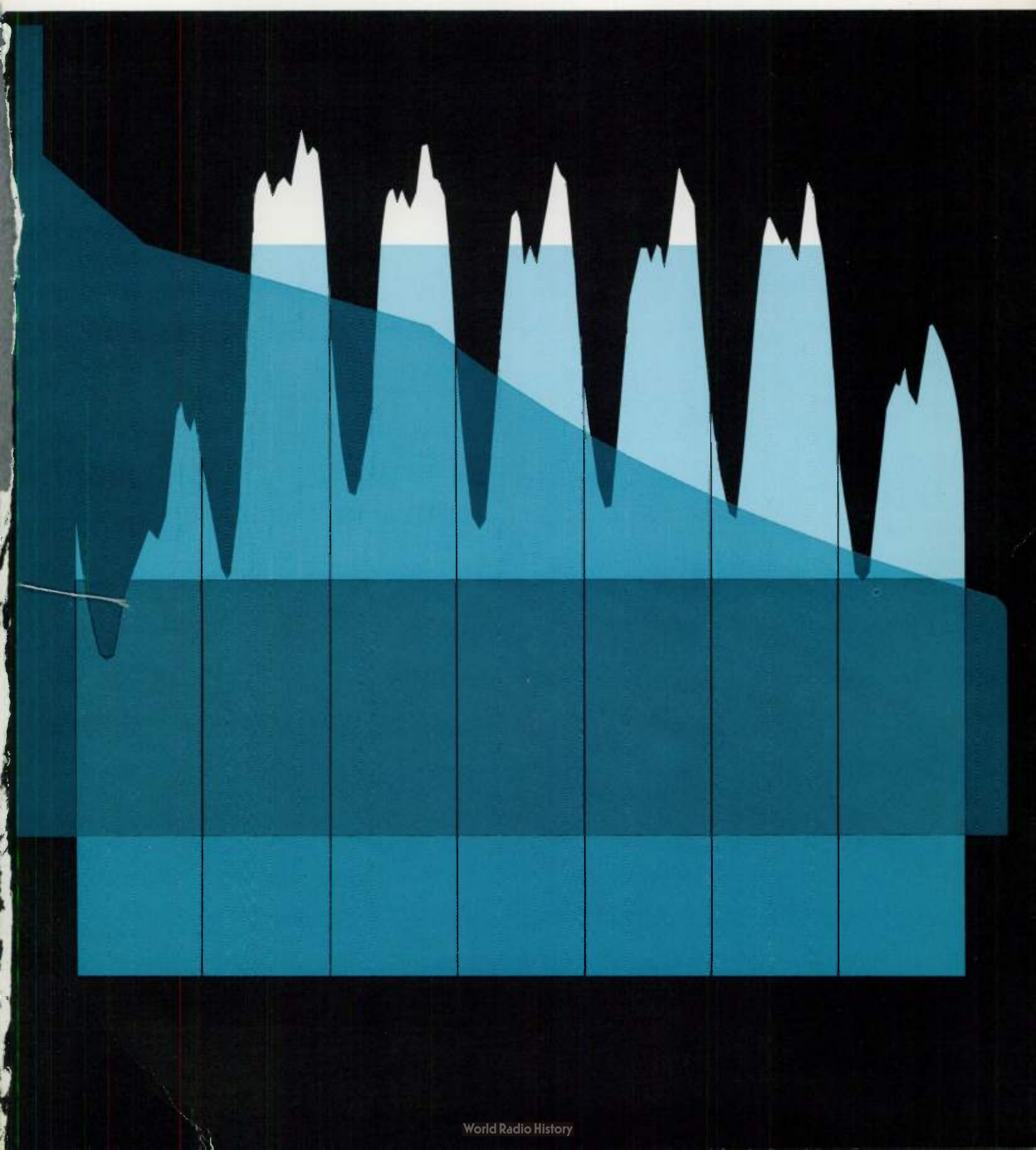
Westinghouse ENGINEER

January 1971



DC Armature Insulation Improved

The commutator of a dc motor or generator presents a formidable barrier that has made it difficult to clean surfaces to prevent electrical creepage. Now, however, a new insulation process has virtually eliminated the need for the tedious cleaning of armatures.

The Digard insulation process employs epoxy resins that have high insulating characteristics and are impervious to moisture, dust and other contaminants. It also provides very long creepage paths.

A heavy dielectric film of epoxy is first applied to all parts in the area of the risers to insulate all conductors and ground paths extending from the commutator to the shaft and from the riser connections to the core plates. Armature coils are then covered with an epoxy-bonded tape, which is coated with a high-temperature heat-reactive epoxy resin. Creepage surfaces on the risers behind the commutator, surfaces under the front coil extensions, sharp corners, and edges of bare metal are covered with an epoxy powder that is fused into a glass-like surface at high temperature. The process was developed by the Westinghouse Large Rotating Apparatus Division.

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Front cover: The lead article in this issue discusses some of the factors that will affect selection of generation capacity to provide for a utility system's base-, intermediate-, and peaking-load demands. Cover artist Tom Ruddy has synthesized the cover design from two of the curves commonly used to graphically depict these system loads: an annual load-duration curve and a weekly load curve.

