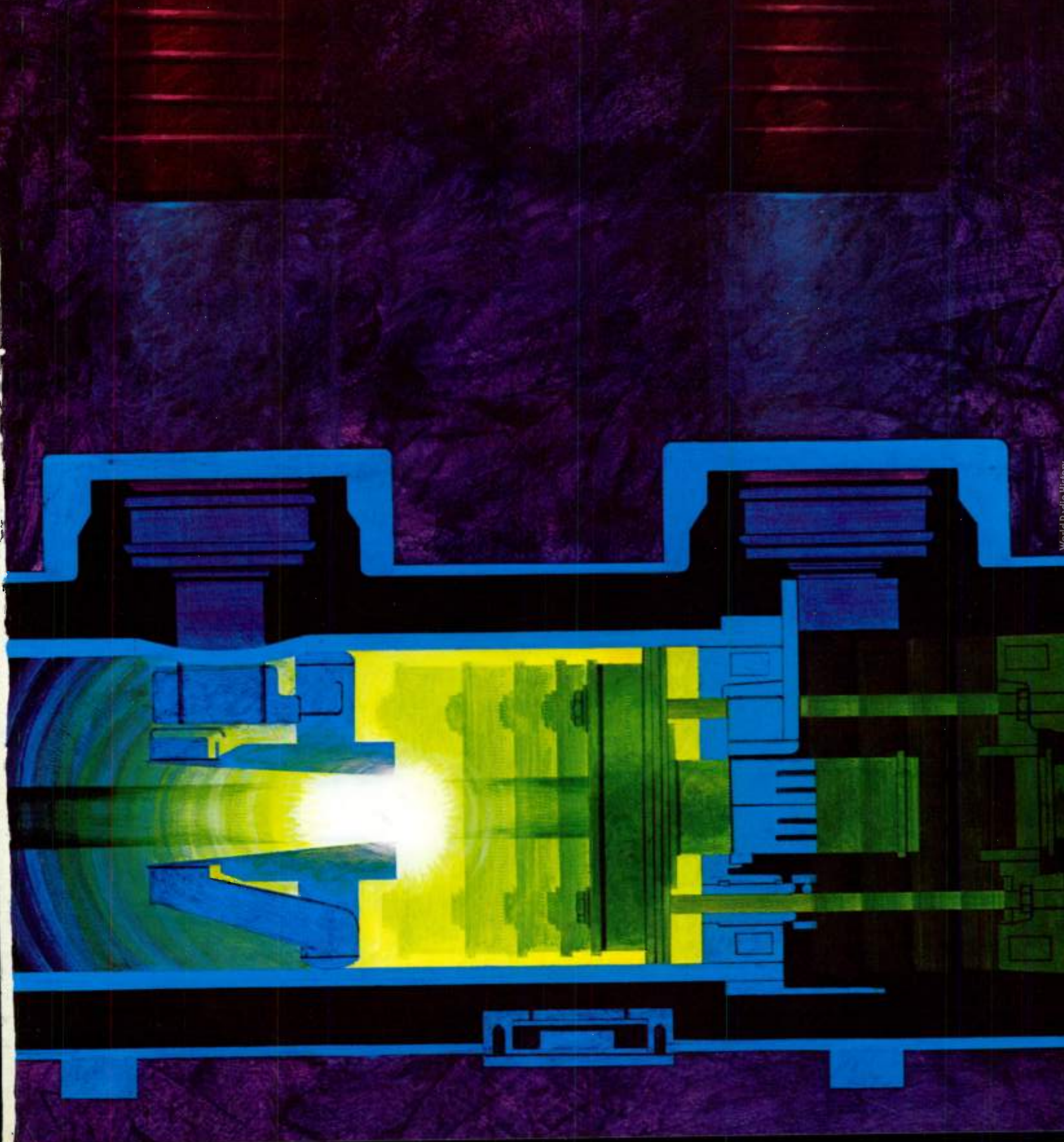
Westinghouse ENGINEER

May 1968



The prototype 500,000-kVA 765- to 345-kV autotransformer for American Electric Power's 765-kV transmission system has successfully completed plant testing and has been shipped to the Ohio Power Company's Kammer substation. Field service tests will continue there for about 12 months for final verification.

Experience gained in other EHV installations, supplemented by new design techniques, enabled engineers to investigate stress conditions throughout all the individual components of the unit's complex insulation structure. Component development and testing programs to assess the effects of sheer physical size resulted in new static plate designs, corona shielding of core edges, sectionalizing and multiple grounding of cores, and extension of the already proven condenser bushing.

The plant verification test program included all standard tests and was supplemented by standard-impulse, front-of-wave, switching-surge, and corona tests at levels associated with the 1800-kV BIL of the high-voltage winding. Another series of impulse and switching surge tests gave additional verification of the integrity of the unit's insulation structure. The transformer is shown on test with its 100-MVAR shunt reactor (at left).

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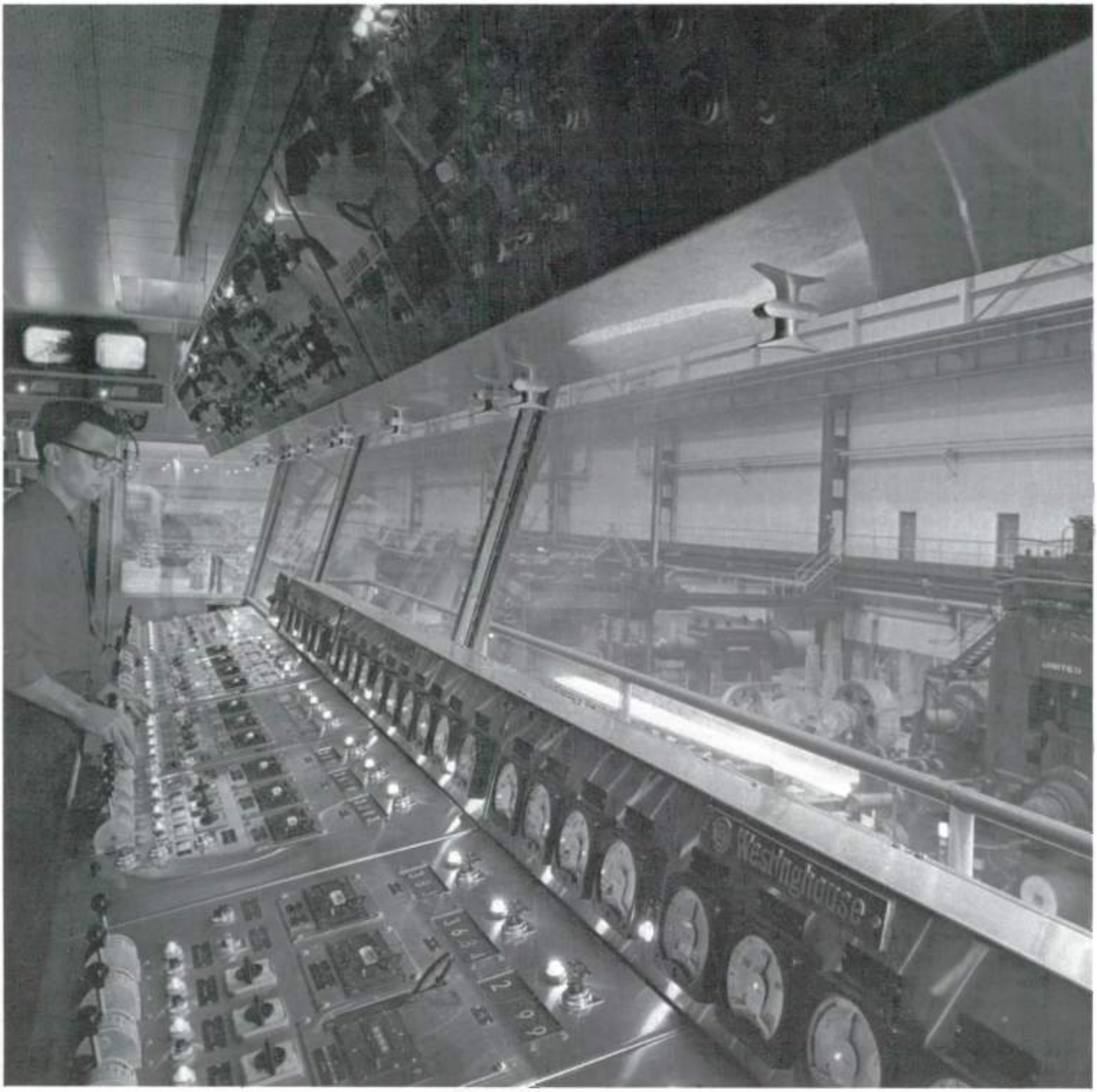
Cover design: The high interrupting efficiency of sulfur-hexafluoride gas has been put to use in a new circuit breaker design for metal-clad switchgear. Artist Tom Ruddy symbolizes the puffer arc-interrupting element on this month's cover—for a more comprehensive description, turn to page 71.



A computer control system calculates the rolling schedule for this roughing train in a hot-rolling mill from simple input information about the slab and the desired finished product. The entire mill is under the direction of the Prodac 580 digital computer, from slab depiler at the starting end to strip coiler at the finish. Operators can communicate with the computer to initiate process changes.

The Solid-State Revolution in Industrial Drive Systems

W. R. Harris

Solid-state equipment has taken over most control and power functions because it is more capable and more economical than earlier equipment.

In just the past few years, solid-state equipment has almost completely taken over the control and power functions for industrial automated drive systems. Although the takeover has been evolutionary, the pace has been so rapid that it is in reality another industrial revolution.

In control, solid-state equipment has become standard for digital computers, programmers, and data loggers and for a line of excellent and flexible analog feedback-control systems. In dc power, solid-state equipment has obsoleted the mercury-arc rectifier and the m-g set.

The advantages to industry are more efficient and flexible power conversion equipment, and sophisticated control systems that have made it possible (through programmed and computer logic) to replace much of the human factor in manufacturing process control with engineering and management intelligence. The solid-state revolution is in full bloom, and the proliferation of devices and technology gives every indication that much more is to come.

One of the two major factors responsible for the revolution is the development of the required components: reliable solid-state devices that have major operation, maintenance, or efficiency advantages over previous equipment. It started in the late 1950's with low-power devices such as diodes and transistors for digital and analog control equipment. High-power devices such as power thyristors grew out of the initial work and are now being applied over a wide spectrum of applications ranging up to very high power—for example, a 73,000-horsepower drive system for the finishing train of a recent hot-strip mill.

The second major factor responsible for the revolution is the great and increasing demand from industry for sophisticated automation systems: solid-state equipment simply is necessary to get the performance users demand. Most industrial companies face a serious cost-price squeeze brought about by competition. They have to make every effort to reduce product cost or increase salability by maximizing throughput, making more efficient use of raw material, improving product quality, or maintaining closer tolerances. An example of such efforts is the exponentially rising demand for numerically controlled machine tools.

There is interaction between these factors, of course: solid-state devices make the sophisticated systems possible, and demand for the systems stimulates device development. It would have been impractical, if not impossible, to build the complex automated systems of today with previous equipment such as electron tubes, rotating regulators, and magnetic amplifiers. Control for the continuous hot-strip mill just mentioned, for example, is enormously complex. A solid-state digital computer oversees the operation of the entire mill, which processes a huge slab all the way from the reheating furnaces to the strip steel of correct gauge and temperature at the coilers about half a mile away. A myriad of solid-state feedback controls operate their respective drives to execute the computer commands for speed, tension, roll force, position, and gauge. Because the strip is in most stands simultaneously, each adjustment interacts with the others, a situation that requires fast, accurate, and stable feedback systems.

The three major classes of solid-state equipment are digital logic systems, analog feedback-control systems, and dc power sources. Digital logic systems include data loggers, programmers, and computers. Analog (linear) feedback systems are generally used to control a specific function such as speed, position, tension, voltage, or current. The dc power sources convert ac power to adjustable-voltage dc power for process drive motors.

Digital Logic Systems

Development of reliable solid-state devices ranks as one of the most important breakthroughs of the past decade because it enabled industry to take complex digital logic out of the laboratory and put it into on-line service in manufacturing operations. Relays, magnetic logic, and electronic tubes had been used for a variety of sequencing, programming, and computing functions, but they were not suited for complex systems because they were too short-lived, slow, unreliable, expensive, or high in power dissipation. The solid-state digital logic devices, however, are so much better in all those respects that they make practical such large and complex systems as data loggers, on-line programmers, process-control computers, gauge controls, position controls, and numerical machine-tool controls.

Data loggers serve as tireless and dispassionate record keepers, providing such operating and production information as tension, gauge, pressure, and total length of material. They also provide the basic data from which the rules for further automation can be derived. For example, gathering material for a mathematical

The Model 20 numerical control system for machine tools applies solid-state integrated circuits for small physical size and for efficient logic operations.

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model of a process requires an extremely close look at all of the surrounding parameters; data loggers are essential to such work because they can take information from sensing devices and report it in a coordinated manner.

Digital programmers are used where production apparatus can be put through a series of predetermined operations. For example, the first digital programmer for reversing mills (installed in 1957) was used to program and coordinate screwdown positions, mill speed, and direction of rotation so that a bloom could be made into a slab by the most desirable sequence of reductions and with minimum strain on mill and drives. Its advantages in increased productive efficiency, reduced mill maintenance, and replacement of operator art with engineering and management technology were so apparent that all but one of the approximately 40 mills supplied since then have had digital programmers or computers.

The digital computer is an even more capable means than the digital programmer for synthesizing engineering and management intelligence into manufacturing operations that were previously controlled empirically. The reason is the computer's ability to do complex calculations quickly and to apply adaptive control and memory to improve or optimize operating parameters.

The computer's speed, versatility, and effectiveness have led to results in control and in information handling and reporting undreamed of a few years ago. The computer assembles information about the process from a variety of sensing devices and compares it with input data that describe what is desired from the process. It then calculates—on the basis of a mathematical model stored in its memory—the adjustments to be made or the sequencing to be followed to optimize the process in cost, quality, or output. The interface between the computer and the power equipment usually is a feedback control system that executes the computer commands rapidly and precisely.

As the computer grows in sophistication, its influence also will increase. As a general rule, however, computers do not take the place of feedback control apparatus but are superimposed. (Although direct digital control also has found a place, mainly in the chemical process industries to date.) Computers actually increase the demand for feedback control systems and frequently impose more stringent performance specifications.

Nor will solid-state logic devices completely take over from electromechanical contactors and relays in the foreseeable future. Economics will prevent it. While a complex logic system such as a programmer or computer is not practical except through the use of solid-state devices, there are many simpler controls where the speed and versatility of solid-state devices are not required and where relays can do the job simply and considerably more economically.

Analog Feedback-Control Systems

Most feedback regulating systems are analog types because most of the inherent relationships in machines and process equipment are analog in nature. Digital feedback systems have advantages in certain uses such as position regulators, but those uses require analog-to-digital conversion at some point in the control loop. Because the conversion equipment is expensive, and because of the inherent analog nature of most equipment, most feedback systems will remain analog.

Development of solid-state equipment has caused a major change in both the technology and the hardware for industrial analog feedback-control systems. Modern systems almost invariably make use of operational amplifiers, fast high-gain electronic amplifiers capable of summing or integrating electrical signals. The techniques are similar to those used in analog computers. Solid-state equipment now enables us to build operational amplifier systems (including sensors, gates, and switching equipment) with the advantages of low signal level, fast response, very high gain, excellent flexibility, and good stability.

Flexibility and adaptibility to different modes of operation are the major advantages of solid-state operational-amplifier feedback systems. The amplifiers can be connected for proportional control, integral control, or a combination of the two, and ramp functions, gates, anticipating circuits, and stabilizing circuits are easily added. Systems of amplifiers are usually arranged for multiple-loop or parallel-loop operation, both of which inherently provide limiting functions with sharp cutoff and good stability.

For example, stability problems made it difficult to obtain a good current-limit function with either rotating or magnetic-amplifier speed or voltage regulators. But with operational amplifiers, in either multiple-loop or parallel control, stability is much more easily attained because of the speed, high gain, and ease of adjustment of the solid-state amplifiers. Effective current limit is obtained with negligible overshoot, and, more important, the resulting system is relatively simple to set up and adjust during field installation.

Moreover, the flexibility of solid-state equipment enables us to build far more complex systems. As a result, we can put more of the variables inside the control loop to more easily meet the sophisticated requirements of automated systems.

With previous types of equipment, each variable in a system (such as speed, voltage, current, tension, and position) was individually regulated; by keeping all variables constant, the output was kept constant. American industry built an enviable position with that technology. However, many modern process lines have unavoidable interaction between individual regulating systems, so the response and stability of the whole complex must be considered. For example, the automatic gauge-control system for the seven-stand finishing train of a hot-strip mill includes the following feedback loops: a gauge loop around all stands with an X-ray gauge as a sensor, roll force loops on each stand, position regulators on the 14 screwdown drives, looper position regulators between stands for constant interstand tension, and speed regulators for each stand. Every regulator action affects to some degree all other regulators in the system, so the entire complex must be engineered into an accurate, fast, and stable system that considers the interaction between the various regulators and the overall results to be obtained.

That requires good systems engineering, good feedback systems components, and fast stable operation of each feedback control. The excellent results regularly obtained are a tribute to the solid-state regulating equipment and the systems engineering that are applied.

Of course, plant engineering and maintenance staffs have had to learn how to handle a completely different hardware and technology. A considerable amount of training is involved, and selection of qualified personnel is of paramount importance. The control supplier's field engineers, instruction books, and in-plant training programs can be most helpful. Most plants have adapted quickly to the new equipment, and the growing pains are almost at an end.

DC Power Sources

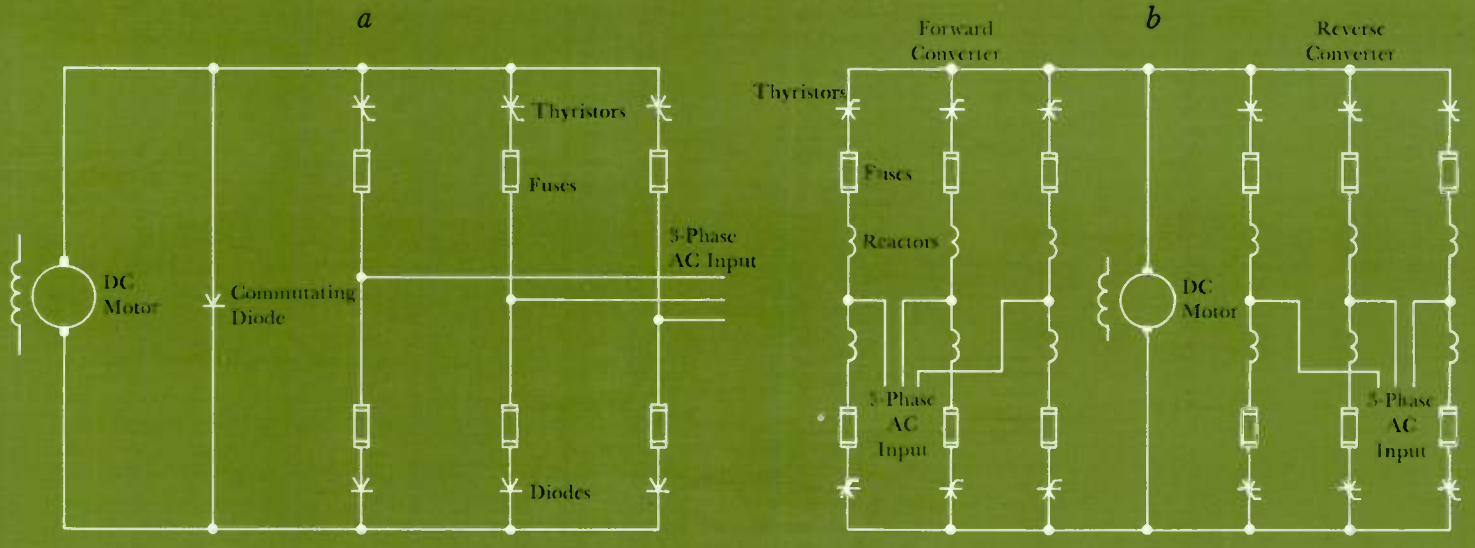
Beginning in 1955, germanium diodes and then silicon diodes in power ratings began to be used to make constant-voltage dc power supplies because of their advantages of higher efficiency, less maintenance, and simpler control circuitry as compared with the mercury-arc rectifier. The silicon diode soon entirely obsoleted both the mercury-arc rectifier and the m-g set for constant-voltage power supplies for electrochemical processes, aluminum potlines, and general industry shop supply.

Then engineers began to look for a rectifier device that could be controlled to provide an adjustable-voltage power supply. They found it in the thyristor, or silicon controlled rectifier. The first thyristors were of relatively small power capability but were ideal for feedback regulating-system amplifiers, supplying the field excitation of dc motors or generators. Their low time delay and controllability led to quick acceptance.

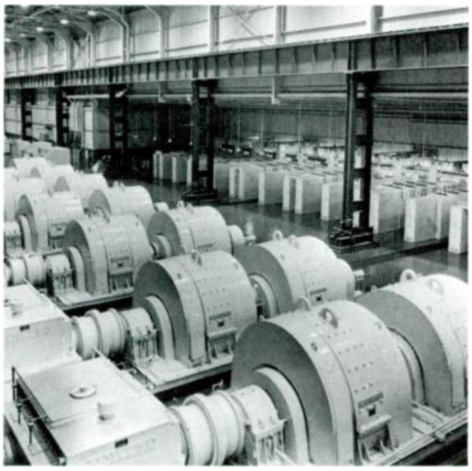
As thyristors of higher power were developed, they were used to build motor armature power supplies. Since the first installations about five years ago, the trend toward thyristor power supplies has moved explosively: they have obsoleted the mercury-arc rectifier and encroached on the m-g set to a considerable extent. By 1970, 80 percent of new installations probably will employ thyristors.

