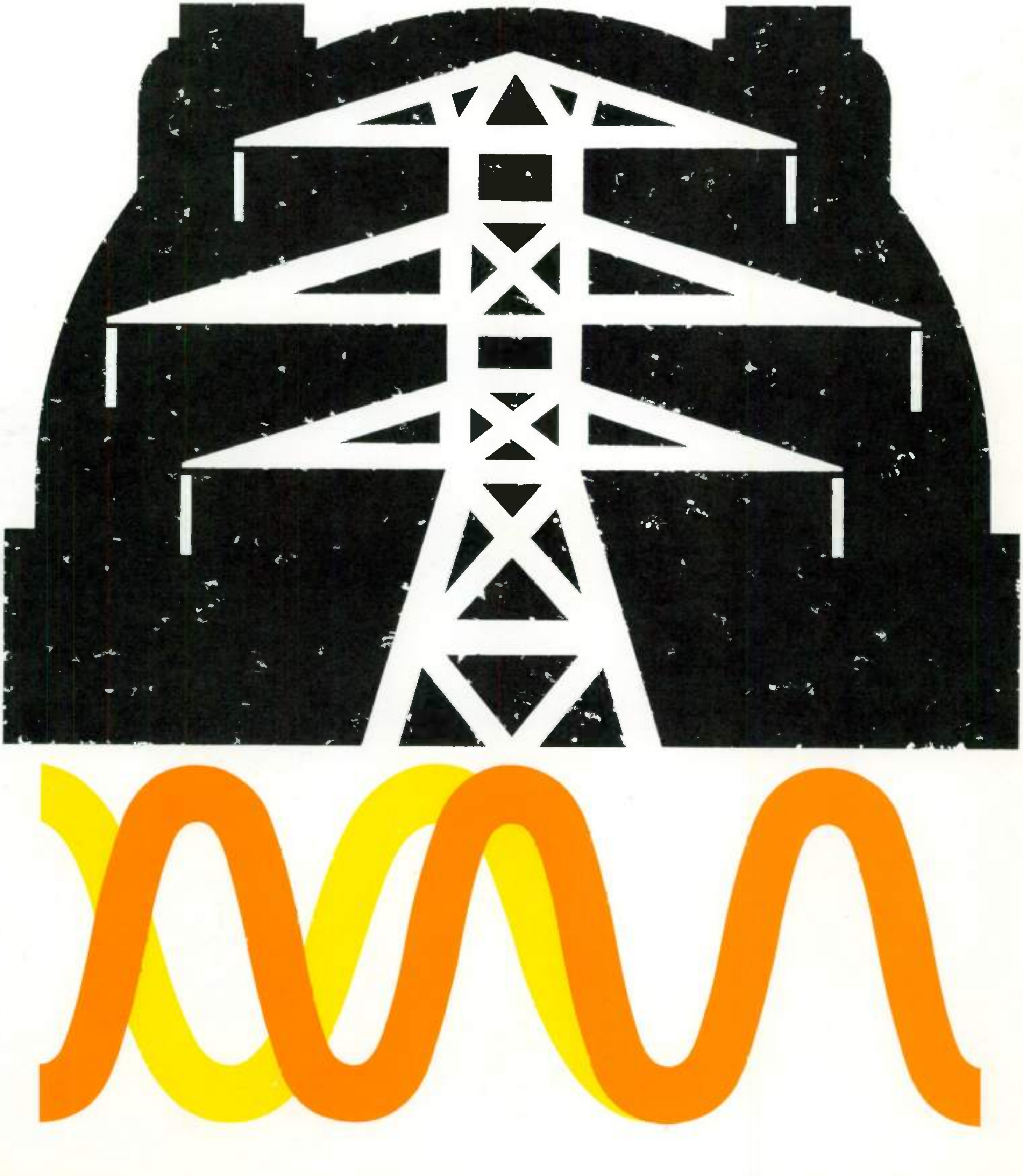
Westinghouse ENGINEER September 1968



Radar Makes Mapping Image of Cloud-Covered Darien

This composite radar image shows the Republic of Panama's Darien Province, a region (like many others in the world) that has been unmapped or poorly mapped because its perpetual cloud cover prevents effective aerial photography. Radar, however, is not limited by weather and light conditions, so it was able to penetrate the cloud cover and make this image. The technique is being developed as a topographic mapping tool.

The image is a composite made from radar reflections converted to light patterns and recorded on individual film strips by an airborne side-looking radar. Film strips were made in successive parallel passes over the area being mapped. The image was made during Project RAMP (Radar Mapping in Panama), a program of the U.S. Army Engineer Topographic Laboratories. Army mappers used an AN/APQ-97 unit developed for the U.S. Army Electronics Command by the Aerospace Division of the Westinghouse Defense and Space Center. (For more information about side-looking radar, see "All-Weather Mapping by Radar," A. A. Nims, *Westinghouse ENGINEER*, May 1968, pp. 76-81.)

Westinghouse ENGINEER
September 1968, Volume 28, Number 5

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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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Cover design: A new automatic synchronizing system described in this issue (p 143–50) quickly matches frequency and voltage of an incoming generator to the system, and signals the breaker to tie the generator to the system. Artist Tom Ruddy symbolizes the process on this month's cover.

Gas-Turbine Package Provides Both Power-Plant Startup and Peaking Service

Paul A. Berman
Peter O. Thoits
Arnold J. Uijlenhoet

A 25-MW gas-turbine generating unit has the features required for both peaking and black-plant startup. The unit can be operated as an individual power plant or as part of a plant consisting of several gas-turbine generators with a central control room.

Most of the large number of gas turbines installed in recent years by the electric utility industry are intended primarily for peaking support, but they may also be called on for emergency power to start up large generating plants in which they are installed when no power is available from other sources. For the latter use, the gas turbine must have auxiliary equipment of such design that it can be started without help from other power sources, and its generator and excitation system must be designed to minimize voltage dips during startup of the plant's large auxiliary motors. Only if those two features are included in the gas turbine package is the unit suited for both peaking and black-plant startup.

A new gas-turbine generating unit, the W-251 Econo-Pac package, has been designed specifically for peaking and black-plant startup of large generating plants (Fig. 1). Its main auxiliaries are driven from the turbine shaft; only a small turning-gear motor and an emergency lubricating pump motor must be supplied from a battery during startup. Once running, the generator can start the largest power-plant motors that are presently anticipated.

Most motor starting applications can be handled with an excitation system having a 0.5 response ratio, but excitation systems with higher response ratios are available. An overexcitation protective system also can be provided; that equipment limits excitation to safe values and thereby prevents damage to the generator while permitting use of optimum field forcing.

Turbine-Generator Package

The unit has a peaking rating of 25,000 kW on natural gas fuel at NEMA conditions, and it has a capability of about 30 percent over that rating at low ambient temperatures. Base load rating is 20,000 kW. It can start and reach load in ten minutes at NEMA conditions, or in five minutes when a higher powered starting diesel is used. The package can be operated either as an individual power plant or as part of a plant consisting of several gas turbines with a central control room.

Several features enable the turbine to be started reliably without an external source of electric power. First, a full-capacity 3600-r/min lubricating oil pump is mounted directly on the main reduction gearing, and an auxiliary oil pump driven by a dc motor and capable of delivering 80 percent of the main pump flow is provided for startup and cooldown. For oil-fired units, a fuel pump mounted on the main gearing provides sufficient pressure and flow from ignition to rated load. Enough atomizing air is available for several starts. A diesel starting engine and dc-motor turning gear are provided for starting and cooldown. (The diesel's radiator and fan are mounted outside the Econo-Pac building to keep engine heat out of the building.) Finally, a source of cool lubricating oil is provided for subsequent starts.

Startup of Power Plant Auxiliaries

Boiler feedpump motors in fossil-fuel plants may be as large as 10,000 hp, and fan motors 8000 hp; in nuclear plants, the largest motors are usually the reactor coolant pump motors at 9000 hp and the feedpump motors at 6000 hp.

The problem in starting those large motors from a gas turbine is the voltage dip that occurs at the motor terminals. Since the motor loads are a large percentage of the gas-turbine rating, the voltage dip is greater than the dip that occurs when the motors are started from the power system. The torque developed by an induction motor is proportional to the square of the voltage, so if the voltage is too low, a motor being started may overheat or may not develop enough torque to start.

Moreover, when the terminal voltage of a *running* motor is reduced to a value at which maximum motor torque is less than load torque, the motor may stall (depending on speed-torque characteristics of the motor and load, inertia of the motor-load assembly, and duration of the voltage dip). A typical value for the maximum or pullout torque of an induction motor at rated voltage is twice the rated torque. Therefore, a close check must be made of the speed change of such a motor when the voltage dips to less than about 70 percent with a resulting dip in the motor torque to less than 50 percent.

Fortunately, the torques of pumps and fans are proportional to the square of the speed. Therefore, when running pumps and fans slow down during startup of another motor, the load torques of their driving motors are strongly reduced. A special load characteristic is found with reactor coolant pumps in multiple loop plants, where the running pumps cause backflow in the pumps that are not running and thereby increase the starting load torques for the motors driving those pumps.

In general, the best sequence for starting auxiliary motors is to start the largest first. The largest motor causes the greatest voltage drop, so it is best if no other motors are running at that time. Starting the smaller motors doesn't cause such a severe drop, so the danger of stalling the running motors is less.

Electrical Characteristics

The voltage dip at the generator terminals depends on the size and characteristics of the motor, the reactances and transient time constant of the generator, the response ratio of the generator excitation system, and the external impedance connected between generator and motor. Large locked-rotor currents in the motor, high internal machine reactances, and high external reactances increase the voltage dip at the motor terminals. An

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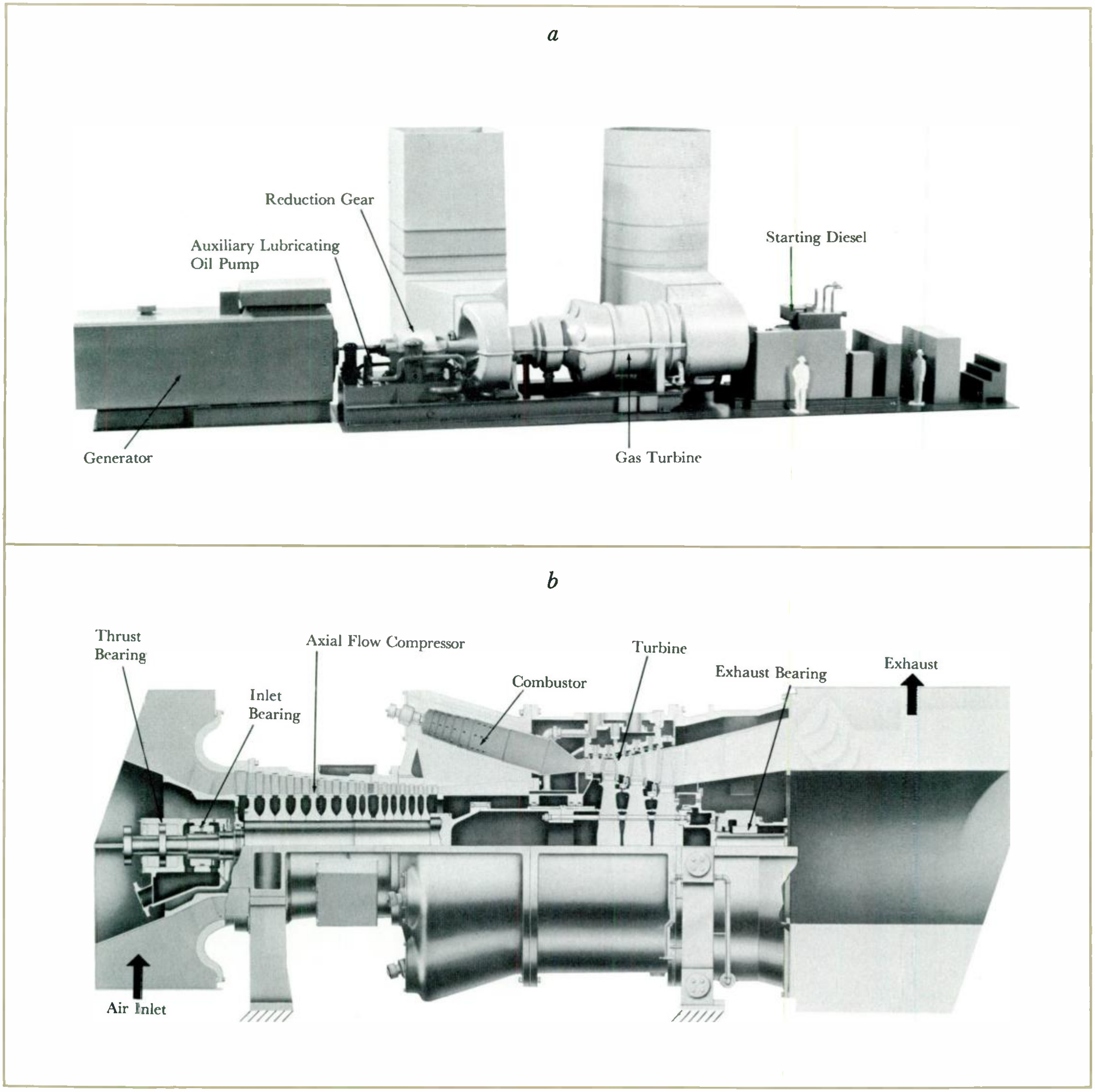
This article is adapted from a paper presented at the Annual Meeting of the American Power Conference, April 23–25, 1968, Sponsored by Illinois Institute of Technology, Chicago, Illinois.



1—W-251 Econo-Pac gas-turbine generator package is made practically self-sufficient so that it can start without help from other major electric power sources; the unit then can energize the large auxiliary motors that have to be started to start up a steam generating plant. It also is suited for peaking duty. Major elements of the package are indicated on the model *(a)*. The fuel pump and main lubricating oil pump are driven by the turbine reduction gear, and the auxiliary lubricating oil pump is driven by a dc motor energized by a station battery. Cutaway view *(b)* shows main elements of the turbine used in the W-251 Econo-Pac generator package.

excitation system with high speed of response, on the other hand, makes the voltage dip less severe.

To show the effect of the generator reactances and transient time constant, the voltage dips were determined for two different generators starting the same motor (Fig. 2). An excitation system with a response ratio of 0.5 was used for both generators, and the motor was a 10,000-hp induction machine with locked-rotor current five times rated current.

Generator *A* in Fig. 2 is typical for a round-rotor generator, and generator *B* is typical for a salient-pole generator. With generator *A*, voltage dipped to 71 percent of rated and recovery time was 4 seconds, whereas, with generator *B*, voltage dipped to 59 percent and recovery time was about 6 seconds. The machine reactances mainly affect the magnitude of the voltage dip, and the generator time constant mainly affects the voltage recovery time.

The generator supplied with the W-251 Econo-Pac gas-turbine package is a round-rotor machine with low reactance values. Startup voltage response of the generator equipped with a brushless excitation system with a response ratio of 0.5 is shown for different motor sizes in Fig. 3.

The effect of external reactances, such as those of transformers and cables, on starting voltage response is determined by using data from Fig. 4 with Fig. 3. For example, if a 6000-hp motor is to be started through a transformer with an impedance of 10 percent, the initial motor terminal voltage is first determined from Fig. 4 for 6000 hp and 10 percent reactance. The value, 78.5 percent, is then used as the initial value in Fig. 3, and the voltage curve for the 6000-hp motor is shifted down to that point. While this method of including the external impedance is not mathematically exact, it can be used to get a close enough answer as long as the external impedance is relatively low.

For motors with inrush currents higher than five times normal, an equivalent horsepower rating must be calculated before using Fig. 3. For example, a 4000-hp motor with an inrush current of 7.5 times normal is equivalent to a 6000-hp motor with an inrush current of 5 times normal. The starting voltage characteristic of the 4000-hp motor is, therefore, the same as the Fig. 3 characteristic for a 6000-hp motor.

For the curves of Figs. 3 and 4, it was assumed that the initial generator terminal voltage was equal to the rated value. However, for motor starting it is best to start with a terminal voltage 110 percent of rated. The curves shown in Fig. 3 then are shifted upward by about 10 percent.

Fig. 4 illustrates the importance of keeping the external impedance between the gas turbine and the motors to be started as low as possible. When the auxiliary system of the power plant is split and served from different transformers, the starting of a motor on one bus causes less severe voltage dip on the other bus. It may, therefore, be worthwhile to consider a split bus arrangement with ability to connect the gas-turbine generator to either or both busses.

The kVA rating and generator characteristics of the W-251 Econo-Pac unit are such that it can handle most existing black-plant startup conditions when equipped with an excitation system with a response ratio of 0.5, but excitation systems with higher response ratios are available. Fig. 5 shows voltage curves when starting two reactor coolant pumps in a nuclear plant, with the generator having a brushless excitation system with a response ratio of 0.5. The 6000-hp pump motors were started with inrush currents of 6.5 times their rated current, through a 20,000-kVA transformer with a reactance of 8 percent. The initial generator voltage was 100 percent. When the second pump was started, the voltage dip was 5 percent greater than when the first one was started, and the first motor slowed from a rated slip of 0.9 percent to a slip of 2.5 percent during the voltage dip.

When several very large motors with high inrush currents have to be started, it may be necessary to use an excitation system with a higher response ratio. The effect of a higher response ratio when starting the first reactor coolant pump in the preceding example is also shown in Fig. 5. The minimum value of the voltage does not change much, but recovery of the voltage is distinctly faster for the system with response ratio of 2.0: it recovers in approximately 2 seconds compared with 3.5 seconds for the system with 0.5 response ratio. The faster recovery reduces the chance of running motors stalling.

Starting voltage response can be calculated relatively simply when a motor is started without other loads connected to the gas-turbine generator. However, if other loads such as motors are connected when a motor is started, it is difficult to account for the change in current of the running motors during the period of reduced system voltage.

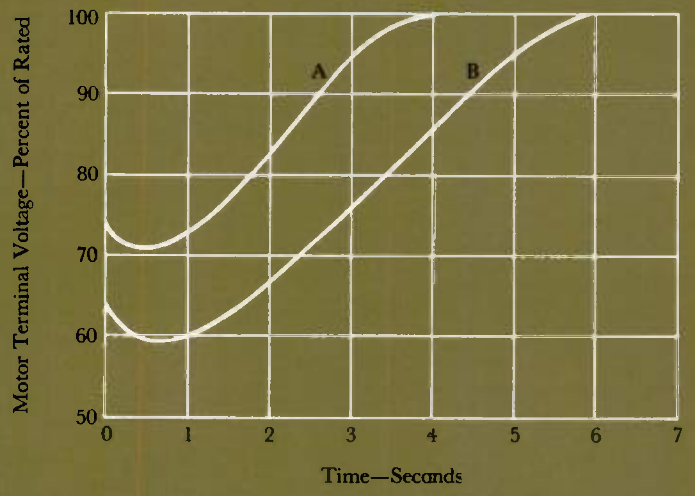
2—Voltage dip when starting a 10,000-hp motor is less with a round-rotor generator *(A)* than with a salient-pole generator *(B)*. Consequently, a round-rotor type was chosen for the W-251 Econo-Pac package. (Both generators in this evaluation are rated at 28,000 kVA. Synchronous reactance is 175 percent for generator *A* and 227 percent for generator *B*, saturated transient reactances are 23 percent and 45 percent, respectively, and open-circuit transient time constants are 5.5 seconds and 7.5 seconds, respectively.)

3—Starting voltage response of the W-251 generator is shown for motors of several sizes. The standard excitation system is a brushless type with response ratio of 0.5, though systems with other response ratios can be provided when needed. The motors are assumed to be directly connected to the generator terminals, and the motor locked-rotor currents are assumed to be five times their rated currents.