Back cover: Reactor fuel rods for the Westinghouse fast breeder demonstration plant will be held in position by honeycomb grids. This view from the top end of a test rod support structure shows the honeycomb pattern reflected on the inner walls of the tube that will enclose the fuel rod array. It was made at the Advanced Reactors Division, Waltz Mill, Pennsylvania.

Some Future Dimensions of Electric Power Generation, Circa 1970–1990

P. N. Ross
L. G. Hauser

Never before an important factor in planning new generation capacity, the intermediate and peaking sized plants now will have both economic and environmental advantages in the years ahead.

During the next 20 years, the electric utility industry will face a challenging era of tremendous electrical load growth. We believe this growth will occur despite misguided, though probably well-intentioned, counsel of many that the United States should cut back on its use of electrical power to minimize environmental degradation—because there will be a continuing demand to increase the use of this vital resource to enhance the quality of life. However, concommitant with load growth will be an increased emphasis on developments in power generation that can help minimize the nation's environmental problems.

P. N. Ross is Manager, Power Systems Planning, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania.
L. G. Hauser is Manager, Fuels and Energy Systems, Power Systems Planning, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania.

The forecasted peak load and the required capacities for the entire electric utility industry in the United States for the 1970-1990 period are shown in Fig. 1. In 1970, we expect the noncoincident summer peak load to be approximately 275 GW, while the industry will have more than 300 GW of installed capacity. The noncoincident peak load represents the sum of all the electric utilities' peak loads during the summer. The various peak loads do not necessarily occur at the same hour or even the same day. By 1990, we expect the summer peak demand to exceed 1000 GW, and the installed capacity to be in excess of 1300 GW. This represents a growth rate of almost 7 percent per year.

One especially interesting aspect of this very large load growth is the summer weather-sensitive component (Fig. 2), which is basically due to the anticipated increase in air-conditioning load. This load will grow from its present value of 40 GW to an estimated 125 GW by 1980.

Thus, with a present generating capacity of about 300 GW, the additions between 1970 and 1990 must total more than 1000 GW, or three times the amount now installed. To make these additions in a way that is both economic and compatible with the environment is the challenge, the greatest that the power industry has ever faced.

Types of Generation

This massive increase in generation capacity will be made up of three basic types of generation, as defined by the annual load-duration curve (Fig. 3). This curve provides a profile of the demand on a typical power system as a function of the number of hours per year that the demand occurs. The *base-load generation* area includes those units that are operated essentially full time throughout the year. A majority of the system's kilowatt-hours are provided by this base-load generation even though it represents less than half of the installed capacity. The *intermediate-load* area consists of plant units that do not operate full time and are sometimes called "daylight plants," "two

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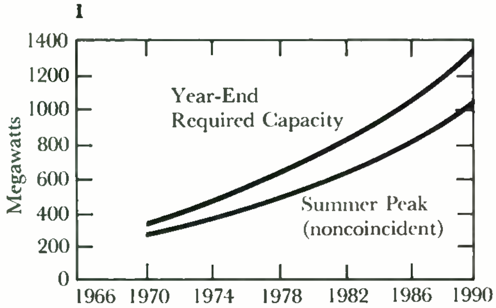

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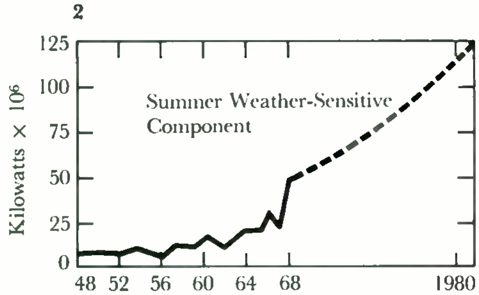

1—Forecast of peak load and required capacity for U.S. electric utility industry.

2—Summer weather-sensitive component of electric load.

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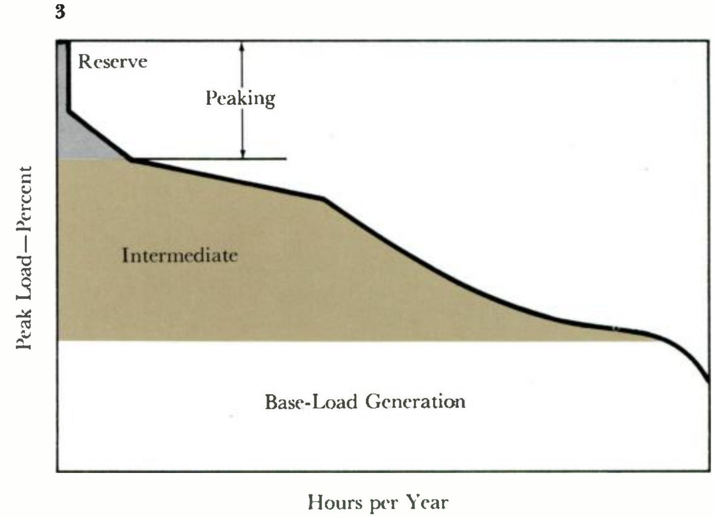

shift plants," or "five-day plants." *Peaking generation* includes those units that operate for a relatively few hours a year, plus units on standby reserve.