The two main types of thyristor power supply in general use are the semiconverter and the full converter. (See diagrams below.) The semiconverter power supply is applied extensively in applications from 5 to 200 hp that can use a nonreversing drive and do not require regenerative braking. It costs less than an m-g set and is easily mounted and installed; the entire power supply and control equipment often is mounted in an enclosure that also forms the operator's desk, as in the top photograph on the next page.

The full converter is used where reversing and regenerative capability is needed. Two of them used together form a dual converter, which is fully equivalent to an m-g set: it provides power for both directions of rotation of the dc machine and can absorb the stored energy in the moving parts of the drive system and return it to the ac line. For large amounts of power,



Semiconverter thyristor power supply (*a*) consists essentially of a three-phase rectifier bridge with only three of its legs controlled. It provides unidirectional current and voltage. A commutating diode is connected across the dc motor so that the inductive energy in the motor circuit can recirculate at low voltages. Gating circuits fire the three thyristors in proper sequence and vary the phase of the firing pulses to provide dc power over a voltage range. *(b)* Full converter has all six legs of the rectifier bridge controlled. It provides unidirectional current, voltage reversal, and inversion of dc to ac current. When two are used together, as here, the resulting dual converter supplies power for both directions of rotation. Its control provides for both rectification and inversion modes as the dc machine either motors or regenerates. Its gating circuitry eliminates the possibility of current circulating between the forward and reverse converters.



Top—**This semiconverter dc power supply and its controls are mounted in a combination control cabinet and operator's benchboard. It powers the motor drive for a corrugating machine in a boxboard plant.**

Bottom—**Hot-strip mill motor room has main and auxiliary drives powered and controlled by solid-state equipment. The thyristor dc power supplies that provide adjustable-voltage power for the motors are in the background.**

several bridges are paralleled.

The reasons behind the quick acceptance of thyristor power supplies for motor armature power are their many inherent advantages: Five to ten percent higher efficiency than that of m-g sets, and also considerably lower no-load losses; less foundation requirements because of light weight and lack of heavy rotating members; low maintenance because of absence of brushes, bearings, and large rotating members and because of simple air cooling; flexibility because they can be reversing or nonreversing, regenerative or nonregenerative, large or small, with full or partial capacity in the reverse direction; and extremely fast response compared with large m-g sets.

Thyristor power supplies do have their disadvantages. Power factor is good at maximum dc voltage but drops about in proportion to voltage reduction, so a power system evaluation is necessary when large blocks of power are required and extended operation at low voltage is planned. Also, the sawtooth shape of the current wave applied to the dc motor causes additional motor heating and affects motor commutation adversely. Both effects are taken care of by motor design or by dc reactance to smooth the current.

Westinghouse has supplied more than 300,000 kilowatts of thyristor power supplies for uses ranging from one-horsepower drive systems for machine tools to thousands of horsepower for large rolling mills. In between are applications such as drive systems for galvanizing lines, paper machines, ore bridges, corrugating machines, and extruders. The thyristor power supply is adaptable to either general-purpose or sophisticated drive systems and is designed and packaged to cover a broad range of application and economic requirements. Its quick acceptance is one of the most significant phenomena of the 1960's.

The Future

Solid-state control equipment is a potent factor in the continuing and long-standing trend toward more automatic control. The amazing versatility and effectiveness of these devices has led to results undreamed of a few years ago and to future control possibilities far beyond the scope of today's devices. Moreover, the digital computer especially has led to new insight into the functions of other control devices and has introduced concepts of information processing and communication that will have far-reaching effects on industrial process control.

The explosive trend in development and application of low-power devices for analog and digital control is likely to continue—in fact, it will probably move even faster than it has before. Integrated circuits, for example, are rapidly finding their way into numerical machine-tool control, digital logic modules, operational amplifiers, and other digital and analog equipment. Their reliability capability is greater, and cost and space requirements less, than conventional circuits.

New fabrication techniques for solid-state devices are being pursued, and developments look very promising. Hybrid arrays, for example, which are combinations of thin-film, thick-film, monolithic integrated, and discrete components, show promise of reducing cost and improving reliability. A number of new components such as field-effect transistors are on the market or under development but have not yet reached their maximum potential.

All future digital control systems will have to use either integrated-circuit or hybrid devices to be competitive. In analog equipment, the story is similar but the pace is somewhat slower. A number of integrated-circuit operational amplifiers are on the market; they are suitable for specific applications but most of them do not tolerate as wide a range of parameter variation as present industrial-type discrete-component amplifiers. However, with the addition of modifying circuits using discrete components, they can be applied quite widely.

In heavy power equipment, silicon diodes and thyristors are well on their way toward replacing the m-g set. The future holds even higher promise because device cost is still trending downward and because devices of higher voltage and current ratings keep appearing, which further improves the cost picture.

An SF_6 Circuit Breaker for Metal-Clad Switchgear

Russell Frink
J. M. Kozlovic

A new circuit breaker design that uses a magnetically driven SF_6 puffer element makes possible an extension of metal-clad switchgear to higher distribution voltages and interrupting ratings.

The development of a removable breaker element for 23- to 34.5-kV service now makes it possible to use metal-clad switchgear with higher distribution voltages. These higher voltages are increasingly desirable as electric utility loads and load density continue to grow in urban areas. The new metal-clad gear also helps solve other problems that arise when large substations must be located in densely populated areas, such as the need for minimum space requirements and low operating noise level.

The new breaker element is a single-pressure, dead-tank SF_6 circuit breaker that uses the fault current to drive a puffer element magnetically, forcing SF_6 gas through the arc. The breaker has an interrupting capacity of 1500 MVA and an interrupting time of three cycles. Continuous current-carrying capacities are 1200 and 3000 amperes.

Before the development of the new SF_6 puffer breaker, the only breakers available with 34.5-kV, 1500-MVA ratings were the compressed-air breakers used in station cubicle switchgear and oil breakers. Substation assemblies using either of these breakers require considerably more space than the new 34.5-kV metal-clad switchgear, and therefore are usually not as desirable for urban installations.

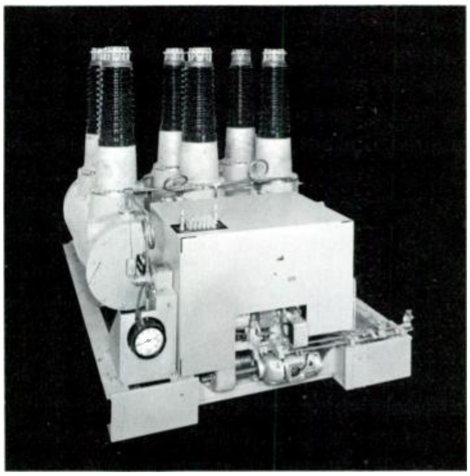
Puffer Interrupters

A puffer interrupter consists essentially of a pair of contacts, a piston, and a cylinder, all mounted in a reservoir containing a suitable interrupting gas. When the contacts are separated, the piston moves in the cylinder to drive gas through the arc and interrupt it. These devices were investigated 20 years ago, but until the discovery of the high interrupting efficiency of SF_6 gas, puffers were not suitable for circuit interrupters on systems in the power voltage class.

The first puffer application with sulfur-hexafluoride gas was in a load-break switch that was capable of interrupting load currents at voltages through 161 kV. This development was followed by a series of prototype SF_6 puffer circuit breakers, some of which have been reduced to practice.[1]

One of the prototype models, developed to demonstrate high interrupting capacity, was found capable of interrupting 50,000 amperes at 22 kV on a single break, with a transient recovery voltage of 1.2 kV per microsecond. This promising performance led to further work on a circuit breaker with the necessary interrupting capacity for large substations in the 23- to 34.5-kV class. The one major problem of the prototype puffer design was the high driving force required because of the back pressure on the piston created by the high-current arc.

The search for a solution to this driving force requirement led to the investigation of a magnetic system in which the arc current itself provides a powerful assist to driving the puffer piston. A three-coil arrangement, wound for attraction and repulsion, was found to be the answer to the problem of interrupting large currents.



1—The removable circuit breaker element consists of three pole units and the operating mechanism.

Breaker Operation

The removable circuit breaker element consists of three pole units, each in a grounded metal tank, and a spring stored-energy mechanism. The three pole units and the operating mechanism are mounted on a structural steel frame, equipped with wheels to facilitate handling (Fig. 1).

The interrupter mechanism in each pole unit (Fig. 2a) is operated by insulating links attached to a bell crank. The crank shaft passes through a seal in the tank to an external lever that is attached to the operating mechanism.

The electrical operation of the breaker is shown in Fig. 3. With the breaker closed, the normal current path is from the front bushing *1*, to the front main contacts *2*, to the moving tubular contact member *3*, to the rear main contact *4*, to the rear bushing *1*. The mechanical arrangement of the interrupter components is shown in Fig. 4. As the breaker begins to open, arcs are drawn between contacts *2* and *4*. Movement of the piston causes gas in the cylinder to be driven through the arc at the main contacts *2* and across the arcing contacts *5*. (Contacts *2* and *5* are in close physical proximity.) The arc quickly transfers to the interrupting circuit shown in Fig. 3b. The magnetic coils are now in series with the arc, piston coil *9* is attracted by the cylinder coil *12*, and the driver coil *7* is repelled by cylinder coil *12*. As the piston moves, it forces SF_6 gas in the cylinder through an annular passage in the piston and through the arcing space *5*, extinguishing the arc. When fault current is interrupted, the magnetic driving force vanishes, and the compressed gas behind the piston acts as a cushion to bring the piston to rest.

The magnetic driving force is proportional to the square of the fault current, so that piston driving force is proportional to interrupting requirements. At low fault current, the magnetic assist is negligible, but at the maximum fault rating, 10 percent of the piston driving force is supplied by the spring-loaded operating mechanism and 90 percent by the mag-

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[1] Easley, G. J., "A New Low-Voltage SF_6 Power Circuit Breaker," *Westinghouse ENGINEER*, May 1961, pp. 82-3.

Russell Frink is Manager, Advanced Development, Switchgear Division, and J. M. Kozlovic is a design engineer at the Switchgear Division, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania.

netic coils. Since the magnetic coils only come into the circuit by arc transfer, they are not energized during breaker closing.

Operating Mechanism

The operating mechanism is of the spring stored-energy type, similar (except for size) to those used with magnetic air circuit breakers, with separate closing and opening springs. Closing the breaker charges the opening springs, and the closing springs are immediately recharged by a small motor, which requires about 10 seconds. During normal operating conditions, both sets of springs are charged, making possible an instantaneous reclosure, followed by close-open operations at 10-second intervals. The spring charging motor can be operated from either a 125-volt dc or ac supply. Provision is also made for hand charging the closing spring so that the breaker can be closed even if station power is not available.

SF_6 Gas System

The SF_6 gas system is a single-pressure design, with the three tanks manifolded together and charged to a normal pressure of 75 psig. Gas at this pressure cannot liquify above −31 degrees C, so auxiliary heaters are not required. A temperature-compensated pressure relay trips the breaker if pressure drops. The relay is set to trip the breaker before ability to perform at full rating is lost.

A container of activated alumina is mounted in each interrupter tank to remove the arc decomposition products from the gas and to absorb moisture.

The SF_6 gas in the interrupter tanks is also the insulation in the bushings, as shown in Fig. 2b. The bushings have essentially zero power factor, and the insulating medium does not deteriorate with age.

Switchgear Housing Design

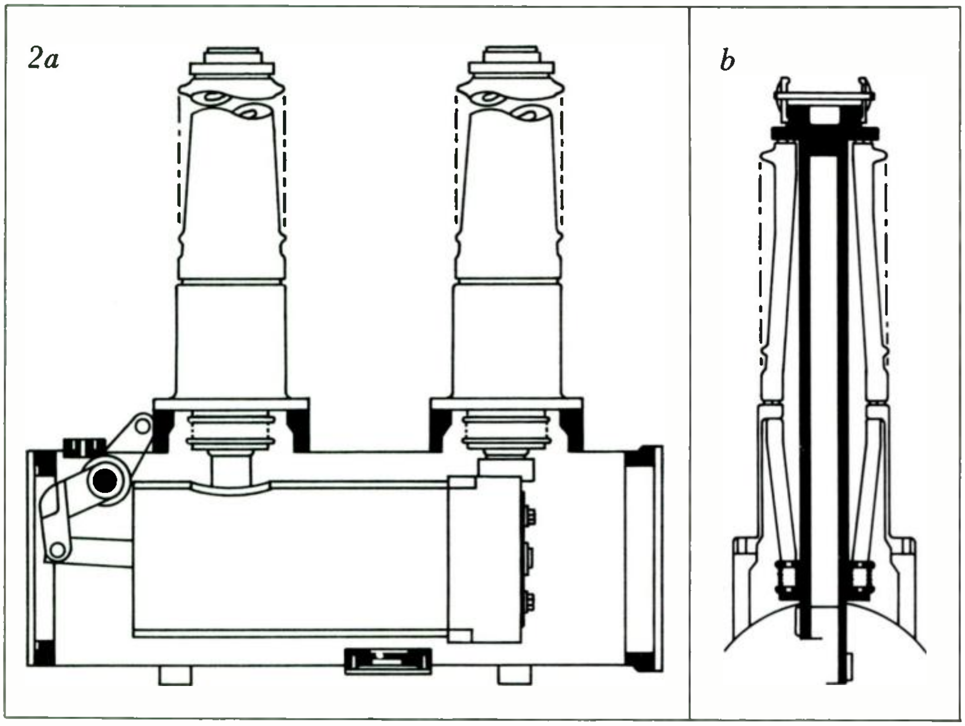
The basic 34.5-kV metal-clad switchgear unit is divided by metal barriers into three compartments—a breaker compartment, a bus compartment, and a line compartment as shown in Fig. 5.

The breaker compartment, located at the front of the cell, contains the removable three-pole breaker element, the breaker lifting mechanism, shutter, current transformers, and control panel. The breaker is raised to the engaged position by four jackscrews, which are coupled as a unit and motor driven. The porcelain bushings on the interrupter tanks connect with primary contacts mounted in porcelain receptacles in the bus compartment above the breaker compartment. Both the up and down positions of the breaker are controlled by limit switches that stop the motor when the breaker element is in position.

The shutter, a grounded barrier between the breaker compartment and the bus compartment, is operated by the lifting mechanism and closes when the breaker is removed. Ring-type current transformers are mounted directly below the shutter. When the breaker is removed from the cell, the current transformers are safely accessible for maintenance even with high-voltage circuits energized. Sufficient room is provided for four transformers per phase, or a total of 12 per cell.

The control panel is located across the top of the breaker compartment (Fig. 6). Behind the control panel is the stationary secondary contact block. The moving secondary contact block, mounted on the breaker, makes contact only when the breaker is in the operating position. The breaker can be operated in the disconnected position with a test jumper.

The bus compartment, above the breaker compartment, contains the primary contacts, risers to the bus, and the main bus. To minimize the possibility of tracking, all insulation that is stressed to ground in the bus and line compartments is either all porcelain such as the porcelain primary contact support bottles, or a combination of porcelain and glass polyester as where the bus passes through the

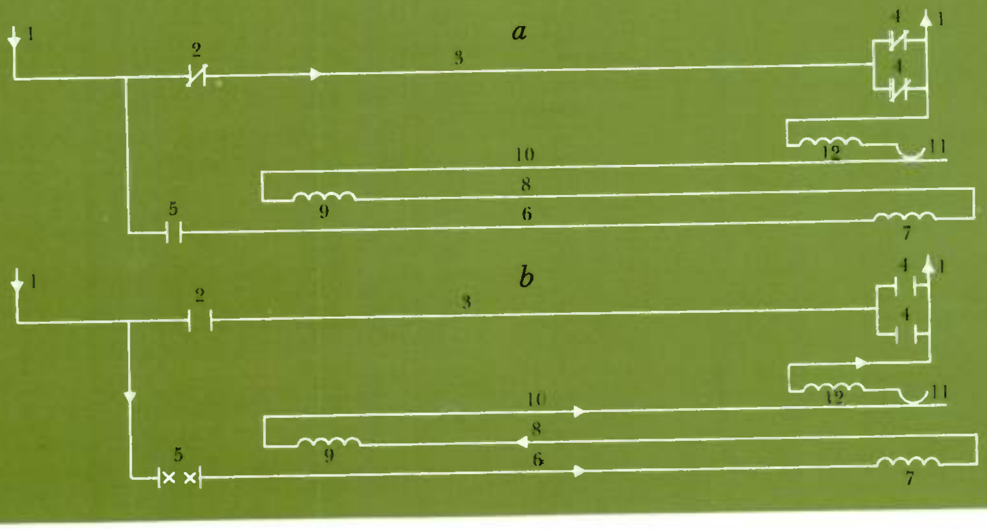


2—Section view (*a*) of a single-pole unit shows the magnetic puffer interrupter, bushings, and operating linkage arrangement. The breaker bushing (*b*) uses SF_6 gas as the insulating medium.

3—The electrical circuit in the interrupter is shown for the breaker closed (*a*) and for the breaker during interruption (*b*).

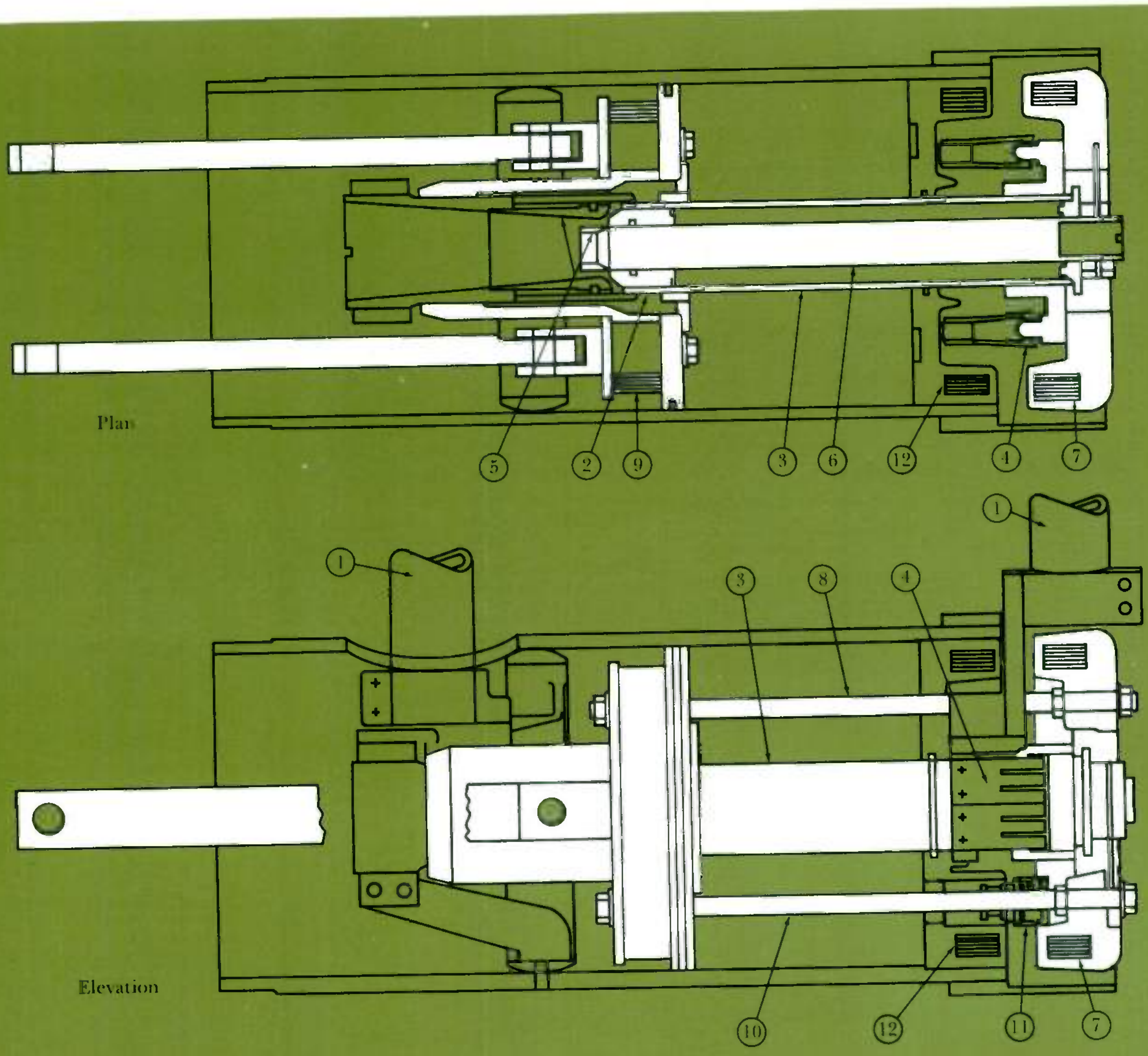
4—Plan and elevation sections of the interrupter are shown for the interrupter in the closed position.

3



Legend:
1. Primary Bushings
2. Front Main Contacts
3. Main Moving Contact Tube
4. Rear Main Contacts
5. Arcing Contacts
6. Moving Arcing Contact Tube
7. Driver Coil (moving)
8. Upper Guide Rod
9. Piston Coil (moving)
10. Lower Guide Rod
11. Sliding Ball Contact
12. Cylinder Coil (stationary)

4


Plan

Elevation

cell wall. In this arrangement, the bus is supported on porcelain rings, and these rings are attached to glass polyester plates bolted to the cell wall.

Cast epoxy insulation is used for encapsulating the risers and wound Insuldur-epoxy is used on the bus sections. Bus joints are insulated with a room-temperature-vulcanizing silicone rubber compound. A polyvinyl-chloride boot is placed around the completely assembled joint and the cavity is filled with the rubber compound.

Where potted joints or connections are not practical, as for flexible leads to potheads, self-adhering silicone rubber tape is used. It bonds at room temperature and the layers become inseparable within 24 hours.

The line compartment extends the full height of the rear of the cell. Sufficient room in the line compartment has been provided to accommodate many different arrangements of incoming or outgoing lines.