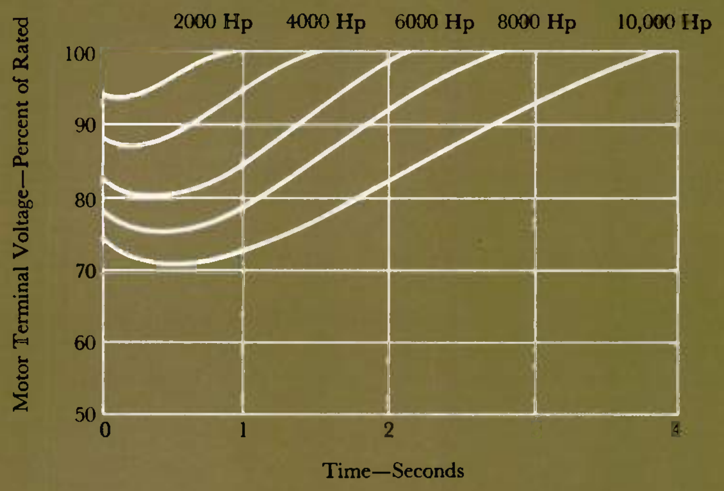
4—Effect of external impedance on initial voltage dip at motor terminals, shown here, is used with Fig. 3 to find starting voltage response for the particular combination of motor and external reactance. Initial generator terminal voltage is assumed to be equal to the rated value.

5—Voltage response of the W-251 generator when starting two 6000-hp reactor coolant pumps in succession is illustrated by the white curves. The generator can handle most black-plant startups when equipped with an excitation system having a response ratio of 0.5, as here, but excitation systems with higher response ratios are available; the black curve shows the effect on the first pump's startup of an excitation system with response ratio of 2.0. Voltage recovery is faster than it is with the standard 0.5 response ratio.

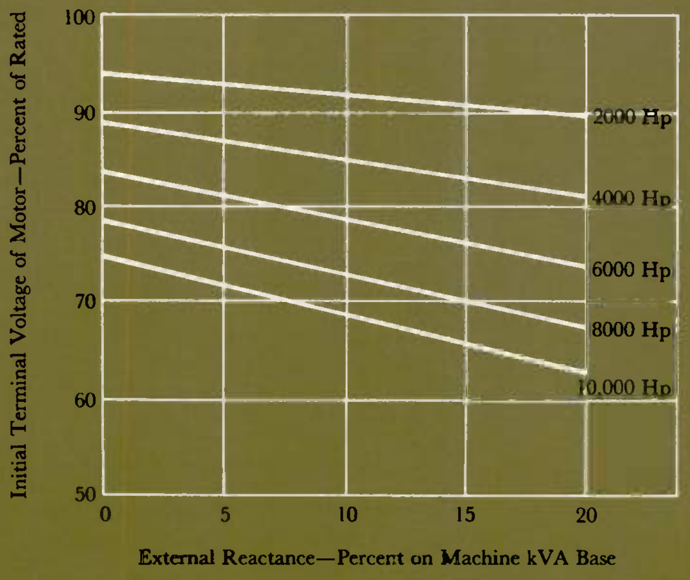
2


Motor Terminal Voltage—Percent of Rated
100
90
80
70
60
50
0
1
2
3
4
5
6
7
Time—Seconds
A
B

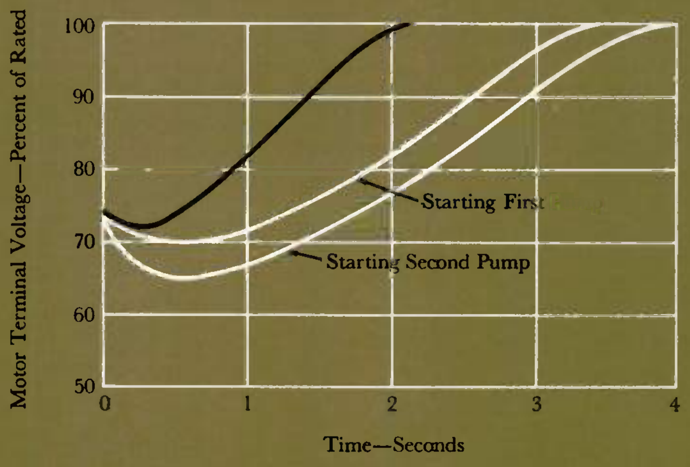
3


2000 Hp
4000 Hp
6000 Hp
8000 Hp
10,000 Hp
Motor Terminal Voltage—Percent of Rated
100
90
80
70
60
50
0
1
2
4
Time—Seconds

4


Initial Terminal Voltage of Motor—Percent of Rated
100
90
80
70
60
50
0
5
10
15
20
External Reactance—Percent on Machine kVA Base
2000 Hp
4000 Hp
6000 Hp
8000 Hp
10,000 Hp

5


Motor Terminal Voltage—Percent of Rated
100
90
80
70
60
50
0
1
2
3
4
Time—Seconds
Starting First
Starting Second Pump

Westinghouse has overcome that difficulty by developing a digital computer program to study motor starting problems. The generator and the excitation system can be represented in full detail in the program, as they are in dynamic stability studies, with transient and subtransient circuits and in both direct and quadrature axes. Also, the saturation of the generator and rotating exciters can be included.

The motors can be represented by their equivalent circuits, including the rotor and stator reactances and resistances and the magnetizing reactance. The program calculates the effective rotor resistance by including slip. Motor load torque can be represented by a quadratic function of the slip according to the following formula:

$$Torque = constant + constant\ (slip) + constant\ (slip)^2.$$

The program not only calculates voltage response but also determines the developed motor torque and the load torque, and it calculates from those quantities the accelerating torque and motor speed at any moment.

Overexcitation Protection

For most startup applications, it will have been determined in advance that the gas turbine can start all necessary power-plant auxiliary motors in the sequence required. However, for some unexpected reason a motor might either not start or start very slowly, causing generator terminal voltage to remain depressed for a relatively long period. The exciter would put out ceiling excitation during the period of depressed voltage, which would overheat the generator rotor if maintained beyond the design limits. Overexcitation protection should be applied to prevent such overheating—especially with excitation systems having high response ratios, because higher ceiling values are generally used in such systems.

Several protection schemes are available. One with a time-current characteristic that can match the generator rotor thermal capability curve as defined in ASA standard C50.13–1965 is shown in Fig. 6. With it, maximum benefit can be obtained from the excitation ceiling without overheating the rotor. Intelligence to the relay is obtained from a dc shunt in the main field of the generator or the field of the brushless exciter, and a transductor converts the dc signal to an ac quantity to operate a CV voltage relay. A contact-making milliammeter (relay *D*) and auxiliary relay *DX* are used to energize the CV relay, sound an alarm, and energize the base adjuster so that it moves to a position corresponding to full-load field current.

Relay *D* operates when the full-load field current value is exceeded. The CV relay has an inverse time-current characteristic that matches the generator rotor thermal capability curve. It trips the regulator, and trips the generator after a short time delay if the field current does not return to its full-load value.

Conclusion

The new gas-turbine package has been designed specifically as a peaking unit and for emergency black-plant startup of large generating plants. It can start the largest power-plant auxiliary motors anticipated, and the overexcitation scheme available for it prevents damage to the generator while permitting optimum field forcing.

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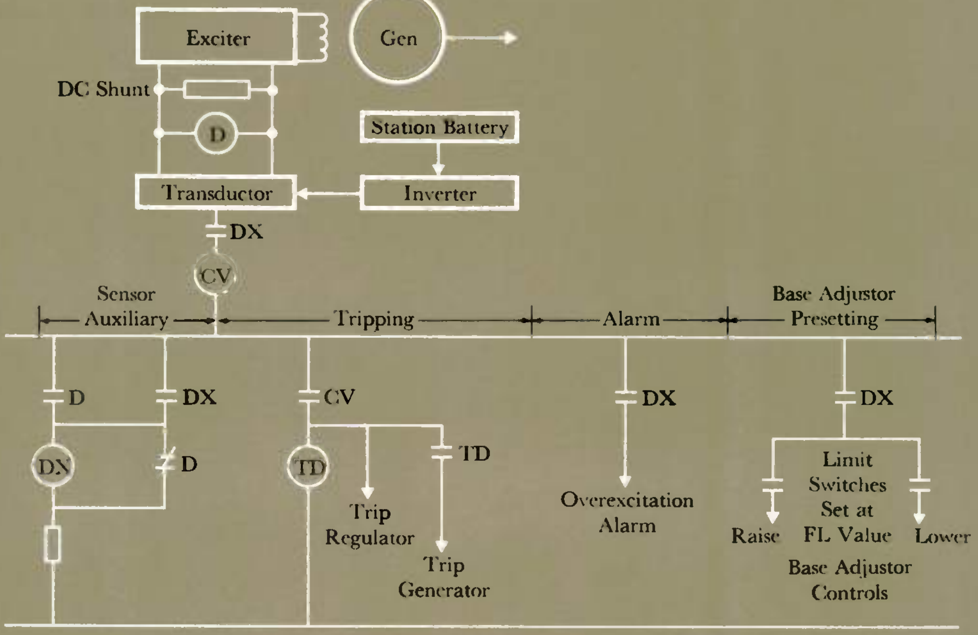


6—Overexcitation protection system guards against overheating the generator if a large motor supplied by the generator fails to start or starts very slowly.

Industrial Process Control and Instrumentation...Many Approaches, but a Place for Each

P. E. Lego

More often than not, a new approach in process control and instrumentation does not supplant the earlier technology but instead competes with it. The competition improves both, but the resulting variety of techniques requires wide experience to choose the best (or the best combination) for the particular application.

Technological innovations in instrumentation and control techniques appear regularly, but there can be few "good, better, or best" generalizations about one approach with respect to another. Because of the great variety of process requirements, or because of a user's experience or personal preference, each new control concept must compete with its predecessors, and the competition leads to improvements in all. Thus, a new approach does not supplant an older one, because each continues to be applied where its particular merits are superior. Only an objective evaluation of all competing approaches leads to the best selection of techniques for a particular application.

Analog or Digital?

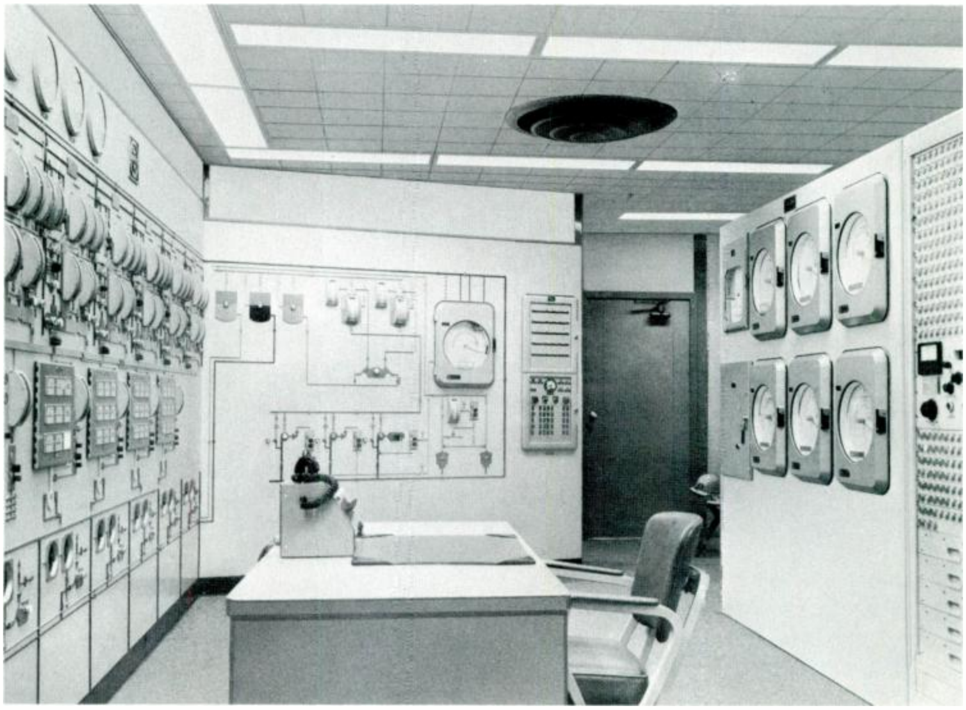
The most significant competition affecting the development and application of control and instrumentation today is that of analog techniques versus digital techniques. Probably the most obvious competition is between conventional analog feedback process control and direct digital control, but the competition of ideas covers a much wider range. Some of the more obvious alternatives include: Digital data loggers versus analog recorders; scanning alarm monitors versus individual analog annunciators; data loggers with computation ability versus special-purpose analog computers; digital computers capable of logging, monitoring, and control versus a combination of digital data logger and analog control; digital computer supervisory control over conventional analog control versus digital computer supervisory control over direct-digital control; and, when digital techniques are selected, wired logic versus programmed logic.

A detailed analysis of those alternatives is beyond the scope of this article, but one fact becomes increasingly clear: in developing instrumentation and control systems, any or all of the alternatives should be considered to determine the best approach to a given process control application.

Often, the scope of a particular process control requirement identifies the techniques required. For example, large data collection requirements or large sequential logic systems usually dictate time-shared digital equipment; small logic systems or systems that require instantaneous response to many logic requirements generally imply a wired-logic approach; small continuous control systems, systems with high dynamic response, or trend recording systems often need continuous analog control.

At other times, several approaches are possible, and the user must evaluate the merits of each. Or the best approach may be some unique combination of techniques that suits a particular situation. Some recent applications illustrate solutions to typical control and instrumentation requirements.

In one new power plant, for example, a compact data collection unit that types log sheets was installed. The unit requires less operator attention because it eliminates the handwritten log sheets required to operate earlier plants, and it saves panel space because it eliminates the need for many analog recorders and annunciators. However, a few analog trend recorders were also installed to provide a quick graphic picture of dynamic trends of the critical control variables, such as steam flow, feedwater flow, and temperatures of fuel, air, and steam. Thus, the data collection system combines a digital data logger and several analog strip-chart recorders.



1—Central control room for open-hearth furnace waste-heat boilers and air pollution controls provides for monitoring and regulation of hundreds of variables with various types of recorder-controller units. Alarm indicating monitors are provided for the more critical variables associated with the process.

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In a dust-cleaning installation for waste-heat boilers associated with open-hearth furnaces, hundreds of variables had to be monitored. Some variables were more critical than others, and space and cost were important considerations. The solution was a combination of time-sharing scanning monitors to read and record most of the variables, such as flows and pressures, and a number of individual analog annunciators for such critical variables as stack-gas temperatures, dew-point temperatures, and water temperatures (Fig. 1).

For an oil refinery, a number of flows, temperatures, and pressures had to be recorded. Many of those inputs required computation, which was accomplished with a data logger that had limited digital computation ability. In a similar plant, a data logger without computation ability was used along with a few small special-purpose analog computers for the inputs that required computation. In the latter installation, the digital-analog approach was more economical because the cost of the few analog computing elements was considerably less than the cost of digital computing equipment.

For a huge chemical processing plant, five Westinghouse Prodac-50 digital control computers and 500 solid-state analog control loops are required to handle the massive control requirements. Much of the conventional process control is handled by the analog loops, employing recorder-controllers, while the data logging, monitoring, and sequential control of the plant's cryogenic process are performed by digital computer.

In a recent combined boiler and turbine-generator control installation, a Prodac-250 digital control computer works directly with a Hagan PowrMag analog computer to coordinate the control between boiler, turbine, and generator from initial startup through the normal operating range to unit shutdown. The digital computer performs data logging, monitoring, and overall control coordination, while the analog computer provides the control of fuel flow, air flow, water flow, and many other plant auxiliary subloops. In addition, molecular-electronic wired logic elements provide many of the system interlocks required for safe operation with a minimum amount of human attention.

2—Pneumatic controllers and transducers regulate combustion and pressure for a steel mill's soaking pits. The devices include temperature recorder-controllers and transmitters, manual control stations, fuel-air ratio stations, fuel and air flow recorders, and various indicators, lights, and switches.

Hydraulic, Pneumatic, or Electronic Control?

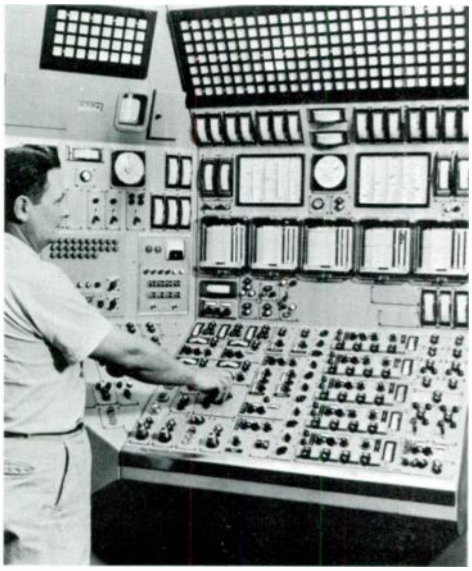
The continuous analog controls that were once thought of as systems have today become the subloops of more comprehensive control systems. Many of the earliest control techniques used in those analog loops were hydraulic. Pneumatic techniques came next, and now many of the more recent developments have been electronic. However, all three types of control continue to be used for the applications to which they are best suited.

For example, in the 1940's many of the fuel-air ratio controls, furnace pressure controls, and gas pressure-reducing stations for the steel industry's open hearth furnaces and coke ovens used hydraulic control systems. When pneumatic control systems were introduced in the late 1940's their flexibility plus the convenience of clean oil-free control room floors caused quick acceptance (Fig. 2). Although the high resolution and smooth positioning performance of the low-pressure (80 psi) hydraulic systems continued to offer real competition for the pneumatic systems, over the years pneumatic controllers and transducers have displaced the traditional hydraulic controls in most steel plant applications.

Electronic analog techniques for the control of flows, pressures, levels, and temperatures in the steel, utility, and chemical industries were introduced in the 1950's as an answer to the signal transmission lag inherent in pneumatic controls. However, electronic systems were not used extensively at first because they were more expensive and because the vacuum-tube amplifiers used in them were not as reliable as the devices used in pneumatic systems. Then, beginning in 1959, the development of highly reliable solid-state electronic devices started a new trend (Fig. 3).

The trend began in the electric utility industry with an all-solid-state electronic analog control system for control of fuel flow, air flow, feedwater flow, steam temperature, drum level, and the many other variables associated with a large utility steam generator. The advantages of electronic systems were quickly demonstrated. Signal transmission lag is negligible, so it is possible to centralize all of the control functions in one control room even with large distances between the room and the final control elements. Miniature panel stations permit an extremely compact boiler-turbine-generator board (Fig. 4). And the electrical signals are compatible with digital computers used in data gathering.

3—Analog recorder-controller units such as this provide control input and data output for analog control loops.



4—Electronic analog control based on compact and reliable solid-state devices permits grouping of many control and display elements in a small area remote from the equipment controlled. This boiler-turbine-generator station for an electric utility plant includes flow and pressure indicators; syncroscopes; flow, pressure, and temperature recorders; manual switches for combustion control; an alarm annunciator; and various indicating lights.

However, those advantages have not eliminated pneumatic systems. Today, approximately equal amounts of pneumatic and electronic control equipment are applied, and the use of both types continues to grow. Pneumatic systems still have advantages, where signal transmission distances are less than 300 feet, because equipment cost is lower and only mechanical maintenance personnel are needed. Typical applications include small industrial steam generators, packaged air-compressor control systems, and municipal water treating plants. Electronic systems are used more extensively in the larger process control systems where centralized control is required, signal transmission distances are great or compatibility with digital computers is required.

For many applications, combinations of electronic, pneumatic, and hydraulic techniques provide the best overall solution to the control requirement.

Power Positioners

The final control element in the analog control loop, the power positioner, was the last of the hydraulic control elements to give way to pneumatic units. Control of open-hearth furnace pressure, for example, requires the servo positioning of large slide dampers, and the high inertia and friction of those loads was a real test for pneumatic positioners. Although the pneumatic power positioners do not have the smoothness of oil-operated units, they do provide adequate positioning accuracy and higher stroking speed, and they have the inherent advantages of cleanliness and ease of maintenance.