An integrated load duration curve (Fig. 4) provides some insight into the usage of the various types of generation capacity. The curve shows the percent of electrical energy produced by a given percentage of capacity. The base-load portion of the curve is a straight line. For typical systems, less than 50 percent of the installed capacity produces 65 to 75 percent of the energy. The upper portion of the curve represents intermediate and peaking capacity. As indicated by the curve, peaking capacity, which represents a large portion of the total system capacity, produces only a small fraction of the total electrical energy.

Perhaps the best way to identify intermediate capacity is to look at a typical weekly load curve (Fig. 5). A substantial part of the weekly load demand is on a continuous basis and is supplied by base-load capacity. The energy provided by intermediate capacity is that portion needed during the normal working hours of weekdays. These weekday loads drop off during late-night hours and on weekends. Thus, it is obvious from the curve why the units supplying these daily loads are called "daylight plants," "two-shift plants," or "five-day plants."

Nuclear-Fossil Mix of Base-Capacity Additions

Forecasted load growth leads us to expect the *base-load additions* for the next 20 years to be approximately 500 GW. Of this, nuclear power will supply approximately 75 percent of the additions, or about 385 GW. The remaining 115 GW will be fossil fueled. Aside from the environmental considerations, which strongly favor nuclear, the estimated split between nuclear and fossil units is based on our assessment of the future economics of the two fuels.

Several key factors will affect the competitive positions of these two fuel systems in the years ahead. Looking first at oil as one of the three fossil fuels, there are many fundamental reasons why it will not be a major base-load fuel:

1) Since the electric utilities are the least attractive market for oil, the price and supply of oil will primarily be determined by other market demands.

2) The high cost of domestic crude oil precludes its use as an economic base-load utility fuel. The present cost of $3.25 per barrel is equivalent to 55¢ per million Btu.

3) Many political and foreign policy influences on import restrictions make foreign oil supplies unreliable.

4) Both the high cost of overland transportation and the possibility of environmental contamination caused by oil spills tend to discourage extensive use of oil in the interior of the United States. (Today's barge costs are more than 5¢ per million Btu per thousand miles.)

The second fossil fuel, natural gas, is a highly valuable natural resource, and its use as a boiler fuel is just not commensurate with its intrinsic worth. Furthermore, a severe shortage of natural gas for fuel purposes is developing in this

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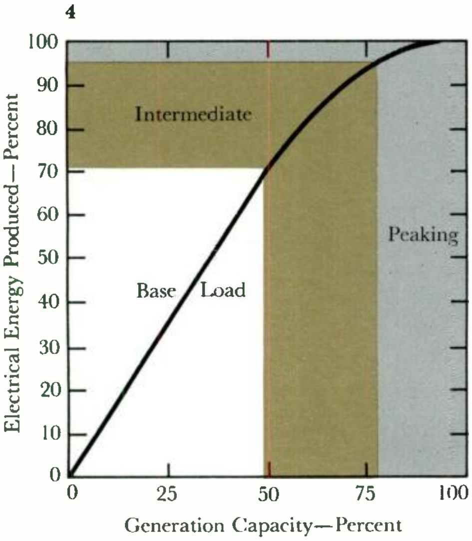

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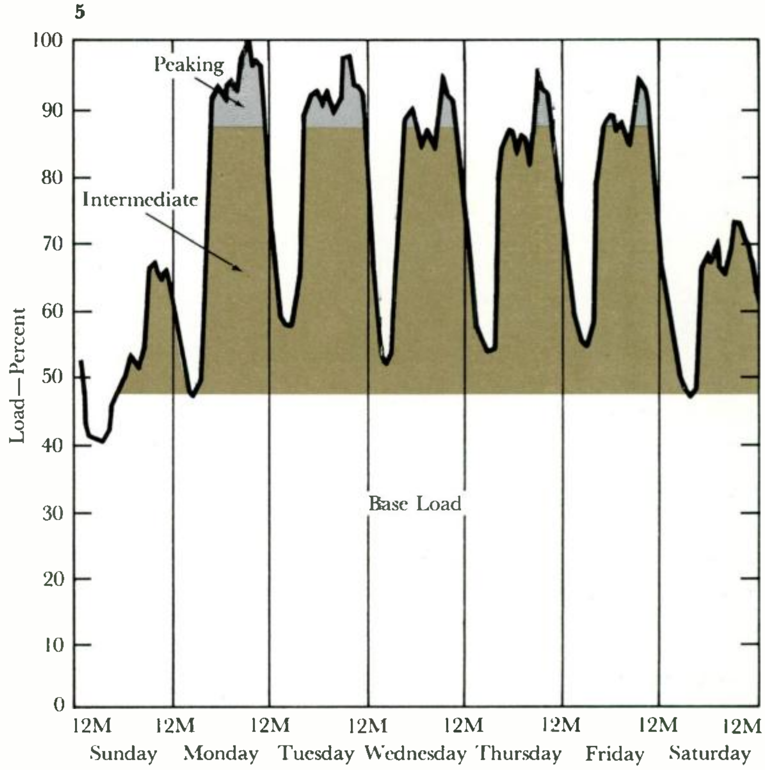

3—Typical annual load duration curve.