The standard 34.5-kV metal-clad switchgear unit is of indoor construction (Fig. 7) but can be applied outdoors with a weather-proof housing. The outdoor housing unit, shown in Fig. 8, includes a sheltered aisle for handling and servicing the breaker.

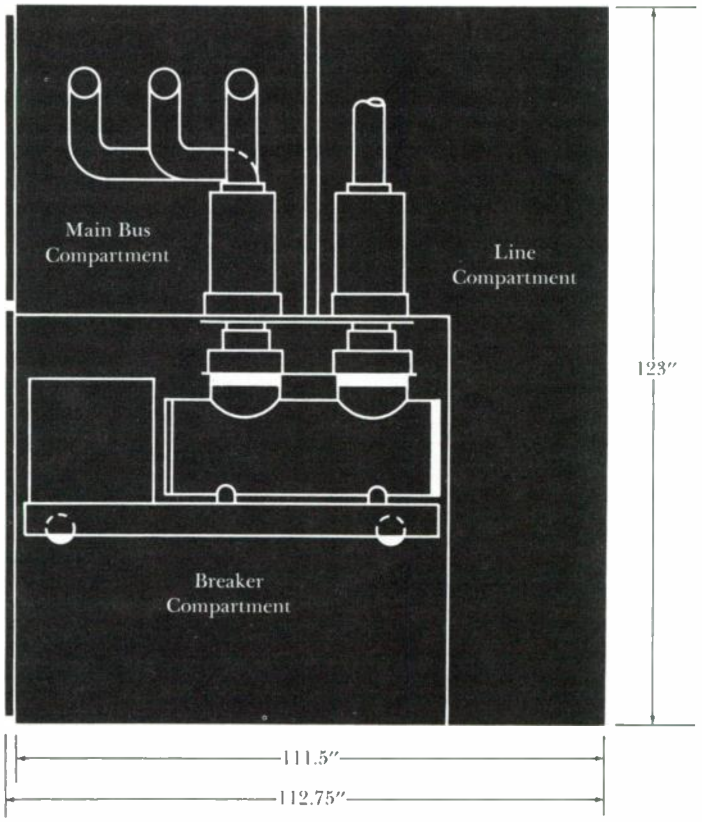
Safety Interlocks

A number of safety interlocks are provided to protect operating personnel. An automatic trip device discharges the closing mechanism springs and trips the breaker open when it is first placed in a cell, or when it is removed from the cell. A position switch in the lift mechanism circuit checks that the breaker is in the proper position before the lifting mechanism can be energized. Another interlock holds the breaker in the tripped position when it is being raised or lowered. A contact in the lift mechanism control switch will trip the breaker if it is not open when the switch to lower the breaker is operated. If the breaker is to be operated from a remote location, the *close* and *trip* buttons on the breaker control panel are inoperative when the breaker is in the cell; when the breaker is out of the cell and the test jumper is connected, the control at the remote location is inoperative and the breaker can be operated only at the control panel.

Design Tests

The magnetic puffer circuit breaker has been exhaustively tested under all conditions covered by standards. The final assembled switchgear has been tested in accordance with the standards prescribed by ASA, IEEE, and NEMA. These design tests included 60-cycle voltage withstand, BIL, current-carrying ability, momentary, four-second, interrupting, radio influence, mechanical operation, and weatherproofing.

In addition to standards tests, other special tests have been made to prove individual items. For example, the lifting mechanism was life tested by raising and lowering the breaker over 200 times, the equivalent of some 20 years of service. Low-gas-pressure tests were made to investigate circuit breaker performance with less than normal gas pressure in the tanks. Tests were made with gas pressure

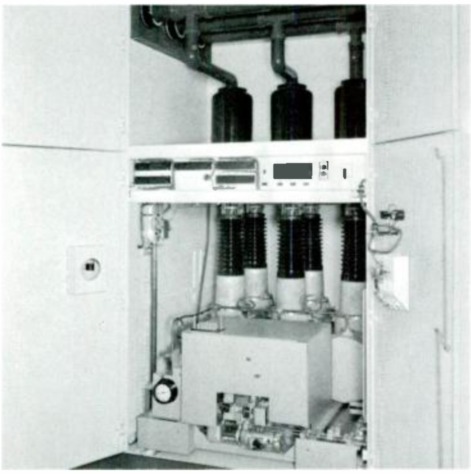


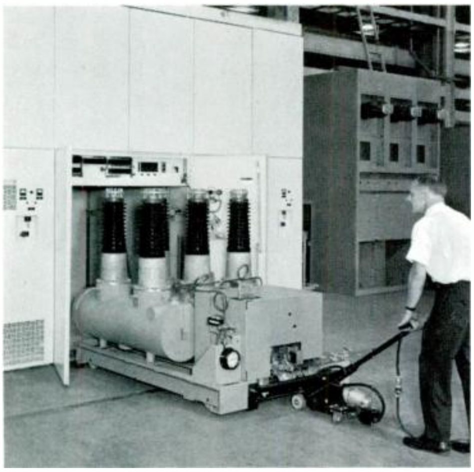
5—Typical indoor breaker unit consists of three compartments, separated by grounded-metal barriers.

reduced from normal in five-pound steps. Performance was essentially unchanged down through 40 psig, but at 35 psig the interrupting time increased by approximately ½ cycle. Consequently, the low-gas-pressure relay is set to alarm at 50 psig and trip the breaker at 44 psig.

Many substations where this breaker can be applied have large capacitor banks that must be switched. A number of switching tests were made, including repetitive switching of a 30,000-kvar bank back-to-back against a 60,000-kvar bank. The circuit breaker performed without reignitions, restrikes, or severe overvoltages, and deterioration of the contacts was insignificant.

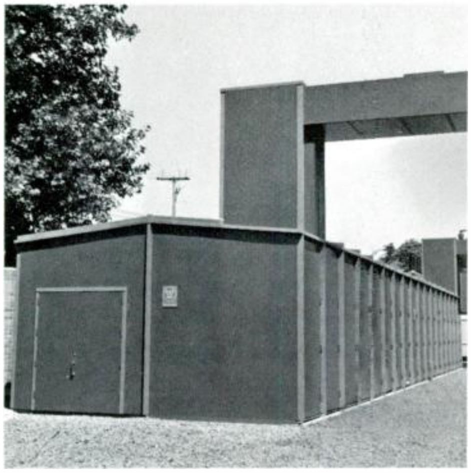
Since loud noise is objectionable in urban areas, sound-level tests were made to establish the acceptability of the new metal-clad equipment. The maximum peak impact sound recorded was less than 80 dB, which is equivalent to the sound of a closing automobile door. Because arc interruption takes place in an enclosed volume of gas with no exhaust to the atmosphere, and with little transmitted mechanical shock, there is little difference between the sound generated by an operation at maximum fault current and a no-load operation.





6—(*Top*) **The SF$_6$ breaker element is shown in the breaker compartment, ready for raising to the operating position.**

7—(*Bottom*) **Breaker elements can be easily removed from the metal-clad housing for maintenance.**



8—**The first installation of the 34.5-kV metal-clad switchgear with an outdoor Sheltered-Aisle enclosure was at the East Pine Substation of Seattle City Light, Seattle, Washington (*top*.) Indoor view of this same installation (*bottom*) shows the wide aisle space provided for handling and servicing breakers.**

Metal-Clad Substations

Until the development of the SF$_6$ magnetic puffer breaker, metal-clad switchgear with magnetic air breakers had been essentially limited to voltages of 15 kV with 1000-MVA interrupting rating. The new SF$_6$ magnetic puffer breaker now permits the use of metal-clad switchgear with higher distribution voltages in urban substations, thereby increasing the flexibility and economy of substations built with this type of equipment. The space required for this switchgear, either in the indoor or outdoor form, is small when compared to switchgear of other types. For example, studies of several proposed substation designs have shown that space required for switchgear of conventional open-type construction is about eight times that required by this SF$_6$ metal-clad design. Installation costs are minimized because height and depth dimensions are small enough to permit complete factory-assembled switchgear to be shipped by conventional shipping methods.

The 34.5-kV metal-clad switchgear is simple and rugged. SF$_6$ gas is inert and nonflammable, and pole units are sealed so that no arc products are expelled into the cell. The single-pressure puffer design does not require a blast valve or a compressor with associated control equipment. There are no sequential operations requiring precise timing. Circuit breaker operation does not depend on an externally maintained or stored medium, and low internal gas pressure eliminates any need for heaters to keep SF$_6$ in the gaseous state. As far as the breaker itself is concerned, the only requirement for circuit protection is a tripping signal.

References:

Frink, Russell, "SF$_6$ Magnetic Puffer Circuit Breaker for 34.5 kV–1500 MVA," *IEEE Transactions Paper* 31 TP 67–414.

Kozlovic, J. M., "34.5-kV Metal-Clad Switchgear for SF$_6$ Magnetic Puffer Circuit Breakers," *IEEE Conference Paper* 31 CP 67–437.

All-Weather Mapping by Radar

A. A. Nims

Modern side-look radar has a unique ability to delineate physical characteristics of the earth's surface, providing an image of photographic quality independent of visibility or weather conditions.

Before World War II, the idea of using reflected radio waves for remote target locating purposes evolved in several countries. By the end of the war, the techniques (collectively named radar) and their basic principles had been developed to a high degree. Since then, the technology has been continuously refined, and new and useful tasks for radar have been discovered. One such development concerns the branch of radar having to do with earth surface reconnaissance or surveillance from aircraft. The basic purpose of this type of radar is to provide pictorial information about the earth's surface and objects thereon over an area viewed from an aircraft.

Such radar is loosely described as *mapping radar*, although the direct product of the radar is not a map but a visual output called *imagery*, from which maps can be constructed. Although the resolution capabilities of mapping radars do not match those of photography, performance is not affected by darkness nor by many forms of weather. The usefulness of mapping radar in the earth sciences has only recently been recognized and is now being explored. Mapping radar shows promise of becoming a useful tool for the geologist, the geographer, and the agronomist.

Geometric Resolution

The earliest mapping radars employed the physical arrangement shown in Fig. 1. The antenna was located in the nose of the aircraft where it could scan an area forward of the aircraft by oscillating about axis *O-h* (Fig. 1). This arrangement is still a common form of radar, and it produces maps such as shown in Fig. 2. As each pulse of length τ propagates out and back, it scans a range within the antenna elevation beam pattern. The ability to determine that there are two geometrically adjacent targets *A* and *B* is determined by the relative pulse length τ, in equivalent feet as it intercepts the pair, and the spacing *A-B*. As a rule of thumb, then, the *range resolution* is said to be *A-B* feet when the pulse length is equal to *A-B*.

As can be seen in Fig. 1, pulse length (τ) is the thickness of a spherical shell radiating from the antenna; the length of its oblique intercept with the ground is a function of the height of the antenna above the ground and ground range to the target. Thus, range resolution for a given system is a function of range (Fig. 3) and approaches τ asymptotically at long range.

In the azimuth direction, the ability to resolve geometrically adjacent targets *C* and *D* is determined by the width of the antenna azimuth beam as it intercepts the ground at the target location. As a rule of thumb, *azimuth resolution* is said to be *C-D* feet when the width across the beam angle (measured from the sides of the antenna pattern where gain is three dB down from maximum) equals *C-D* feet.

Since the azimuth beam is angular in shape, the width across the beam is a function of slant range. For the large antenna apertures (l) that are commonly used for mapping radar, beam angle (β) is a function of aperture and radar wavelength (λ):

$$\beta = k\frac{\lambda}{l}\ \text{radians}$$

where a typical value of the constant k is 0.9. This beam angle formula holds for range

$$R \geq K\frac{2l^2}{\lambda}$$

where K has an arbitrary value between 1/2 and 1.

Azimuth resolution, as determined by the antenna, can be improved by reducing the wavelength, by increasing the antenna aperture, or by both methods. Almost from the beginning, however, usable apertures for antennas located in the nose of the aircraft were limited by the width of aircraft fuselages. This limit-

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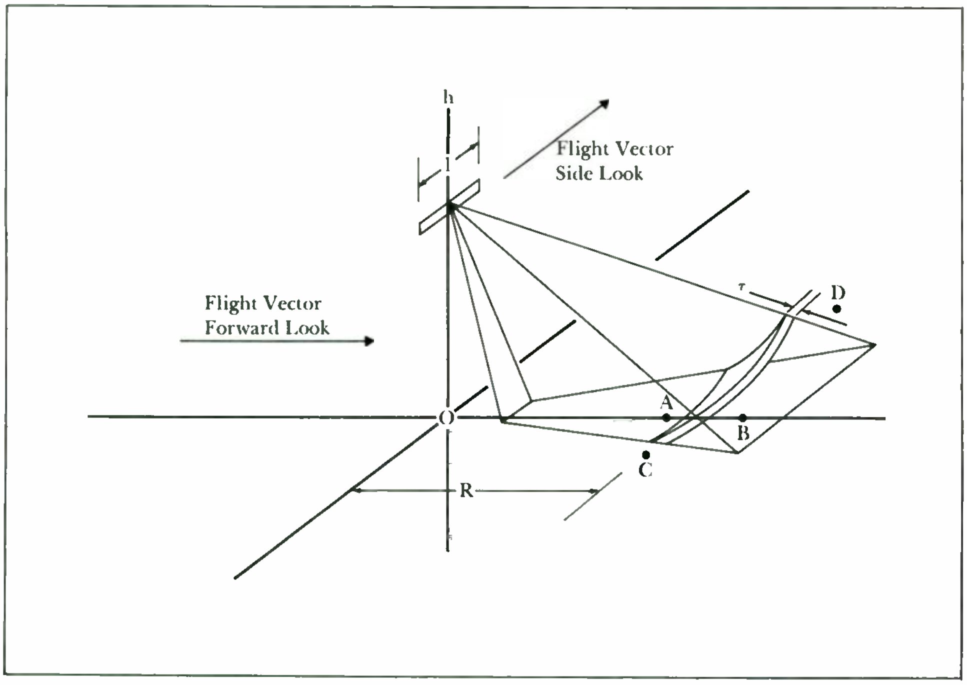


1—The physical arrangement of mapping radars illustrates the resolution geometry.

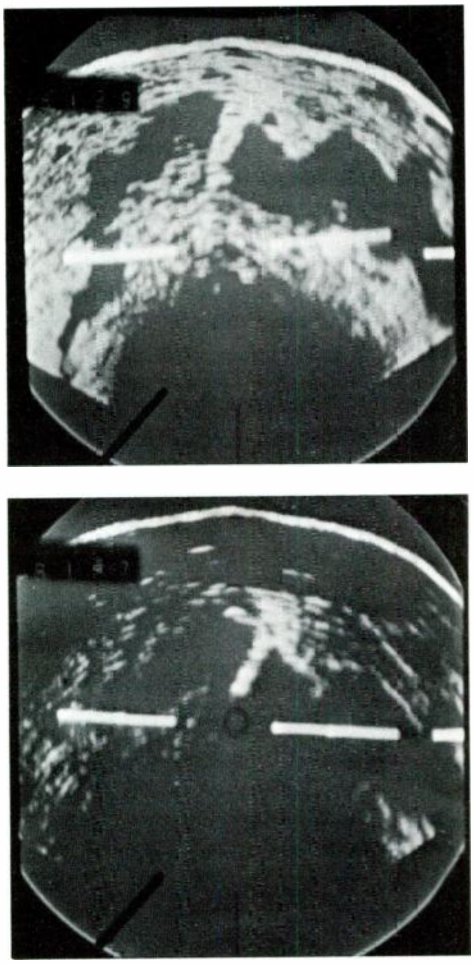
ing condition still prevails for forward-looking radar.

Although the concept of *side-look radar* (SLR) had been known for some time, it remained a concept until the 1950's when modern techniques and components for the centimeter wavelength band were developed to the point of practical usefulness. In a side-look radar, the antenna is fixed to the side of the aircraft rather than the nose, and azimuth scanning is provided by the motion of the aircraft itself. (In practice, antennas are placed on each side of the aircraft so that mapping can be done simultaneously from both sides.) Azimuth antenna apertures can be increased by factors as high as six with concomitant improvement in resolution. For example, typical side-look antenna lengths built by Westinghouse are about 15 feet. Component improvements that have resulted in wavelength reduction have further improved resolution by another factor of three. Because of these longer permissible apertures, significant imagery improvement has resulted, as can be seen by comparing Fig. 2 with Fig. 7.

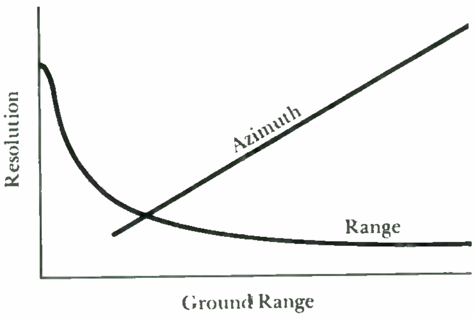
There are other techniques that require coherent radiation and employ signal processing to provide further reduction in azimuth resolution capability. These techniques are known as "synthetic aperture," and they permit the resolution to have a much freer relationship to the antenna aperture than that indicated by the above formulas. This article, however, will consider those side-look radars in which azimuth resolution is *directly* related to antenna aperture, and which are therefore called real-aperture side-look radar. These real-aperture radars operate most typically in the K_a frequency band (33-36 GHz, or 0.9-0.8 centimeter wavelength).

Power

Targets that are of interest to mapping radar vary from those giving very small return signals, such as concrete and fields with short grass, to large targets such as buildings and other man-made objects that give large signal returns. These latter targets are not only large physically, but in many cases reflect in a near specular manner (i.e., as light reflected from a mirror, with no diffraction or scattering). The resultant power variation between reflected signals may be as large as 70-90 dB. This great variation in reflected signal is a major difference from (and a major advantage over) photography, but it also imposes several compromises upon the system design.



2—Typical images produced by forward-looking radar. Both images are of the bridge across the Choptank River at Cambridge, Maryland. Receiver sensitivity is reduced *(bottom)* to put strong signals from Cambridge into the more linear-density range of the cathode ray tube.



3—Both range resolution and azimuth resolution are a function of ground range.

Although a radar may have the necessary geometric or spatial resolution, a target cannot be resolved unless its reflected signal strength differs from that of the background or an adjacent target. This difference must exceed some threshold value for the target to be discernible.

As will be described, present display devices for side-look radar produce their images on film. The limited number of shades of gray obtainable with even the best films imposes a significant limitation upon system effectiveness because this factor determines the threshold value of the difference in signal strength required for discernibility of adjacent targets or between a target and background. Thus, the required exposure is determined by the signal strength of the background as well as the targets in question. Input signal dynamic range selection is usually provided so that a selected part of the input signal range can be distributed over the total film density capability. This permits smaller signal level variations to be distinguished, but signals from the excluded signal range are lost.

In the conventional radar situation, a reflected signal from a small target decreases as the inverse of the *fourth* power of range. However, side-look radar is usually concerned with targets that are a beam width wide or larger, and since one dimension of such targets is always determined by the width of the azimuth beam, the return signal strength varies as the inverse of the *third* power of range. Because of this range sensitivity, radar signals are greatest for objects at close range, and decrease in intensity as range increases. It is desired, however, that the intensity of each target be determined by its reflectivity and be independent of its range. This goal is accomplished by designing the shape of the antenna beam in the vertical direction so that radiated energy is distributed as a function of range to compensate for the range effect. Therefore, the vertical pattern generally has gain that varies as

$$Gain \sim \sqrt{\cos\theta}\,\csc^2\theta$$

where θ is the vertical angle from horizontal. The vertical angle is large enough in practical side-look radar systems that the needed vertical aperture is seldom more than about a foot for K_a band frequencies.

The signal returned from a target also depends on the *average* power illuminating it. However, as resolution is improved by narrowing the transmitted pulse, the power duty cycle (hence average power) gets smaller. Also, the signal return from the smaller targets obviously will be weaker. Thus, as systems are designed for smaller and smaller resolution, the amount of peak power required tends to increase not only to maintain the average power, but also to maintain the required reflected signal strength from smaller targets. For ranges beyond 30 miles, the difficulties of generating and distributing peak powers necessary to achieve the desired average powers have become so great as to constitute a practical limit on radar performance. Recent developments in parametric amplifiers at K_a band frequencies will reduce the required reflected signal strengths for suitable operation. Use of these amplifiers promises to postpone this performance limit a little longer.

For real-aperture radar, other restrictions on range become effective before peak power becomes the limiting parameter. For example, the effects of weather must be considered. Generally, radar backscatter and propagation losses through the atmosphere increase with increased radar frequency. Backscatter, the major difficulty, is caused by water in the air and is an approximate function of the amount of water per unit volume—whether this water consists of many small droplets or fewer large drops. Some of the gaseous constitutents of the atmosphere also affect propagation attenuation in significant amounts at frequencies higher than X band (above 5 to 10 GHz).

