsed." With reasonable antenna-scan speeds, the amount of eclipsing may not change appreciably during the dwell time of the antenna main beam on a target during a particular scan. However, when the antenna returns to the target on the next frame, the target will have moved to a new position where the eclipsing may be more or less than on the previous frame. Typical frame times are of the order of one second, so a Mach 2 target would move about 2000 feet between frames.

If the target velocity is such that it moves a distance corresponding to an integral number of interpulse periods during the frame time, the target may be eclipsed on all looks and range performance would be significantly degraded. To prevent such "blind" target speeds, the PRF can be changed in a periodic manner. This has the effect of averaging the eclipsing from frame to frame instead of from target to target. For example, with a single PRF, one target could be completely eclipsed while another target could be completely clear. Periodic changing of PRF would cause the eclipsed target to be alternately clear and eclipsed.

A representation of range performance for a pulse doppler radar can be developed for a target assumed to start at a range where the probability of detection is small and to move radially toward the radar at uniform speed (Fig. 8). A probability of detection curve is derived from the true detection curve for this situation, which is a series of loops with loop spacing determined by the PRF Thus, return signal strength varies from frame to frame, depending on frame time, relative velocity, PRF, pulse width, and range.



7—The target returns of a two-PRF ranging system coincide at true range only.



8—A smoothed detection curve that represents probability of target detection can be derived from true detection curve.

Elements of a Pulse Doppler Radar

A block diagram of a typical pulse doppler radar for aircraft application that will search for a target and track it in velocity, range, and angle is shown in Fig. 9.

In the *search* mode, the target is located in velocity and angle. The modulator keys the transmitter to produce a pulsed sine wave, and the return signal is routed to a mixer via an isolator. The mixer translates the received frequency to an appropriate intermediate frequency (i-f), which is amplified and passed through a band-pass filter. Filters for rejection of clutter may also be included at this point to provide additional clutter attenuation. Bandwidth is reduced as early as possible to simplify amplifier design by reducing dynamic range requirements.

The output of the band-limited i-f stage feeds another mixer which translates the frequency spectrum to one satisfactory for a contiguous filter bank that encompasses the target doppler frequency range of interest. (An analogy to a contiguous filter bank in the power frequency field is the vibrating reed frequency meter, in which a bank of resonant reeds is used to measure frequency.) The contiguous filter bank arrangement permits the radar to search the whole desired doppler frequency range simultaneously.

When a target is detected, the detection and decision unit switches the radar to the *track* mode. Antenna scanning is stopped, the velocity track loop is locked on target using information from the contiguous filter bank for velocity track positioning, range track is initiated, and angle track is started.

Techniques similar to those used in conventional pulse radar are satisfactory for range and angle track, and velocity track is performed with either a phase or frequency track loop. It is common practice to also feed velocity information to the range track feedback loops to aid in target range tracking.

The precise signal generation and signal processing requirements of airborne pulse doppler radars are not easily satisfied. For example, the signal strength of a typical target return might be only 10 dB above thermal noise, whereas main beam clutter will be some 90 dB above thermal noise. Any spurious modulation of the transmitted carrier would have the effect of spreading the clutter spectrum and completely masking the target return. Thus, all spurious modulation of the carrier must be kept at least 80 dB down from the level of the transmitted carrier. This means that the carrier signal must approach a textbook sine wave, completely free from the influence of aircraft vibration, power supply ripple, or leakthrough from any other part of the system. Furthermore, the carrier frequency must be completely free from short-term drift.

These high performance requirements have required continual advancements in the technology: oscillators that are extremely accurate and free from the effects of aircraft or missile vibration, filters that can remove or select frequency bandwidths with high precision, and components that can withstand the difficult airborne environment with high stability and reliability. In fact, the technology that existed only 20 years ago would simply not have permitted the development of today's operational pulse doppler systems.

Systems for the Future

In multipurpose airborne radar systems, pulse doppler is often just one of several possible required modes of operation. For example, the total radar system may also provide a pulse mode, a chirp mode, and a mapping mode. Each mode requires a specific combination of transmitted signal and return signal processing.