4—Typical integrated load-duration curve.

5—Typical weekly load curve.

country. The ratio of reserves to annual production has been declining steadily (Fig. 6), and this trend is expected to continue through 1990. The 20-year reserve that existed in 1960 is expected to dwindle to slightly more than 5 years by 1990. For these reasons, natural gas will be channeled towards the higher valued markets, and it will not be a significant factor as a base-load utility fuel.

The third and principal fossil fuel is coal. The reserves of coal in this nation are tremendous, and even at the present rate of consumption could easily supply our energy demands for at least 500 years. However, coal faces the problem of severe cost escalation.

The most important factor that must be considered when analyzing future coal prices is the effect of the mine health and safety legislation that was recently passed. This bill's biggest effect will be to sharply decrease productivity on a tons-per-man-day basis in the next two years. This is a complete reversal from the trend of a continuing increase in productivity that the coal industry experienced from 1950 to 1968. Productivity is expected to drop from 20 tons per man-day in 1969 to approximately 14 tons per man-day in 1971, as shown in Fig. 7. After this low, productivity should again begin to increase but at a much slower rate than was experienced between 1950 and 1968.

By coupling the decrease in productivity with the expected escalation in costs for labor and material, the increases in the cost of coal through 1980 can be projected (Fig. 8). (The bottom curve shows the average mine-mouth price of coal, and the top curve shows the price of coal 200 miles from the mine with transportation by dedicated unit train.) As indicated, the price of coal will approximately double during this decade.

The future economics of nuclear fuel differ from those of the fossil fuels and especially coal. In analyzing future nuclear fuel costs, we found the following:

1) The price of yellow cake in 1970 constant dollars will remain at $7 per pound during the next ten years. However, as shown in Fig. 9, this price will be subject to escalation of labor and material rates, so that the actual dollars per pound will increase to slightly more than $8 per pound by 1980.

2) The price of fabrication per kilogram of uranium will decline during the 1970-1980 period because fabrication is a manufacturing process, subject to the economics of volume, automation, and the learning curve. The lower curve in Fig. 10 shows the projected price in 1970 constant dollars, and the upper curve reflects the escalation factors that will apply during this ten-year period.

3) Costs of reprocessing and reconverting spent fuel will decline in the middle to late 70's as additional capacity and volume throughput come on stream. As shown by Fig. 11, price in dollars per kilogram will decrease from the $35 to $40 range in 1970 to a $25 to $30 range by 1980.

4) The total effect of these results will be a moderate decline in the cost of nuclear fuel in actual dollars (Fig. 12) to about 17¢ per million Btu by 1980.

Therefore, to substantiate the predicted fossil-nuclear split (385 GW of nuclear additions and 115 GW of fossil additions by 1990), it is only necessary to compare the projections of the future costs of coal and nuclear fuel (Fig. 13). By 1980, nuclear fuel will be less than one-half the cost of mine-mouth coal. As a result, the competitive position of nuclear power will grow even stronger through the next decade.

Another way of looking at this difference in fuel cost is to examine its effect on the capital cost differential (Fig. 14). The break-even capital cost differential at the present time between a nuclear plant and a coal-fired plant obtaining coal at a distance of 200 miles is $50 per kW. By 1980, this break-even differential will have increased to more than $100 per kW in favor of nuclear power.

Intermediate Generation

The second class of electric power generating equipment that will be put on line in the next two decades is called cycling or intermediate type generation. This type of unit operates in the middle range of the annual load-duration curve (Fig. 3) and serves the additional daily load above base load between the hours

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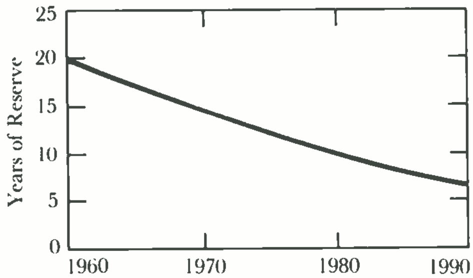

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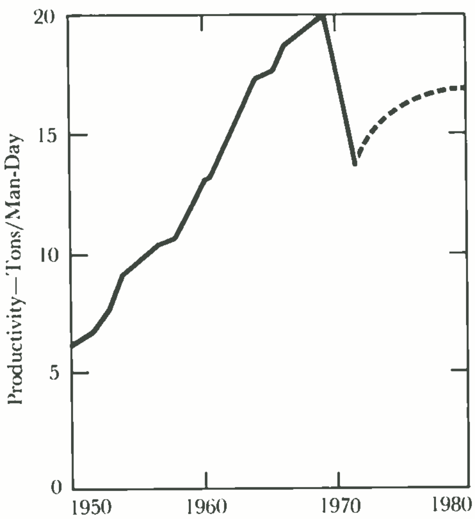