Present radar systems that operate in the K_a band have ranges up to 10 miles, and they are practically unaffected by weather except for moderately heavy rains. Observations in the eastern United States indicate that only small parts of an area being mapped are affected at any particular time. But a further decrease in radar frequency to improve resolution will undoubtedly restrict side-look radar

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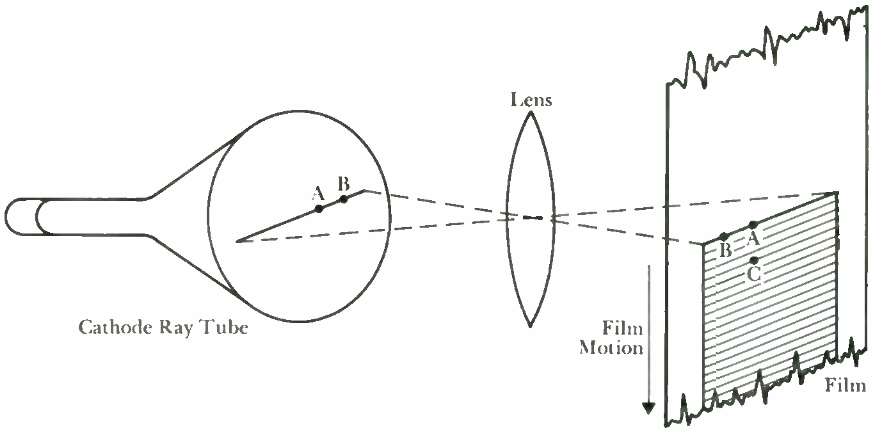
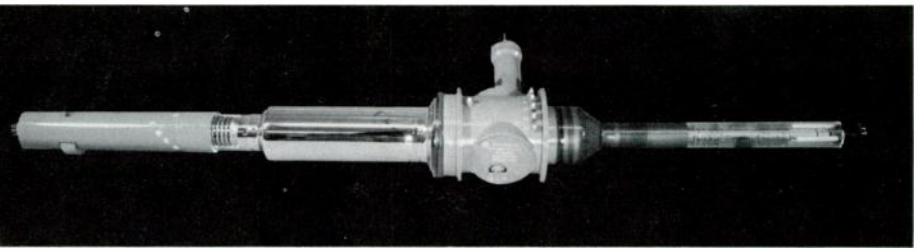


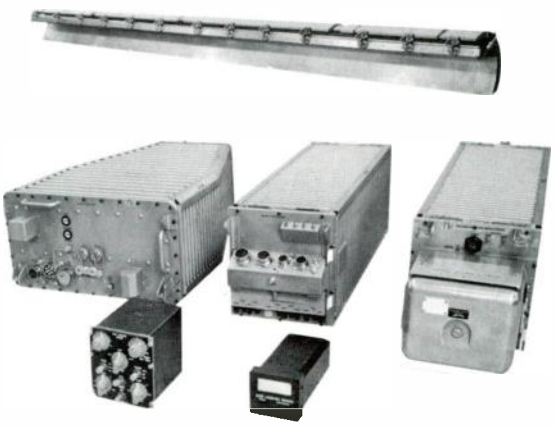
4—The recording arrangement for side-look radar consists of a single-line image from a CRT projected on a moving film strip.

5



5—The experimental Westinghouse Electrechon recording device provides high storage density, multireadout, and reusable electronic signal storage.

6



6—The components for a typical real-aperture side-look radar system weigh about 420 pounds.

systems to shorter ranges because of attenuation and weather effects.

Recording

With forward-looking radar, all parts of the field of view are illuminated and recorded again and again—once each scan. This information can be continuously displayed on a cathode ray tube (CRT) since the scan period is usually about a second or two and phosphor decay times of this order are easily obtainable. A permanent record is often made by photographing the CRT face (Fig. 2).

With side-look radar scanning, however, each azimuth increment of the total field is illuminated only during the time it takes the increment to pass once through the antenna azimuth beam. It must then be retained until the rest of the field is scanned. If, for example, an aircraft moving at 500 ft/sec scans a five-by-five-mile field with a radar having a mean azimuth resolution capability of 50 feet, each azimuth increment will be illuminated for about 1/10 second, and complete scan of the field will require one minute. (Illumination time should not be confused with the radar repetition rate; repetition rates are about 2000 pulses per second, so there are many pulses per illumination interval.) As a result of the long period required for a complete field scan, a different form of image storage is required for side-look radar. The storage medium should have high density (so that display areas can be of practical size), long time storage, wide dynamic range (many shades of gray), wide band widths, and real-time capability (immediate display of stored information). The best solution to these requirements today is a film record of each azimuth increment as it is displayed on a cathode ray tube (Fig. 4). The azimuth display is fixed in one position on the face of the CRT and the film is moved past the tube to duplicate actual spatial scanning produced by the motion of the aircraft.

The principal difficulties with this system of image storage or recording are that a real-time display cannot be provided because time is required for film development, and the density of the storage is limited by the smallest spot size obtainable in the CRT. The best tubes obtainable today have spot sizes of 0.0007 inch and tube widths of four inches (or about 5700 spots per sweep). Films are available that have resolutions of 200 lines per mm or the equivalent of 20,000 spots per sweep with adequate illumination. However, light output from CRT's tends to decrease as spot size is decreased, whereas film resolution tends to get poorer as film speed is increased. These two factors are already approaching incompatibility. (The most common size of film used in side-look radar systems today is 5 inches wide, although 35-mm, 70-mm, and 9½-inch widths have also been used.)

Except for the real-time display factor, the cathode ray tube is the limiting component in film recording of side-look ra-

Cathode Ray Tubes for Mapping Radar

Cathode ray tubes used in early radar units were usually 5- to 12-inch diameter tubes, similar to the early television picture tubes. Displays were of a type intended for direct observation; display resolution and accuracy capabilities were low compared to present performance standards.

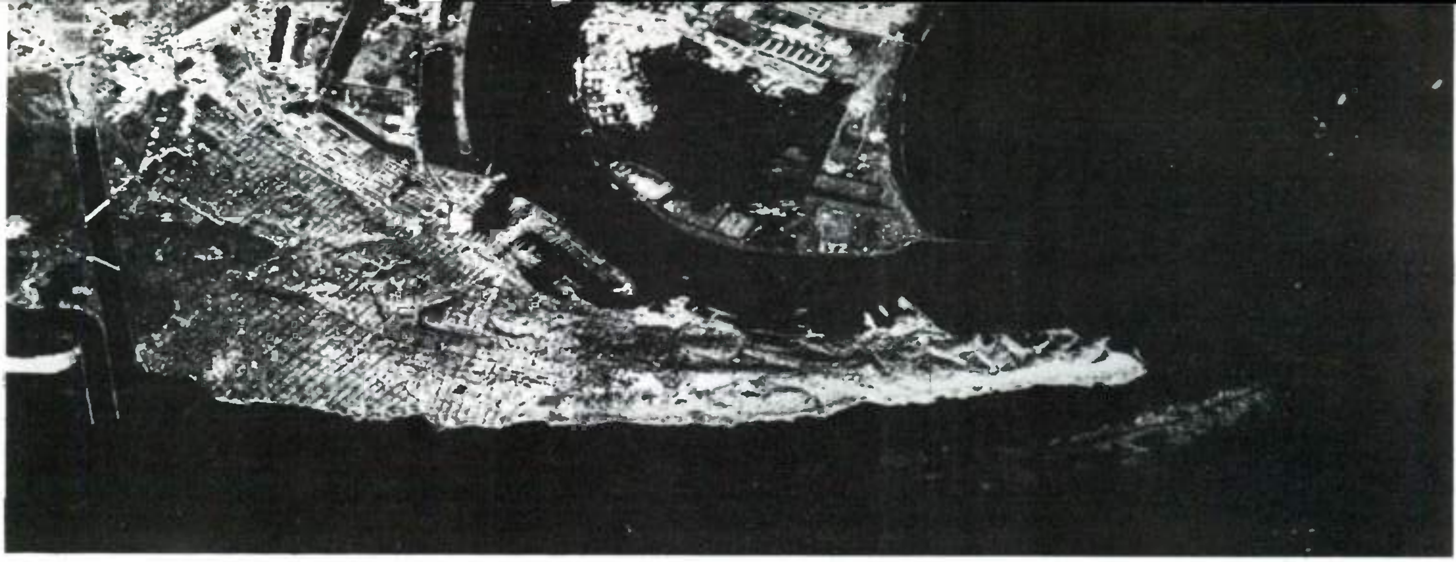
Modern radar systems are capable of excellent resolution performance, and the CRT is becoming a limiting factor in spite of having spot size capabilities nearly two orders of magnitude smaller than those available in early radar units. Significant improvements in high-resolution CRT's for modern radar recording have been made in the past five years and are incorporated in a line of packaged units now available.

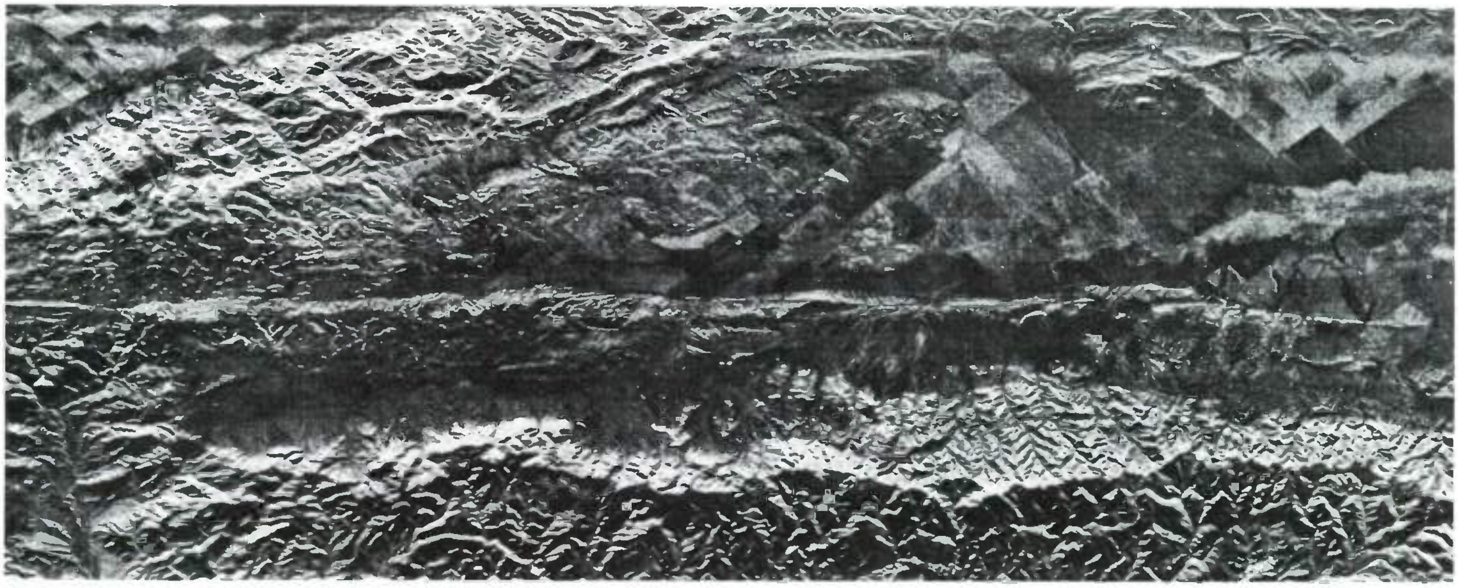
These units are made with screen sizes ranging from 0.9- to 5-inch diameter. They provide a CRT, a deflection yoke, and a magnetic shield in one unit. Spot size at the half amplitude of the intensity distribution runs from 0.00065 inch at the screen center to about 0.0008 inch maximum at the edge. The deflection yoke is matched to the CRT and the assembly is aligned for optimum electrical centering of the tube in the yoke to minimize deflection differential linearity errors. As a result, these units can be installed and positioned properly and are ready to operate without time-consuming alignment procedures commonly required in many CRT installations. The CRT packages are rugged and are designed to meet severe environmental conditions without loss of performance. All electrical connections are sealed so that the units may be operated at high altitudes without requiring pressurization.

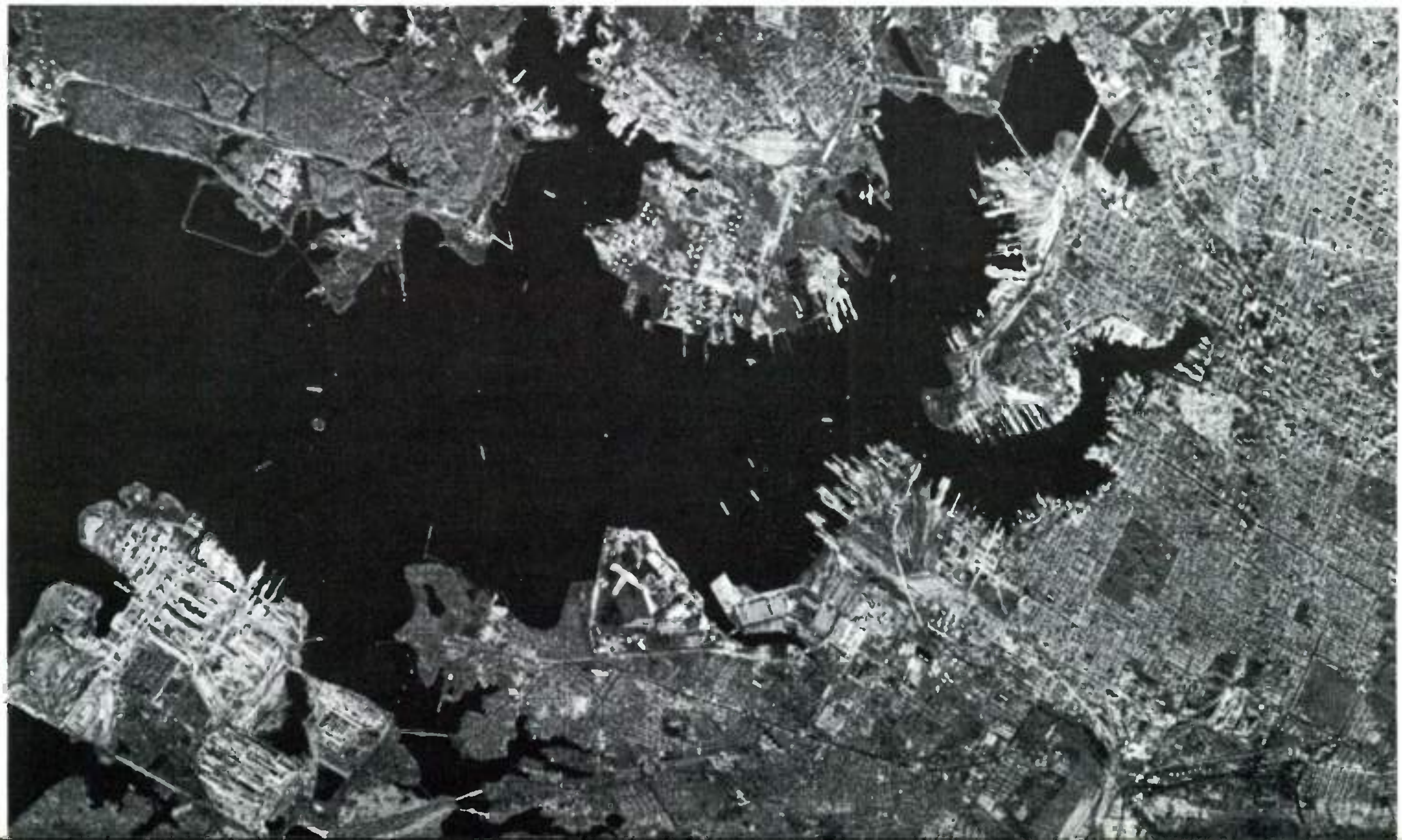
Packaged CRT units are available with normal face panels or with fiber-optic strips, curved to allow passage of film with good optical contact. Glass quality and dimensional tolerances are carefully controlled to minimize optical problems.

One of the major factors required in high resolution CRT units is a good phosphor screen. The P11 phosphor used in most of the radar mapping applications is the result of considerable development effort to produce thin, efficient phosphor coatings characterized by low noise and freedom from unwanted light output variations caused by defects.

These CRT package assemblies are accurate mechanical and optical units that can simplify many of the problems associated with installation and adjustment of a CRT in a precision recording system. To meet the demand for higher resolution systems, improvements are continuing in mechanical and optical accuracy. Development of CRT's that can produce spot sizes as small as 0.0004 inch provides a significant performance improvement that is needed in modern radar mapping systems.







dar data. Replacement of the CTR with some other electricity-to-light transducer is difficult because the light source must be small, must be capable of intensity modulation at tens of megacycle rates, and must be capable of being scanned across the film at very high speeds.

Some potential applications of side-look radar, such as unmanned systems, require a reusable all-electronic storage medium, a requirement that has not yet been fully satisfied. Other required characteristics are the same as for any other storage medium, with the exception of immediate viewing.

The Aerospace Division has demonstrated a development model of a device known as the Electrechon Storage Tube which satisfies many of the above requirements (Fig. 5). It is an analog of the CRT-film recorder. A cathode-ray gun writes a spatially distributed charge on a thin ceramic dielectric deposited on a continuous metallic foil enclosed in the CRT housing. The foil is physically moved past the beam in the same manner that photographic film is moved in the film recorder. The spatially distributed charge is read off by another scanning cathode-ray gun, also enclosed in the CRT housing. The foil is electronically erased before re-use. Although it has almost the same performance limitations as the combination of CRT and photographic film, it can store the information as long as several days, it has a nondestructive readout mode, and the foil can be reused many times. Furthermore, the scan coordinates and the characteristics of the read-out function do not have to duplicate those of the write-in function. Readout delay is determined only by the tape transit time from the write-in station to the read-out station. This device has the potential of providing a near real-time display of SLR imagery using television-type displays located at one or several locations in the aircraft.

7—*(Above)* **The near-photographic quality provided by side-look radar is demonstrated by this radar image of Baltimore.**

8—*(Center)* **The San Andreas fault can be clearly identified with side-look radar.**

9—*(Below)* **Side-look radar image of San Diego harbor shows, in addition to the topography of the area, the kelp beds off the tip of the peninsula in the upper left part of the image. These kelp beds are often invisible to the eye or to a camera.**

System Design

The design of a radar system must be tailored to the geometry of the anticipated mapping conditions. Illumination of the targets to be imaged is determined by aircraft altitude, and by roll, pitch and yaw attitudes of the aircraft. Since aircraft attitude can change drastically and often, especially in rough air, the system design must either compensate or adapt to these variations.

Systems are generally optimized for one or more altitudes, and some reduction in range and illumination consistency must be accepted for intervening altitudes. Effects of pitch in real-aperture side-look radar are usually negligible and can be ignored. However, the antenna is usually physically roll stabilized. Yaw is usually compensated, either by physically stabilizing the antenna or by compensating the position of the azimuth increment displayed on the recorder CRT. Electronic stabilization of the antenna has been considered, but the technique is extremely difficult to do in roll and yaw combined, and in fact, has not yet been considered practical for even one axis.

Uses

Real-aperture side-look radar is already highly developed and gives excellent results at ranges up to six nautical miles. For certain purposes it is useful at ranges as great as 30 miles.

Although its principles are those of simple radar and are easily understood, materials and techniques of construction must be carefully engineered and executed to achieve optimum performance.

Typical SLR equipment is illustrated in Fig. 6. The total airborne package for this radar system weighs 420 pounds. However, weight can vary from this by as much as 150 pounds, depending on the specific performance and environmental requirements for which it is designed.

Typical imagery obtained from real-aperture side-look radar is shown in Fig. 7. Side-look radar can (and must) take images without passing directly over the area to be mapped. This is done with little or no distortion, as contrasted to the distortion obtained with oblique photography.

The unique ability of side-look radar to delineate large-size surface pattern characteristics better than any other sensor has been demonstrated by the application of mapping radar to provide information for NASA's earth science resources program. Over the past two years, a large number of mapping flights have been made to obtain data on remote sensing techniques for the NASA program.

By varying radar signal characteristics and processing methods, scientists have used side-look radar for such purposes as large-scale topographic mapping, agronomy investigation, and making profiles of geological characteristics. For example, the San Andreas fault, a well-known geological feature in California, can be easily seen in Fig. 8. A radar image of the San Diego harbor (Fig. 9) shows, in addition to the topography of the area, a "vegetation" characteristic—kelp beds off the tip of the peninsula in the upper left part of the picture. These kelp beds are at times, depending on light conditions, not visible to the naked eye or to a camera, even on sunny days. However, because they reflect radar signals in a different way than do their surroundings, the kelp beds are "visible" to the mapping radar.

Some other studies under way or being considered are sea ice mapping, sea state determination, polar ice cap profiling, subsurface profiling, soil moisture content analysis, and determination of undulations in the geoid.

Radar for geoscience research enables scientists to utilize the unique characteristics of another part of the electromagnetic spectrum, the microwave region, in addition to the visible and near-visible regions. These new uses for side-look radar are only now beginning to be realized, and they are stimulating further effort to improve the performance of this type of radar.

Computer Program Simulates Proposed Transit Systems and Evaluates Them Economically

William B. Stewart
Ralph Mason

Urban transportation planners now have a tool for making rapid analyses over a wide range of alternative yet interdependent choices involving both urban planning and transit-system design.

Renewed interest in urban rapid-transit systems as possible solutions for the increasingly unmanageable traffic snarls in our cities has focused attention on the variables that affect such systems. Those variables are many, and, unfortunately, they have been poorly understood.

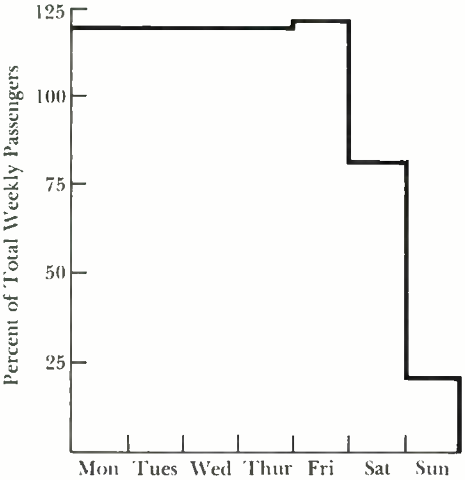
For example, the initial set of problems in planning a transit system may seem to be merely the choice of an optimum route on plan and profile. But plan and profile criteria are often irrelevant to the factors that determine whether the public will patronize or ignore the system: the public responds to such matters as the minimizing of walking distances to downtown stations; the locating of stations near civic centers, educational facilities, sports arenas, and the like; or simply the intercepting of trunk highways in a manner that maximizes the efficiencies of feeder bus services. Also, plan and profile criteria usually accept predetermined design parameters, such as grade maxima and curve minima, imposed by assumed equipment limitations that may no longer be valid with new equipment.

Thus, the urban transportation planner badly needs an analytical tool competent to provide speedy evaluations over a wide range of alternative yet interdependent choices. The computer program discussed here provides that tool.