But again, pneumatic power positioners have not supplanted hydraulic positioners. In applications such as wind tunnel control valves, power positioners with extremely high power and high dynamic response are required; only high-pressure (2000 lb/in^2) hydraulic positioners controlled by electrohydraulic pilot valves can do the job. Such electrohydraulic pilot valves are capable of controlling up to 300 horsepower with speeds of response and positioning accuracies ten times better than can be provided by pneumatic positioners—but that performance also costs ten times more. Thus, the choice between pneumatic power positioners and high-performance electrohydraulic units must be evaluated on the basis of performance requirements and cost of the alternative systems.

Until recently, pneumatic power positioners as used in the steel, electric utility, and chemical processing industries had little competition from the "all electric" units. Small control valves are easily operated with inexpensive pneumatic positioners; larger valves or dampers that require greater power than can be provided by the conventional diaphragm positioners can be operated with double-acting cylinder type power positioners, which provide output torque ratings up to about 6000 ft-lb. Electric positioners, on the other hand, have until recently been the low-performance nonmodulating type with inadequate dynamic performance, or the ac or dc servo motor type with higher cost.

However, recent development effort on electric power positioners has been channeled toward the higher powered applications found in the steel and utility industries. The development was prompted by specific utility applications where a unit that required no air or hydraulic fluid was desired. Other requirements were that the positioner would sit still on power failure without air or solenoid locks, would provide bumpless transfer from automatic to manual control, and would perform as well as or better than pneumatic positioners.

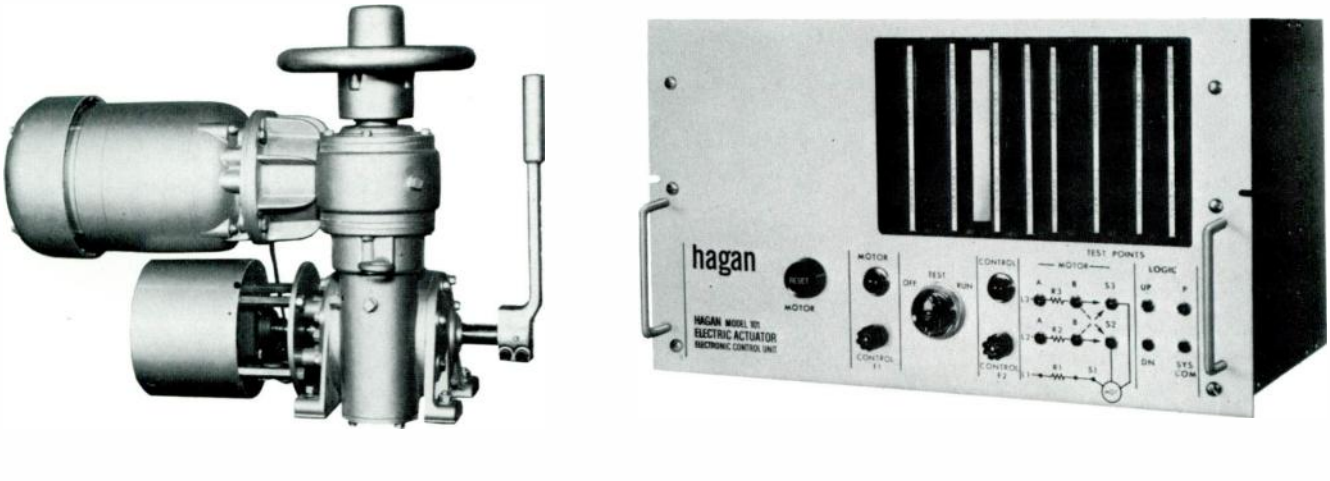
A combination of analog and digital techniques was used to develop a new all-electric positioner, the Hagan Model 101 (Fig. 5). The new device employs solid-state components to make a standard three-phase ac motor perform dynamically like a servo motor. The positioner is not limited in power as was the conventional ac servo motor, and it does not have the commutation problems associated with dc motor brushes. The electric positioner provides a positioning accuracy of 0.2 percent with good dynamic response.

That excellent performance has led to quick acceptance of the electric power positioner in the electric utility and steel industries. It is being used to operate feedwater valves, fuel control valves, air dampers, and many other final control elements. Although the electric positioner will not supplant pneumatic power positioners, it offers another good alternative for solution of control problems.

Conclusion

The success of any control or measurement idea is determined by the long-term value it provides its user in a specific situation. Predicting that long-term value requires both experience and familiarity with equipment application. The scope and complexity of the process, the desired degree of automation, and the economics of the particular installation should determine which of the various techniques provided by modern technology should be selected to fill the control and instrumentation needs of the application.

Westinghouse ENGINEER **September 1968**



5—All-electric power positioner *(left)* for moving large valves, dampers, and other mechanical elements is operated by an electronic control unit *(right)*. The motor is a standard three-phase ac motor, but the combination of analog and digital techniques in the control unit makes it perform with the positioning accuracy of a servo motor.

Let Process-Control Computers Do More

G. C. Turner

The digital computer control system has literally revolutionized some industrial processes through more effective control. Many more processes could be benefited similarly now that advances in computer technology have greatly broadened its economic practicality.

Digital computer control systems really should be thought of as process controllers instead of as computers (even though they have great computational ability), because that is primarily what they are. When computer control systems were first applied to steel and electric-utility plants about 1960, they were simply the next logical step in industrial control: they permitted better control of more complex processes at lower overall cost. The same is true today, although by now many design and application advances have greatly increased the number of control jobs to which computers can be economically applied.

The largest barrier now to more widespread exploitation of the capabilities of computer control systems appears to be a fear that they are too expensive to acquire and maintain, or too complex and therefore unreliable, or both. Actually, relatively inexpensive control computers are now available. Moreover, they are complex only *internally*, and the internal components are static solid-state devices that are more reliable than such familiar control devices as relays. *Externally*, the control computer can be evaluated in economic and capability terms like any other controller.

In making an evaluation, however, control computers must not be confused with data-processing computers. While both perform calculations rapidly to achieve their results, the two are quite different. The control computer is built to tolerate a hot and dirty plant environment and to perform many tasks simultaneously; data processors work in a comfortable office environment and usually process one batch of work at a time. Data processors are designed for such "white-collar" jobs as accounting and design, while control computers are designed for "blue-collar" work such as reading instruments, logging data, controlling valves, starting motors and controlling their speeds, and sounding alarms when plant conditions get out of limits.

Part of the aura of mystery that has surrounded control computers no doubt stems from the jargon that necessarily develops in a new technology. But what is far more important than knowing the technician's jargon is knowing what the computer is supposed to control (or what data it is to acquire and log, since control is not always possible or desirable). The earlier tendency of users to try to borrow computer technology from the accounting department has been recognized as a mistake, and the application of computers for control purposes is now being assigned to control experts—the user's and supplier's engineers.

When to Apply Computer Control

Economic Considerations—Some simple rules give a first-look indication of whether or not further investigation is worthwhile. First, the value of the product produced by the process in question must be sufficient; even a small computer cannot be justified in a very small operation. Second, the value added to the product during the process must be sufficient to enable product or process improvement to cover the computer cost. Third, the degree of control that can be exercised must be sufficient to permit significant control improvement (or, in a data-logging application, the amount of information to be logged must be worthwhile).

If conditions appear favorable for computer application, a more detailed investigation should be made. It is best to call in the computer supplier at this point, since he can give valuable guidance based on the experiences of other users. There usually is no charge for such a preliminary study; an extensive study, however, carries the same charges as any other engineering work.

Technological Considerations—The control functions that are particularly suitable for computer control are:

1) Controlling many variables. In general, the greater the number of variables the greater the opportunity for improvement through computer control. An operator can watch one or two variables, such as temperatures, but he loses efficiency as the number increases.

2) Calculating results. Deriving intermediate or final results from continuously sampled data can save time and often can circumvent instrument inadequacies. For example, the temperature inside a pulp digester cannot be measured, but it can be calculated from a heat balance performed by the computer from available temperature and flow measurements.

3) Storing information for later use. "Later" is a relative term, meaning periods of milliseconds or years. Large steam turbines, for example, may be started up only once every 18 months; computer control is used because its memory is perfect and consequently it does not lose its proficiency between startups. The plant's periodic log, on the other hand, may be calculated and printed every half hour. An example of millisecond storage is when the status of a contact changes. The change may require action if the new status is retained for say 100 milliseconds but not if the change is only temporary, as when caused by contact noise.

4) Changing operations. Few plants operate for their usable life spans with everything just the way the designers planned. A computer's ability to change operations completely when new instructions are put in can save great amounts of money otherwise required for wiring or altering conventional controls. That ability also permits automation of random operations, as in one power capacitor plant where a card punched with each capacitor's test requirements travels down the assembly line with the unit. From the card information, a computer establishes the test procedure for each capacitor and conducts the complete test.

5) Sequencing operations in a desired manner. Examples range from the infrequent but critical steam-turbine startup procedures to rapid sequencing for repetitive manufacturing operations, as in transfer lines (Fig. 1).

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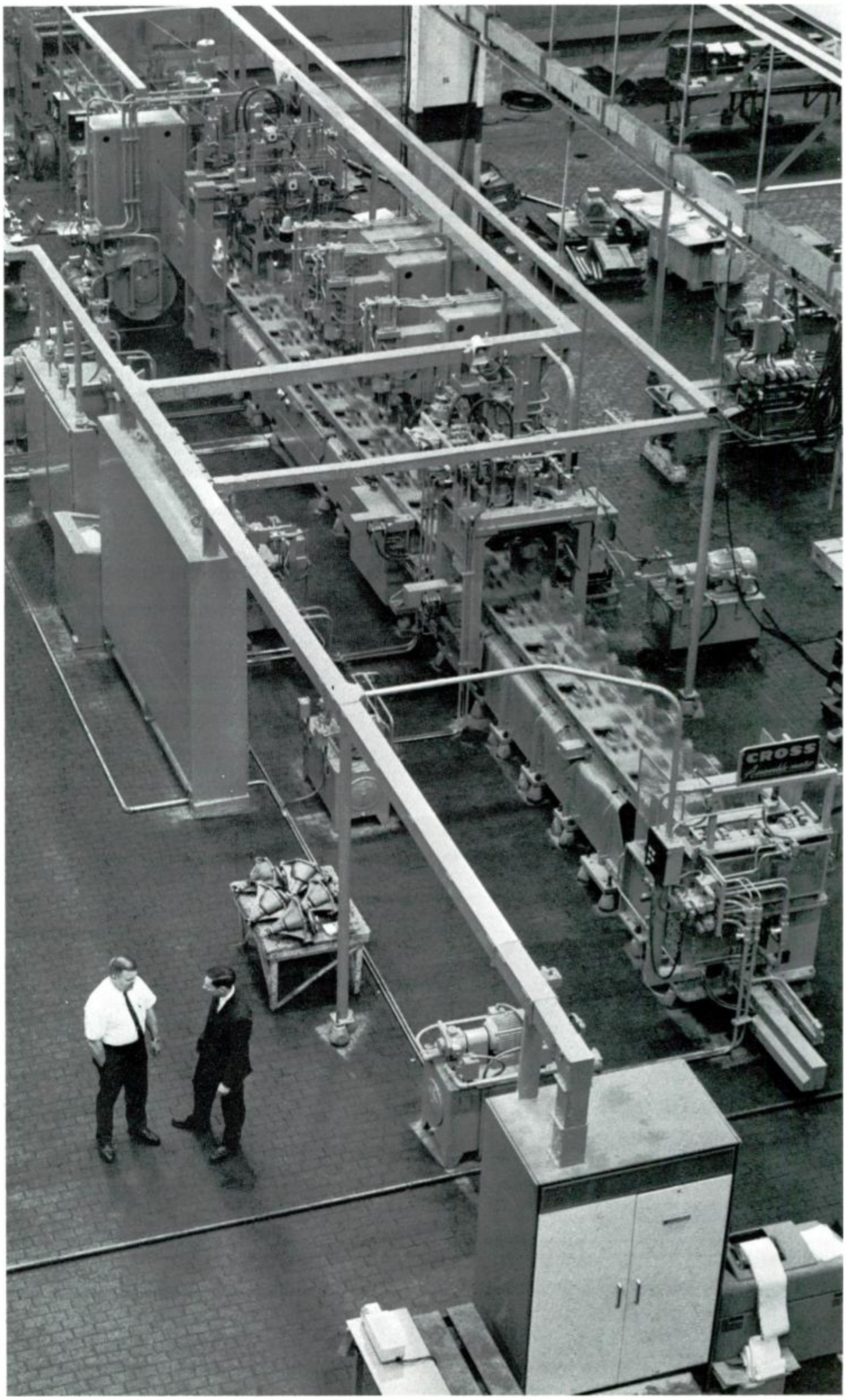
How to Apply Computer Control

Once a decision to go to computer control has been reached, the first step is to determine exactly what functions should be brought under the control. This can be looked on as getting inside the process, learning more than ever before about what is going on and why. (Even if no computer is ever applied, the cost of a feasibility study is often justified by the increased process knowledge gained!)

As would be expected, the original uses of computer control systems were obvious—situations with many variables and little time available for decisions, as in rolling mills and power plants. However, computers can and should be used in many less obvious applications that require abilities other than speed.

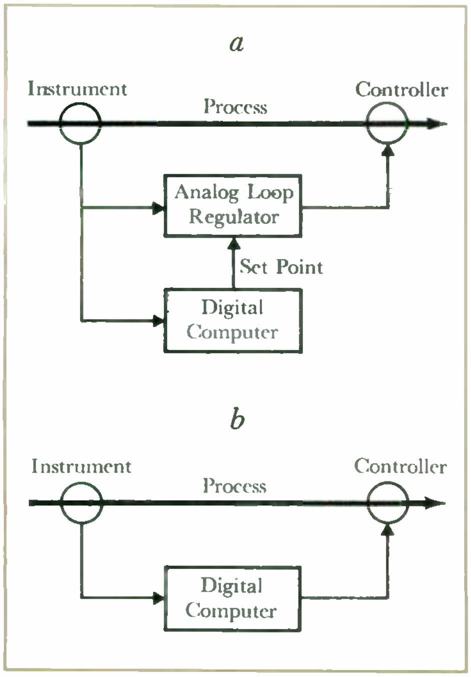
For example, a computer can determine unmeasurable quantities by manipulating heat or mass balances. One application is determination of particle size distribution in a ball-mill grinding operation. The computer can make a series of small step changes in the inlet velocity to a cyclone separator operating on a sample stream and then measure the separator's overflow and underflow; a plot of that ratio is particle size distribution. That method removes the need for an exotic meter, since it requires only conventional flowmeters, pressure transducers, and valve control, and it measures grinding efficiency as well.

Availability of small computers makes the use of computer control economically feasible even in simple applications. Electrical demand control of an arc furnace is an example. Pulses from rotation of the furnace's watt-hour meter disc indicate kilowatt-hours, and the computer counts the pulses to maintain a running record of demand in kilowatt-hours per hour. By controlling the furnace



1—Automatic transfer line is sequenced through assembly operations at its 35 stations by the Prodac-50 computer control system in the foreground. The Assemble-matic machine, built by the Cross Company, can turn out automotive differentials at the rate of almost three a minute. No wiring or control-system changes are needed to change operations; instead, operators simply alter the program.

2—Testing is automated in the Hagan/Computer Systems Division manufacturing shop by using a small digital computer (seen in the background) to check various assemblies that will go into other computers. Here a wired panel into which electronic circuit cards will later be plugged is checked for short circuits, open circuits, bad connections, and wiring errors. The computer prints out its test findings to guide any corrections required.



3—Digital process-control computers can be applied either in set-point control systems (*a*) or in direct digital control systems (*b*). Direct digital control often makes more sophisticated control approaches practical, and it also eliminates some conventional control equipment otherwise needed.

transformers so as not to exceed a certain demand, a Prodac-50 computer system has improved load factor enough to pay off the investment for a three-furnace control system in less than a year. If a plant has both purchased and generated power, the computer program is more complicated than if the plant uses only purchased power, but the savings can be even greater.

Expansion of the computer system later—as for improving steel chemistry control by determining the amounts of alloying agents needed for each arc-furnace heat—can be considered separately and need not cloud the initial issue. (Such field expansion of Prodac systems costs only about 10 percent more than factory assembly.) For chemistry control, the operator would dial in the desired percentage of, say, manganese in the finished heat and also the actual percentage as determined by spectrographic analysis of a sample. Then he would enter the weight of the heat, or the weight might be calculated and entered automatically by the computer from weights of charge materials. With that information and a memory-stored ferromanganese efficiency factor (the proportion of manganese retained in the steel to that lost in the slag), the computer would calculate the amount of ferromanganese to add.

Another useful ability of computer control systems is that of reading process instruments. Modern cement plants, for example, have X-ray spectrometers to analyze the material fed to the kiln. The signals produced by the spectrometer are analog (continuous variable dc voltages analagous to the amounts of the elements in the sample). While this information can be produced as a line on a graph, it is more easily read in tabular form. As a result, many spectrometers are being supplied with a digitizer to convert the analog signals to a digital form. A small computer control system is barely more expensive than a digitizer, and the computer system has the advantage of not only producing the table but also acting on the information to maintain the desired cement composition.

Similarly, in dynamic control of a basic oxygen furnace, the computer is wired directly to a waste-gas analyzer and differential pressure flowmeters. From the information on gas composition and flow during the oxygen blowing period, the computer calculates the amount of carbon remaining in the molten steel. For the arc furnace demand control, digital information from watt-hour meters is integrated to give the key information. Distance is not a limitation in instrument reading because, when direct wiring is not practical, telemetry is used.

Computer systems have also justified themselves in centralized information collection, as in power plants, even when the system does nothing further after logging the information. The fact that all the plant readings are taken within a fraction of a second (even though it may take several minutes to type them out) means that transient conditions are observed as in a snapshot. Such data logging just naturally gives a more accurate picture of conditions than does logging with clipboard and pencil because it takes far less time and affords far fewer opportunities for error.

When information is collected by a computer, the computer can easily be programmed to check the information against limits and actuate an alarm if conditions are dangerous. Limit checking can be done on absolute values, absolute deviation, percentage deviation, or even on trends or rate of change. Manipulation of the data in the form of averages, standard deviation, or percentages is an easy but often important addition.

Testing and quality control are major opportunities for automation wherever repetitive manufacture is done. Looking at hundreds of parts and spotting the one that is out of tolerance is difficult for people, but a computer's ability to remain alert in boring work suits it for testing and inspection. And its computational ability can be used effectively to produce management reports directly from the test data. Several Prodac-50 control computers were installed recently to test power transistors and capacitors; in one of those installations, the computer not only rejects faulty units automatically but also classifies the acceptable ones, indexes a positioning table, logs data, and records trends for management study. Another Prodac-50 computer has been used for four years to test back-panel wiring, printed circuit boards, and cable connectors for other Westinghouse computers in the manufacturing plant (Fig. 2). It compares the unit on test with a standard unit known to be good, a method that minimizes programming costs because the computer does not have to be programmed for each type of panel, board, and connector it will test.

High-speed scanning of values and mathematical capability can also be used advantageously to find the relationships between variables, which often are more important than the absolute values. Determination of relationships can take two forms—the on-off operations of a sequence, as starting a power plant, or continuously variable values such as the velocity and composition of a mixture flowing in a pipe.

4—Process simulation laboratory enables systems engineers to test their control concepts and even their detailed control programming before the user's process is involved. One computer is programmed to simulate the process to which the control will be applied, and another is given the newly designed control programs. The second computer tries to control the process simulated in the first, which then "grades" the second computer by printing out how well it did. The engineers correct the control programs as necessary, and they may try a number of different control approaches before selecting the approach that performs the process control job in the best manner, as judged by the first computer.

Computational ability also can be used to perform difficult mathematical operations. Integration, for example, can frequently be performed as a series of additions; it is the technique used to measure arc-furnace electrical demand.