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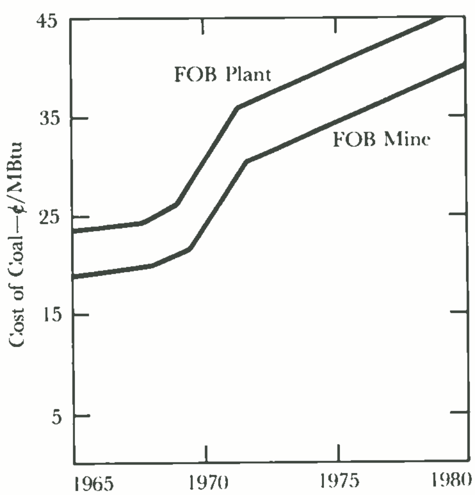

6—Gas inventory forecast (reserves/annual production).

7—Average annual coal production (tons/man-day).

8—Projected average coal price, fob mine and fob plant (actual dollars).

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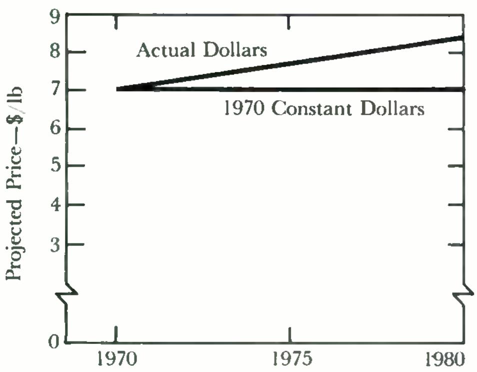

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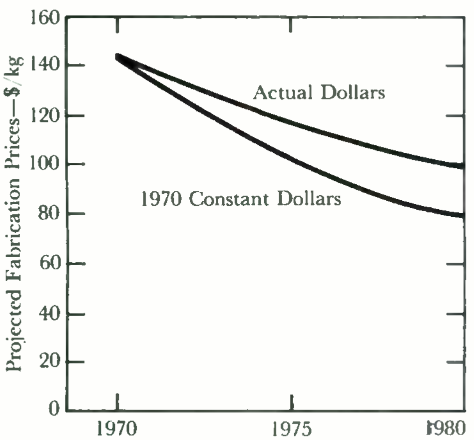

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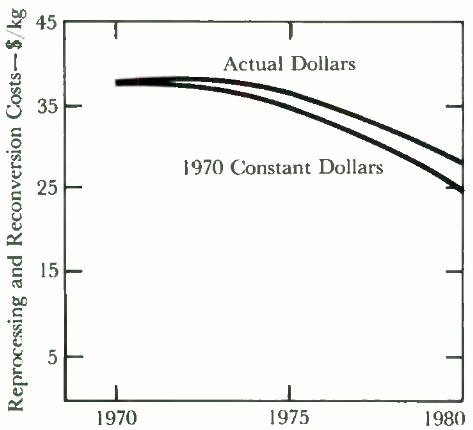

9—Projected price of uranium (U_3O_8).

10—Projected fabrication prices for uranium fuel.

11—Projection of nuclear fuel reprocessing and reconversion costs.

of approximately 7 a.m. and 12 midnight (Fig. 5). The units have a considerably lower capacity factor than base-load units, and they must be capable of rapid load change and daily start-up. In the 1970 to 1990 period, more than 400 GW of this type of capacity is expected to be installed in the United States. The size of this market was determined by using the definition of intermediate generation that was established earlier and also by using the forecasted load growth.

In the past, the usual practice of electric utilities was to install new and highly efficient steam units, either nuclear or fossil, to supply the base-load portions of their loads. The older less efficient steam plants were moved out of base-load service and were used to serve the cyclic portions of the load. This method has worked well because the older units, with their low steam pressures and temperatures, were quite adaptable to cyclic operation. Furthermore, the higher heat rates of these older units did not penalize the system because of the low capacity factor of intermediate duty. However, there are now several forcing factors tending to change this past pattern of only installing new base-load units:

First, there has been a recent trend to install very large, highly efficient base-load steam electric units that are not designed for flexible peaking service. These high-temperature, high-pressure steam units are not capable of being cycled without major and costly alterations. Therefore, the units will not be adaptable to intermediate duty and must continue to supply the base-load portion of the utilities' demand load. This will create a need for additional intermediate capacity.