One of the more promising techniques now being demonstrated for the next generation of multimode airborne radar is digital signal processing. With digital techniques, signal processing is accomplished with programmed instructions rather than with specific arrangements of circuitry required for analog signal processing. The operation of multimode systems would be simplified because changes from one mode to another could be accomplished merely by changing programs rather than hardware.

Digital signal processing in the radar frequency range requires extremely high data rates. These high rates are now feasible with high-frequency molecular circuits that are small, lightweight, and reliable. In addition to simplifying operational techniques, digital signal processing also offers the potential of radar systems that are smaller, lighter, and more flexible than today's analog designs.

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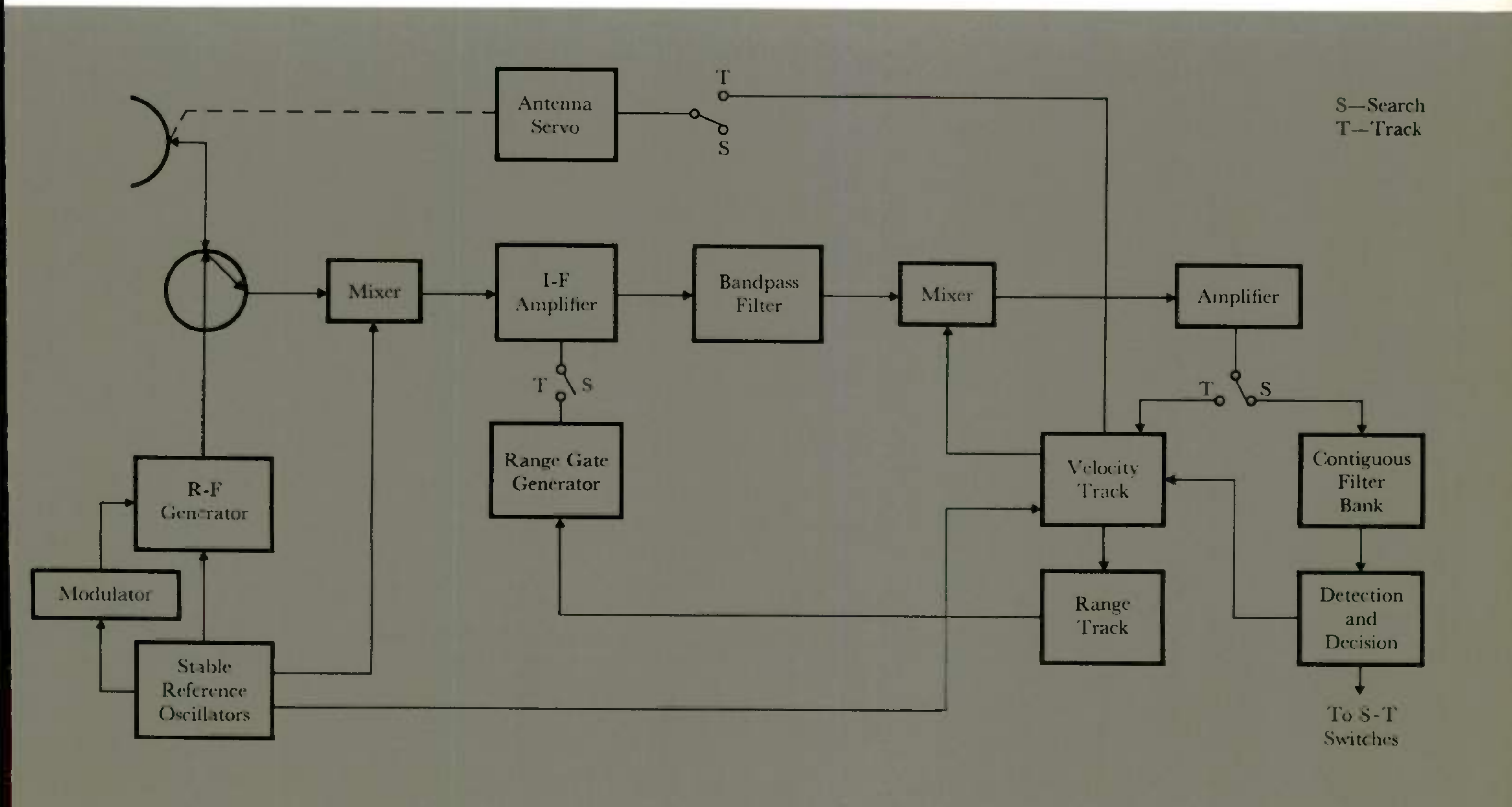
REFERENCE:
Goetz, L. P. and Albright, J. D., "Airborne Pulse-Doppler Radar," *IRE Transactions on Military Electronics*, Vol. MIL-5, No. 2, April 1961, pp. 116-126.