Another process application is direct digital control, which now has that glamorous name but has been practiced for a long time in such applications as sensing product temperatures in rolling mills and regulating the flow of cooling water accordingly. A digital device, such as a computer, receives process information and sends control signals directly to the process controllers instead of to an intermediate regulator (Fig. 3). The most apparent benefit is elimination of some conventional control hardware, but experience has shown that the ease with which more sophisticated control approaches can be implemented is of greater potential value. Some installations perform only direct digital control, as when a computer is used for position regulation of variable- and constant-speed drives for a rolling mill. A more common practice, however, is to incorporate some direct digital control wherever it can be used effectively—as in the cooling-water regulation example, where it is incorporated in a computer that also performs such supervisory tasks as collecting data, calculating, and scheduling.

Any control computer can grow, although some do it more easily than others. A design criterion for the Prodac-50 and Prodac-250 computer systems was that field expansion involving hardware changes had to be easy. The user then can start with something less than the universe; he can apply a computer control system, if initial conditions warrant it, and evaluate subsequent additions on their own merits. An example of such an addition is in physical expansion into new plant operations, as when a user applies a control computer for process development in his laboratory and then ships it to the plant site and expands it to be the process control system for the plant. Another example is in changes of scope of the initial application, such as incorporation of chemistry control in a system initially installed for arc-furnace demand limiting.

Hierarchies of computers have been shown to be feasible, as in the use of five computer control systems in one new hot strip mill. Two Prodac-50 computers control roll position, a third performs automatic gauge control, and a fourth handles product conveying and warehousing. Over those four is a large Prodac 550 computer handling essentially management functions, such as scheduling the product through the mill, recording quality performance, and calculating roll gaps, furnace firing temperatures, and other variables with the aid of stored model equations. Physical considerations frequently make multiple computer installation less expensive and more reliable than running all the signal and control wiring to a central computer.

Programming

Programming the control computer is a very important part of the system application. Westinghouse eases the task by extensive use of compiler languages, vigorous problem definition before programming, and schools for the purchaser's personnel. The purchaser is encouraged to participate in the programming, a practice that familiarizes his personnel with the programs and also makes use of his process experience in addition to the extensive process and control experience of Westinghouse personnel. Programs and control concepts are tested thoroughly in the simulation laboratory before they are applied to the user's process (Fig. 4).

Conclusion

Computers have unique characteristics for process control—they can solve problems that baffle other approaches, they can completely change their purpose and application with only programming alterations, they can be used in teams or hierarchies, and they can grow to any size. Their reliability is far greater than that of conventional control.

Computer control is now low enough in cost that buying a system need not be a major corporate decision. Prompt application can produce process savings that sometimes pay for the whole system within a few months.

Generators Synchronized Rapidly and Accurately by Automatic System

J. H. Bednarek
T. D. Rubner

A new automatic synchronizing system is built of solid-state components, is of modular construction, and can provide all functions necessary to synchronize a generator to the system bus.

Precise accuracy in synchronization of today's large generators is imperative because an error could cause extensive damage to the generator and a serious electrical disturbance to the running system. Furthermore, for fast startup generators, such as peaking units, high speed of synchronization is needed to permit the incoming unit to furnish power to the running system as quickly as possible. To satisfy those fundamental requirements—accuracy and speed—a new automatic generator synchronizer system has been developed. Unique circuitry with reliable silicon semiconductor devices provides the necessary accuracy and reliability.

The small size of silicon devices makes it practical to include and coordinate other generator startup functions, such as speed and voltage matching, in a common package with the synchronizer. Thus, a single compact unit can manipulate frequency, voltage, and phase of an incoming generator and then, at the first permissible opportunity, signal the breaker to tie the generator to the bus. A breaker antipump circuit feature is also included in the synchronizer. This arrangement forms a total automatic generator synchronizing system.

The new solid-state synchronizing system consists of a rack assembly enclosed in a semiflush case with a removable glass-front cover. The rack assembly houses a power supply, relay panel, connectors, terminal blocks, and five plug-in printed circuit modules, as shown in Fig. 1. The plug-in module design permits various combinations of functions for particular installations, and it also simplifies service operations.

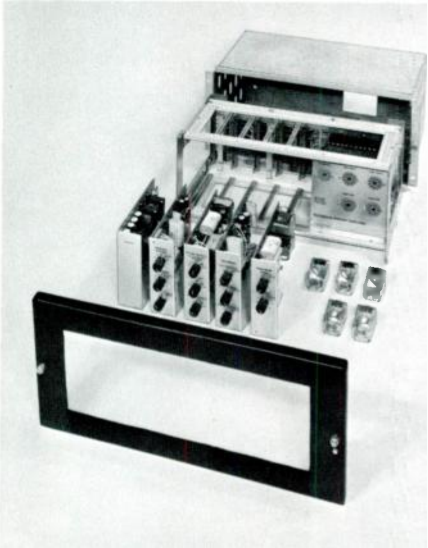
The XASV Synchronizing System

The new synchronizer is called the XASV system.[1] This name is derived from the basic functional components that make up a complete system:

Basic Synchronizer (X)—This component provides the closing command to the breaker at the correct instant before phase coincidence. It consists of the case-and-rack assembly furnished with a plug-in converter printed-circuit module, a plug-in synchronizer printed-circuit module, and the synchronizer relay.

Voltage Acceptor (A)—This optional component provides voltage lockout to inactivate the synchronizer if either generator voltage or bus voltage is outside preset limits. The voltage acceptor circuitry is on the third plug-in printed circuit module shown in Fig. 1.

Speed Matcher (S)—Another optional module can provide raise or lower signals to control the speed of the prime mover governor and thereby correct speed of the oncoming generator to bus frequency. The speed matcher consists of the circuitry on a fourth plug-in printed circuit module and a pair of relays.



1—All components of the XASV synchronizing system are mounted in a rack assembly designed for switchboard mounting. Major components are: cover and case; chassis with power supply, relay panel, connectors, and terminal blocks; five plug-in printed-circuit modules; and five plug-in relays. Plug-in modular construction permits various combinations of synchronizing functions to be conveniently selected to fit a particular application.

Voltage Matcher (V)—The third optional modular component provides raise or lower signals to the voltage adjuster of the incoming generator. It is a pulse-and-wait controller, which brings the generator voltage to within the set values of the voltage acceptor to allow synchronizing. The voltage matcher consists of the fifth plug-in printed circuit module and a pair of relays.

Depending on the application, a synchronizing system can consist of the basic synchronizing function and any or all of the optional functions. A typical complete XASV system application for synchronizing two incoming generators (individually) to a running bus system is shown in Fig. 2.

A further feature is required when two generators in the same scheme have breakers with different closing times, as illustrated in Fig. 2. A breaker closing-time equalizer (Type EQ), to be described later, is included in the generator No. 2 breaker closing circuit. This device permits the XASV system to be used with the same synchronizing settings for either generator.

Synchronization

For synchronizing generator No. 1, switch *SS1* is closed. The synchronizing switches *SS1*, *SS2*, etc. must be operated by a common handle, which is removable only when a synchronizer switch is in the off position. Thus, only one generator can be synchronized at a time.

When the synchronizer switch is closed, *SS1*, for example, connects the generator No. 1 potential transformer to the converter module and the bus potential transformer to the power supply and converter module. Connections are also made to auxiliary contacts on the No. 1 breaker and to the speed and voltage controllers of the No. 1 generator.

Synchronization is accomplished in the XASV system with semiconductor circuitry that develops a triangular waveform voltage to precisely represent the phase relationship between generator and

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bus system voltages. This triangular waveform has a maximum value at phase coincidence of generator and bus voltages, and a zero value at the 180-degree relationship. In the synchronizing procedure, the frequency (speed) of the generator is slightly different from bus frequency, so that the phase difference between the generator and bus voltage is a linear function of time. The triangular phase-difference waveform represents exact variation of phase difference with time and therefore permits accurate phase coincidence prediction.

The triangular waveform is developed in the *converter* module; it is independent of generator and bus system input voltage magnitudes and of frequency and temperature variations (Fig. 3). With this technique, the basic *synchronizer* module provides the command to close the generator breaker within three degrees of phase coincidence, even under the worst possible combination of voltage magnitudes, frequency difference, and temperature (—25°C to 65°C).

Since the generator breaker has a definite operating time before its contacts close, the breaker must be signalled by the synchronizer to close before the exact point of synchronism is reached. This requires that the closing circuit of the breaker be energized before the incoming generator and running systems have actually reached synchronism. The required advance angle is computed from the rate at which the systems are approaching synchronism. For example, if the generator is coming into synchronism rapidly, the closing circuit must be energized at an angular position well in advance of synchronism to allow enough time for the circuit breaker to close. On the other hand, if the generator is coming into synchronism at a slow rate, the circuit breaker closing circuit is energized at a small advance angle because the relative angle between the generator and the running system changes very little while the circuit breaker is closing.

Since it is not desirable to tie an incoming generator to the bus system when the generator is approaching synchronism too rapidly, the automatic synchronizer locks out if the angle in advance of synchronism at which the circuit breaker closing circuit must be energized exceeds a preset value.

The synchronizer module (Fig. 4) allows the synchronizer relay to close only when the following conditions are satisfied:

1) The generator breaker is open;

2) The voltage acceptor module (when used) gives a release signal indicating that the generator and bus voltages are within required limits; and

3) The rate at which the systems are approaching synchronism is slow enough to allow the breaker to close at exact phase coincidence with minimum system disturbance.

To further enhance the accuracy of synchronization, the following additional conditions must be satisfied:

4) The incoming voltage which energizes the internal power supply of the synchronizer must be above a minimum value; and

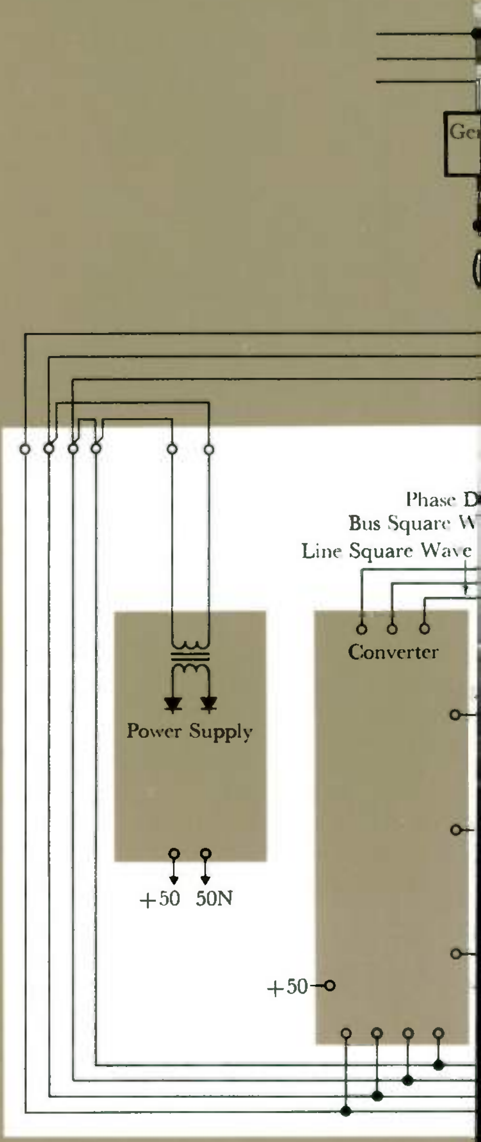
5) The synchronizer must have been energized for at least one second to permit all circuitry to stabilize.

A breaker antipump feature is also included in the synchronizer scheme. It is shown as a timing circuit in Fig. 4. The object of the timer is to disable the synchronizer for approximately 15 seconds after the breaker closes. If the breaker remains closed during this period, the synchronizer is automatically reset; however, if the breaker trips within the 15-second period, the synchronizer remains disabled until it is de-energized. This allows time for the fault to be corrected before the synchronizer is turned on again.

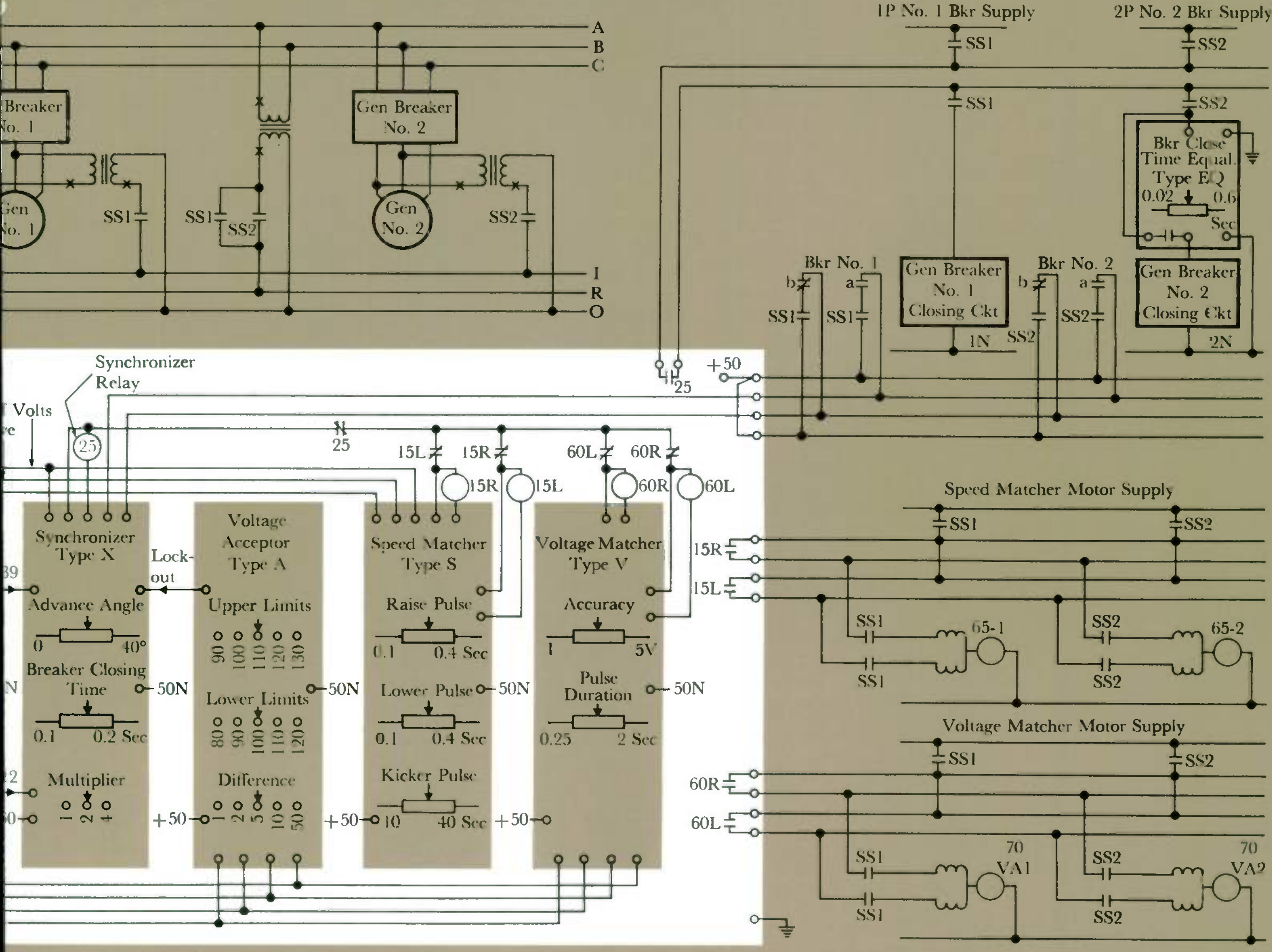
Voltage Acceptance

As previously stated, the basic synchronizer closes accurately, independent of generator or bus voltage limits, because the phase-difference triangular waveform is developed independent of these voltage magnitudes.

Generator and bus voltages can be monitored by the optional voltage ac-



2—Typical application diagram for a complete XASV system for synchronizing two generators (individually) to a system bus.



Legend:

⑮ Speed Matching Relays (Raise and Lower)

(60) Voltage Matching Relays (Raise and Lower)

(65) Governor Control Motors (No. 1 and No. 2)

(70) Regulator Voltage Adjusting Motors (No. 1 and No. 2)

ceptor module (Type A). This module will lock out the synchronizer unless voltage parameters are within the desired limits. As shown in Fig. 5, the voltage acceptor has three limit settings of generator and bus voltages. They are:

Lower voltage limit—A five-position undervoltage lockout switch has settings of 80, 90, 100, 110, and 120 volts (potential transformers have 120-volt secondaries). If either the generator voltage or the bus voltage falls below the selected setting, a lockout signal is given to the synchronizer.

Upper voltage limit—A five-position overvoltage lockout switch has settings of 90, 100, 110, 120, and 130 volts. If either the generator voltage or the bus voltage is above the selected setting, a lockout signal is given to the synchronizer.

Voltage difference limit—A five-position difference-voltage lockout switch has settings of 1, 2, 5, 10 and 50 volts. If the voltage difference between the generator and bus exceeds the selected setting, a lockout signal is given to the synchronizer.

Speed Matching

The speed matcher (Type S) option automatically provides raise or lower signals, as required, to the prime mover governor of the oncoming generator (see Fig. 6).

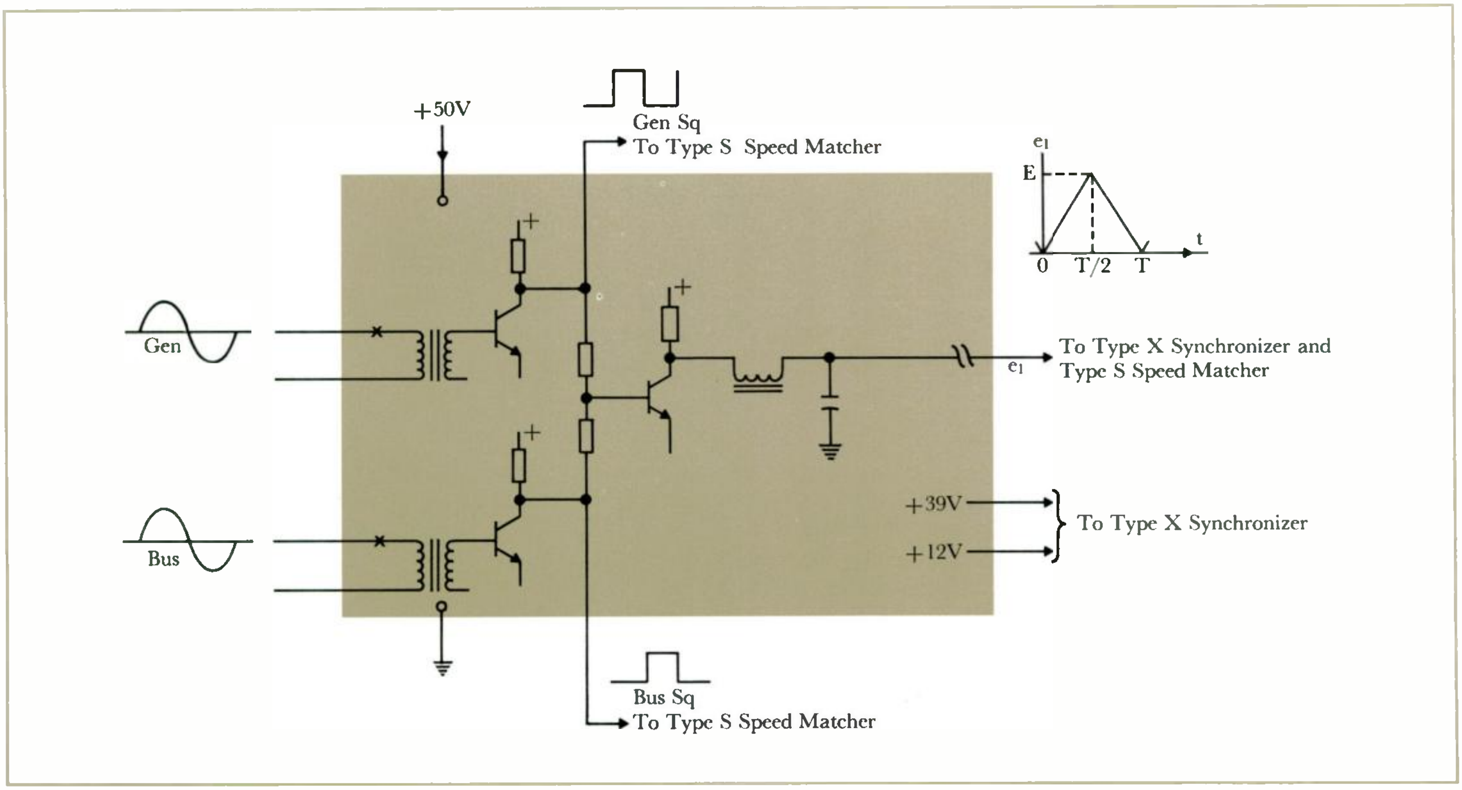
The speed matcher becomes operable when generator frequency is within ±10 percent of bus frequency. It is a proportional type signalling device that gives a speed-correction pulse each beat cycle; i.e., the time intervals between correction pulses become increasingly longer as the frequency (speed) of the incoming generator approaches the frequency of the bus system. The pulses occur at 50 degrees past the phase-coincidence point.