Second, new units in the past have been considerably more efficient than existing units on the system. Therefore, it was logical to operate the newer units in the base-load area and move the less efficient older units to intermediate operation. However, we are now approaching a point where, unless there is a major technological breakthrough, the future efficiencies of new steam plants will not increase as rapidly as they have in the past. In fact, with the new thermal dis-

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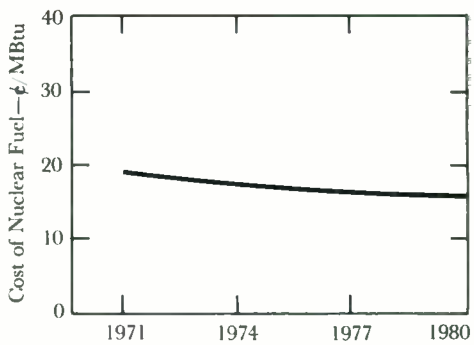

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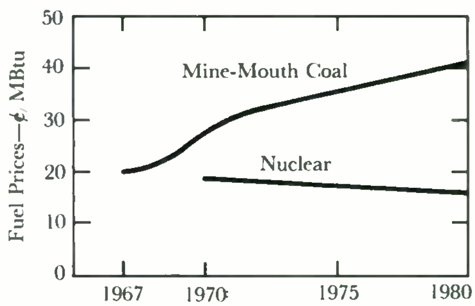

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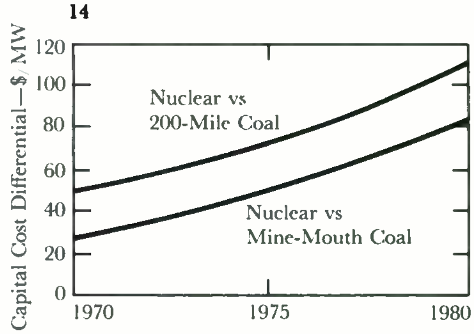


12—Cost of nuclear fuel.

13—Projection of fuel prices (actual dollars).

14—Plant capital cost differential due to fuel cost differential.

charge regulations necessitating supplementary cooling systems, such as cooling towers, the efficiencies of new units may even be lower than those of existing base-load generation.

Another factor that could influence the policy of installing only new base-load units is that the installation of larger and larger units will not have the economic advantage that it has had in the past. The economies of scale are becoming asymptotic as the units become larger, and larger sizes will no longer produce a significant lowering of the capital cost ($/kW) of the plant. These changing economics will create a need for cycling units designed for relatively low capital cost in addition to low heat rate.

And finally, the total load in the United States is now growing much faster than the availability of older type steam units. That is, the intermediate load will grow at such a rapid rate that there are not enough older units installed today to supply this demand. New units will have to be added to the intermediate range to fill this void.

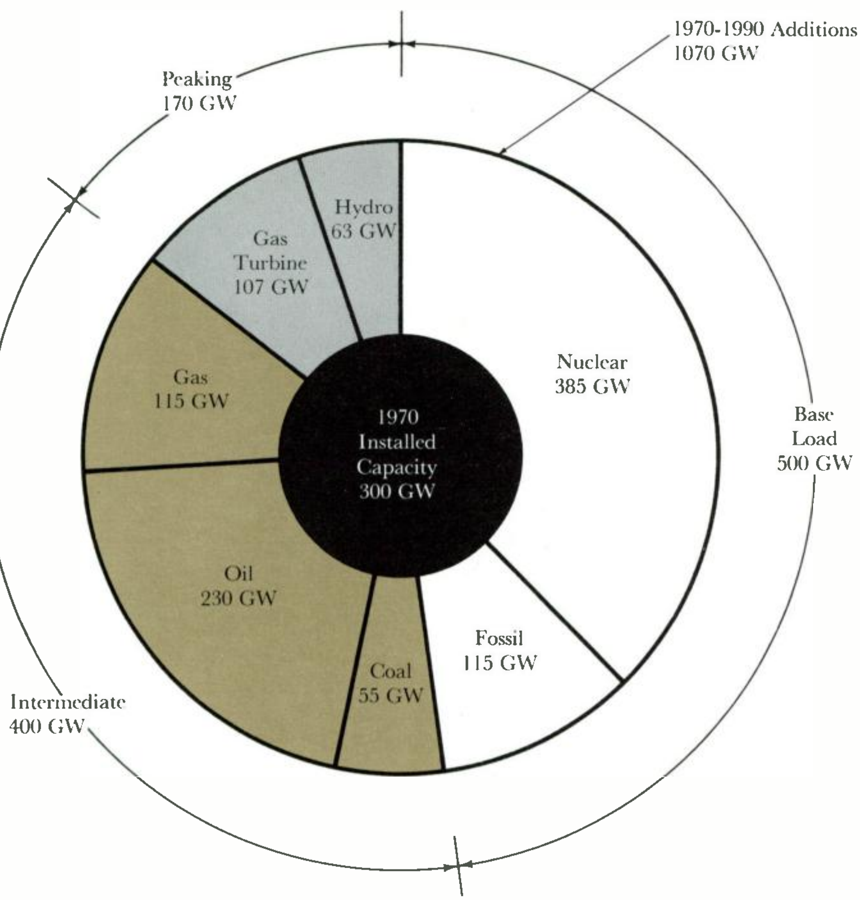
For these reasons, new units are being purchased specifically for intermediate type service. The characteristics of intermediate units will be: 200-MW to 600-MW unit size range; capable of daily start-up; able to change load rapidly; and designed as relatively low capital-cost units.

The combined-cycle plant being designed by Westinghouse[1] is ideally suited for intermediate operation. This new method of power generation will use either gas or oil as a fuel. The combined-cycle plant has several favorable factors that should assure its success as an intermediate load plant.