The technique is that of simulating a system's operation, and the associated costs, for each realistic and promising set of alternatives. Each set is evaluated over a term of years equal to the expected economic life of the system. The computer program permits rapid appraisals of the relative effects of such variables as possible growth or decline in patronage, inflationary trends in operating costs, and possible trade-offs of original capital costs versus economies in future operating payrolls. The program and its inputs integrate all these subjects with choices in routes, equipment, and the quality of service the system can afford to offer the riding public.

System Patronage

Required inputs to the program include data about prospective patronage on the planned system. Such data is commonly developed by origin-destination studies, which are well known and widely used by urban planning groups; the survey and analytical techniques have been developed by the U. S. Bureau of Public Roads. The data is reduced to two forms: the average (two-way) passenger volumes for each planned station in some selected future year, and the set of derivative link volumes. Link volumes are simply head counts of the number of passengers expected to pass between adjacent stations of the transit system; they can also be expressed as ratios to the consecutive summations from one end of the route to the other. It is always the maximum among these link volumes that determines the capacity that must be dispatched, expressed as frequencies and lengths of trains over the whole transit-system route.



1—Daily passenger flow on a hypothetical transit system in a typical week. The flow is almost constant for five days but falls off sharply on Saturday and Sunday.

The initial routines in the computer program introduce dynamic factors by inquiring whether system patronage is expected to grow or decline over the years. The analyst has a virtually unrestricted choice of methods. Any regular growth curve can be specified, either for the system as a whole or differentially as possible rates of change among the individual stations. A typical variation, for example, is the effect of an urban master plan that specifies programs of land development scheduled for completion in irregular patterns over time. The information can be input directly to the computer to generate discontinuous but highly significant variances in revenue prospects.

Daily Load Cycles

The program works out 24-hour passenger load cycles for each projected year of the simulated economic life of the system and for each of the 7 days of the typical week. Those fine details are not trivial. Public behavior on the individual days of the work week may be affected by early or late shopping hours in the central business district or by recurrent special events, and Saturdays and Sundays have their unique patterns of poor patronage (Fig. 1). However, the hourly patterns within the work days are the most decisive in determining the required levels of operation and the consequent costs. Those cycles must be evaluated both in magnitudes and in directions of flow (Figs. 2 and 3). The extreme morning and evening peaks in Fig. 3, for example, are in no way exaggerated. It can fairly be said that "average hourly patronage" on most existing or prospective urban transit sytems is the least likely event, and that to plan "on the average" is to court economic disaster.

Train Schedules and Consists

Train schedules and consists (number of vehicles per train) are the most significant outputs from the simulation routines. Before the analyst can develop the schedules, however, he must go through some preliminaries equivalent to donning the system management hat and telling the computer a few things about how he proposes to run his railroad.

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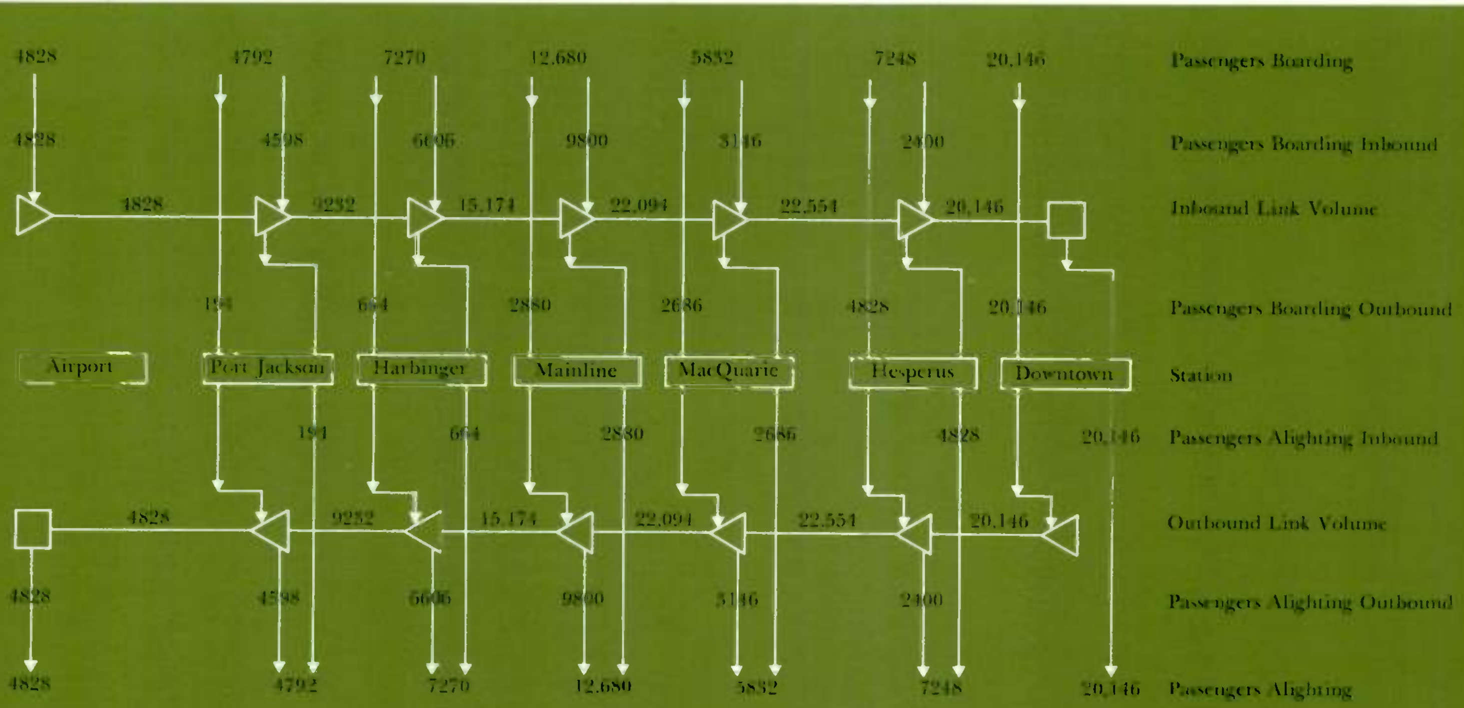
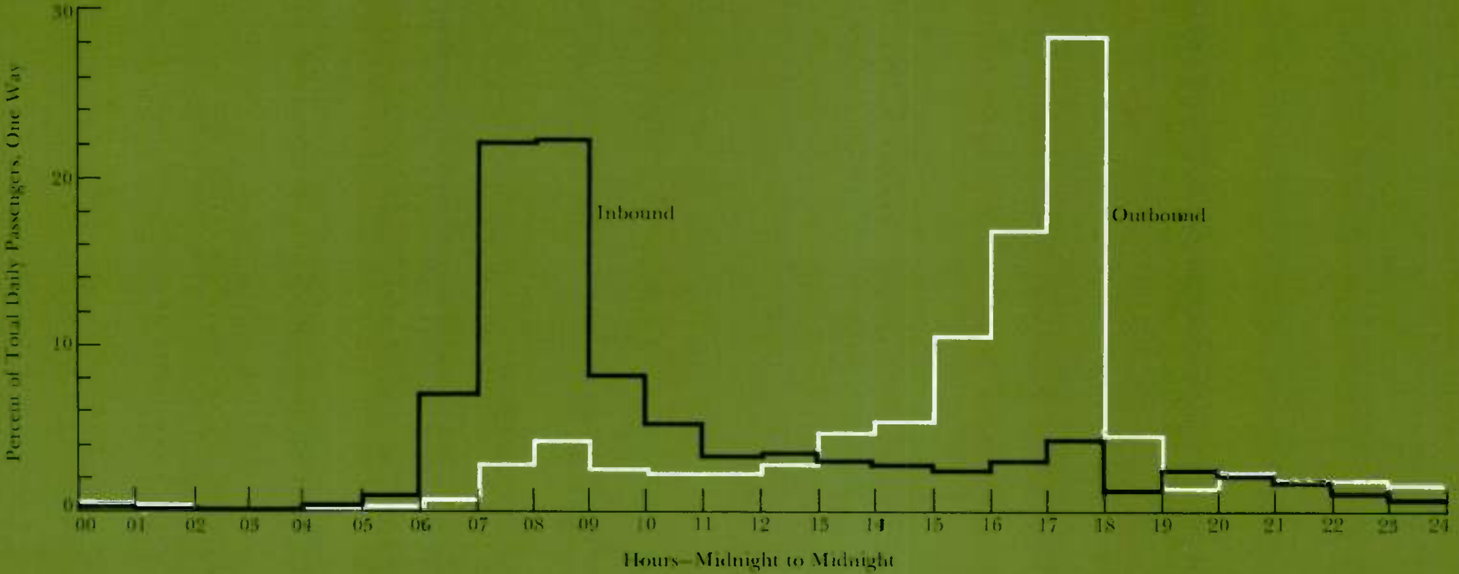


2—Estimated prospective patronage on a planned transit system provides the basic input to the computer program for simulating the system's operation and evaluating its economic potential. Illustrated here are passenger volumes at stations and on the links between stations for a typical Friday in 1970 on the hypothetical system of Fig. 1, which is a seven-mile seven-station route between a central city and its airport. The maximum link volume determines the train capacity needed on the system. Inbound and outbound flows are assumed to be symmetrical for the whole day, but, as shown in Fig. 3, they are not at all symmetrical in the hours of the day.



3—From the patronage information, the computer program works out hourly load cycles for any day of any year. The cycle illustrated is for a Friday in 1970 on the system of Figs. 1 and 2. A system's capacity must be adequate to handle the morning and evening peaks.

His first set of specifications establishes the frequency of service to the public. The analyst is free to specify train headways (time intervals between trains) for each of the 168 hours of the typical week, but it usually suffices to specify only the minimum and maximum tolerable headways. The minimum is likely to be a design parameter, determined by the control sophistication considered economically practical. The maximum is an estimate of the point at which the infrequent service will drive patronage to some other form of transportation.

Another factor in quality of service is the ratio of seating capacity to riders. Although it would be much to the public's liking to assure a seat for every passenger at all times, the cyclical load behavior illustrated in Fig. 3 discourages that practice in the interest of system solvency. For example, the morning peak load in Fig. 3, applied to the moderate passenger volumes in Fig. 2, could not be seated in 180-foot trains of standard-width vehicles even if the trains were dispatched on a two-minute headway.

With the input data described above, the computer can make up its own train schedules and consists. To do so, it first calculates a system capacity matrix (Fig. 4). In the example illustrated, the 26-minute round trip time permits anywhere from 5 trains on the system (at the maximum 5-minute headway) to 13 trains (at the minimum 2-minute headway).

By referring to load cycle data stored in its memory circuits, the computer then identifies the maximum link volume for each hour. It schedules just adequate capacity for each hour, adjusted for the allowable proportion of standees (Fig. 5).

"Just adequate capacity" is a somewhat ambiguous term because the capacity matrix is approximately symmetrical; e.g., equal capacity can be dispatched as say 10 trains with 5-car consists or 5 trains with 10-car consists. The first choice enhances the quality of service to the public, but at what may prove to be ruinous cost in doubling the number of train operators required. The second choice reverses the positions of the public and the transit company. Therefore, the computer must be told whose interests are to dominate. If the system is fully automated and so needs no train operators, as in the Westinghouse Transit Expressway system,[1] the rider is allowed to win. If it isn't, discretion dictates the lesser frequency of service in the interest of system solvency.

The capacity matrix illustrated in Fig. 4 is that for the Transit Expressway system, matched to the route and data of Figs. 2 and 3 for the year 1970. In making the complete weekly schedule (Fig. 5), the program obviously was maximizing the frequency of service on an automated system, within the specified two- to five-minute headway restraints. The program found it possible to accomodate the peak hourly load within the week (6435 passengers) by dispatching 30 trains per hour (13 trains on the system) with 4-vehicle consists on what was known to be a 26-minute round trip, but it could do so only because it had been allowed to load 54 passengers per vehicle in peak hours. That figure includes 26 standees over the seating capacity of 28.

Operating Statistics

The simulation routines are detailed enough to permit generation of virtually complete sets of relevant operating statistics for as many years into the future as desired. "Relevant" means here that the statistics are functions of explicit route characteristics; expected levels of patronage; capacities, speeds, and other design parameters of the equipment; and the previously specified elements of system operating philosophy. Those are statistics quite different from the standard operating ratios obtained by averaging experiences of existing systems that may have little in common except economic woes. The operating statistics include data for annual passenger trips and miles, train and vehicle operating hours and miles, revenue ton miles, changes in required vehicle inventories, and the like. Such quantities are obvious determinants for a long list of operating costs, soon to be discussed.

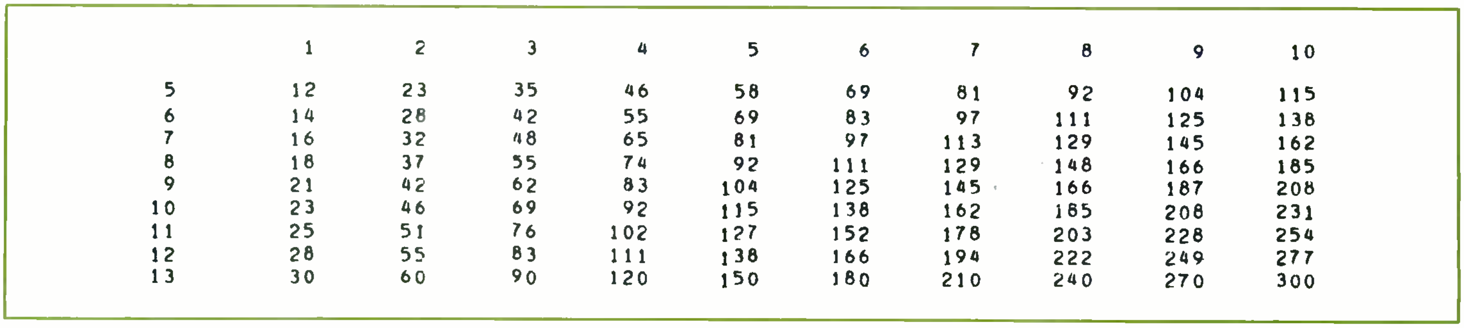
As presently compiled, the program assumes an electrified system. However, other propulsion methods can be evaluated with only nominal changes in the routines.

Considerable sophistication has been built into the simulations for electrical systems, generally to accomodate electric utility rate practices. For example, projected data for system energy use and peak load conditions are fed to the program from the outputs of the Westinghouse Multiple Unit Train Performance Program.[2] That is an engineering type of computer program that simulates the continuous running of a train over a given route. The plan and profile of the route are supplied as inputs, along with details of on-board traction equipment and other power equipment. Results from the program include average schedule speed of the train, power consumption for the total journey, and instantaneous values of current and power at points along the route.

Some elements of operating costs must be more or less spoon-fed to the computer because system operating philosophy again becomes involved. The main items concern maintenance standards (for rights of way, structures, power supply equipment, and rolling stock) and manning requirements at stations for such purposes as collecting fares, loading trains during peak hours, or merely protecting property. The analyst can draw on a considerable body of literature about those subjects, and on the pragmatic experiences of practical operating people. The program itself calls for input data in the form of manning tables for about 25 job descriptions that are reasonably typical of the functions common to all transit systems (Fig. 6).

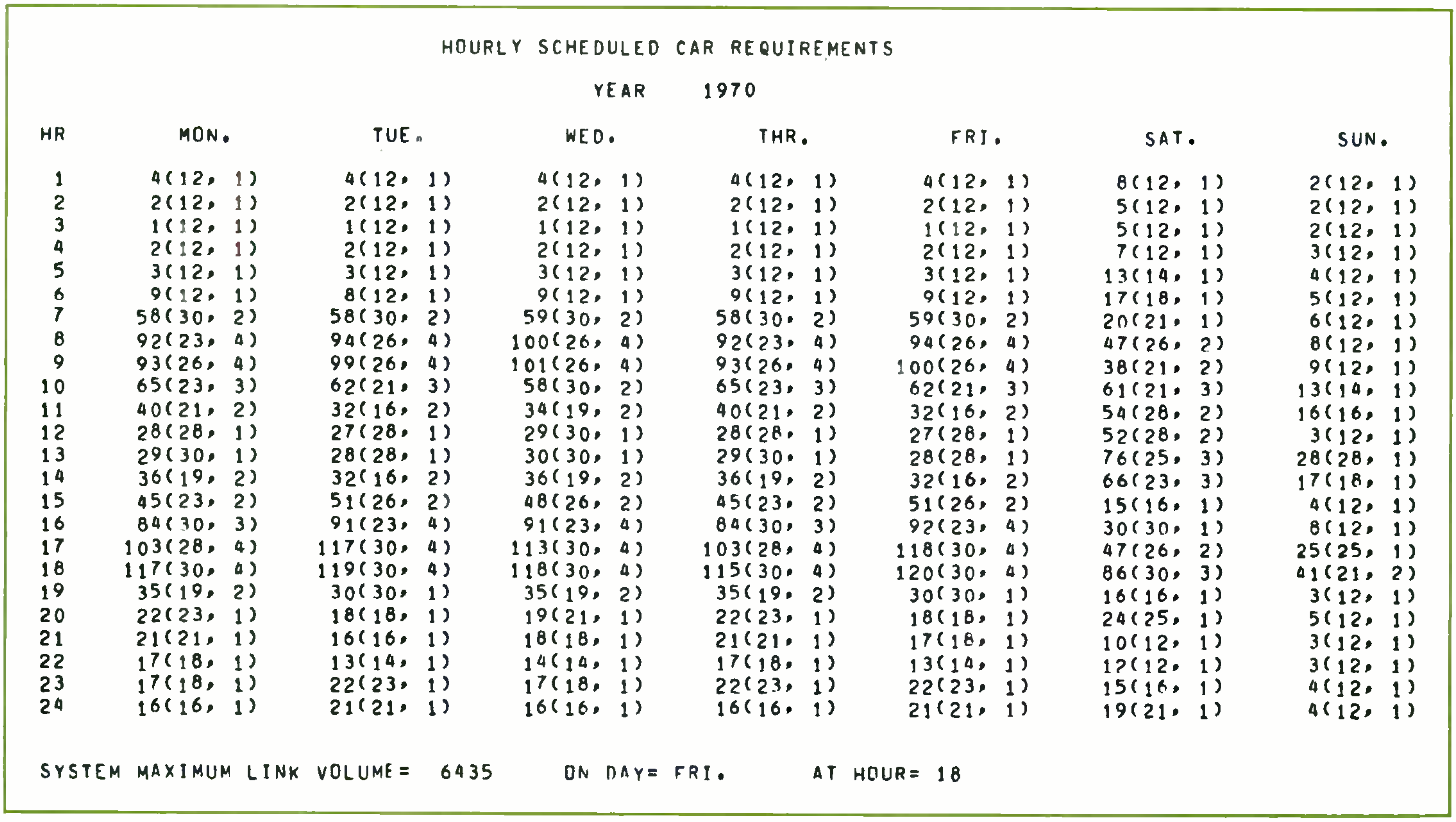
Projected Operating Costs

Continuing beyond operations simulation and the generation of operating statistics, the program develops year-by-year projections of more than 30 direct operating cost or expense accounts. All accounts are functionally dependent on some combination of the simulated annual operating statistics or the manning tables just described. Because the project being studied is usually a part of some larger urban transportation authority, provision has also been made for allocations of general and administrative expenses in whatever fashion might be specified by the sponsoring authority.