Should the incoming generator stabilize at the exact speed of the bus for an extended period of time, the speed matcher energizes the raise relay to slightly increase the generator speed. This "kicker pulse" causes the incoming generator to pass through synchronism to avoid the possibility of the generator remaining in a synchronous but out-of-phase condition.

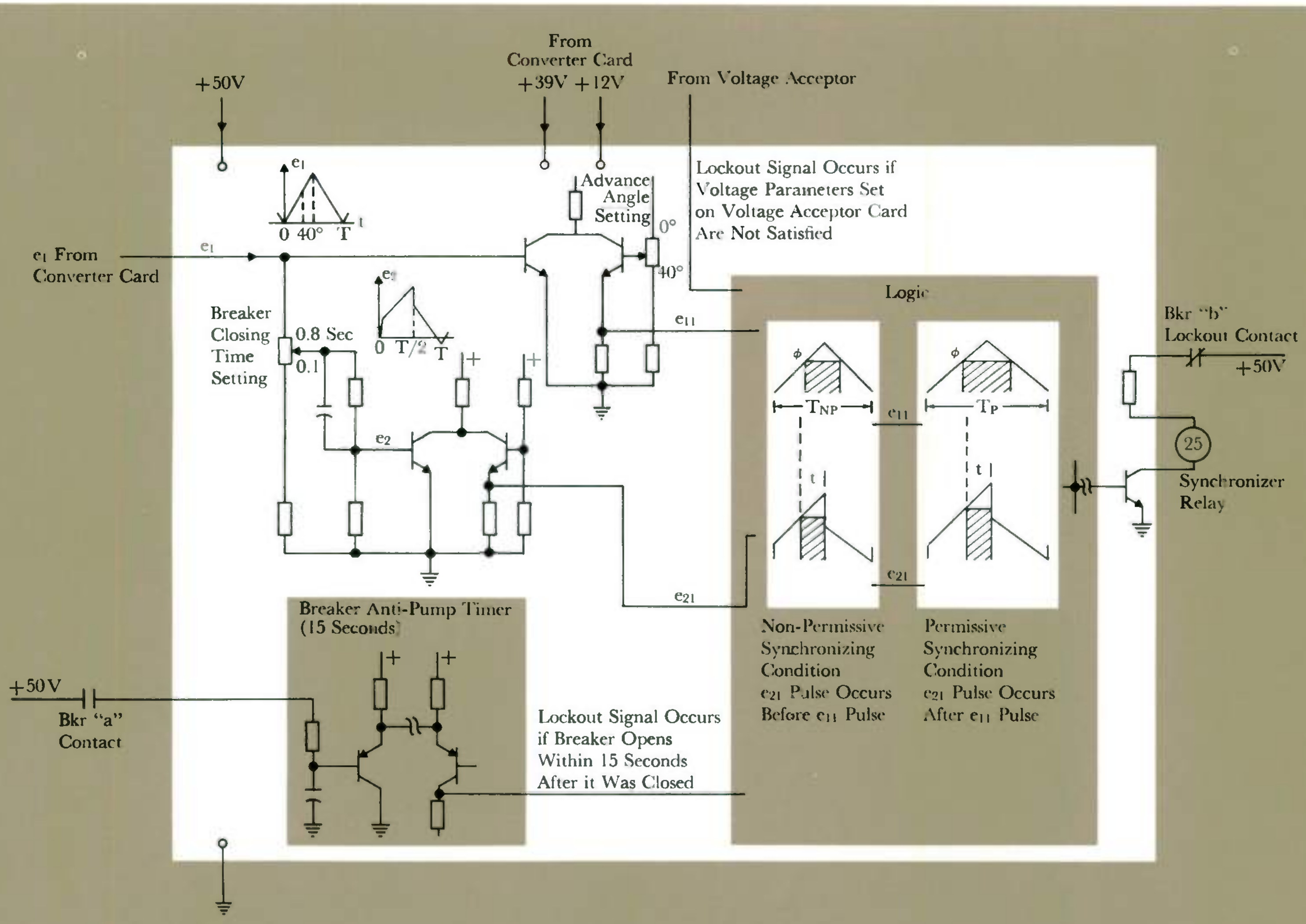
The speed matcher module has three adjustments:

Raise speed relay closure time—The range of adjustment is from 0.1 to 0.4 second.

Lower speed relay closure time—The range of adjustment is also from 0.1 to 0.4 second. Separate adjustments for relay closure time pulses are desirable because many governor controls have different response characteristics for the raise and lower pulses.



3—The triangular waveform signal developed by the converter (Type X) represents the phase relationship between generator voltage and bus voltage. Generator and bus sine-wave inputs, obtained from potential transformers, are applied to transformers whose secondaries drive switching transistors. Outputs from the switching transistors are square waves of constant amplitude with frequencies determined by inputs. These square waves are mixed in an "exclusive OR" circuit to develop the triangular phase difference voltage, e_1. This voltage is at maximum value at phase coincidence of the sine-wave inputs. The low-pass filter eliminates frequency ripple from output.



4—The basic synchronizer circuit consists of two level detectors. The *phase-advance* level detector is connected directly to the triangular output e_1 of the converter module (Fig. 3); its output pulse e_{11} can be adjusted to occur from 0 to 40 degrees before synchronism (before e_1 peak). The *breaker closing time* level detector is fed by the output (e_2) of a differentiator-and-summing network, and it produces an output pulse (e_{21}) at a definite time (adjustable range from 0.1 to 0.8 second) before synchronism.

The frequency difference between generator and bus voltages produces the beat period T (the time for a synchroscope to make one complete revolution). If the frequency difference is too great, the beat period is short (T_{np}) and the output signal from the breaker closing level detector (e_{21}) occurs ahead of the output from the advance angle level detector (e_{11}). The synchronizer logic circuit recognizes this as an unfavorable synchronizing condition and blocks the synchronizer relay from being energized. For a suitable frequency difference (beat period of T_p), the phase angle level detector signal (e_{11}) occurs ahead of the breaker closing time level detector signal (e_{21}), and the logic circuit allows the synchronizer relay to be energized.

When a generator breaker is closed, its "a" contact locks out the synchronizer and starts a 15-second timing circuit. The breaker "a" contact must remain closed for the entire 15-second period if a release signal to the synchronizing circuit is to occur; otherwise, the synchronizing circuit stays locked out.

Raise relay kicker pulse—The range of adjustment is from 10 to 40 seconds and determines the maximum length of time the generator can remain in a synchronous but out-of-phase condition.

The inputs to the speed matcher module are the generator and bus square-waveform voltages and the triangular phase-difference voltage from the converter module. From the generator and bus square waveforms, the speed-matcher circuitry determines whether generator voltage frequency is faster or slower than bus frequency. If generator speed is slow, for example, a raise pulse is supplied to the prime mover governor through the raise relay.

Voltage Matching

The voltage matcher (Type V) compares the magnitudes of generator and bus voltages (obtained from generator and bus potential transformers, Fig. 7). Should generator voltage be low, a pulse is given to the voltage adjuster to slightly increase the generator voltage. After a fixed wait period of six seconds, the voltage matcher appraises the correction and delivers another pulse if the corrected voltage is not within the desired accuracy setting.

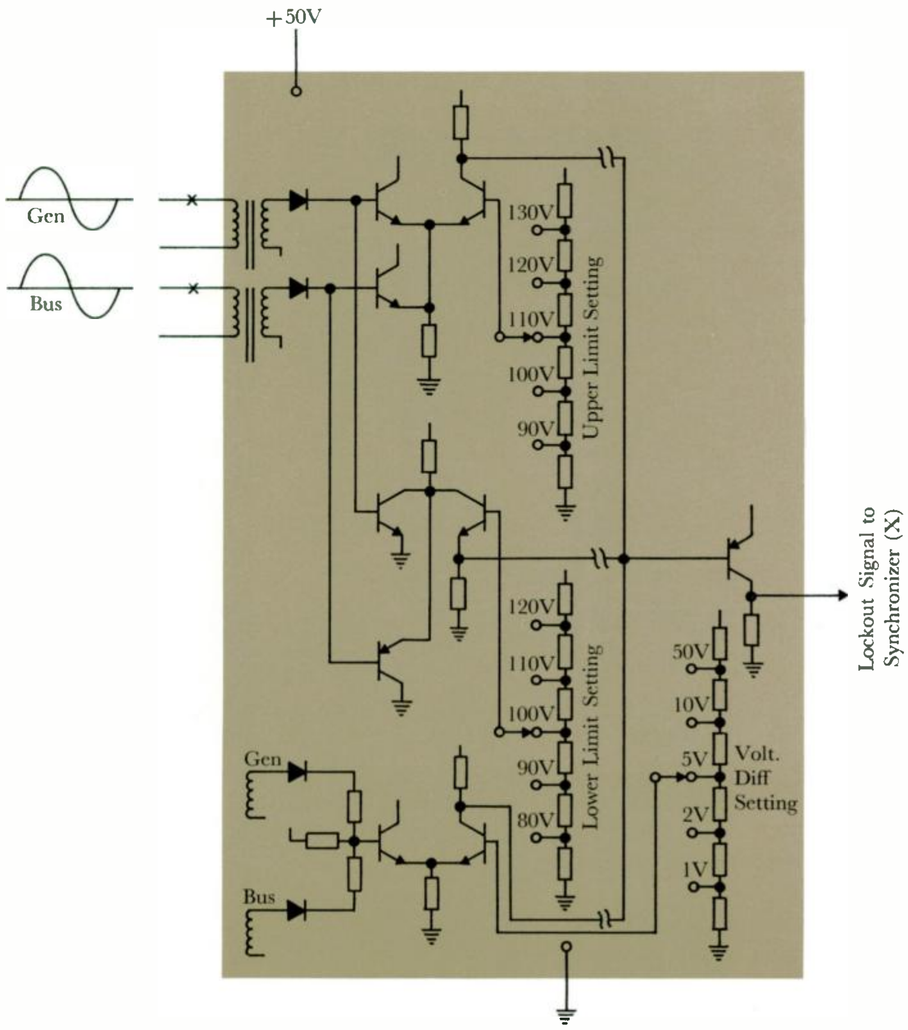
The voltage matcher module has two adjustments:

Voltage accuracy—This adjustment determines how close the voltage must be matched before synchronizing action can occur. Its range is 1 to 5 volts.

Relay closure duration time—This adjustment is set to accommodate the response characteristics of the generator voltage regulator. Its range of adjustment is 0.25 to 2 seconds.

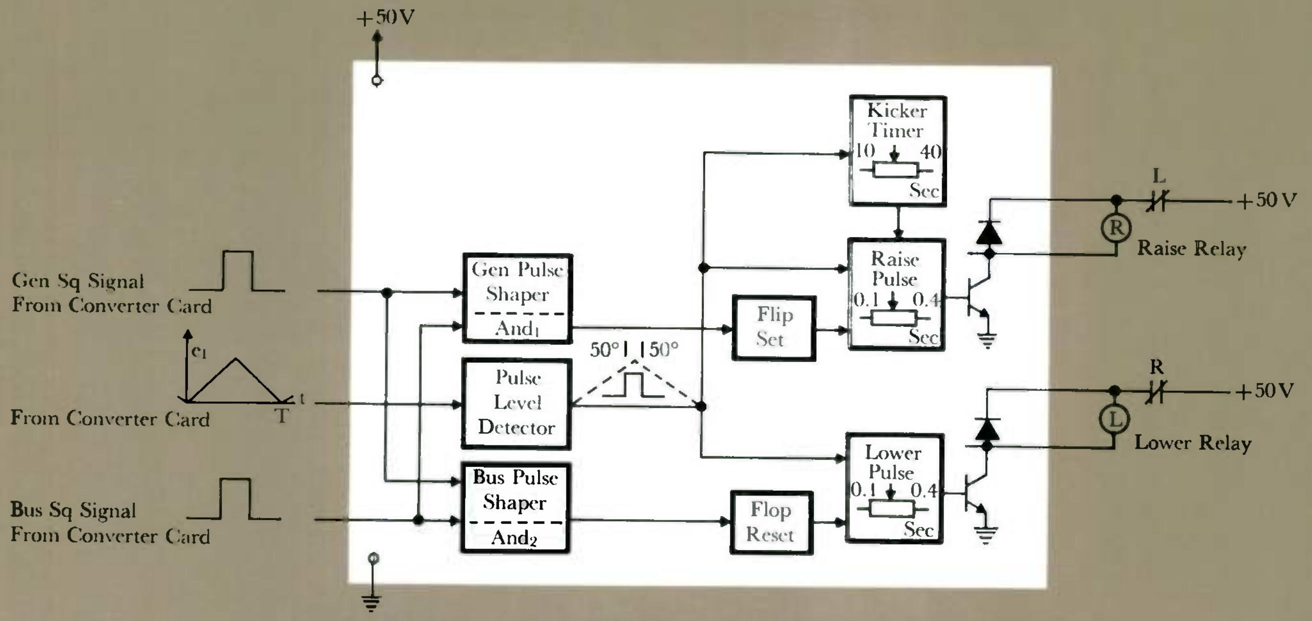
Power Supply

The XASV synchronizing system is designed to operate from potential transformers having 120-volt secondaries on either 50- or 60-hertz systems. The intelligence circuits impose burdens of approximately 5 volt-amperes on the generator and bus potential transformers. The power supply, with a burden of 45 volt-amperes, is normally served from the bus potential through jumper connections at the terminal blocks. However,



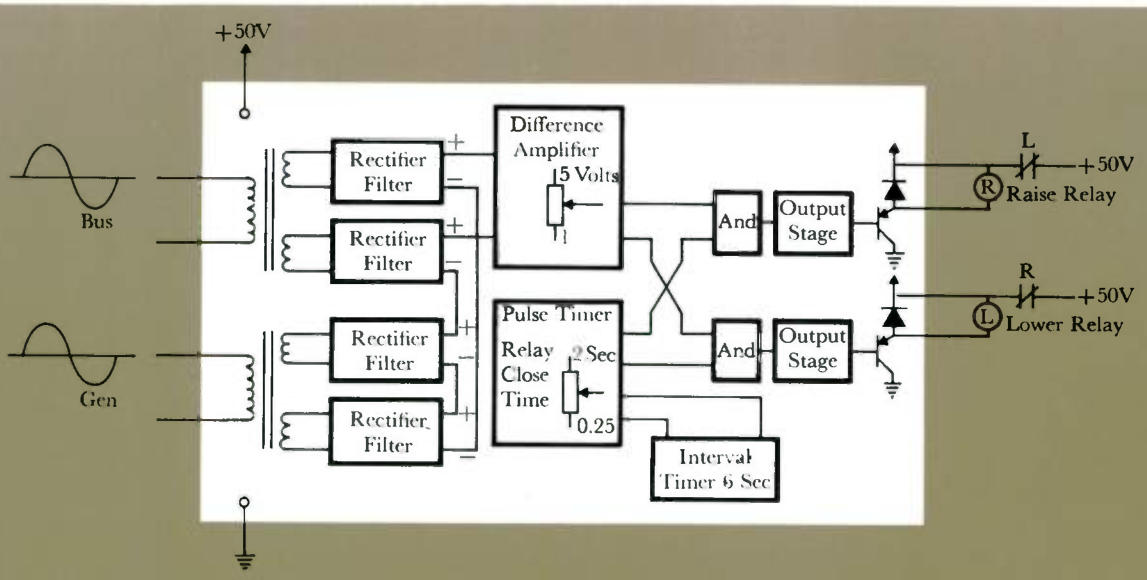
5—The voltage acceptor (Type A) checks bus and generator voltages against upper and lower voltage limits and against a voltage difference limit. The lower-voltage-limit sensing circuit is a three-transistor level detector. If either input falls below the selected value, the output transistor gives the synchronizer module a lockout signal. The upper voltage limit circuit operates in a similar manner.

The voltage difference level detector compares the difference value of the generator and bus voltage against the selected value. If this difference voltage limit is exceeded, a lockout signal is given to the synchronizer.



6—Speed matcher (Type S) determines whether generator speed is faster or slower than bus frequency by comparing generator and bus square-wave signals. If the generator speed is slower, the output of this speed-determining circuit *sets* the flip-flop; if generator speed is faster than bus frequency, the bus speed determining circuit *resets* the flip-flop.

The 50-degree pulse level detector samples both outputs of the flip-flop. If the flip-flop is *set* when the 50-degree sampling occurs, a *raise* signal is given; if the flip-flop is *reset*, a *lower* signal is given. Should the 50-degree sampling pulse not occur during the time set on the "kicker pulse" adjustment, the kicker timer actuates the *raise* circuit. This prevents the generator from remaining in a synchronous but out-of-phase condition.



7—The voltage matcher (Type V) obtains line and bus voltage signals from the potential transformers. These signals are fed to isolation transformers, each with double secondary windings. All secondary voltages are rectified, filtered, and connected to a difference amplifier. The difference amplifier determines which of the input voltages is larger and generates the proper raise or lower pulse. Timer determines the length of pulse duration, and is set to accommodate response characteristics of generator voltage regulator.

should this burden prove to be excessive for special bus sources, such as capacitor potential devices, the power supply can be connected to an auxiliary alternating-current source.

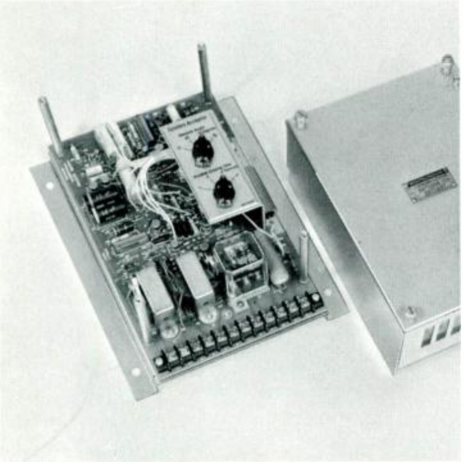
The power supply of the XASV system functions with its input voltage as low as 70 volts. The synchronizer will lock out if voltage falls below this value.

Relays

The XASV system transmits control commands to the generator speed governor control and voltage regulator control and to the generator circuit breaker through five relays—raise and lower speed, raise and lower voltage, and synchronizer. These relays are plug-in types with dust covers. Their contacts are rated five amperes continuous with an interrupting rating of one ampere resistive at 125 volts dc. Interposing relays of higher rating can be added externally if required.

Breaker Closing-Time Equalizer

A single synchronizer may have to control several breakers, each with a different closing time. For example, the breaker for generator No. 2 (Fig. 2) has a faster closing time than the breaker for generator No. 1. To eliminate the necessity of changing synchronizer settings when transferring from the slower to the faster breaker, a breaker closing-time equalizer (Type EQ) is incorporated in the closing circuit of the faster breaker. Thus, the synchronizer can be set for the slower breaker, and the equalizer device pads the faster breaker with sufficient time delay to make it appear to have the same closing time as the slower breaker. The Type EQ equalizer is housed in an enclosure approximately 6 by 6 by 4 inches and can be mounted within the circuit breaker housing. It is energized from the 125-volt dc breaker control supply through the contacts of the synchronizer relay. It has a timing range of 0.02 to 0.6 second.