The plant rating is approximately 230 MW, which fits into the desired size range for intermediate duty. The 230-MW capacity is composed of two W-501 frame industrial gas turbines, each with a rating of approximately 60 MW, and a large single-case, low-pressure, 3600-r/min steam turbine with 28.5-inch last row blade length. The steam for the steam turbine is generated by two waste-heat boilers that use the hot discharge gases from the gas turbines. The plant is designed for maximum packaging of components to reduce to a minimum erection time in the field. Water requirements are half those for a fossil plant.

In addition to having the proper size for intermediate generation, the combined cycle is also an excellent plant for rapid load follow and daily start-up. The plant is capable of being brought up to full load power in one hour from hot stand-by conditions. Half load can be reached in approximately 30 minutes.

Perhaps the most significant factor that favors the combined-cycle plant is economic. The capacity factors of units operated in the intermediate range vary from approximately 30 to 70 percent. Because of these low capacity factors, it is economically advantageous to have a rather low capital cost plant for this type of operation. The generation cost of electricity (mills/kWh) is significantly influenced by the capital cost and it may even be necessary to sacrifice plant heat rate for a low capital cost at the lower capacity factors. This is precisely what the combined-cycle plant accomplishes. The two gas turbines are relatively low in capital cost, but they have a high heat rate when compared to the high-capital-cost steam plants. The combination of gas turbines and a steam turbine in a combined-cycle plant form the most favorable economics for intermediate operation. The capital cost of the combined cycle is considerably less than a steam plant, and the heat rate (8850



15—Projected 1970–1990 generation additions.

[1] P. A. Berman and F. A. Lebonette, "Combined-Cycle Plant Serves Intermediate System Loads Economically," *Westinghouse ENGINEER*, Nov. 1970, p168-73.

Btu/kWh) is lower than present fossil-fired cycling steam units (11,000 Btu/kWh) but slightly higher than base-load steam plants (8800 Btu/kWh). For these reasons, the combined-cycle plant should provide a major portion of the utilities' intermediate capacity needs in the years ahead.

The remaining intermediate generating capacity will consist of conventional fossil-fueled steam plants that will mainly burn gas or oil. Because of their relatively high capital cost, nuclear plants will not be contenders for this type of generation.

Of the estimated 400 GW of intermediate capacity that will be added in the 1970 to 1990 period, 230 GW will be oil fired, 115 GW will be gas fired, and 55 GW will use coal (Fig. 15). The reason coal captures such a small portion of the intermediate generation is that coal-fired steam boilers are more difficult to operate in a cycling fashion than are oil- or gas-fired units. The use of gas as a fuel will be limited, of course, to those areas where natural gas is available at a reasonable cost, such as the Southwest. Heavy-duty fuel oil is expected to capture the major portion of the intermediate type generation for several reasons: oil is relatively easy to control in the combustion process, it can be readily stored, and oil-fired boilers are easier to cycle than coal-fired units. Another factor favoring oil for intermediate generation is that air pollution presents no problem: equipment to remove sulfur dioxide from stack gases is expected to be difficult to cycle, but the sulfur content can be readily removed from residual oil prior to the combustion process.

Peaking Generation

The last segment of generation growth is peaking generation, which operates for a relatively few hours per year (Fig. 3). The basic requirements of peaking units are that they have a low capital cost, that they are capable of a quick start, and that they have the capability of load follow. Industrial gas turbines and pumped-storage hydro are the principal units for this purpose. We expect that of the 170 GW of peaking capacity that will be added over the next 20 years, about 100 GW will be gas turbines and 70 GW will be pumped-storage units (Fig. 15).

The economics of pumped-storage hydro often fit especially well with nuclear power plants. Pumped storage provides generation capacity during system load peaks, and a controllable load to the system during off-peak periods. This helps even the peaks and valleys of the system load cycle so that the nuclear plant can be operated at a high capacity factor.

Gas turbine units, which generally are pre-engineered and largely preassembled, are particularly well suited for peaking operation because of their low capital cost. They are able to follow load quite well and are capable of quick start. Gas turbines can be started and brought to full load in a matter of minutes. In addition to these favorable factors, there are several other reasons for our belief that gas turbines will provide a large share of the generation capacity in the future. Since gas turbines are largely preassembled, the lead time for installation of a unit is much less than other types of electric power generation and the installation of the unit itself is much less complex. Second, gas turbines have a wide choice of site locations. They can be installed at existing steam-electric plants, substations, or new plant sites. They can also serve a dual purpose in that in addition to providing peaking power, they can provide a "black start" capability for a large conventional steam plant. Of course, higher combustion temperatures and air-flow rates, and larger unit sizes—all of which are expected of gas turbines in the near future—make this type of generating capacity even more attractive.

From the standpoint of impact on the environment, the preferred fuel for gas turbines is natural gas. However, as was mentioned earlier, the use of natural gas will be limited to areas where it is available and the cost is reasonable. A second fuel for gas turbines is high-grade distillate oil. This fuel is expensive but sulfur free and produces slightly less nitrogen oxide because of the lower combustion temperatures. Since the fuel has no measurable vanadium or sodium if properly refined and handled, it is clean burning and not harmful to gas turbine components.