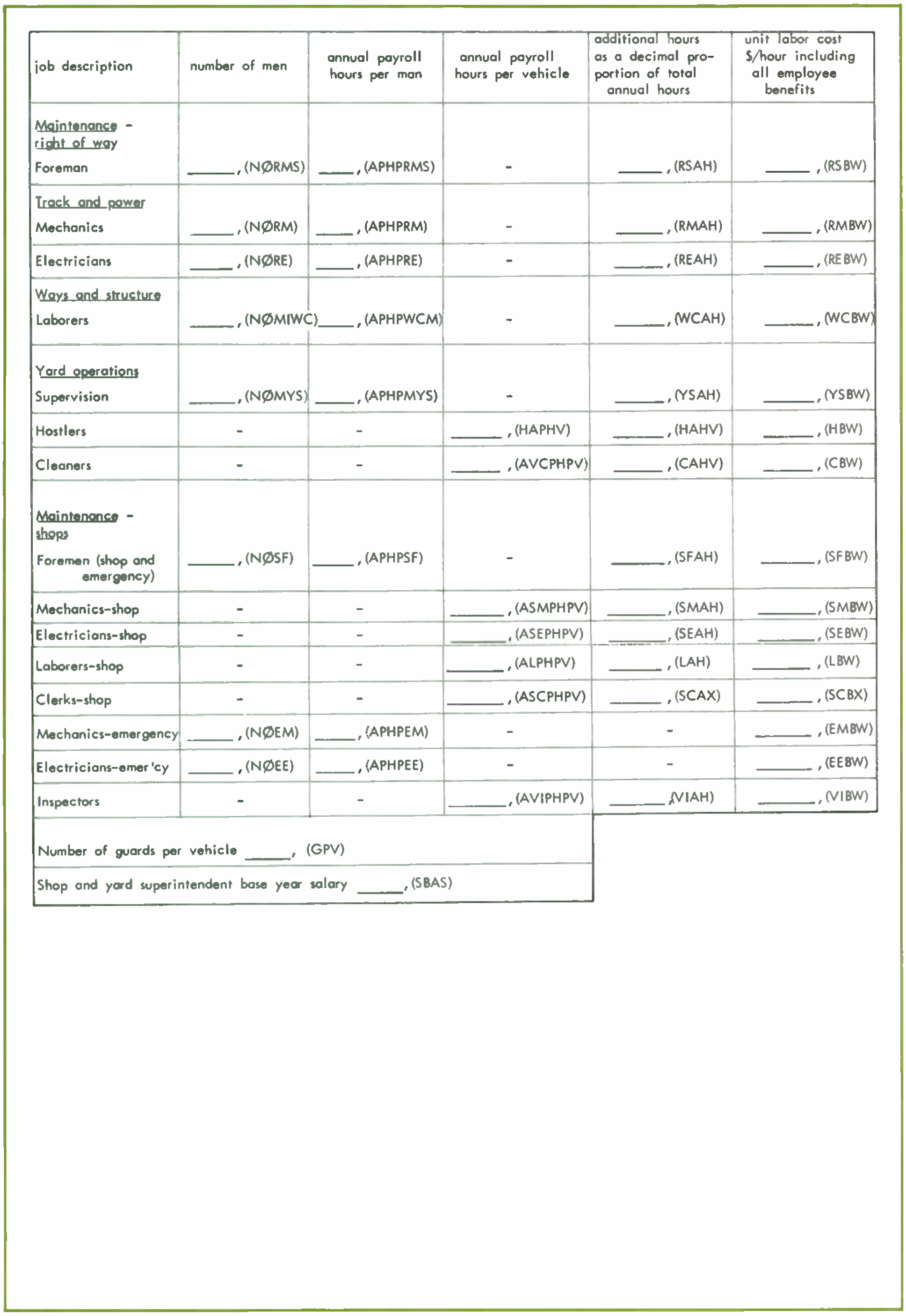
```
              1      2      3      4      5      6      7      8      9     10

   5         12     23     35     46     58     69     81     92    104    115
   6         14     28     42     55     69     83     97    111    125    138
   7         16     32     48     65     81     97    113    129    145    162
   8         18     37     55     74     92    111    129    148    166    185
   9         21     42     62     83    104    125    145    166    187    208
  10         23     46     69     92    115    138    162    185    208    231
  11         25     51     76    102    127    152    178    203    228    254
  12         28     55     83    111    138    166    194    222    249    277
  13         30     60     90    120    150    180    210    240    270    300
```

4—With input data on patronage, frequency of service, and ratio of seating capacity to riders, the computer program calculates a system capacity matrix that shows hourly car-train availability. The column headings are the numbers of vehicles possible per train, from one up to the limit imposed by the current vehicle inventory or by station platform lengths. The row headings are the permissible numbers of trains on the system, taking into account the minimum and maximum headway specifications and the route round trip time. Figures in the columns, then, are the number of cars per hour provided by the various combinations possible.



```
                              HOURLY SCHEDULED CAR REQUIREMENTS

                                          YEAR    1970

 HR        MON.           TUE.           WED.           THR.           FRI.           SAT.           SUN.

  1      4(12, 1)       4(12, 1)       4(12, 1)       4(12, 1)       4(12, 1)       8(12, 1)       2(12, 1)
  2      2(12, 1)       2(12, 1)       2(12, 1)       2(12, 1)       2(12, 1)       5(12, 1)       2(12, 1)
  3      1(12, 1)       1(12, 1)       1(12, 1)       1(12, 1)       1(12, 1)       5(12, 1)       2(12, 1)
  4      2(12, 1)       2(12, 1)       2(12, 1)       2(12, 1)       2(12, 1)       7(12, 1)       3(12, 1)
  5      3(12, 1)       3(12, 1)       3(12, 1)       3(12, 1)       3(12, 1)      13(14, 1)       4(12, 1)
  6      9(12, 1)       8(12, 1)       9(12, 1)       9(12, 1)       9(12, 1)      17(18, 1)       5(12, 1)
  7     58(30, 2)      58(30, 2)      59(30, 2)      58(30, 2)      59(30, 2)      20(21, 1)       6(12, 1)
  8     92(23, 4)      94(26, 4)     100(26, 4)      92(23, 4)      94(26, 4)      47(26, 2)       8(12, 1)
  9     93(26, 4)      99(26, 4)     101(26, 4)      93(26, 4)     100(26, 4)      38(21, 2)       9(12, 1)
 10     65(23, 3)      62(21, 3)      58(30, 2)      65(23, 3)      62(21, 3)      61(21, 3)      13(14, 1)
 11     40(21, 2)      32(16, 2)      34(19, 2)      40(21, 2)      32(16, 2)      54(28, 2)      16(16, 1)
 12     28(28, 1)      27(28, 1)      29(30, 1)      28(28, 1)      27(28, 1)      52(28, 2)       3(12, 1)
 13     29(30, 1)      28(28, 1)      30(30, 1)      29(30, 1)      28(28, 1)      76(25, 3)      28(28, 1)
 14     36(19, 2)      32(16, 2)      36(19, 2)      36(19, 2)      32(16, 2)      66(23, 3)      17(18, 1)
 15     45(23, 2)      51(26, 2)      48(26, 2)      45(23, 2)      51(26, 2)      15(16, 1)       4(12, 1)
 16     84(30, 3)      91(23, 4)      91(23, 4)      84(30, 3)      92(23, 4)      30(30, 1)       8(12, 1)
 17    103(28, 4)     117(30, 4)     113(30, 4)     103(28, 4)     118(30, 4)      47(26, 2)      25(25, 1)
 18    117(30, 4)     119(30, 4)     118(30, 4)     115(30, 4)     120(30, 4)      86(30, 3)      41(21, 2)
 19     35(19, 2)      30(30, 1)      35(19, 2)      35(19, 2)      30(30, 1)      16(16, 1)       3(12, 1)
 20     22(23, 1)      18(18, 1)      19(21, 1)      22(23, 1)      18(18, 1)      24(25, 1)       5(12, 1)
 21     21(21, 1)      16(16, 1)      18(18, 1)      21(21, 1)      17(18, 1)      10(12, 1)       3(12, 1)
 22     17(18, 1)      13(14, 1)      14(14, 1)      17(18, 1)      13(14, 1)      12(12, 1)       3(12, 1)
 23     17(18, 1)      22(23, 1)      17(18, 1)      22(23, 1)      22(23, 1)      15(16, 1)       4(12, 1)
 24     16(16, 1)      21(21, 1)      16(16, 1)      16(16, 1)      21(21, 1)      19(21, 1)       4(12, 1)

 SYSTEM MAXIMUM LINK VOLUME=  6435     ON DAY= FRI.       AT HOUR= 18
```

5—From its input information and capacity matrix, the program makes up a complete weekly schedule of car requirements. Numbers preceding the parentheses show the number of vehicles that must pass through the stations bounding the link that has the maximum volume within each schedule hour. Within the parentheses, the first value is the number of trains dispatched in the hour, and the second value is number of vehicles per train. Here, the program has maximized frequency of service while scheduling just adequate capacity.



job description	number of men	annual payroll hours per man	annual payroll hours per vehicle	additional hours as a decimal proportion of total annual hours	unit labor cost $/hour including all employee benefits
Maintenance - right of way Foreman	______, (N0RMS)	______, (APHPRMS)	-	______, (RSAH)	______, (RSBW)
Track and power Mechanics	______, (N0RM)	______, (APHPRM)	-	______, (RMAH)	______, (RMBW)
Electricians	______, (N0RE)	______, (APHPRE)	-	______, (REAH)	______, (REBW)
Ways and structure Laborers	______, (N0MIWC)	______, (APHPWCM)	-	______, (WCAH)	______, (WCBW)
Yard operations Supervision	______, (N0MYS)	______, (APHPMYS)	-	______, (YSAH)	______, (YSBW)
Hostlers	-	-	______, (HAPHV)	______, (HAHV)	______, (HBW)
Cleaners	-	-	______, (AVCPHPV)	______, (CAHV)	______, (CBW)
Maintenance - shops Foremen (shop and emergency)	______, (N0SF)	______, (APHPSF)	-	______, (SFAH)	______, (SFBW)
Mechanics-shop	-	-	______, (ASMPHPV)	______, (SMAH)	______, (SMBW)
Electricians-shop	-	-	______, (ASEPHPV)	______, (SEAH)	______, (SEBW)
Laborers-shop	-	-	______, (ALPHPV)	______, (LAH)	______, (LBW)
Clerks-shop	-	-	______, (ASCPHPV)	______, (SCAX)	______, (SCBX)
Mechanics-emergency	______, (N0EM)	______, (APHPEM)	-	-	______, (EMBW)
Electricians-emer 'cy	______, (N0EE)	______, (APHPEE)	-	-	______, (EEBW)
Inspectors	-	-	______, (AVIPHPV)	______, (VIAH)	______, (VIBW)

Number of guards per vehicle ______, (GPV)

Shop and yard superintendent base year salary ______, (SBAS)

6—Manning tables for about 25 job descriptions are put into the computer. With that and other cost information, and the operating statistics previously generated, the program projects system operating costs for any year desired. The form used for the manning tables illustrates how manpower requirements are related to operating statistics; for example, employment of car cleaners, hostlers, electricians, and mechanics relates to vehicle inventories, vehicle operating hours, or both. The jobs are typical for transit systems.

About 40 routines are invoked for calculating the cost projections. As computer statements, they generally take a linear form, using some annual constant for fixed costs plus multipliers against one or more of the time-ordered sets of operating statistics. The program recognizes that some costs are not incurred annually but recur after considerable spans of years. Such costs are typified by the need to paint steel structure about once every six years and to replace steel rails or concrete running surfaces at like intervals. To handle such situations, reserves are charged against current revenues and assumed to be invested by a prudent system comptroller against the day of judgment.

With complete sets of projected annual operating costs for ventures with expected economic lives exceeding 25 years, the effects of escalating wage and material costs become highly significant. That is particularly true in evaluations of labor-intensive systems in comparison with highly automated systems. Nonsupervisory wage rates in the transit industry have risen at rates markedly greater than the average for all unionized labor over the past eight years, while the industry itself has not yet benefited from technical innovations that would improve labor productivity. To keep those issues squarely in the foreground, the program provides for escalation of all future labor and material costs at whatever rates might be dictated by local experience.

Development of the cost accounts is illustrated in the accompanying table. (To conserve space, the original computer printout has been condensed and values taken only at six-year intervals.) The general pattern appears to be one of smoothly rising costs, due to the compounding effects of improving patronage and escalation of labor and material costs. However, within the fine details there are innumerable discontinuities or "cost jumps" associated with abrupt increases in schedules, consequent acquisitions of vehicles, and like factors.

Financial Evaluations

Projections of future annual operating revenues can be tied to annual passenger trips, passenger miles, or even station passenger volumes. The choices permit almost any rational fare structure, ranging from a fixed trip charge through a rate per passenger mile to a zoned fare between sets of stations, as desired.

The annual gross cash generated, as the difference between revenue receipts and total operating costs, is the significant final line on each of the annual operating statements developed by the computer. That brings the comparative evaluations down to the crucial issues of their comparative financial performances relative to their individual capital investments.

Financial analysis routines can be written to the taste of all affected parties in the financial community. The standard routines, as now written, apply available funds from the annual gross cash generation to the computer-calculated schedules of debt service, in order of priority. Funds in excess of all charges for debt service are reinvested for future use, including protection against cash deficits in later years. If cash generation fails to cover debt service, the difference is borrowed at a premium rate and added to future years' debt service.

For convenience, the computer routines use debt-service formulas that levelize both interest and sinking fund payments over the full terms of the debt agreements. In the simplest version, all capital costs might be funded by a single bond issue with a term equal to the number of operating years specified for the program run. In practice, however, financial underwriters are likely to require long-term issues to specific purposes, supplemented by successive series of equipment trust notes with shorter maturities. Also, subsidies and grants in aid might be funded on contingent, or "if-earned," bases. With respect to successive series of equipment trust notes, the simulation routines are alert to needs to purchase vehicles in economic lots as much as five years before being put into service. The financial routines are also alert to changes in fixed investment and to the comptroller's cash requirements.

The program also evaluates present worth so that the analyst can make a valid economic comparison between alternative system technologies over an extended time period.

Conclusions

Perhaps more than any other activity that seriously affects modern city life, the urban transportation business is burdened with outmoded concepts and standards. A third of a century passed between the last major subway planning in the 1920's and the dawn of the BART project in San Francisco during the late 1950's.

That lack of development is most unfortunate, for most of our cities are either dusting off old plans or initiating new plans in the hope of creating rapid-transit systems that will lift their citizens out of traffic jams. The hand of the past is too often evident: routes go to neighborhoods that no longer matter, along rights of way previously abandoned by railroads or interurban lines for lack of patronage but now revived out of slavish acceptances of grade and curvature restrictions imposed by outdated equipment.

Any successful revival of urban mass transportation will occur only by conjunction of two things: new ideas in urban planning for future city growth, and new transportation systems that are freshly conceived as the instruments of growth and not merely repetitions of past concepts or mistakes. The program described here has been conceived and is being used as a tool to pretest the greatest possible ranges of conjunction between progressive urban planning and modern transportation.

Westinghouse ENGINEER **May 1968**

Projected Operating Cost Accounts
(Condensed, for Selected Six-Year Intervals, Thousands of Dollars)

Account	*1970*	*1976*	*1982*	*1988*	*1994*
Purchased Power	313	349	389	435	490
Automatic Train Operations	184	220	263	314	374
Station Operations and Maintenance	441	549	708	940	1236
Roadway Maintenance	150	177	210	249	290
Yard Operations	102	147	205	283	399
Vehicle Maintenance	311	424	574	777	1063
General and Administrative Expense	311	406	536	713	958
Total Operating Costs	$1812	$2272	$2885	$3711	$4810
Financial Memoranda:					
Gross Revenues	5079	6065	7241	8647	10,325
Operating Costs (above)	−1812	−2272	−2885	−3711	−4810
Gross Cash Generated	$3267	$3793	$4356	$4936	$5515
Debt Service on Bonds	−1984	−1984	−1984	−1984	−1984
Debt Service on Equipment Notes	−627	−790	−361	−447	−651
Net Cash Generated	$656	$1019	$2011	$2505	$2880
Reinvested Cash Flow	$656	$7073	$18,996	$41,336	$74,643

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[1] J. K. Howell and W. J. Walker, "Transit Expressway . . . A New Mass-Transit System," *Westinghouse ENGINEER*, July 1965.

[2] C. R. Richardson, M. B. Newman, and J. E. Pastoret, "The Calculation of Continuous Train Performance for Multiple Unit Electric Cars," Westinghouse Electric Corp., February 1965.

An Improved Induction Resistance Welding System for Steel Tubing

The combination of an induction coil and a motor-generator set for production of steel pipe and tubing results in a trouble-free system operating at optimum welding-current frequency.

Resistance welding has been used for a number of years in making pipe and tubing from steel strip. The strip is continuously formed into a tube by rolls and guides. The edges of the strip are welded together under pressure from squeeze rolls with heat produced by passing an electric current through the seam. The most common method of welding presently in use employs 50- to 360-hertz current, fed into the strip by rotating electrodes. Unfortunately, low-frequency resistance welding has a number of disadvantages, and the industry is changing to other systems. Two alternative choices are presently available: (1) *High-frequency contact resistance welding* (which uses a frequency of about 400 kilohertz) overcomes some of the shortcomings of the low-frequency resistance welding, but it also introduces some new ones; and (2) *induction resistance welding*, which eliminates problems encountered in both high- and low-frequency contact resistance welding systems. Westinghouse has continued to develop the induction resistance welding process because of the inherent drawbacks of contact resistance heating.

In contact resistance welding, current must be applied to the pipe seam by

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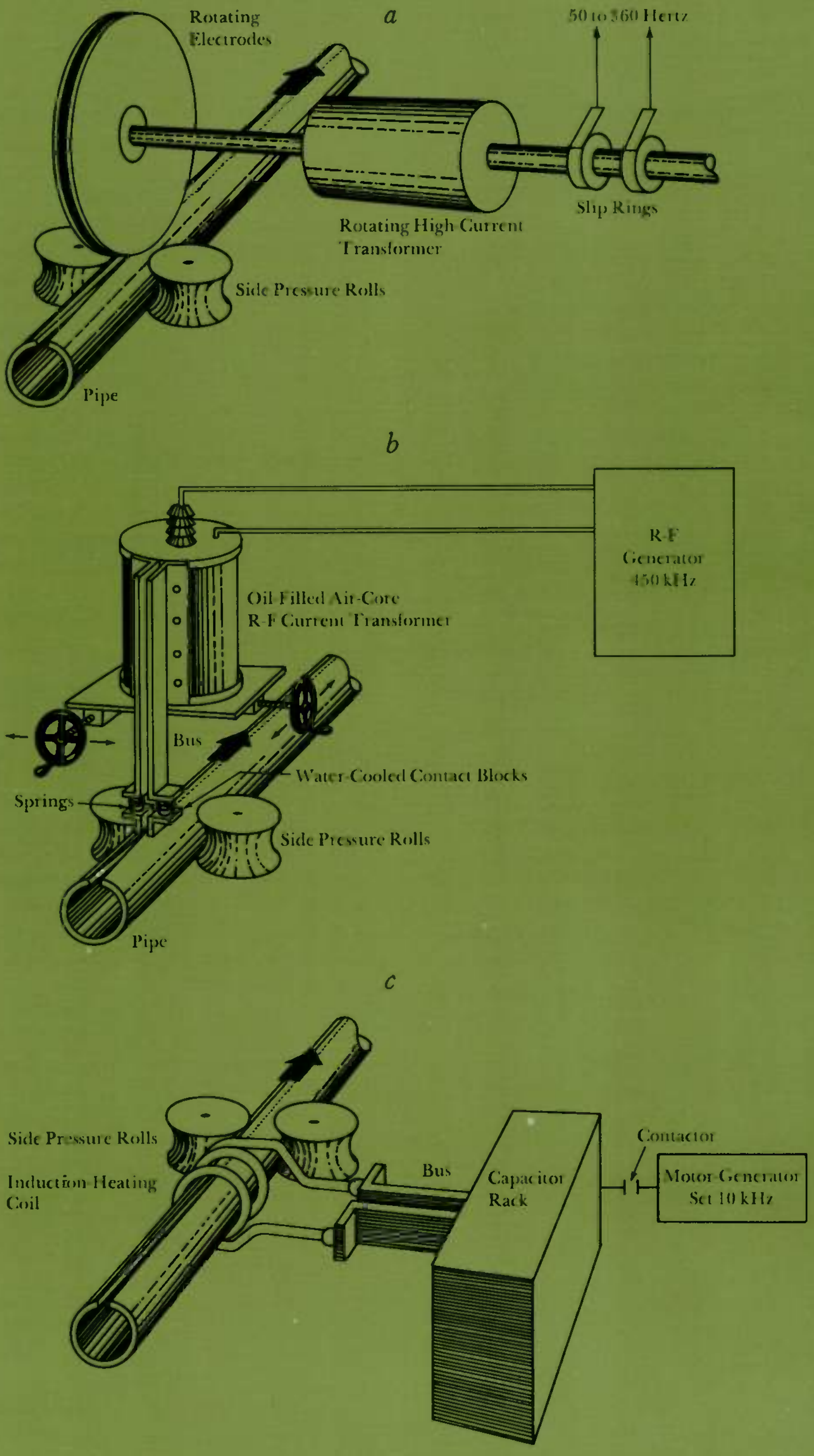
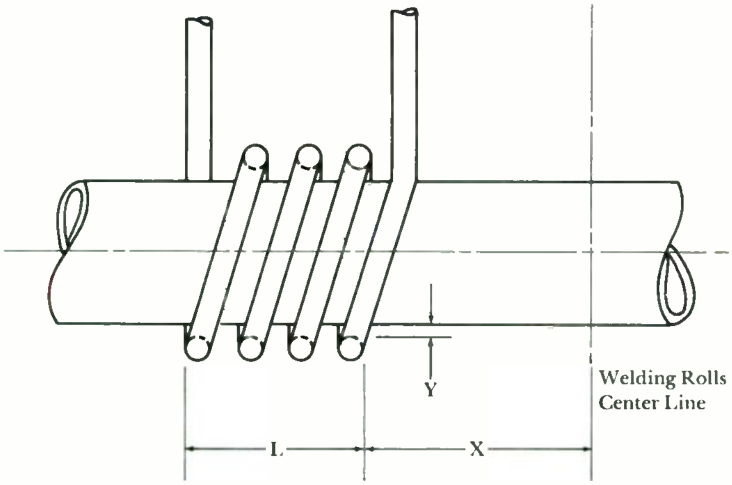
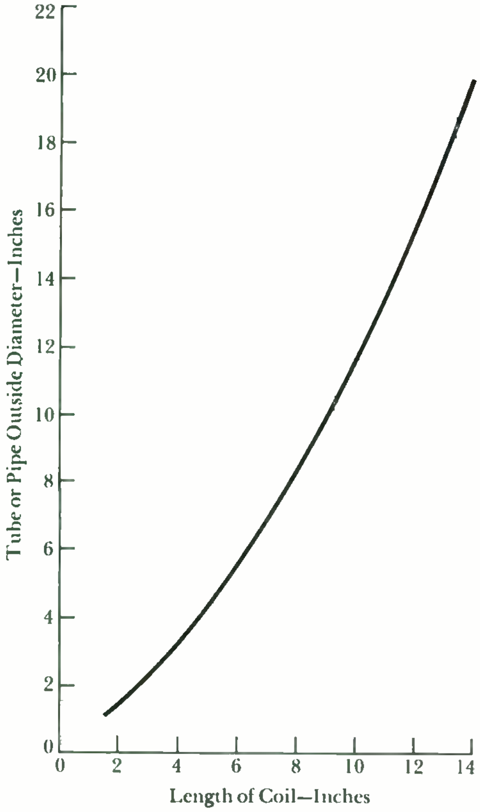


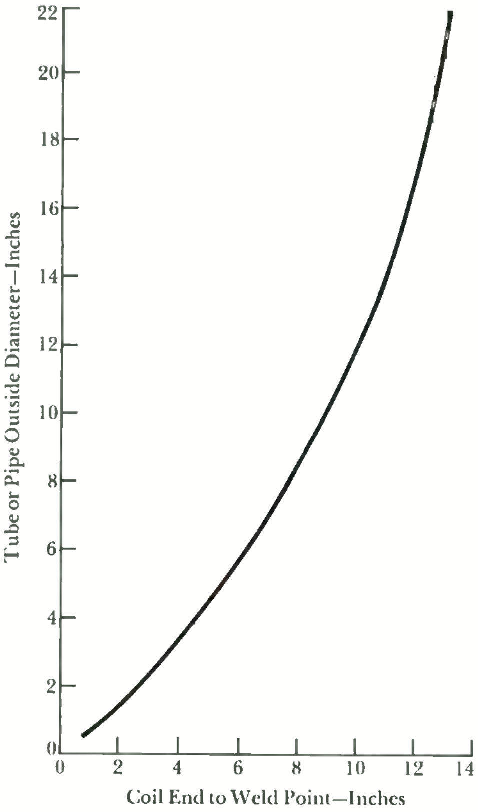
1—(*a*) Low-frequency electric resistance welding process applies 50- to 360-hertz current across seam to be welded by means of rotating copper electrodes. Rotating high-current transformer is used to avoid problems associated with using slip rings for transferring high current at low voltage. (*b*) High-frequency contact resistance welding at 450 kHz develops higher voltages and lower currents, so contacts can be used rather than rotating electrodes. (*c*) A medium-frequency induction resistance welding system, the subject of the article, has the advantage of contactless transfer of current from coil to pipe. Capacitors correct load power factor.