9—Diagram of typical pulse doppler radar that searches for and tracks moving targets.

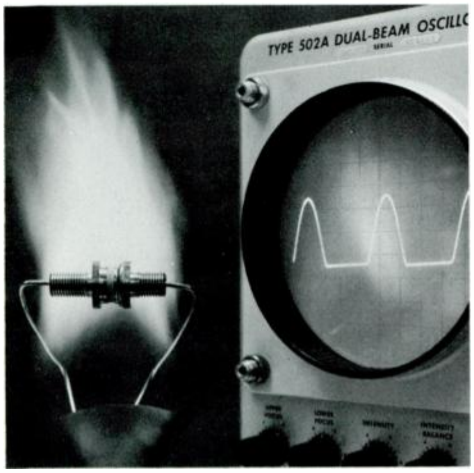
Silicon Carbide Rectifiers Can Operate at 500 Degrees C

Silicon carbide rectifiers have been developed that can operate at more than double the temperature it takes to disable silicon rectifiers: they can function at 500 degrees C and survive temperatures of over 980 degrees C. In contrast, silicon rectifiers are limited to temperatures below 200 degrees C, because at higher temperatures they become metal-like and conduct current in both directions.

Silicon carbide rectifiers with forward currents up to 10 amperes and reverse voltages to 300 volts have been produced. The new devices were developed by the Westinghouse Astronuclear Laboratory from research work done there and at the Westinghouse Research Laboratories. In addition to their higher operating temperature, silicon carbide rectifiers are inert in most atmospheres and are highly resistant to ionizing radiation; preliminary results show resistance to radiation damage at least ten times that of comparable silicon devices.

Junctions are produced in the silicon carbide crystals by adding suitable impurities—p-type and n-type dopants—to form a layered structure. Machining techniques (mechanical and chemical) for the crystals are similar to those used for silicon. However, mechanical machining such as lapping, abrasive cutting, and ultrasonic cutting must be done with diamond or boron-carbide dust because those are the only materials harder than silicon carbide.

Although the encapsulated silicon carbide rectifier is exposed to a torch flame, its output is still a rectified signal.



Chemical machining requires radical departures. Etching, for example, requires great care because hexagonal silicon carbide is a structurally polarized crystal with a carbon face and a silicon face; etching rates on the carbon face are usually much faster than those of the same etchant on the silicon face. Moreover, the etchants themselves can be problems because of their reactivity with silicon carbide.

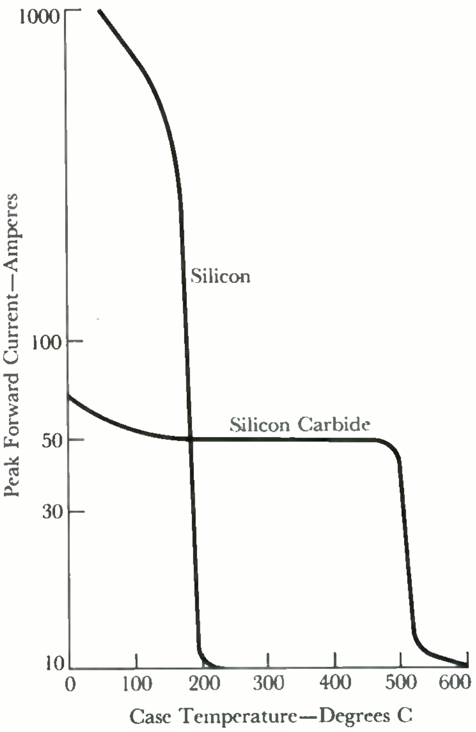
After a crystal has been machined to produce a wafer with the desired characteristics, the wafer is bonded between contact discs. The resulting device can then be encapsulated in a variety of ways to meet differing environmental requirements, such as high rotational and vibrational forces.