8—The synchro-acceptor (Type Y) double checks the acceptable zone in which the automatic synchronizer must have its closing signal. The complete unit is only 8 by 10 by 4 inches, so it is usually mounted within the control switchboard.

Synchronizer Verification

The XASV system is designed to be as failsafe as solid-state circuitry will permit. Conservative application of components coupled with liberal width of printed-circuit conductors and with liberal spacing of those conductors assures a near infinite life for the device. Interlocking of circuit functions also aids in approaching failsafe operation. However, for those applications where the contingencies of failure warrant verification of the synchronizer's action, a second device can be used in series with the breaker closing circuit to supervise synchronizer operation. This device is the synchro-acceptor (Type Y), shown in Fig. 8.

The Type Y synchro-acceptor is a synchronism checking device designed for use with any automatic synchronizer. It double checks the acceptable zone in which the automatic synchronizer must give its closing signal to the generator circuit breaker. The limited zone of breaker closing is broad enough to permit a reasonable interval for precise synchronizer operation and yet sufficiently narrow to restrict breaker closure to safe synchronizing angles and safe rates of change of angle. The Type Y synchro-acceptor is in itself an elementary form of automatic synchronizer. It uses basically the same principle as the Type X synchronizer but provides only the synchronizing function, i.e., no breaker antipump feature.

To obtain a greater degree of failsafeness, the potential connections to the synchro-acceptor can be sources separate from those that are connected to the synchronizer—for example, potential transformers can be connected to different phases. The power source is independent of that serving the synchronizer, operates from the station battery, and uses approximately 10 watts. The output of the Type Y synchro-acceptor operates a relay contact in series with the breaker-closing contact of the automatic synchronizer.

Two adjustments are provided on the Type Y synchro-acceptor: A four-position switch selects breaker closing times of 0.2, 0.4, 0.6, or 0.8 second; another four-position switch selects 10, 20, 30, or 40 degrees for phase-advance angle. The breaker-closing-time and phase-advance settings should always exceed the breaker-closing-time and phase-advance setting of the synchronizer with which the synchro-acceptor is used.

In addition, it is necessary that the breaker-closing-time and phase-advance setting on the synchro-acceptor give a slightly higher lockout frequency than provided by the synchronizer. For example, if the settings on the synchronizer are 0.25 second and 10 degrees, giving a lockout frequency difference of 0.1 hertz, the synchro-acceptor should be set at 0.4 second and 20 degrees to provide a lockout frequency difference of about 0.12 hertz. Thus, in case of a synchronizer malfunction, the maximum error is −8 degrees and 0.02 hertz; or if the synchronizer fails just before synchronism, the maximum error is ±12 degrees.

The new XASV synchronizing system provides the electric utility industry with a reliable compact tool for the startup and synchronization of power generators. Improved circuitry utilizing solid-state devices improves accuracy and saves time in synchronizing. Modular construction facilitates various combinations of functions in a single coordinated package.

Westinghouse ENGINEER **September 1968**

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[1] T. D. Rubner, A. Wavre, and J. Bednarek, "A High Accuracy Automatic Generator Synchronizing System," *IEEE Power Conference Paper*, 31CP 67-488, July 1967.

Microwave Interferometer Calibrates Aircraft Instrument Landing Systems

H. Warren Cooper
C. Herbert Grauling Jr.

An interferometer technique determines aircraft angular position precisely and thus furnishes a means for calibrating instrument landing systems. It can also be applied in a precision landing system.

The interferometer principle is used as an angle-measuring technique in modern radar and navigation systems because it permits conversion of small angular changes in space to large and easily measured changes in electrical phase angle. The technique has now been applied to a new system for calibrating instrument landing systems (ILS) that guide aircraft on their final runway approach. A feasibility model of a Flight Inspection Positioning System (FIPS) has been developed by Westinghouse under contract to the Federal Aviation Administration, and it has successfully undergone preliminary FAA tests at the National Aviation Facilities Experimental Center and at the Greater Pittsburgh Airport.

The FIPS feasibility model has demonstrated angular position measurement accuracies to within 0.01 degree. Since ILS approach accuracies are typically about 0.1 degree, the FIPS interferometer technique has demonstrated the potential accuracy needed for ILS calibrating purposes. Moreover, designers of the FIPS system believe that further development effort can extend the same interferometer technique to a high-precision automatic landing system, although that is not an immediate objective.

FIPS Interferometer Principle

The FIPS airport installation consists of two low-power microwave transmitters, one to provide azimuth information and the other to provide elevation information. The transmitting system generates the microwave equivalent of ILS glide slope (elevation) and localizer (azimuth) beams. The elevation and azimuth microwave signals are radiated from vertical and horizontal antenna arrays, respectively, and they are processed by an airborne receiver to determine angular position of the aircraft relative to the axes of the antenna arrays.

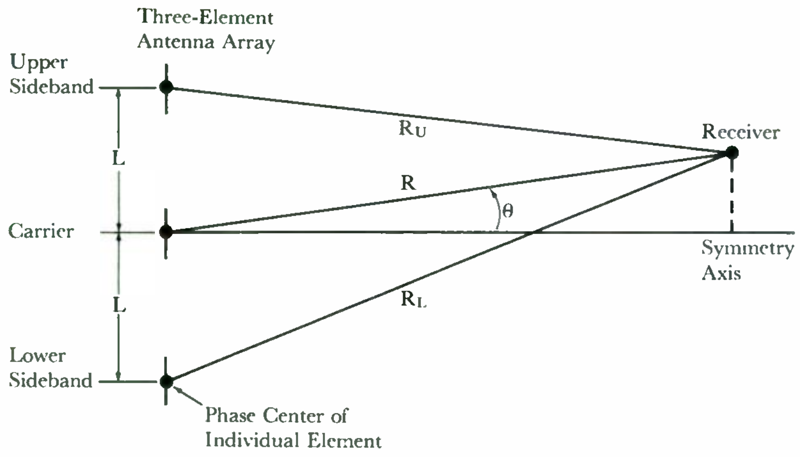
The theory of interferometer angle measurement can be illustrated with the antenna array geometry shown in Fig. 1. Three identical elements of the array are excited by three equally spaced frequencies—a carrier and two amplitude-modulation sidebands. The upper and lower antennas, each separated from the center antenna by distance L, transmit the upper and lower sidebands, respectively, and the carrier is transmitted from the center antenna. When the receiver is located on the symmetry axis, the path lengths from the two outer antennas (R_U and R_L) are equal, and there is no phase difference in the received signals traveling the two paths. However, when the receiver moves off the symmetry axis (as illustrated), the path from one sideband antenna decreases and the path from the other increases. The net result is a difference in phase angle between the two sideband signals relative to the reference carrier phase from the center antenna.

For a given angular displacement (θ) from the symmetry axis, the microwave phase shift of the sideband components is converted to an identical phase change in the detected modulation at the receiver. Denoting this modulation phase change by ϕ,

$$\phi = \frac{2\pi L \sin\theta}{\lambda}$$

where λ is the wavelength at the microwave carrier frequency.

For small values of position angle (θ) from the symmetry axis, the change in sin θ is approximately equal to the change in θ; however, that small change in space angle (θ) can be made to produce a large phase change (ϕ) at the receiver by making the antenna element spacing (L) large compared with the carrier wavelength (λ). Since the phase change (ϕ) can be measured unambiguously only over a range of 360 electrical degrees, this interferometer technique produces a multilobe phase pattern within the radiated beamwidth of the antenna array.



1—Flight Inspection Positioning System (FIPS) employs interferometer technique. By sensing phase difference between upper and lower sideband signals at the receiver, the angle θ from the symmetry axis can be determined.

This article is based in part on work done under Federal Aviation Administration Contract FA65WA1372.

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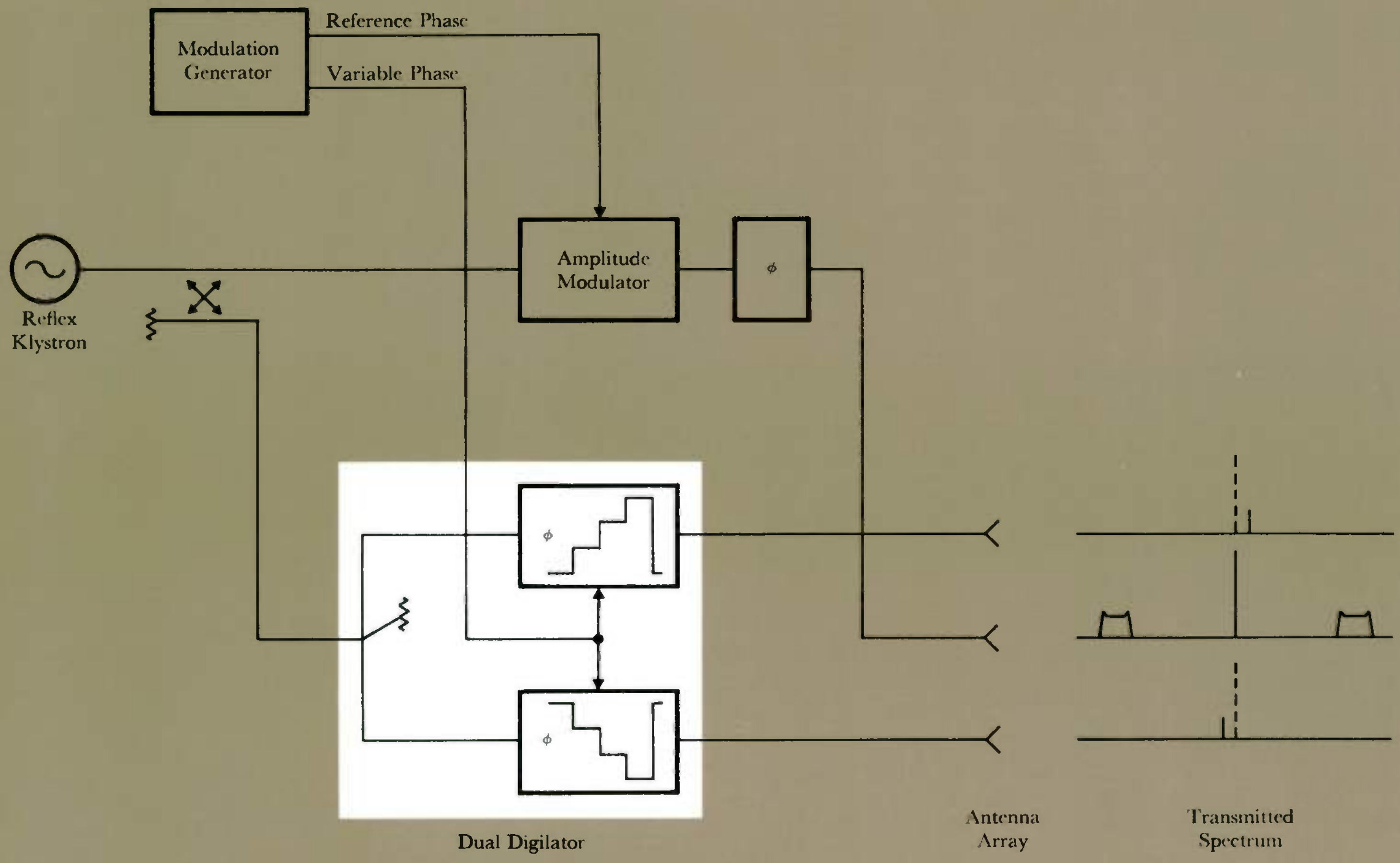


2—Basic components of the FIPS transmitter are the reflex klystron, which is the microwave source, and the modulation generator, amplitude modulator, and dual digilator. The dual digilator consists of two phase-shift units fed from the modulation generator. One unit produces an advancing phase and supplies an upper sideband to the upper antenna; the other produces a retarding phase, resulting in a lower sideband for the lower antenna of the array. The modulation generator also provides a reference phase in the form of a frequency-modulated subcarrier, which is amplitude-modulated onto the main carrier. A pictorial representation of the frequency spectrum transmitted from the various elements of the antenna array is shown at right. Adjustment of the phase shifter in the carrier arm causes the composite signal to appear as the desired amplitude-modulated wave for reception by the airborne receiver. For off-axis conditions, the modulation percentage remains constant and the phase of the modulation varies linearly with angular position.

For the Flight Inspection Positioning System, no difficulties arise from the ambiguity characteristic because the ILS system being calibrated has more than sufficient accuracy to resolve the ambiguity. However, if the FIPS technique should be used for a primary landing aid, some additional less accurate angle reference would be necessary. For example, coarse angle measurements might be made with additional antennas closely spaced to eliminate ambiguity within the radiated beam pattern.

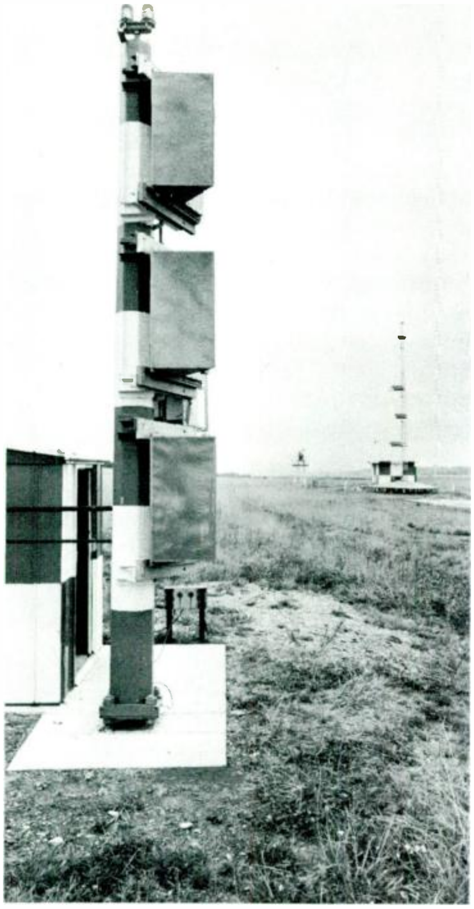
FIPS Transmitter

A block diagram of a FIPS transmitter unit is shown in Fig. 2. The microwave source is an X-band (about 9000 MHz) reflex klystron, which provides the carrier signal to the center antenna of the array. A sample of the carrier is fed to a device called a dual digilator (a digital frequency translator), which generates the sidebands for the outer elements of the antenna array.

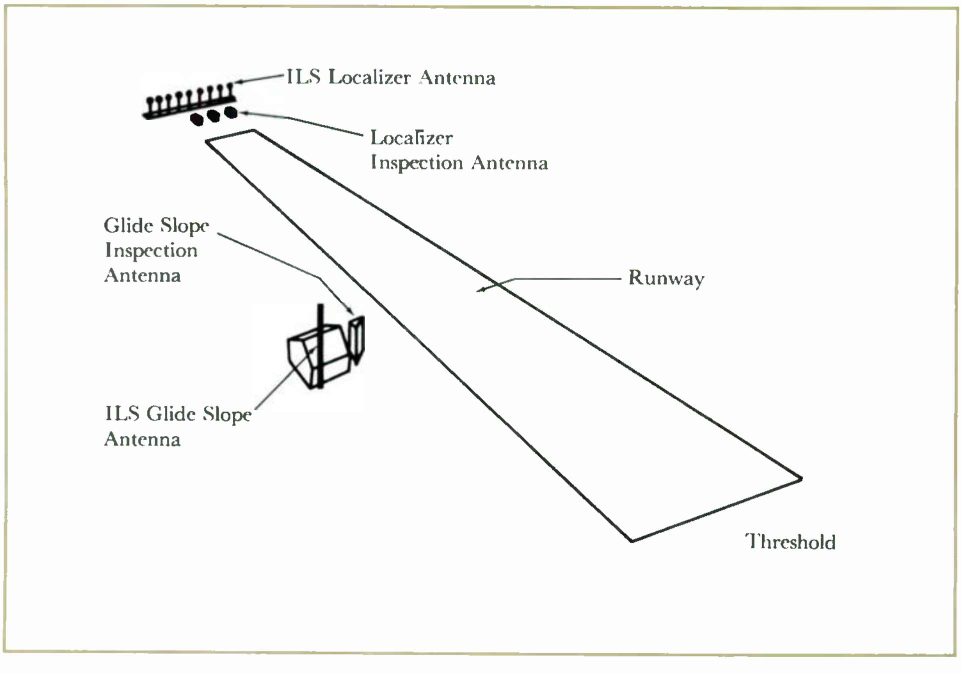
The vertical antenna array used to calibrate the ILS glide slope beam is located near the ILS glide slope installation (Fig. 3). The antenna array is tilted at an angle from vertical so that the symmetry axis of the FIPS elevation array coincides with the ILS glide slope, which, for the demonstration installation, is 2.6 degrees.

The antennas of the vertical array are spaced 48 inches center to center, which for X-band wavelength (3.3 cm) provides the scale factor of 232 electrical phase degrees per space degree. Since phase can readily be determined to an accuracy of 2 degrees in the receiver, angular position measurement to 0.01 degree is possible.

An important factor in the accurate measurement of elevation angle is the effect of ground reflections. The peak of the antenna pattern points along the glide path. Since the equipment is intended to measure a limited angle in the vicinity of 2.6 degrees above the horizontal, the effect of ground reflections can be minimized by protecting a similar sector around the depression angle corresponding to reflection from a plane earth. A sidelobe level 30 decibels below the main beam results in an angular error of less than 0.01 degree. A typical pattern for the demonstration antenna, with the desired protected sector indicated, is shown graphically in Fig. 4.



Operational tests of the FIPS system with an instrument landing system (ILS) installation were conducted by the FAA at Greater Pittsburgh Airport. Elevation *(top)* and azimuth *(bottom)* arrays are located adjacent to ILS installations. Each is self-contained, requiring only a source of power.



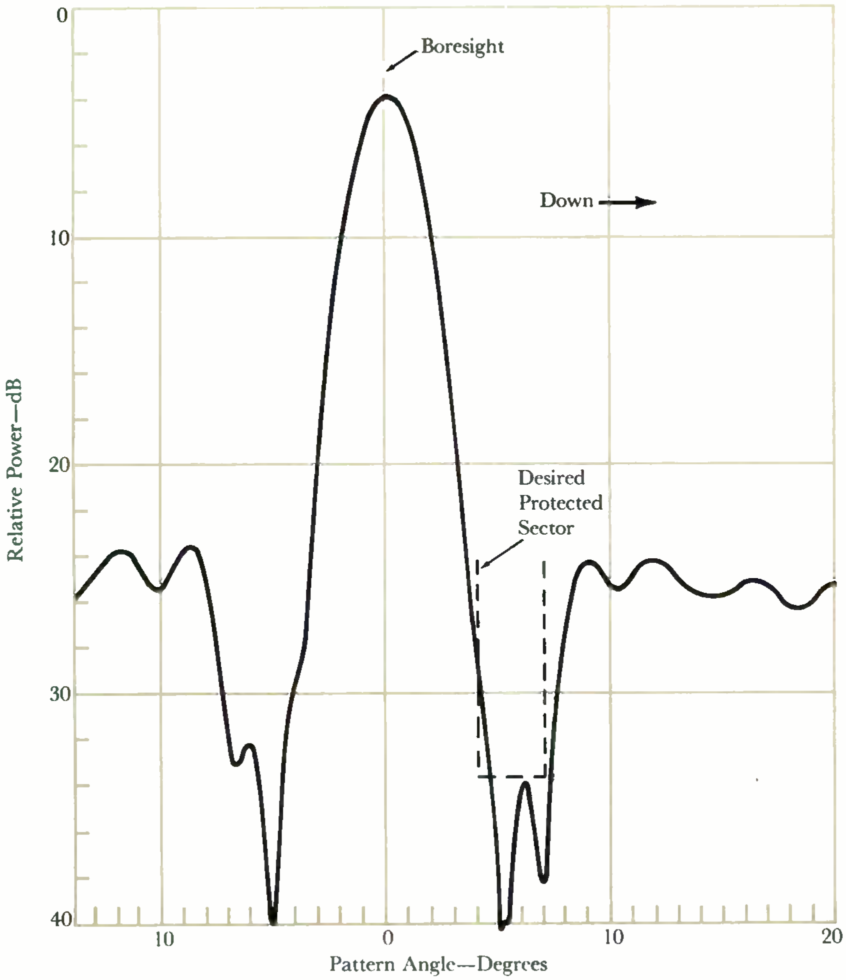
3—*(Right)* Typical ILS installation has separate glide slope and localizer antennas. In a FIPS installation, the microwave inspection antennas are located near the ILS equipment to provide appropriate angular reference axes.