2—The size of the tubing to be welded dictates the values of *L* (coil length), *X* (distance from coil to weld point), and *Y* (clearance between coil and tubing).



3—Recommended length of welding coils varies with tubing diameters.



4—Welding coil location with respect to the weld point varies as the outside diameter of the tubing increases.

means of electrodes. In the low-frequency system, the electrodes are large rotating copper disks (Fig. 1a). Good electrical contact between electrode and pipe is necessary to reduce contact resistance and to prevent burning of the pipe due to the high currents flowing through the contacts. Therefore, the electrodes must be continually dressed, the contact area on pipe having scale must be cleaned by shot blasting or pickling, and high contact pressure is needed. High pressures are difficult to maintain on thin wall pipe.

High-frequency contact resistance welding overcomes some of these problems. Less current is required to produce welding temperatures because the frequency is much higher and the amount of metal heated is much less. Therefore, small sliding contacts can be used for electrodes, and less pressure is required (Fig. 1b). The higher frequency results in higher voltages that "burn through" the scale on the strip, eliminating the need for shot blasting. However, correct contact pressure must be maintained. The contacts must be lifted when the end of the strip comes through, or for discontinuities in the strip.

The fundamental operational advantage of induction resistance welding over both contact resistance welding systems is the use of an induction coil in place of contacting electrodes (Fig. 1c).

Coil Size and Location

The configuration of a typical coil is illustrated in Fig. 2. The number of turns in a coil depends upon the generator used and the production rate required. The clearance dimension (Y) is the maximum clearance that should be maintained between the coil and the tubing at its greatest diameter. The maximum clearance dimension is related to the outside diameter of the tubing as follows:

$$\frac{\textit{Outside Diameter}\ \text{(inches)}}{\textit{Coil Clearance}\ \text{(inches)}} = k = 8$$

A larger clearance dimension will reduce production rates. The clearance dimension for a 6-inch tube is approximately 0.75 inch. This provides sufficient room for the flare-out of the ends and other irregularities to pass.

The coil length (dimension *L* in Fig. 2) must be changed as tube diameter changes. Recommended lengths for welding coils are plotted as a function of tubing outside diameter (Fig. 3).

The recommended location of the coil with respect to the weld point is illustrated in Fig. 4. The weld point to coil end distance for a 12-inch (outside diameter) tube is approximately 10 inches. For tube sizes from 6 to 16 inches in outside diameter, the induction coil can be placed inside the tube, around the plug rod. A roller guide on the plug rod centers the coil. For tubes under 6 inches in outside diameter, the coil is placed outside the tube.

The Effect of Frequency

Heated Depth—Regardless of the welding method used, power supply frequency affects heating performances because current penetration is a function of frequency. Thus, in either the induction resistance or contact welding system (at higher frequencies), current flows in the edge of the strip as illustrated in Fig. 5. The current distribution away from the edge is an exponential function of frequency, resistivity, and permeability of the material.

When the surface of the steel heats to the Curie temperature and becomes nonmagnetic, the area of maximum current density moves further into the strip.

This depth-of-heating characteristic is used in induction surface hardening, and a direct comparison can be made between surface hardening depth and welding etched-heat pattern. Surface hardening depths for frequencies commonly employed in induction hardening are shown in Table I.

In pipe welding, since two heated edges are brought together, the characteristic width of the heat-affected weld area will be approximately twice the characteristic hardening depth. Widths of heat-effected area in pipe welds for typical welding frequencies are shown in Table II.

The variation of heating depth with frequency suggests that frequency can be chosen to suit pipe wall thickness. A logical choice of frequency is one that will produce a heated cross section area nearly equal to wall thickness; this insures uniform heat and a process less sensitive to known variables.

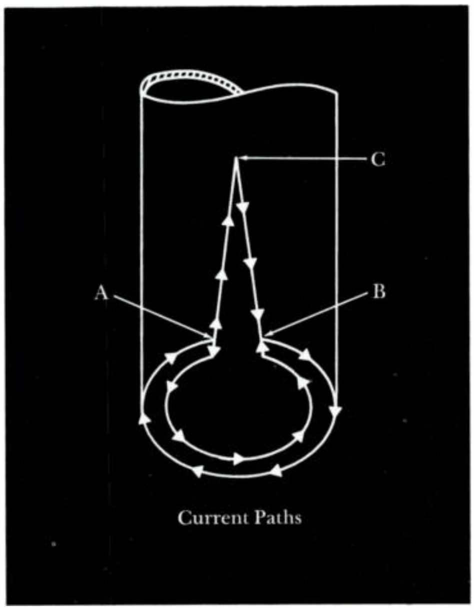
The etched widths of welds on ¼-inch-thick steel are shown in Fig. 6. The etched heat pattern at 1 kilohertz (kHz) is approximately ¾ of an inch. This is unnecessarily deep for this wall thickness. A buckling of the heated material is evident. On the other hand, the heat pattern at 450 kHz is too shallow, and current concentrates on the corners of the strip producing the "hour glass" heat pattern. The overheated corners cause the flash (the extruded metal at the weld seam) to spread out and curl over.

If the frequency is such that the wall thickness is less than or equal to twice the depth of heat penetration, the etched pattern will be straight-sided. The flash tends to be rounded and is easier to remove.

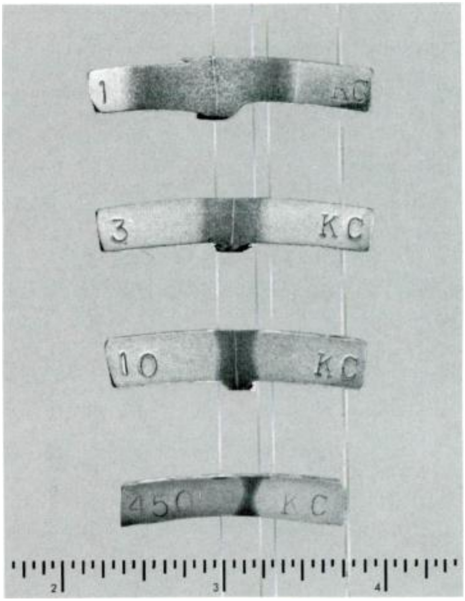
For reasons discussed above, frequency should be selected so that the heated depth of the strip edge will be approximately one-half the wall thickness.

Although induction coils have been used for the past several years for resistance welding, the choice of power-supply frequency to optimize the heat-affected area is an improved approach. Little attention has been paid previously to the proper selection of frequency to accommodate pipe size and pipe wall thickness. Pipe from 4 to 16 inches in diameter is usually made in wall thicknesses from 0.1 to 0.5 inch. A frequency of 10 kHz is best suited to cover this range since it has a characteristic heating depth of approximately ⅛ inch.

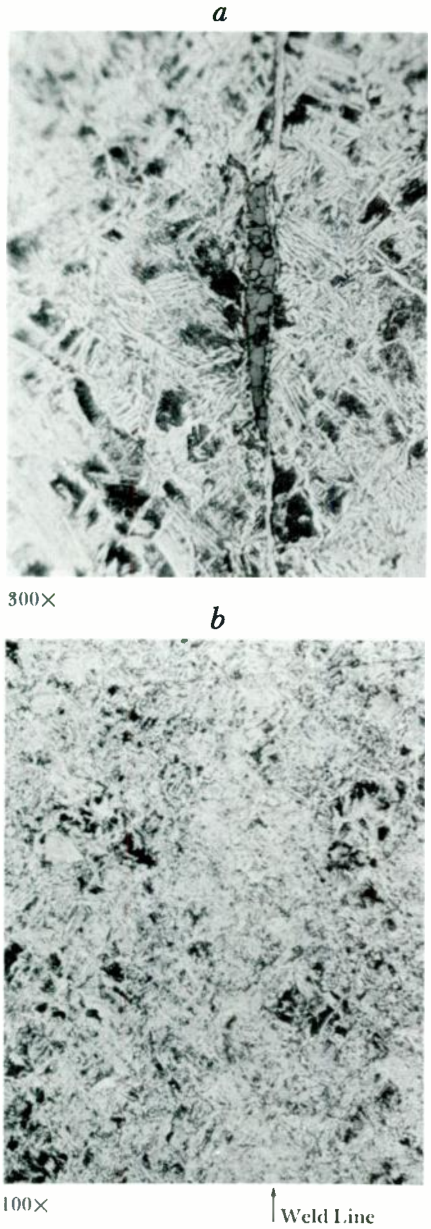
Voltage—There is another very important frequency consideration. This is



5—The "skin effect" of high-frequency current is used in pipe seam welding to obtain heating along the edge of the "V". Points *A* and *B* are contact points in the contact method, or the exit end of the coil in the induction method; *C* is the weld point.



6—Etched cross sections show the effect of frequency on the depth of the welding heat patterns.



7—The current flowing along the edges of the strip heats the edges as they approach the weld point. When the two edges come together at the weld point, the current melts the contacting edges and forms the weld. The scale inclusion seen in the photomicrograph of the edges of the strip before welding (*a*) will be squeezed out into the flash when welding takes place. After welding (*b*), the weld-line area shows good diffusion with only a slight amount of grain growth.

the voltage across the "V" prior to welding. The impedance of the current path down the edge of the V is proportional to the frequency used. Thus, the impedance of this path is approximately 45 times higher at 450 kHz than at 10 kHz. Even though the current required at 450 kHz is approximately 0.4 of the current required at 10 kHz for a similar amount of power put into the edges, the voltage required is 18 times higher at 450 kHz. In large diameter tubes, the frequency, and hence the voltage, should be kept as low as possible while still maintaining good weld patterns.

Self-Quenching—In addition to the heating pattern, frequency can also influence the metallurgical effects that occur during cooling. If the surface of a piece of steel is heated fast enough with cool metal behind the heated area, self-quenching can result (heat flows to the cooler metal). This is a condition to be avoided because it can lead to the formation of martensite, a very hard and brittle crystal stucture that results from rapid cooling. Self-quenching is more apt to be produced by the shallow heating pattern of high-frequency, high-density current. It is not as likely to occur at 10 kHz and below because of the deeper and slower heating produced.

Depth of current penetration can also affect the need for seam annealing after welding. A fundamental advantage of heating at 10 kHz and below over the higher frequencies is the lower, more uniform heat produced in the pipe during the welding process. This reduces the tendency for cracking of the tube prior to post annealing. In fact, a 10-kHz system may even eliminate the need for seam annealing in some cases where annealing would be necessary with 450-kHz heating current.

For example, a medium carbon, high strength, X-60 steel tube (8.625 inches outside diameter by 0.250 inch wall thickness) was welded at 50 feet per minute using 10 kHz. An external coolant was not used. There was no evidence of any untempered martensite in the welds. (See Fig. 7)

This test indicates that seam annealing may not be necessary if deep heating is used and a coolant is not used at the welding rolls. Further tests under various conditions are necessary before any positive statements can be made, but this point should be considered carefully since it may eliminate the necessity for annealing equipment in the line after the welding process.

When seam annealing is required, the induction equipment for annealing is provided in the line following the welder. It heats the welded seam (normally at 200 to 500 degrees F after welding) to approximately 1700 degrees F. The frequency and the power level required are functions of pipe speeds, incoming temperature, final seam temperature, pattern width, wall thickness, and clearance between the pipe and the inductor.

Power Requirements

In comparing the power requirements of induction resistance and electrode or contact resistance welding systems, more should be considered than just nominal generator ratings. Other considerations are the amount of heat that can be put into the pipe, the efficiency of heating, and the beneficial results of the additional heat.

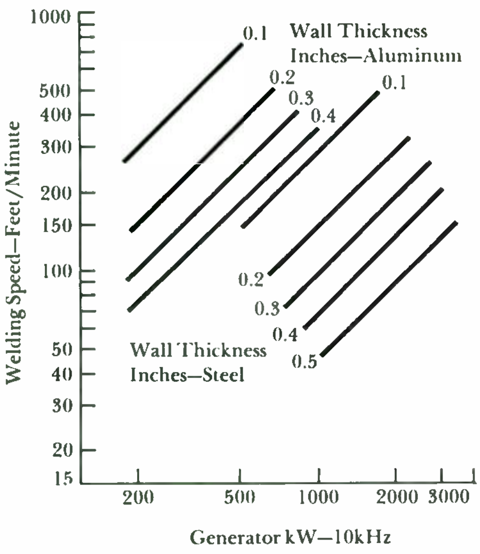
A fundamental difference between the Westinghouse induction resistance sys-

Table I. Depth of Surface Hardening for Typical Induction Frequencies

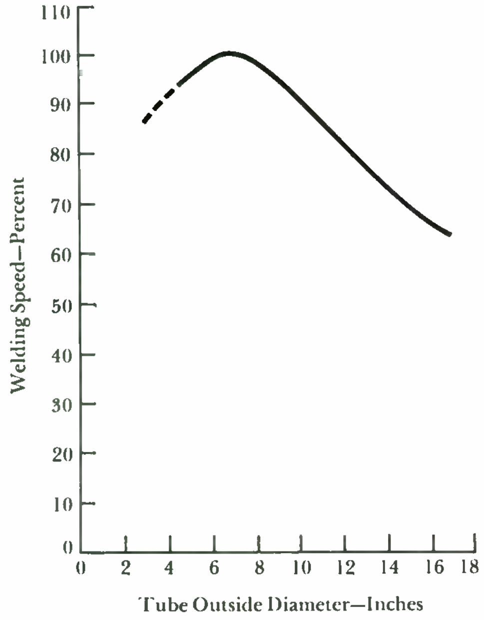
Frequency (kHz)	*Case Depth (in.)*
450	0.030
10	0.125
3	0.250
1	0.375

Table II. Width of Heat-Affected Weld Area, as Shown by Etched Cross Section of Weld

Frequency (kHz)	*Width (in.)*
450	0.060
10	0.250
3	0.375
1	0.875



8—Induction welding speeds (at 10 kHz) for steel and aluminum tubing are related to the wall thickness of the material and to the generator power. The data plotted here are for tubes having outside diameters from 6 to 8 inches.



9—Diameter factors are used to estimate the welding speeds (at 10 kHz) for other tube diameters. The diameter factors shown are multiplied by the welding speeds for the diameters from 6 to 8 inches (Fig. 8).

tem and high-frequency contact resistance welding systems is the ability of the induction resistance system to put several times more heat energy into the pipe. The improved efficiency of putting this additional power into the pipe is shown in Table III below for equivalent 400-kHz contact resistance and 10-kHz induction resistance systems:

A portion of the additional power that is put into the pipe with induction resistance welding at 10 kHz is ultimately utilized if a seam-annealing process is required, such as for higher alloy tubings. Thus, if 10-kHz induction resistance welding is used, the tube weld is already uniformly heated and allowed to equalize at about 500 degrees F when it comes to the seam-anneal position, and much less additional power is required.

Production Rates

The production rates obtainable with an induction resistance welding system compare favorably with production rates of a high-frequency contact welding system from the standpoint of equipment cost and power consumption for pipe sizes of medium wall thicknesses. On thick-walled pipe (over ⅜ inch), the Westinghouse system provides a substantial production advantage because of the deeper current penetration possible with medium-frequency current.

The production rates obtainable at 10 kHz for both aluminum and steel are shown graphically in Fig. 8. The plotted values are for welding tube sizes from 6 to 8 inches. A diameter factor (Fig. 9) must be used to determine the production rates of other diameters. The manufacturer should be consulted before applying 10-kHz welding power to diameters below four inches.

Table III. Comparison of Welding Characteristics

M-g Set Rating (kW)	*Line Input (kVA)*	*Power Input into Pipe (kW)*
400-kHz Contact Resistance System:		
280	515	165
560	1000	330
10-kHz Induction Resistance System:		
750	1130	640
1000	1500	850

The relative simplicity of induction resistance welding requires less technique and can result in further production efficiency improvements. Vacuum tube generators are required to produce the high frequencies used by the contact resistance system. Even under normal conditions, these generators will require more maintenance than the motor-generator sets used at 10 kHz. The contact resistance welding application imposes unusual strain on a vacuum-tube generator because an arcing contact will cause high-voltage transients that are injurious to vacuum tubes, output transformers, and other electronic components. Since the contacts have a limited life, the generator will be unavoidably subjected to surges and transients.

The m-g set power supply used for medium-frequency generation (1 to 10 kHz) offers a high degree of reliability. A group of m-g sets can be located in a common motor room to supply more than one mill. As the power requirements of any particular mill vary, m-g sets can be switched from one line to another. Failure of a single generator will not halt production. Thus, the reliability advantages of a 10-kHz induction resistance welding system stem from both the *method* of inducing current into the pipe, and the *frequency* of the induced current.

Conclusion

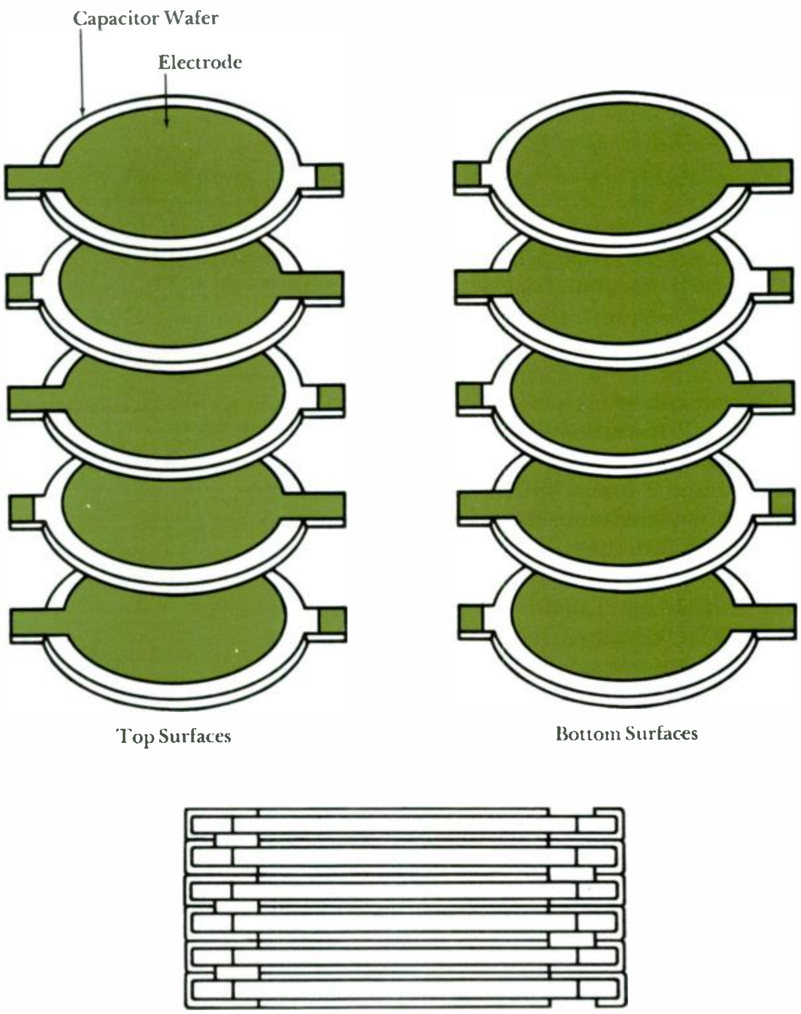
Considerable effort has recently gone into extending the use of the induction resistance system for pipe welding. Developmental work was done in the induction laboratory of the Westinghouse Industrial Electronics Division. The simplicity and reliability of this induction resistance welding system, operating at a frequency that produces optimum welding results, should assure its success. Several induction resistance welding installations in use today employ frequencies of approximately 300 kHz, and a few use 10 kHz. In the future, there probably will be more of the 10-kHz units in use and also some units in the 50- to 100-kHz range.

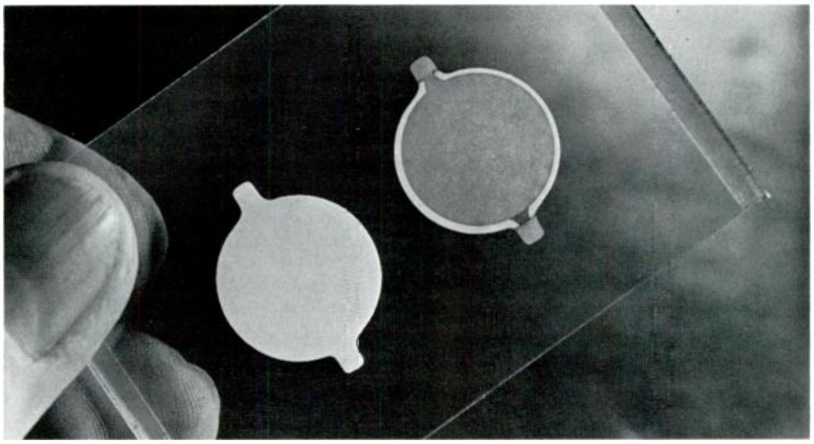
Experimental Lightweight Capacitor Can Operate at 1100 Degrees F

As spacecraft become larger and more complex, their electric power requirement increases, and with it the amount of power lost as heat. That heat must be removed to keep temperature from building up beyond the operating limits of the electrical components. The cooling system adds weight, however, so there is need for electrical devices that can operate at higher temperatures to minimize cooling-system weight.