Silicon carbide rectifiers have been operated for 1000 hours at temperatures up to 500 degrees C without appreciable degradation (Fig. 1). Some specially prepared units have been operated near 600 degrees C. Rectifiers having a peak forward current above 50 amperes have been tested and found to be stable.

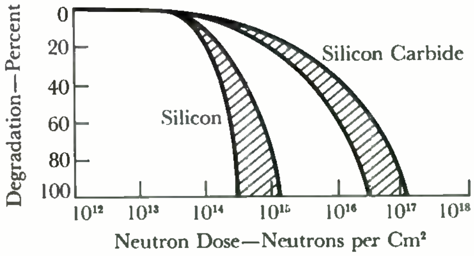
Potential high-temperature applications include alternators and rectifier bridges for power conditioning. The devices are especially attractive for missiles and supersonic aircraft because they would require less cooling or none at all.

In addition to power rectifiers, silicon carbide diodes of milliampere current capacity have been made for various applications. For use in high-efficiency magnetic amplifiers, the diodes can be made with low reverse currents and matching forward characteristics. With suitable series connections, blocking diodes of up to 2000 peak reverse voltage have been prepared successfully.

The inherent radiation resistance should lead to other specialized applications (Fig. 2). One is use near nuclear reactors, as instrumentation diodes for example. Another is in power conditioning for vehicles operating in space.



1—Silicon carbide rectifiers can operate at temperatures up to 500 degrees C with only slight current drop-off. Although silicon rectifiers can have much higher peak current ratings, they are restricted to use at temperatures below 200 degrees C. (Case temperature is the temperature of the outer package; the diode is at a higher temperature.)



2—Silicon carbide rectifiers can be used in radiation doses up to 10^{16} neutrons per square centimeter without significant degradation and, in some specialized applications, up to 10^{17} neutrons per square centimeter. Comparable silicon rectifiers are nearly completely degraded at radiation doses above 10^{15} neutrons per square centimeter.

SEC Television Camera Tubes Map Ultraviolet Stars

Four 12-ounce television camera tubes are giving man a new look at his universe from their telescope mounts aboard the National Aeronautics and Space Administration's largest and most-instrumented unmanned satellite, the Orbiting Astronomical Observatory (OAO-A2). The Uvicon television camera tubes are mapping the stars and interstellar space in an experiment—called Project Celescope—conducted for NASA by the Smithsonian Astrophysical Observatory.

The mapping is done by means of far-ultraviolet radiation, which, though emitted by celestial bodies, never reaches the earth's surface because it is absorbed in the atmosphere. Thus, the orbiting Uvicons give pictures of the heavens that have previously been screened from earth-bound observation. Such pictures offer special promise for studying extremely hot young stars, some perhaps only 100,000 years old, whose major energy output is in the ultraviolet range. (Our own sun, which radiates mainly visible light and heat, is a relatively old cool star thought to be about five billion years old.) Study of the ultraviolet stars is expected to give new insight into their ages and chemical compositions and perhaps lead to new discoveries about how the universe came into being and is evolving.

Project Celescope dates back to the late 1950's, when the Smithsonian proposed it to NASA and began work with Westinghouse on development of the key Uvicon camera tube. The company's Electronic Tube Division and its Research Laboratories developed the tube jointly.

The project is scheduled to survey some 100,000 stars at a rate of up to 700 per day. An ultraviolet map of the entire sky will require about a year to complete.

The satellite has four high-resolution telescope systems. Each consists of three main components: an optical system (Schwarzschild telescope) to form the ultraviolet star images and focus them onto the camera tube; the tube, which amplifies the images electronically, stores them, and converts them into television-type electrical signals; and a digital television system that processes the signals for transmission back to earth, where the original ultraviolet pictures are reconstructed.

The Uvicon is an extremely sensitive camera tube. It is a member of a family of devices known as SEC image tubes (so called for "secondary electron conduction," the electronic amplification principle used). Ultraviolet images are focused on the input surface of the Uvicon through a window of a material such as lithium fluoride that does not absorb the wavelengths of interest. The back surface of the window is coated with a photosensitive material that releases electrons where the ultraviolet image strikes it. Those electrons are accelerated by high voltage toward the rear of the tube, where they strike a target that has a thin porous layer of potassium chloride.