The azimuth antenna array is similar to the elevation array, except that antennas are arrayed horizontally and positioned near the ILS localizer on the runway centerline (Fig. 3). Somewhat smaller antenna spacing is used to permit a larger total coverage angle with a minimum number of ambiguities. Moreover, the ground reflection problem is not as serious as with the vertical array.

A block diagram of the airborne receiver installation is shown in Fig. 5. The elevation and azimuth transmitters operate at different carrier frequencies, and separate channels for processing this information are indicated. The receiver outputs are fed to an appropriate output display, such as a crosspointer, and for the calibrating application are recorded along with the ILS outputs for comparison. In a landing system application, the angular position information would be fed to an autopilot, as also indicated in Fig. 5.

The FIPS interferometer provides the ability to readily select a glide slope other than the symmetry axis of the elevation antenna array. Since a phase-angle indication corresponds to angular position, and is precisely known and linear (in sin θ), the pilot can dial an appropriate phase angle into the indicator to adjust the crosspointer zero to the desired course. This course-select feature is illustrated in Fig. 5; it permits the pilot to select any desired glide slope angle within the beam radiation pattern of the elevation array.

For conventional fixed-wing aircraft, only glide slope selection is likely to be employed because the aircraft must approach parallel to the runway. However, for helicopters and V/STOL craft, azimuth course selection might also be desirable. Both azimuth and elevation course selection were demonstrated with the FIPS feasibility model.



4—Typical FIPS elevation antenna pattern would have low sidelobes in a protected sector to minimize ground reflection.

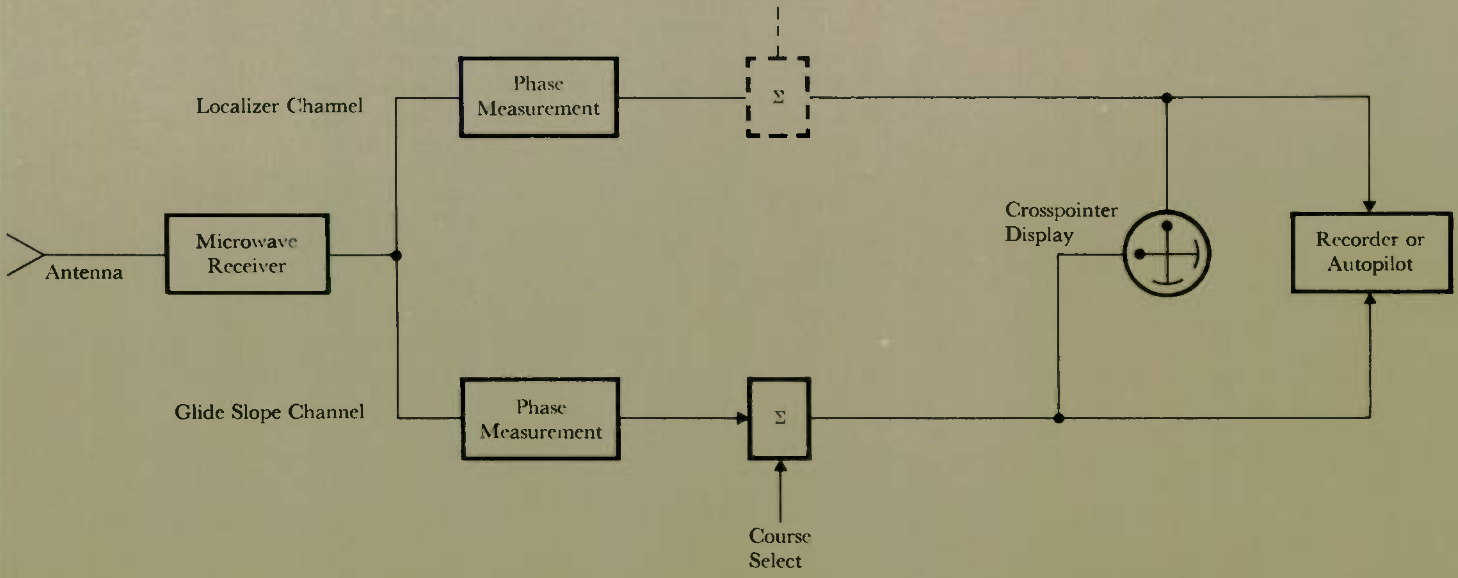
Feasibility Results

The FIPS equipment was tested at the U.S. National Aviation Facilities Experimental Center (NAFEC) in late 1966 and early 1967, and it demonstrated the predicted accuracy of about 0.01 degree. Data were based on simultaneous recordings of system indication and phototheodolite measurements of aircraft position.

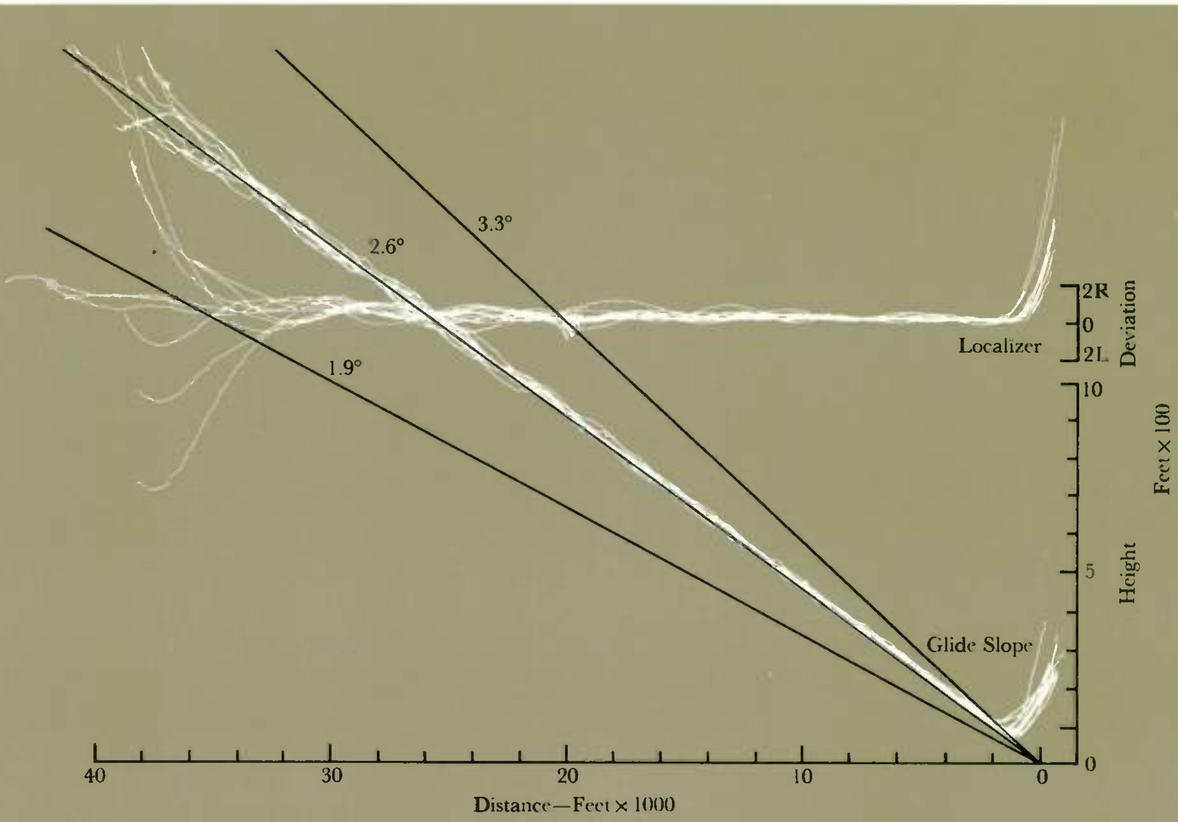
For example, for some 600 points of glide slope data taken at ranges from 5500 feet to about 6 miles on 11 different runs, the indicated standard deviation was 0.015 degree. A typical plot of real-time tracking data taken on the theodolites at NAFEC is shown in Fig. 6. Static tests at threshold (the landing end of the runway) indicated measurement accuracies to within 0.01 degree, which corresponds to about two inches at the 1200-foot range involved.

The equipment was given additional tests at the Greater Pittsburgh Airport late in 1967. The tests demonstrated the feasibility of the system for ILS calibration at a site that is difficult because of the rugged terrain.

Although additional tests at NAFEC are expected, the results thus far have been encouraging. The relative simplicity of the system and the accuracies obtained have demonstrated the potential of this electromagnetic interferometer technique and the flexibility with which the interferometer can be integrated into a navigation system.



5—Block diagram of airborne receiver illustrates the potential to select course and provide position information directly to autopilot.



6—Typical tracking data obtained on the FIPS feasibility model during NAFEC tests. (The letters *L* and *R* on the localizer scale stand for left and right deviation.)

Motor-Starting Studies Avert Electrical System Problems

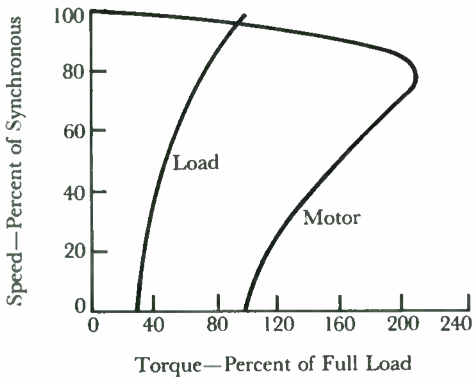
With the trend in industrial processes to larger equipment, many industrial power systems now require large motors that take five to ten percent of the total main substation capability. Such motors can cause serious system problems when started across the line, so a motor-starting study is often desired to investigate the behavior of the electrical system with the addition of a large new motor before the motor is specified.

The new dynamic stability program devised by the Westinghouse Electric Utility Headquarters Department includes the facility for studying a system's reaction to motor starting. The computer program can answer such vital questions as whether or not the proposed motor with its connected load could start when connected to the existing electrical system, what the starting time of the motor would be, and how starting the motor would affect system voltage.

For the study, the motor is represented as an induction motor. (The representation is applicable for synchronous motors as well, since their behavior during starting is similar to that of induction motors.) Such motor characteristics as rotor and stator resistances, reactances, and inertias are determined. The load that the motor is to drive is represented as a torque varying as a function of motor speed; it is of the form:

$$T_L = A + B\omega + C\omega^2$$

where ω is motor speed and A, B, and C are the proportions of the total torque that are constant or speed varying. (See figure.)



Input to the program used to study system effects of large motor starting includes speed-torque characteristics of the load to be driven. The computer calculates a speed-torque curve for the motor and load, as shown here, and also calculates such values as the motor current and the terminal voltage and angle for each desired time interval.

Those motor and load representations are input to the stability program along with the initial conditions for the electrical system as prepared by a load flow study. The program uses the terminal bus conditions and established differential equations for the motor to calculate electrical torque and accelerating torque. It then applies those values to calculate motor speed and establish new terminal conditions.

For each desired time interval, the motor slip, motor and load torques, accelerating torque, terminal voltage and angle, and motor current are automatically printed out. A typical motor speed-torque curve calculated by the program is shown in the figure.

Effects of reduced-voltage starting of the motor can also be studied with the stability program. The initial representation of the electrical system in such a study includes a simulated transformer to reduce voltage to the proper value for starting. At a predetermined time, the transformer is disconnected just as it would be in the actual system.

Deepstar Submersible Being Built for Work at 20,000-Foot Depth

Construction work has begun on an underseas vehicle that, with a depth capability of 20,000 feet, will be the deepest-diving privately owned submersible. The vehicle will be capable of reaching 98 percent of the world's ocean floor for work and exploration. It is the third member of the Westinghouse Deepstar family, a family that includes a 4000-foot vehicle that has been in service for three years and a 2000-foot vehicle now being completed.

The Deepstar-20,000 is scheduled for completion by 1970 at the Westinghouse Underseas Division, where development programs in hull materials, flotation materials, and bouyant structural materials have demonstrated the feasibility of the project. The submersible will be able to transport three men and instruments or equipment to the 20,000-foot depth for 16 hours of work.

Temperature Control Reduces Aircraft Window Replacement

Aircraft pilot windows have to be heated electrically to prevent condensation and ice from obscuring the pilot's vision. However, the resulting repetition of temperature variations has in the past caused thermal stresses that result in defects such as separation of the window layers, minute bubbles, and cracks. The defects necessitate replacement of the window, which may cost as much as $15,000 for a single aircraft.

A new temperature control unit introduced by the Westinghouse Aerospace Electrical Division largely eliminates the temperature variations by controlling window temperature precisely and by increasing or decreasing the heat applied in small steps so that temperature changes are gradual. Thus, the control not only prevents condensation and ice formation effectively but also reduces the frequency of costly window replacement.

The precise heat control also increases safety. Cold glass is much more brittle than warm glass and thus is more easily broken by impact, so the temperature control keeps window temperature at the level for maximum impact strength. That temperature usually is in the range of 85 to 130 degrees F, depending on the type of window.

The temperature control provides a voltage to a transparent conductive layer in the window that acts as a resistance heater. It changes the power to the window in small increments, approximating stepless control but without generating an undesirable amount of electromagnetic interference nor causing harmonic distortion on the ac input as stepless control would.

The window temperature control is

designed for power levels of 1 to 12 kW, or higher if the need arises. The specific power level depends on the size and characteristics of the window.

The control operates on the principle of static tap changing. A temperature sensor in the window supplies a signal to determine which of five driver circuits is to be triggered. Each driver is linked to a solid-state switching circuit that corresponds to the proper tap of an autotransformer. The output voltage of the autotransformer is applied to the conductive layer in the glass.

The tap-changer circuits could be used to control voltage in any single-phase or three-phase ac system with an output of up to 480 volts rms. Maximum rating of the tap changer is normally 12,000 volt-amperes, although higher ratings can be arranged.

Tests have revealed no changes in voltage modulation in an aircraft electrical system during the tap-changing operation. Conducted and radiated radio-frequency noise levels were below those required by existing aircraft specifications with a minimum of filtering or suppression devices. There were no malfunctions in the 30,000 cycles of a tap-changer life test, and a reliability greater than 26,000 hours MTBF has been calculated.

Gear Units Tailored for Water Aeration

As population growth and industrialization put increasing pressure on water resources, new techniques and equipment for purifying streams and lakes are developed and greater equipment capacity becomes desirable. One of the techniques is aeration with large impellers to speed decomposition of organic impurities. To maximize efficiency in aeration installations, vertically oriented gear speed reducers have been developed by the Westinghouse Medium AC Motor and Gearing Division.

One or two drive motors provide power input. The motors are mounted vertically on the gear unit even in the larger sizes, which range up to 800 horsepower. That departure from the more common horizontal arrangement with right-angle speed reducers allows for balanced mounting, weight reduction, and 100-percent use of helical gearing.

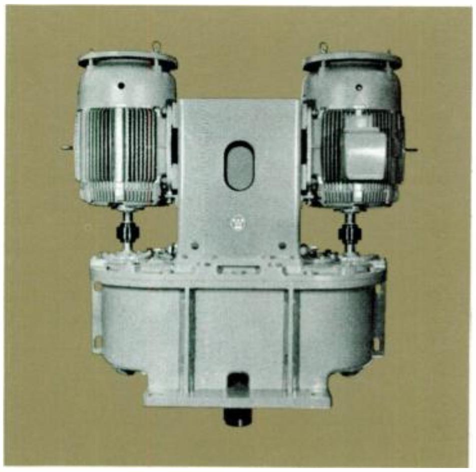
Those advantages are maintained in the larger horsepower sizes that have two motors. The twin units combine two standard NEMA-frame motors, couplings, and mounts into a compact balanced design that transmits power through two pinions instead of the more traditional single-mesh arrangement. Tests indicate that load is shared to within one percent; however, pinions, low-speed gear, and bearings are over-sized to assure long life.

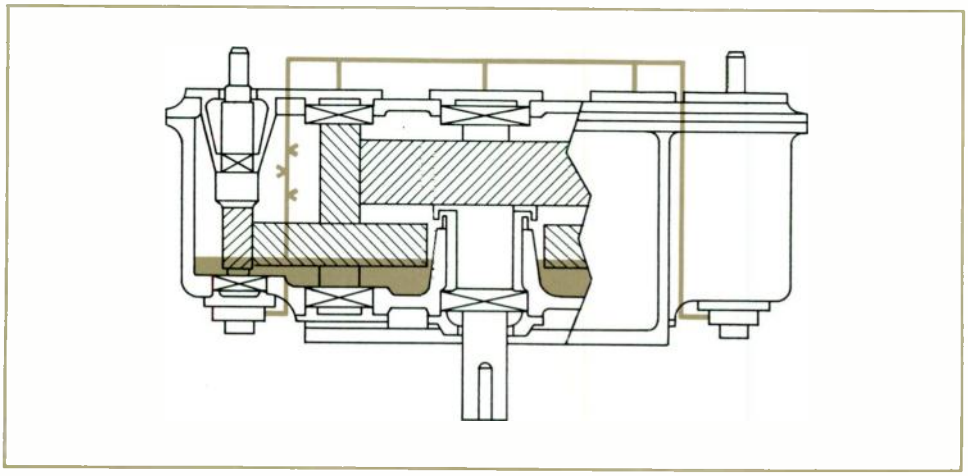
The gearing systems are known as Veri-Dri units because of dry-well construction around the output gear shaft: the lower casting of the gear case extends up to form a cylinder around the shaft that prevents oil leakage along the shaft while still permitting the bottom of the case to serve as an oil reservoir. (See drawing.) The lower bearing on that shaft is grease-lubricated. The other bearings and the gear meshes are lubricated with oil supplied by a pump at the bottom of the motor pinion shaft (or shafts). The pump draws oil from the reservoir in both forward and reverse operation and feeds it to all parts.

The Veri-Dri units are rated 1 through 800 horsepower, with speeds from 7½ to 280 r/min.

Users Custom-Design Their Own Integrated Circuits

A do-it-yourself design program now enables users of integrated circuits to tailor the circuits to their own particular needs. The program in effect provides each user special integrated circuits, with their lower system cost potential and





Veri-Dri gear reducer with twin 75-hp, 6-pole drive motors provides 37 r/min output *(left)*. The vertical arrangement conserves valuable floor space in water purification installations. Colored line in diagram *(right)* shows how oil pump at base of each motor pinion shaft supplies oil. Bottom bearing on output gear shaft is grease-lubricated and enclosed in dry well to prevent oil leakage around shaft.

inherent higher reliability, for much less than the cost of subcontracting the work or developing an in-house capability.

The program is based on a set of integrated-circuit manufacturing processes standardized by the Westinghouse Molecular Electronics Division, so it enables users to prepare designs compatible with those processes. It thereby avoids long development times, offsets lack of experience, and offsets lack of proprietary knowledge. The "U-Design" program includes a continuously updated manual and training of customer engineers.

Laser Material Operates Efficiently at Room Temperature

A new crystalline laser material shows unusual promise for efficiently generating extremely pure infrared laser light. The material has the lowest energy threshold of any room-temperature laser crystal, meaning that it takes relatively little applied energy to cause it to emit its infrared radiation. Consequently, it has potential uses where a small portable laser system is desirable, as for distance measurement or object detection.