Capacitors are one of the components that now limit permissible operating temperature. Other electrical components are either available or under development for operation at about 1000 degrees F, but capacitors are presently available for operation only to about 750 degrees F because their electrical losses become excessive at higher temperatures. Even mica, the dielectric (nonconducting) material used in capacitors that can operate at 750 degrees, has poor dielectric properties at that temperature; a lot of it has to be used, making the capacitors bulky and heavy.

Now, however, a new type of construction promises to provide practical lightweight capacitors that can operate at 1100 degrees F. The development units also have low electrical losses, high capacitance, stability, and a volumetric efficiency (microfarad-volts per cubic inch) comparable to that of capacitors designed for normal operating temperatures. The development program is being conducted by the Westinghouse Aerospace Electrical Division for the National Aeronautics and Space Administration's Lewis Research Center as part of a contract for development of high-temperature electrical and magnetic materials.





(*Photograph*) The high-temperature capacitor wafer (*right*) is formed by depositing a thin-film electrode on both sides of a slice of boron nitride ¾ inch in diameter and 0.001 inch thick (*left*). Roundness minimizes local field concentrations. (*Diagram*) Capacitor wafers are stacked to make a multilayer capacitor. The electrode pattern is such that tabs overlap to connect alternate electrodes in parallel.

The dielectric material used is pyrolytic boron nitride. This material, formed by a chemical vapor deposition process, is denser and purer than compressed and sintered boron nitride. It is sliced into wafers that are then lapped and polished. Since capacitance varies inversely as the thickness of the dielectric material, the wafers are finished to a thickness of only 0.001 inch. Thin-film electrodes of platinum and rhodium are then deposited by vacuum sputtering to form single-wafer capacitors.

Electrical tests of the single-wafer capacitors in a vacuum at temperatures up to 1100 degrees F have demonstrated a dissipation factor (ratio of power loss in watts to volt-ampere input) of less than 0.001. Change in capacitance from room temperature to 1100 degrees is −1.7 percent. (Negative values are less than room-temperature capacitance; positive values are greater.) The measured breakdown voltage is 7000 volts per mil of dielectric thickness.

Multilayer capacitors have been made by stacking individual capacitor wafers one on top of another with alternate electrodes interconnected. The total measured capacitance of such a stack is the sum of the capacitances of all the wafers. Electrode thickness is negligible (about 0.00001 inch), making total stack height essentially the sum of the thicknesses of the wafers. This construction produces higher capacitance per unit volume than that of other capacitor types, and also considerably higher volumetric efficiency.

The stacked units perform well in tests. One five-layer capacitor, for example, has been tested for more than 1000 hours at 1100 degrees F in a vacuum. A working voltage of 500 volts per mil was impressed for the first 250 hours, 750 volts per mil for the next 200 hours, and 1000 volts per mil for the remainder of the test. Stability proved to be good, as capacitance decreased only three percent from the initial value of 0.0014 microfarad.

These qualities add up to potentially high stability and reliability over long periods in a wide range of environments and operating conditions, so the new capacitors should find use in other demanding applications as well as in spacecraft. The heating from high current flows or rapid cycling in energy-storage applications should not be as detrimental to their life and performance as such heating is to present types.

Present development work is aimed at making further improvements in design, processing methods, and performance. The next phase being considered is development of efficient hermetic packaging methods, fabrication of 100-wafer stacked capacitors, and extended life testing (up to 5000 hours). Also being considered is a study of methods of producing deposited boron-nitride films ¼ to 1 mil thick. If high-temperature electrical properties of deposited thin films prove to be as good as those of the bulk material, the cost of making capacitor wafers can be significantly reduced by eliminating the slicing and lapping steps.

Reverse Osmosis Studied for Water Desalting

Graphitic oxide has been found to be a promising material for desalting water by "reverse osmosis." A thin membrane of the material acts as a sort of molecular sieve, allowing water molecules to pass through but being less permeable to the dissolved salts. (Normally, the direction of osmosis is from a weak solution into a more concentrated one, thus tending to dilute the stronger solution; in reverse osmosis, however, applied pressure reverses the process, causing water to flow from the more concentrated liquid to the less concentrated one.)

Water desalting by reverse osmosis has been investigated by various research groups for some time as one of several promising approaches to the overall problem of water purification. The researchers working with it at the Westinghouse Research Laboratories do not see it as competing with the large-scale process of seawater desalting by flash evaporation, in which pure water is condensed from the vapor of heated seawater, but rather as more applicable to treatment of brackish water (salt concentration lower than that of ocean water). The growing demand for pure water and the increasing shortage of it suggest to the Westinghouse researchers that reverse osmosis and other methods of desalting must be thoroughly studied and improved if the world is to meet all the diverse and specialized fresh-water needs of the future. The work is being done under contract with the Office of Saline Water, U.S. Department of the Interior.

In the experiments, a layer of graphitic oxide is deposited on a thin film of plastic material or some other porous support structure. The combination of oxide and support structure forms a semipermeable membrane, which detaches the salt from the water that flows through it. To maintain the flow, pressure on the salt water is kept above its osmotic pressure (which is roughly 370 pounds per square inch for seawater).

The three major technical requirements of a practical desalting membrane are that it reject a high percentage of the salt in the water, pass large quantities of desalted water per unit area, and withstand the required pressure on the salt-water side. Those factors vary with the type of supporting structure, thickness of the graphitic oxide deposit, amount of pressure applied, and other conditions; furthermore, they are interdependent. For example, in some thicknesses, increasing the thickness tends to improve salt rejection but lower water flow. Thus, useful membranes will have to be a compromise among various structural and operating considerations.

Various combinations of graphitic oxide thickness, supporting structure, feed-water pressure, and salt-water salinity and alkalinity have been evaluated in the experiments. Salt rejection of up to 90 percent was achieved with a graphitic oxide thickness of about three-tenths of a micron, with concentration of the saline solutions ranging up to 40,000 parts per million. Pressures up to 1700 pounds per square inch were applied to the salt water. Essentially, it was found that increasing pressures increased the water flux through the membrane. At 600 pounds per square inch, flows of eight to ten gallons per square foot per day were achieved with membranes capable of rejecting almost 80 percent of the salt in the saline water. The flux varied with thickness of the graphitic oxide deposit and duration of the tests.

Another significant finding was that the percentage of salt rejected could be increased by making the water alkaline; tests on alkaline water with a salinity of 5000 parts per million showed 87 percent rejection of salt. By contrast, the cellulose acetate membranes used in much of the earlier work on reverse osmosis rapidly lose their salt-rejection capability in alkaline water.

Simple Pumping Principle Applied for Molten Metals

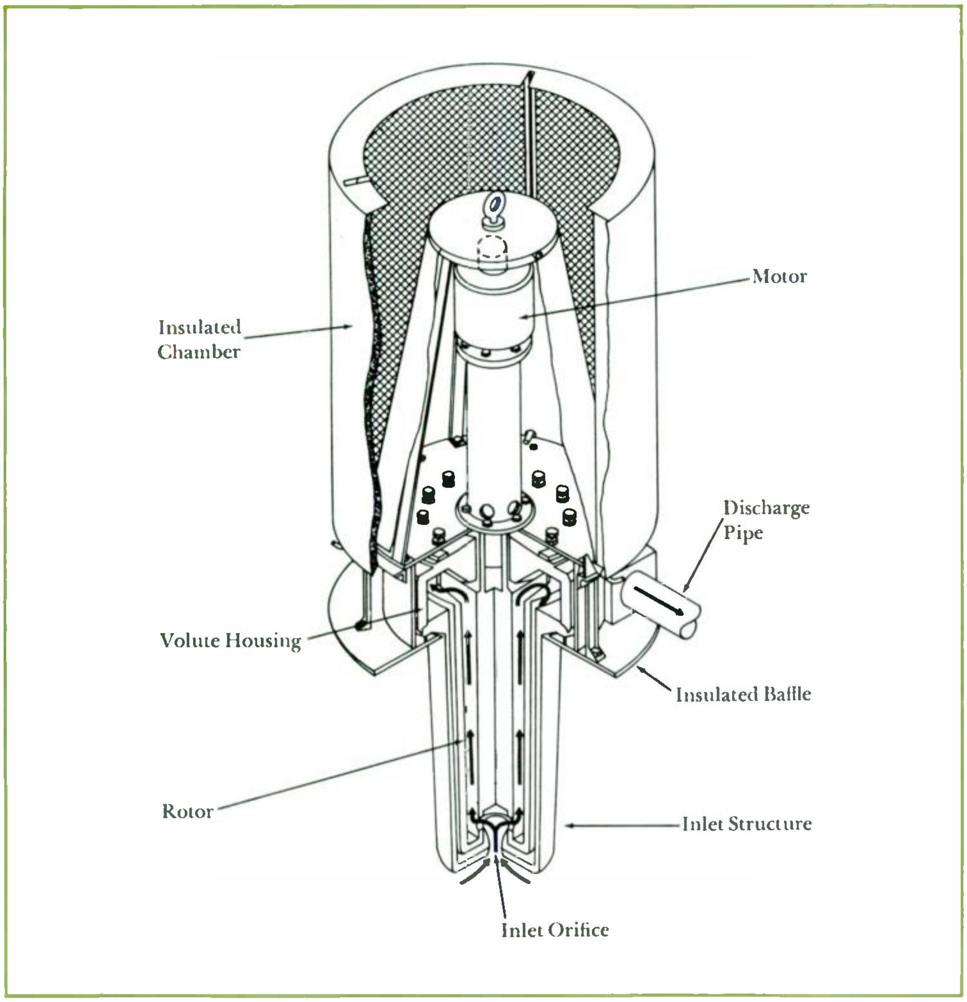
A new concept for moving molten metal has led to development of a pump that is more reliable than previous devices and requires less maintenance. Although the concept is a result of aerospace research and development work with liquid-metal coolants, the pump is expected to find applications in such industrial processes as aluminum and magnesium production and fabrication.

Key elements of the new pump are ceramic components for all parts that contact molten metal, a new metal-to-ceramic coupling, and a rotor that moves the metal by means of an induced vortex. The induced vortex is the same effect produced by axially spinning a bucket of water: the spinning induces the water to spin also and then to climb the sides of the bucket and spill over the top.

The pump consists essentially of an inlet chamber, a rotor, and a discharge volute (see illustration). Accessories include either air or electric drive, drive control, a discharge adapter, an insulated chamber, instrumentation, and installation support rings. In use, the inlet chamber is partly immersed in molten metal in the furnace well. Ports in the inlet housing allow the metal to enter the housing and rotor, and the spinning of the rotor forces the metal to rise to the top of the rotor where impeller vanes force it out through the discharge volute.

The initial model is a multiple-range pump that can move from 10,000 to 400,000 pounds of molten aluminum per hour at a discharge head of six feet of water. Flow rate is controlled by rotor speed and the size of the inlet orifice, which is preselected for a particular flow-rate range.

The new pump is designed to alleviate problems caused by thermal shock, corrosion, and consequent unscheduled shutdown of the pumps presently used. Thermal shock and corrosion are largely eliminated through use of nitride-bonded silicon carbide for all parts exposed to molten metal. These extremely durable components plus simplicity of design and construction give the pump inherent high reliability.



Pump for molten metal applies the principle of liquid rising inside a spinning rotor to achieve a simple and reliable means of moving such metals as aluminum and magnesium in the melted state. The simplified diagram illustrates the arrangement of components.

Utility, Builder, and Manufacturer Operate Distribution Laboratory

To test new ways of improving the appearance and performance of electric distribution systems, an "electric laboratory" is being installed in Coral Springs, Florida. The community is a planned city for 60,000 potential residents taking shape near Fort Lauderdale. The laboratory will encompass 70 homes and apartments, which will be served with the latest in underground electric equipment and engineering techniques.

The project is expected to yield new concepts in service that should benefit electric customers across the nation. It is a cooperative effort of Florida Power & Light Company, Coral Ridge Properties, and Westinghouse Electric Corporation.

All power lines in the laboratory area will be buried. Four basic types of transformers will be used, ranging from the completely buried transformer to the pad-mount type that sits on the ground behind concealing shrubbery. Several corrosion-resistant coverings will be used on the equipment to determine which offers the best protection against the local soil. New flush-mounted electric meters, set into the outside walls of houses, will be installed at several locations to gain operating experience with them.

Frequent inspections and sensitive monitoring devices will determine which equipment, and which combination of equipment, provides the most reliable and economical service to customers. A Westinghouse Pulse-O-Matic computerized metering system will automatically collect data in a form ready for processing by other computers. Variables that will be recorded and studied include customer load characteristics, transformer loads and temperatures, earth temperatures, and wind velocities, all of which influence the distribution of electricity.

Products for Industry

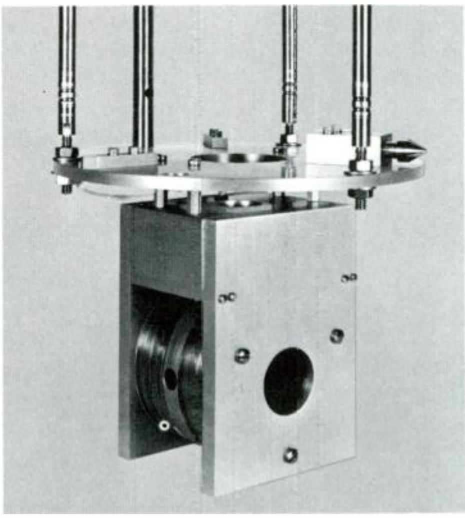
Silicon power transistor provides the high current-handling capability needed for power-switching applications such as regulators and amplifiers. Type 1441 diffused NPN transistor dissipates 350 watts and handles collector currents up to 150 amperes. Its staturation voltage is low (2 volts maximum at 100 amperes), and it is rated in 20-volt steps from 40 to 120 volts V_{ceo} sustaining. Minimum gain is 10 at collector currents of 50, 75, and 100 amperes. Junction temperature can range from −65 to 200 degrees C, permitting reliable operation even under extreme ambient conditions. Freedom from thermal fatigue is assured by compression-bonded encapsulation. *Westinghouse Semiconductor Division, Youngwood, Pennsylvania 15697.*

Superconducting magnet of split-solenoid type has magnetic field strength up to 50 kilogauss. It operates at cryogenic temperatures to achieve superconductivity and consequent strong magnetic fields with small equipment. The magnet is composed of two portions of a solenoid spaced along the same axis; it thus differs from the usual superconducting magnet in permitting access to the magnetic field from two directions—along the axis of the magnet, and perpendicular to the axis. That feature is important in such applications as MHD work, where hot plasma must move perpendicular to the direction of the magnetic field. *Westinghouse Cryogenic Systems Department, P.O. Box 8606, Pittsburgh, Pennsylvania 15221.*

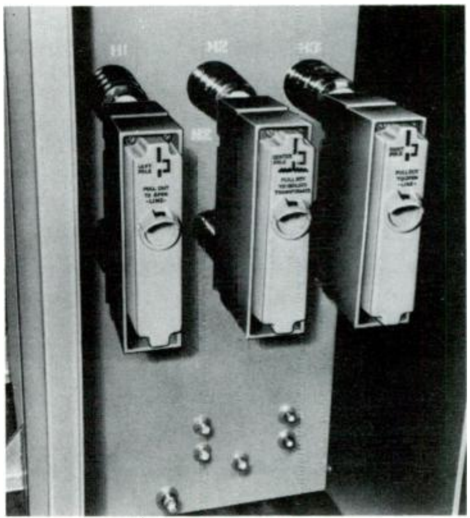
Load-break switch, Type EFD, is for underground distribution systems using pad-mounted transformers. The single-pole switch is applicable for single-phase and three-phase radial-feed distribution on 15-kV grounded-wye systems. For three-phase, three single poles and mounting boxes are provided for each line; each switch is mounted on a standoff insulator and a through-type bushing. The switch's two sets of arc-quenching plates are molded of a durable glass-polyester material that generates a deionizing gas in the presence of an arc. *Westinghouse Distribution Transformer Division, Sharpsville Avenue, Sharon, Pennsylvania 16146.*

Copper-clad laminate for printed-circuit panels does not absorb moisture and therefore will not blister, warp, delaminate, or develop the surface spots known as "measles" even under extreme humidity and high temperatures. G-10 glass-epoxy laminate is manufactured under clean-room conditions from an epoxy resin formula that gives both high strength and inertness. It is especially useful in airborne computer circuits and similar applications where high quality must be combined with savings in space and weight. *Westinghouse Industrial Micarta Division, Hampton, South Carolina 29924.*

Silicon Power Transistor



Superconducting Magnet



Load-Break Switch

About the Authors

Russell Frink received his BSEE from the University of Washington in 1942, and later added an MS in Engineering from the University of Pittsburgh. Frink came to Westinghouse upon graduation from the University of Washington and went to work in the Switchgear Division. He has spent his career in a variety of switchgear development and engineering assignments, and during this time has accumulated 50 patents for switchgear developments. He is a member of both the NEMA and the IEEE Power Circuit Breaker committees. Frink is presently manager of Switchgear Advanced Development Engineering.

John M. Kozlovic graduated from Tulane University in 1951 with a BSEE and came with Westinghouse on the graduate student program. He joined the Switchgear Division and has spent his time since as a design engineer. In fact, he has helped design all of the magnetic air circuit breakers in production in the Switchgear Division today. In 1965, Kozlovic moved to the division's advanced development section to work on the new SF_6 puffer breakers and metal-clad switchgear described in this issue.

Albert Nims received his BSEE from Worcester Polytechnic Institute in 1939 and his MSEE from the same school in 1940. He joined the Electronics Division of Westinghouse, and his first assignment was the design and engineering of shipboard and aircraft communications transmitters. During World War II, he worked on the development of various radar equipments. Nims' next assignment was in the Westinghouse Stratovision program, which proposed the long-range broadcast of television signals from high-flying airplanes.

In 1951, Nims was transferred to the newly formed Air Arm Division (now Aerospace Division) and made a section manager responsible for the design of fire-control radar. He was made manager of Surveillance Radar Systems in 1957, and since 1963 he has been manager of Reconnaissance Radar Systems and Special Programs.

W. R. Harris began his career as an application engineer, and he has stayed close to that first love in the management positions he has filled since then. As Engineering Manager of the Systems Control Department, Industrial Systems Division, he oversees both the development and the application of power and control equipment for many kinds of industrial systems.

Harris graduated from the University of West Virginia in 1937 with a BSEE degree and joined Westinghouse on the graduate student course. A training assignment in the general mill section of the former Industry Engineering Department turned out to be permanent: he spent the next seven years as an engineer in the section, mostly applying paper-mill drive and control systems. (He also earned an MS degree in Electrical Engineering through part-time study at the University of Pittsburgh.) Harris transferred to the metal-working section in 1946 to do similar application engineering for metal-rolling mills, and he was made manager of the section in 1948. He became manager of the Industrial Systems Engineering Department in 1953, and in 1954 he moved to Buffalo to take his present post.

Harris has served on national and local AISE, ASME, and IEEE committees. He has been chairman of the IEEE Pittsburgh section and is now chairman of the Chapters Department of IEEE's Industry and General Applications Group. He has 19 patents to his credit and about 50 technical papers and articles.

The article that describes the induction-resistance welding equipment was written by **John A. Redmond.**

Redmond is Section Manager, Induction Heating Engineering, Industrial Equipment Division. He joined Westinghouse in 1936 on completion of the academic program at Bliss Electrical School. He worked first in the test department of the former Radio Division, and this experience assisted him in designing units for Naval communications.

Redmond moved to the Industrial Equipment Division engineering department in 1944, and in 1956 he was made Section Manager. In this position, he is responsible for the design of industrial rf generators and other electronic products and processes such as high-voltage dc power supplies, strip-line heating, induction welding, and induction heating for the semiconductor industry.

William B. Stewart approaches transit system analysis from the point of view of an economic analyst, while **Ralph Mason** approaches it from an engineer's viewpoint. That fruitful combination has resulted in an effective computer program for simulating and evaluating proposed transit systems. It also produced this issue's article describing the program.

Stewart attended Trinity College, Hartford, Connecticut, and has since taken courses in operations research at M.I.T., Case Institute of Technology, and Carnegie-Mellon University. He worked as a financial analyst with Dun and Bradstreet before joining Westinghouse in 1948 as an economic consultant in Tax Accounting. He served as secretary of the Business Projections Committee from 1951 to 1958 and now is Manager, Economic Research, Headquarters Market Planning Department.

Mason combines his two main professional interests—the rapid and unhindered movement of people and the economic analysis of alternative investments—in his engineering evaluations of transportation alternatives. Since joining the Transportation Division in 1966, he has worked in application engineering in transporation systems, especially the Transit Expressway system.

Mason attended the University of Birmingham, England, after serving a year at sea in the British merchant navy. He received his BSc degree with honors, in mechanical engineering, in 1966 and then joined Westinghouse on the graduate student course. He is presently studying part time for an MBA at the University of Pittsburgh.

The first of eight proposed antennas that will tune in signals from radio sources in and beyond our galaxy was installed recently at California Institute of Technology's Owens Valley Radio Observatory. The pedestals of the eight units will be able to aim their 130-foot dish antennas as required, and, in addition, they will move on rail tracks so that the units can be arrayed in a system equivalent to a dish larger than can be built. One of the problems scheduled for the observatory is determination of the size and shape of the universe. The antenna, its gears and drives, and other equipment were manufactured by the Westinghouse Marine Division at Sunnyvale, California, and were installed by the Electric Service Division.