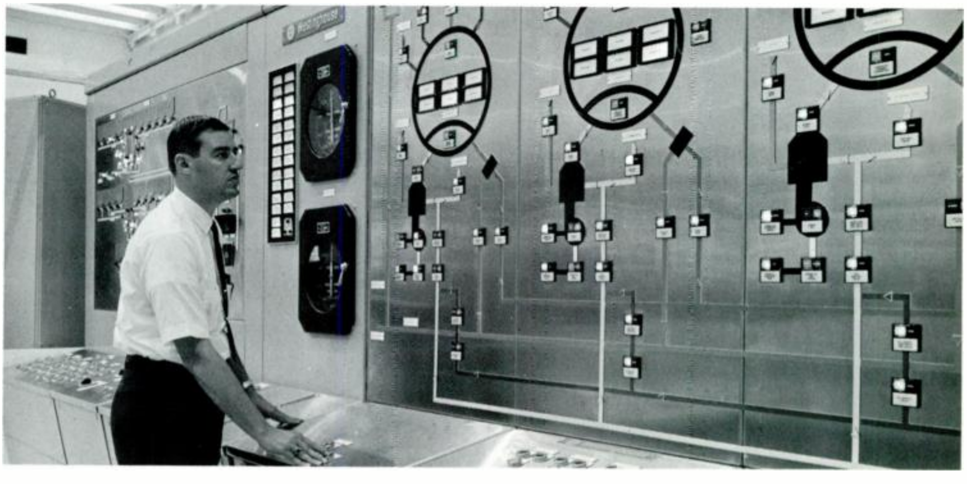
The impact of each speeding electron on the target causes it to emit as many as 300 additional electrons, called secondary electrons, that are conducted through the porous layer to a metal film. There the electrons create an electric charge pattern that is an exact reproduction of the original ultraviolet image. The charge pattern is read out as electrical signals by scanning the target with a beam of electrons, and the signals then go to electronic circuitry that amplifies, codes, and stores them. On command from the ground, the coded information is transmitted to earth and fed to decoding circuitry that recreates the Uvicon's signals and, thereby, the ultraviolet pictures. The input windows and photosurfaces of the four Uvicons are designed to respond to four bands of ultraviolet radiation in the wavelength range from 1050 to 3000 angstroms. (For an application of SEC image tubes in earth-bound astronomy, see inside front cover.)

EMR, a division of Weston Instruments, Inc., is systems contractor for Project Celescope and was responsible for development of the ultraviolet telescopes and their associated electronic equipment. Grumman Aircraft Engineering Corporation is prime contractor for the OAO program.

Blast Furnace Automation Extended for High Production and Uniformity

The potential for cost reduction inherent in the basic oxygen steelmaking process depends on a process for making pig iron—the principal raw material—that is fast, efficient, and consistent. Consequently, steelmakers have been enlarging their blast furnace facilities, improving operating practices, and applying improved furnace control systems to obtain larger quantities of pig iron having more consistent and predictable quality.

Panels for a computer-automated blast furnace charging control system are checked before being shipped for installation.



A computerized automatic furnace charging control system developed by the Westinghouse Industrial Systems Division is the latest step toward the goal of complete automation of the entire blast furnace complex with a closed-loop control system. It controls the weighing and sequencing of coke, limestone, iron ore, and other raw materials to assure efficient production of iron of the desired uniform composition. Use of the control system enables an average blast furnace to produce 4000 to 5000 tons a day.

Test Facility Begun for Breeder Reactor Development

Work has begun on the Fast Flux Test Facility, the major test location for fuels and materials in the U.S. Atomic Energy Commission's Liquid Metal Fast Breeder Reactor program. It is located near Richland, Washington, and is expected to be in operation in 1973.

The AEC is developing breeder reactors—nuclear reactors that produce more fissionable material than they consume—to conserve the available supplies of nuclear fuel materials. It will use the Fast Flux Test Facility for irradiation testing and post-irradiation examination of fuels and materials being considered for use in such reactors.

Westinghouse is providing reactor plant design services to Battelle-Northwest for the project. The company is responsible for design of the reactor and associated nuclear systems, with most of the work to be done by its Advanced Reactors Division. Atomics International Division of North American Rockwell is a subcontractor to Westinghouse.