The material is calcium fluorophosphate, which is found widely as the mineral fluorapatite. It is made to "lase" by adding about one percent neodymium, the element commonly used in doping glass to make neodymium-glass laser rods. The neodymium emission from the new material is unusual compared with that element's emission in other advanced host crystals, such as yttrium-aluminum garnet, in that more than twice as much of the emission is concentrated at a single frequency. Emission is centered at a wavelength of 1.06 microns.

In experiments at the Westinghouse Research Laboratories, where the new material was developed, rods of the material were compared with rods of yttrium-aluminum garnet having the same physical dimensions (0.25-inch diameter by 3.0 inches long). They were pumped with light from xenon flash lamps in reflecting cylinders. With identical test procedures and equipment, slope efficiency of the calcium fluorophosphate rods was measured to be 3.0 percent while that of yttrium-aluminum garnet rods was 1.7 percent.

Electromagnetic Probe Detects Generator Insulation Voids

Much as a stethoscope enables a doctor to listen for signs of trouble in the human chest, a recently developed electromagnetic probe permits routine examination of large electric power generators for symptoms of abnormal electrical discharges within coil insulation. The probe not only detects such discharges but also locates them.

Electrical discharges occur in air pockets and separations that may appear in the coil insulation over the generator lifetime of 30 years or more. They could lead to insulation breakdown, and conceivably destruction of the generator, so a variety of tests have been devised to detect them. Those tests are applied in regular examinations of the hundreds of coils in a generator so that any problems can be found early and remedied.

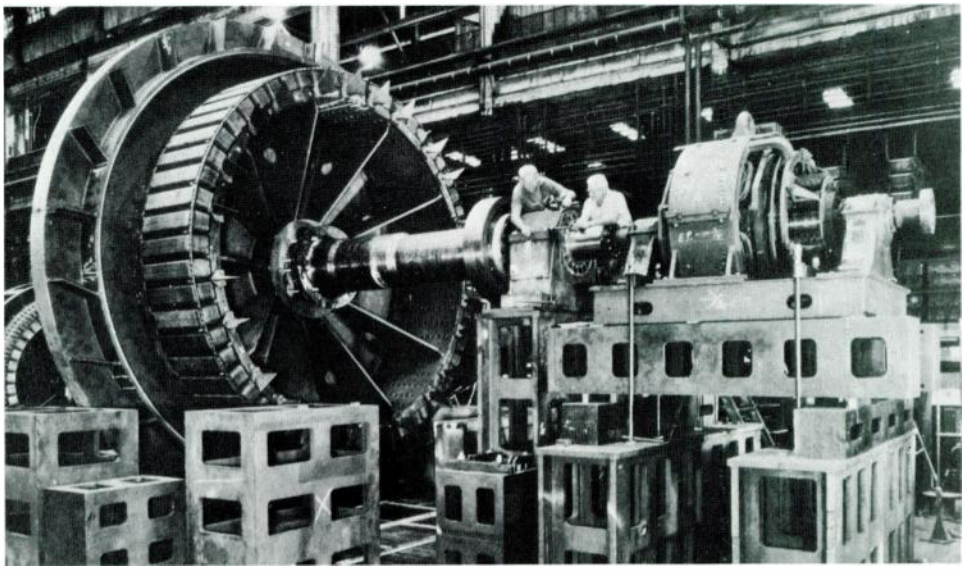
A deficiency of previous test methods is that they indicate only the existence of insulation voids, not how many there are nor where they are located. The electromagnetic probe, however, both detects and locates voids. Moreover, it distinguishes large harmful voids from the numerous small ones that normally occur during aging without causing harm.

The probe consists of a small horseshoe electromagnet that exactly bridges the gap over the generator slot in which the coil section under test is lodged. It is wired to a meter that shows the magnitude of radio noise produced by discharges at a frequency of five megahertz, the frequency found to give the best combination of sensitivity and ability to locate the discharge. (See photograph on outside back cover.) The instrument was developed by the Westinghouse Research Laboratories and the Large Rotating Apparatus Division.

Large Generators Diesel-Driven

Two of the world's largest diesel-driven generators are being installed at the village of Freeport, Long Island, N.Y. Each 13.8-kV generator is rated at 9480 kW, 0.8 power factor, 124.1 r/min, three phase, 60 Hz. The stator frame measures about 28 feet in diameter, with Thermalastic insulation used on the form-wound stator coils.

Diesel generator, one of the world's largest, is shown during shop assembly before shipment.



The 77-ton rotor, approximately 16 feet in diameter, includes a 50-ton flywheel, and each assembled generator weighs more than 180 tons. The units were built by the Westinghouse Large Rotating Apparatus Division.

Record Power Level Attained in PWR Nuclear Plant

A record level of linear power density for nuclear reactors has been achieved in the Saxton Nuclear Station with a pressurized-water reactor core containing plutonium fuel. The power density of 18.5 kW per foot of fuel is about 25 percent higher than that in presently operating commercial pressurized-water reactors. The operation thus establishes technical parameters that verify the improved economics of power reactors now on order.

Linear power density is a measure of the amount of heat extracted from a given length of fuel. It is affected by the mechanical strengths of the fuel and cladding and the heat transfer characteristics of the fuel, cladding, and coolant.

The Saxton reactor core has a mixture of uranium and plutonium oxides in 40 percent of its central part, which is surrounded by enriched uranium oxide. Its successful operation is the first step in demonstrating the plutonium recycle concept, in which plutonium produced as a by-product of reactor operation is used as fuel in other cores. Plutonium recycle will become increasingly important in the next few years as more and more plutonium accumulates from operation of the many nuclear plants being ordered and built. Ability to use that plutonium as fuel is important to keep nuclear power economically attractive.

All of the plutonium-uranium oxide fuel in the Saxton core is enclosed in Zircaloy-4 cladding. The light-water coolant is borated.

The increase in power density raised the reactor's thermal power output from the original design value of 23,500 kW to 31,000 kW, and the electrical output from 4300 kW to 6100 kW. The plant will operate at that level until it is shut down for installation of a third core.

The power density experiment was conducted jointly by Westinghouse and Saxton Nuclear Experimental Corporation (SNEC). Westinghouse is conducting a research and development program along with an operator's training program at the reactor, which is owned by SNEC. SNEC is a subsidiary of the General Public Utilities Corporation, whose operating companies include Pennsylvania Electric Company, Metropolitan Edison Company, New Jersey Power & Light Company, and Jersey Central Power and Light Company. Participating members are Rutgers University and the Pennsylvania State University.

Products for Industry

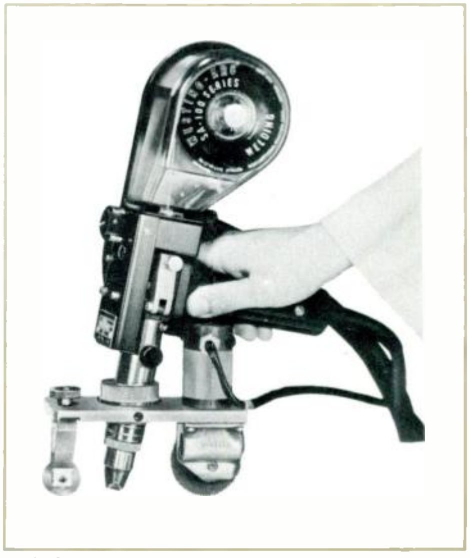
Sealed mercury-lamp floodlight does not take in air, so the interior of the optical system remains clean throughout the life of the 1000-watt lamp. As a result, beam spread does not vary, and the only reduction in efficiency is due to dirt accumulation on the outside of the cover glass. Floodlight has die-cast aluminum housing and lens holder, heat and impact-resistant lens, and integrally mounted ballast. *Westinghouse Lighting Division, Edgewater Park, P.O. Box 5817, Cleveland, Ohio 44101.*

Analog-to-digital converter converts to nine-bit digital words at a rate of 10^6 words a second. It was designed for such high-speed applications as radar moving-target indicators, data collecting and logging, and computing systems. The converter is suitable for 19-inch-wide rack mounting. Its printed-circuit cards, which are accessible from the front panel, contain the converter as well as the sample, hold, and timing circuitry. *Surface Division, Westinghouse Defense and Space Center, P.O. Box 1897, Baltimore, Maryland 21203.*

Weld pacer for use with West-Ing-Gun arc-welding unit gives precise control of travel speed and gun angle in semi-automatic MIG (Metal Inert-Gas) welding of light-gauge metals. The Pacer holds the gun at the desired welding angle, with proper work-to-nozzle spacing, and traverses the seam to be welded at the precise speed set by the operator. Operators can be quickly trained since they need only guide the gun. Main com-

Sealed Mercury-Lamp Floodlight

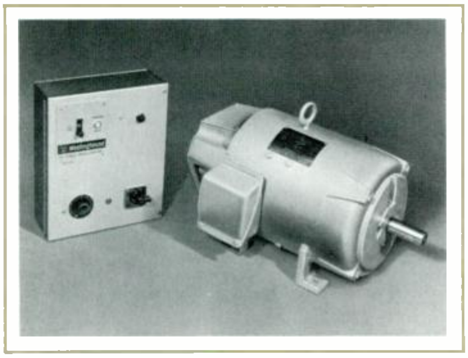
Analog-to-Digital Converter

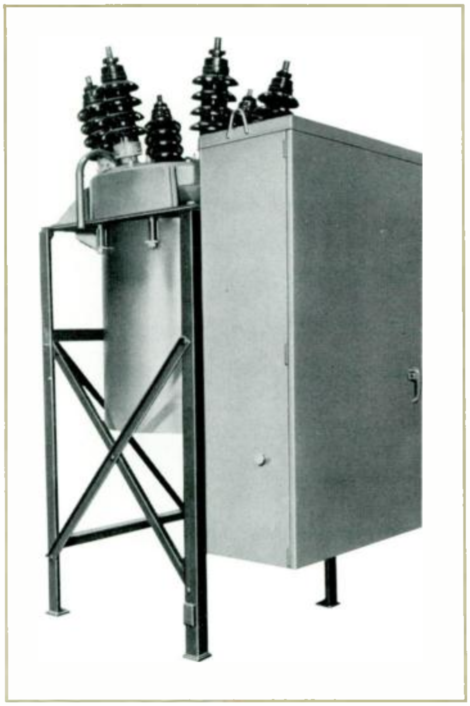


Weld Pacer

ponents are a speed control box and a motor-driven carriage (see photo) with 30 feet of control cable. Travel speed can be set from 0 to 200 inches a minute. *Welding Department, Westinghouse Industrial Equipment Division, P.O. Box 300, Sykesville, Maryland 21784.*

Adjustable-speed dc drive in 1½- and 2-hp ratings extends the rating range of compact Hi-Torque solid-state drives. Its speed control unit applies transistor circuitry to provide constant torque over entire 20:1 speed range, with speed regulation varying from 5 to 8 percent over the range. It provides motor reversing and dynamic braking, and it has built-in current limit and capability to respond to remote control signals. The control operates from a 230-volt, single-phase, 60-Hz source. Its 180/190-volt dc output is supplied to motor armature and field, with armature voltage varied to give speed variation. Gear heads can be mounted to the motors to increase speed range. *Westinghouse Specialty Motor Plant, P.O. Box 1611, Springfield, Massachusetts 01101.*


Adjustable-Speed DC Drive


Outdoor Oil Circuit Breaker

Outdoor oil circuit breakers (Type GS) combine high interruption capability, short arcing time, and high-speed reclosing. They are rated for 14.4- through 34.5-kV power transmission systems. Single-tank construction minimizes space requirements, reduces oil demands, and reduces foundation needs. Silver-tungsten is used on all contact surfaces exposed to arcing to extend the useful life of the contacts and reduce maintenance requirements. "Wipe-type" construction burnishes the contact surfaces during each breaker operation. *Westinghouse Power Circuit Breaker Division, Trafford, Pennsylvania 15085.*

Services for Industry

Electrostatic air cleaning costs are lowered by replacing rotating-spark-gap or tube-type rectifiers in old precipitator equipment with solid-state silicon diodes that operate with substantially less power and are long lasting, quiet, and maintenance free. Typical industrial precipitator applications are in smoke elimination, chemical residue recovery, fly-ash removal, and gas purification. *Westinghouse Electric Service Division, R&D Center, Pittsburgh, Pennsylvania 15235.*

Inert-gas autoclave is available for heating long specimens to high temperatures. It can be pressurized with helium to 30,000 psi, and it accommodates specimens up to 6 inches in diameter and 36 inches long. A resistance furnace heats uniformly to 1000 degrees C. Many combinations of time, temperature, and pressure are possible. Typical applications are material compaction, pressure bonding, diffusion bonding, and device fabrication. *Materials Marketing, Westinghouse Astronuclear Laboratory, P.O. Box 10864, Pittsburgh, Pennsylvania 15024.*

New Literature

Westinghouse Fast Breeder Reactor Research & Development Facilities is a booklet that explains and illustrates facilities for plant systems and components development, reactor mechanical development, fuels and materials development, sodium technology, and technical support. Each section is indexed for reference. *Westinghouse Advanced Reactors Division, P.O. Box 158, Madison, Pennsylvania 15663.*

The New American Continent, a booklet on the products and services of the Westinghouse Underseas Division, describes the Company's undersea research and development capabilities and some of its ocean engineering. Among the subjects discussed are the Cachalot prolonged-submergence diving system, Deepstar submersibles, sonar equipment, and a man-rated test facility that can simulate depths to 1500 feet. *Ocean Research and Engineering Center, Westinghouse Underseas Division, P.O. Box 1488, Annapolis, Maryland 21404.*

Custom electromagnets for science and industry are discussed in a 12-page booklet that describes the advanced techniques used to manufacture electromagnets, coils, and accessory electromechanical equipment to exacting specifications especially for particle accelerators and related applications. The booklet explains how electromagnets and beam-transport systems can be manufactured directly from customer drawings or designed and engineered by Westinghouse to suit customer needs. It lists typical products, describes metal-joining techniques and quality-control methods, and illustrates products at various stages of manufacture. *Westinghouse Repair Division, 5899 Peladeau Street, Emeryville, California 94608.*

About the Authors

Paul A. Berman graduated from the University of Pennsylvania with a BSME in 1953, and he earned his MSME there in 1956. He joined the Westinghouse Gas Turbine Division (now the Small Steam and Gas Turbine Division) in 1953, where he worked first on cycle analysis and compressor and turbine design in the thermodynamics section. He then moved to the special project section to design nuclear gas turbines, marine gas turbines, and circulators for gas-cooled reactors. Berman has also worked in the Division's application engineering and product engineering sections, contributing to the design of the COSAG marine gas-turbine plant, gas-turbine exhaust heat boiler systems, and the gas-turbine package described in this issue. He is now Supervisor, Value Engineering.

Peter O. Thoits graduated from Purdue University with a BSEE degree in 1958. He served in the U.S. Army for two years and then joined Central Maine Power Company as an engineer in the Substations Operating Department. He returned to school, at the University of Maine, in 1962 and earned his MSEE in 1964. Thoits joined Westinghouse the same year as an Assistant Sponsor Engineer in the Electric Utility Engineering Department, where he worked on a variety of problems in power system analysis. He is now a Generation Engineer in the Electric Utility Headquarters Department, responsible for the generation aspects of power systems.

Arnold J. Uijlenhoet graduated with an MScEE degree from the Technical University of Delft (Netherlands) in 1961. He served two years in the Dutch Army signal corps, testing equipment and writing specifications, and then joined Westinghouse on the graduate student course. Uijlenhoet's first assignment was as an Assistant Sponsor Engineer in the Electric Utility Engineering Department, where he worked on utility systems studies including power system stability, short circuit, relay application, and equipment application. He is now a Generation Engineer in the Electric Utility Headquarters Department. His major professional interest is in generator excitation systems and their effects on power system performance, and he has contributed to the development of packaged gas turbines. He has taken graduate work at the University of Pittsburgh and is co-founder of the Netherlands Club of Western Pennsylvania.

P. E. Lego earned his BS in Electrical Engineering at the University of Pittsburgh in 1956 and his MS there in 1958. Lego joined Westinghouse on the graduate student course in 1956 and was assigned to the Advanced Systems Engineering and Analytical Department, where he worked on regulation and simulation problems and on digital computer programming. In 1958, he joined the Computer Advisory Service in Engineering, a group organized to acquire computer technology and apply it in engineering operations.

Lego returned to Advanced Systems in 1960 to work on basic control computer programming techniques. He joined the Computer Systems Division in 1962 as a Senior Engineer in charge of the application programming group. The following year he was made Manager, Application Programming Section, and in 1964 he became Manager, Metals Section. Lego went to Headquarters Manufacturing in 1966 on the rotation program for senior engineering personnel. In 1967 he joined Hagan Controls Corporation as Engineering Manager. When that organization was merged with the Computer Systems Division later in the year, Lego became Product Line Manager, Major Systems.

G. C. Turner graduated from Clemson A&M College in 1952 with a BS degree in electrical engineering. He joined Westinghouse on the graduate student course and then held a variety of engineering and supervisory positions in the Electronics Division (now the Surface Division of the Westinghouse Defense and Space Center). He was named Manager of Product Reliability for the division in 1962.

Turner was appointed General Manager of the Computer Systems Division in 1965. That division merged with Hagan Controls Corporation last year, with Turner continuing as General Manager of the new Hagan/Computer Systems Division.

J. H. Bednarek of the Switchgear Division and **T. David Rubner** of the Research Laboratories worked together in developing the new automatic synchronizer they describe in this issue.

Bednarek joined Westinghouse after graduating from the University of Delaware with a BEE in 1951. From the graduate student course he moved to the Switchgear Division, where he has worked on low-voltage switchgear, supervisory control, Navy switchgear, turbine supervisory instruments, and synchronizers.

Rubner attended Queen Mary College, University of London, where he received his BScEE in 1962. He joined the Westinghouse Research Laboratories in 1963. His major responsibilities have been in the area of instrumentation, control, and digital circuitry. Rubner has worked on the Prodac 50 computer, a computer telephone data link, core memories, overspeed trip for rapid transit systems, and the automatic synchronizer. He is presently working on a new line of turbine supervisory instruments and on a video disc recording system. He obtained an MSEE from Carnegie Tech in 1966.

H. Warren Cooper graduated from New Mexico State University in 1947 with a BS in electrical engineering and earned his MS at Stanford University the following year. He joined Airborne Instruments Laboratory, working as a project engineer on antenna and microwave components, and then in 1953 he went to Maryland Electronic Manufacturing Corporation as head of the antenna and microwave components section. He joined Litton Industries, Maryland Division, in 1957 as Director of Research and Development.

Cooper joined the Westinghouse Aerospace Division in 1958 as an Advisory Engineer in space antenna and microwave systems. In 1961 he was made Technical Director, Orbiting Astronomical Observatory, Ground Operation Equipment. He became Manager, Research and Development Programming, in 1962, Manager, Space Systems, in 1964, and Manager, Strategic Operations, later that year. Since 1965 Cooper has been Manager of the Electromagnetic Technology Laboratory.

C. Herbert Grauling Jr. served as Director of Engineering and is now Program Manager for the flight inspection positioning system described in this issue. In addition to that responsibility, he is a general consultant for microwave techniques and applications in the Aerospace Division.

Grauling graduated with a BE from the Johns Hopkins University in 1944 and then joined the U.S. Navy, where he attended school under the radio technician program and served as an instructor in the Radio Materiel School. He joined the Johns Hopkins University staff in 1946 as an instructor in electrical engineering, and in 1950 he moved over into the university's Radiation Laboratory to do research on proximity fuses and various microwave problems.

He joined Westinghouse in 1955 as a Senior Engineer in microwave development work on the stable oscillator and other rf components for pulse doppler radar. He became a Fellow Engineer in 1958 and an Advisory Engineer in 1961, and he earned a Doctor of Engineering degree from Johns Hopkins in 1957.

An electromagnetic probe detects and locates voids in generator winding insulation so that the voids can be corrected before they cause trouble. The probe picks up radio noise from electrical discharges, and the noise is measured by the meter in the background. For more information, see page 158, "Electromagnetic Probe Detects Generator Insulation Voids."