Products for Industry

High-power tetrode cooled by forced air has been developed for oscillator, modulator, and amplifier applications in communications systems at frequencies up to 110 MHz. The compact ceramic and metal tetrode is designated WL-8171/4CX10,000. A pair of them can deliver 17.5 kW of audio-frequency or radio-frequency power with zero driving power. The tetrode has a plate dissipation rating of 10,000 W. It is approximately 9 inches long, has a maximum diameter of 5 inches, and weighs 9½ pounds. It is operated with its axis vertical and at temperatures below 250 degrees C. *Westinghouse Electronic Tube Division, P.O. Box 284, Elmira, New York 14902.*

Enclosed high-voltage capacitors (Type IDP) for increasing the efficiency of plant distribution systems can be installed indoors or outdoors. The capacitors are rated 15, 25, 50, 75, and 100 kVAc at 2400 and 4160 volts. They are dustproof and corrosion proof, with a protective exterior finish of zinc and outdoor enamel paint. *Westinghouse Distribution Apparatus Division, P.O. Box 341, Bloomington, Indiana 47402.*

Hydraulic-pump motors provide long life and high power for aircraft and ground support equipment. The line of direct-drive pump motors is made up of 400-Hz units with three basic sets of ratings: 7 hp at 4600 r/min, 10 poles; 8 hp at 5700 r/min, 8 poles; 13 hp at 5700 r/min, 8 poles. Many combinations of ratings can be made from the basic models. All motors are 6.33 inches in diameter and from 7.25 to 9.25 inches long. They weigh from 20.0 to 26.5 pounds. The motors are housed in a one-piece metal shroud and mounted on a rib-reinforced foot. *Westinghouse Aerospace Electrical Division, Utilization Systems Department, P.O. Box 989, Lima, Ohio 45802.*

Static voltage regulator and associated static excitation switchgear are connected directly into the fields of existing main exciters to replace electromechanical regulators. The type PRX regulator controls generator terminal voltage by supplying a buck-boost control signal above and below the base excitation signal. Its sensing circuit responds to average three-phase voltage and is insensitive to frequency. It controls excitation by governing the firing circuit to vary the output of the power amplifier. *Westinghouse Switchgear Division, 700 Braddock Avenue, East Pittsburgh, Pennsylvania 15112.*

Services for Industry

Load-flow and stability computer programs provide analytical tools to resolve voltage fluctuation difficulties in steel-producing arc furnaces. A load-flow study determines the optimum system parameters, i.e., the impedance of the capacitor and reactor and the kvar rating of the condenser. Economics and steady-state voltage fluctuations are the design criteria. With those parameters selected, a stability study is performed to observe transient behavior of the synchronous condenser and to verify that its angular swing does not aggravate voltage disturbances at a critical bus. Consideration is given to furnace loading and to faults that produce severest disturbances. *Westinghouse Advanced Systems Technology, East Pittsburgh, Pennsylvania 15112.*

Westinghouse ENGINEER Bound Volumes Available

The 1968 issues of the *Westinghouse ENGINEER* have been assembled in an attractive case-bound volume that can be ordered for $4.00. The cover is a durable black buckram stamped with silver. Order from *Westinghouse ENGINEER*, Westinghouse Electric Corporation, P.O. Box 2278, Pittsburgh, Pennsylvania 15230.

About the Authors

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

Baldwin has had a variety of assignments in the Power System Planning Department. He is presently manager of development, Advanced Systems Technology, where he is responsible for developing new digital computer applications for solving power systems problems and for managing Westinghouse consulting services for utility and industrial customers.

Baldwin was chosen for Eta Kappa Nu's Outstanding Young Electrical Engineer Award for 1961. In 1967, the University of Texas designated him a Distinguished Engineering Graduate. A key factor in his selection was his work in the development of power system simulation techniques.

Robert C. Fear, Robert R. Madson, and **Joseph M. Urish** all contributed to development of the propulsion and maneuvering system for the DSRV, and they bring a variety of technical backgrounds to its description in this issue.

Fear is a Supervisory Engineer in the solid-state systems development section at the Aerospace Electrical Division, with the added responsibility for planning and coordination of in-house and contractual programs for development and production of deep submergence motors, controllers, and associated equipment. He joined Westinghouse on the graduate student training program in 1957 after graduating from Purdue University with a BSEE. Fear was assigned to the Aerospace Electrical Division, where he contributed to the development of oil-cooled aircraft generators, an electrostatic generator design and test program, generator design and systems studies for space power, and electrical design of submersible motors. He was made program manager for DSRV propulsion systems in 1967 and became Manager of Deep Submergence Programs in 1968. He assumed his present position last December.

Madson graduated from Illinois Institute of Technology with a BSME in 1947. He joined International Harvester Corporation, working as a project engineer in the design, test, and manufacture of power train components and rotary equipment for off-highway and construction equipment. Madson joined Westinghouse in the former Nutall Division in 1956 for similar engineering work on hydrodynamic power shaft transmission products. He went to the Aerospace Electrical Division in 1961, where his responsibilities have included design of electric-powered hydrostatic propulsion equipment for vehicles, mechanical components for nuclear space power systems and lunar vehicle propulsion systems, and the mechanical parts of deep-submergence propulsion systems (including pressure containers).

Urish earned his electrical engineering degree at Wayne State University in 1965 and then joined Westinghouse on the graduate student training program. His first assignment was with the Materials Handling Group. In 1965 he moved to the Aerospace Electrical Division, where he contributed to the development of a lunar core drill and more recently has been project engineer for the DSRV motor controllers.

James C. Wachob has been designing and applying dc motors since he joined DC Motor Engineering in 1958. His contributions include development and application of special motors for machine tools, refinement of permanent-magnet motor theory, and application of permanent-magnet motors to new uses. Wachob graduated from North Carolina State University with a BEE in 1958 and has since taken graduate work through the University of Buffalo extension program.

John C. Erlandson earned his BSEE degree at Tri-State College in Indiana in 1957, and he also has taken graduate work through the University of Buffalo extension program. He joined Westinghouse on the graduate student training program and was assigned to DC Motor Engineering. He served as a design engineer, and then an interest in computer application led him to his present responsibility for development of computerized design programs for dc motors.

G. S. Rambo is Manager, Metals and Process Systems, Hagan/Computer Systems Division. He is responsible for the design, manufacture, and installation of computerized process control systems for the metals and process industries. Before assuming that position, his responsibilities had included being projects manager for computer projects in the steel-mill application area, project director for the computer portion of a large hot strip mill, and developer of software for sequencing control of a plate mill at Taranto, Italy.

Rambo graduated from Virginia Polytechnic Institute with a BSEE in 1961, and he earned a master's degree in engineering administration at George Washington University in 1964. He worked two years on design and installation of solid state telegraphy switching apparatus at Bendix Radio Division before joining Westinghouse in 1963.

Vester S. Buxton graduated from the University of Southwestern Louisiana in 1957 with a BSME degree, and he has since taken graduate work in electrical engineering at the University of Pittsburgh. He joined Westinghouse on the graduate student training program and worked first in the former Industry Systems Department. He contributed to the application of process controls in the paper industry, including a ground-breaking application—the first successful process control computer in that industry (for a digester at Gulf States Paper Corporation).

Buxton moved to Hagan/Computer Systems Division in 1964, where he applied another industry first—the first computer for mill position regulators and automatic gauge control (for an Armco Steel Corporation hot rolling mill). He is now the division's Industrial Sales Manager.

Louis P. Goetz graduated from the University of Idaho with a BSEE in 1938 and joined Westinghouse as a test engineer in 1940. His first work with radar began in 1941 when he served as a communications officer in the U.S. Army Signal Corps. After a year as an observer with the British, he was assigned to the Evans Signal Laboratory to work with radar research and development projects. Goetz continues to serve in the Army Reserve today as a colonel in the Signal Corps, commanding a research and development detachment.

In 1946, Goetz moved to the oil industry, where he worked for several companies, principally in the design of instrumentation for that industry. Goetz returned to radar and Westinghouse in 1955 when he joined the Aerospace Division to work in pulse doppler radar systems design. He is presently a staff engineer, associated with the system mechanization section of the radar systems group.

The wrapping machine in use here adds speed and precision to the job of wrapping a current transformer coil with insulating tape. It was developed by engineers at the Westinghouse Distribution Transformer Division.