Today, heavy, high-viscosity fuel oils that contain small amounts of vanadium and sodium are being tested by gas turbine manufacturers, oil companies, and electric utilities as a new fuel for gas turbines. Although these fuels are clean and may burn well, there are other problems that must be overcome. For example, the pour-point temperature of some of these fuel oils that have a high wax content is over 100 degrees F. They would require heated storage tanks and lines to prevent fuel solidification. However, if the world oil situation stabilizes, these fuels should sell for approximately one-half the cost of distillate. When this new, relatively inexpensive heavy fuel oil is developed, it will make the industrial gas turbine even more attractive for peaking applications.

Conclusion

The electric load growth rate over the next 20 years is expected to require generation capacity additions totaling more than 1000 GW by 1990—a threefold increase. In contrast to the past, only about one-half of this tremendous growth will be provided by base-load generating units (Fig. 15). Instead it is anticipated that the utilities will find it increasingly advantageous to install intermediate and peaking-type generation as well as base-load capacity. Seventy-five percent of future base-load additions are expected to be nuclear with all of the intermediate-sized units being fossil fueled. Gas turbines will predominate for peaking additions.

Automated Transit System Reduces Walking in Expanding Airport

Ralph Mason

Airport terminal buildings and their parking areas increase in size as air traffic increases, usually resulting in ever-longer walking distances for airport users. At Seattle-Tacoma International Airport, however, a combination of good design of the current expansion and an automated transit system will reverse the trend toward increasing walking distances.

A modernization program under way at Seattle-Tacoma International Airport will eliminate most of that usual hike of ¾ mile or so between the air traveler's car and his airplane seat. The program includes an increase from 23 aircraft gate positions to 65, but creative planning and design have greatly shortened the walk usually required and also kept the expansion in passenger- and airplane-handling capacity from taking acres of new land.

The terminal concept employs two new satellite buildings. In addition, existing concourses are being extensively rebuilt, and a multistory parking facility is under construction.

Each satellite terminal is a building whose total perimeter can be used for airplane positions, and around which the jets of today and tomorrow can maneuver and taxi without hindrance. The concept depends on a method of moving people to and from the satellite buildings and to and from the ends of concourses 900 feet from the main terminal. That method is the automated Satellite Transit system developed by Westinghouse with the Port of Seattle and its major consultant—The Richardson Associates, architects, engineers, and planners. The system consists of automated vehicles running through tunnels, singly or in trains according to traffic demand.

Transit System Requirements

The requirements of the system were determined by forecasts of passenger movement, which took into account the possibility of near-simultaneous arrival of two or more jumbo jets such as the 747, L-1011, and DC-10 carrying 250 to 400 passengers each. Extensive system studies led to the development of a plan employing vehicles on two single-track loop lines and on a single-track shuttle line connecting the two loops (Fig. 1). All track is totally underground. The two loop lines connect the main terminal building with concourse and satellite buildings to the north and south.

A computer simulation study of passenger movement through the airport provided the basis for specifying the passenger-carrying capacity of the transit system. The initial computer model simulated the movement of passengers and their friends, airline crews, and airport employees for typical days in 1967; its results were checked against actual records to develop a valid model. This program was then used to forecast the movement of people in 1970, 1975, and 1980 on the basis of expected growth of passenger traffic.

Besides estimates of gross movements around the airport, the simulation revealed that considerable peaking could be expected; therefore, the planners determined that a period of five minutes was the relevant time interval in determining maximum passenger flow rates. The consequent capacity requirements for the Satellite Transit are shown in the accompanying table.

Since there will always be passengers in a hurry to catch planes about to depart, the transit system must provide the shortest practical journey time. The two basic components of journey time are waiting time and trip time. Waiting time is a function of train frequency ("headway"), and trip time depends on the average speed of the train between stations and the time that trains spend stopped in stations ("dwell time"). The headway that minimized passenger journey time on the loop lines was found by extensive system studies to be approximately 120 seconds, although headways as low as 100 seconds are possible under light load conditions when dwell times can be reduced. Top speed is about 25 mi/h, and station dwell times in the continuous operating mode vary from 40 to 60 seconds. Journey time normally will not exceed 4 minutes for any user.

Aside from the overall passenger-capacity and speed requirements just mentioned, the size and layout of individual vehicles are largely determined by the number of seats to be provided, the average weight of a passenger (including carry-on baggage), and the space allowed for that passenger. Anthropometric data from a number of sources were used to determine average passenger weight and size, and standards developed in urban rapid transit and other transportation systems were reviewed. Omitting seats in a short-ride vehicle maximizes the capacity of the vehicle. However, it was determined that at least 10 percent of the passengers carried in a fully loaded vehicle should be provided with seats because of the possible effects of accelerations on the elderly and infirm. The design arrived at allows 2.5 square feet for all 92 standing passengers expected in a fully loaded vehicle (106 passengers) in the peak 5 minutes of the peak hour. Vehicles are designed for an average passenger weight, with carry-on luggage, of 170 pounds. In many off-peak hours, the 14 seats will suffice for all passengers.

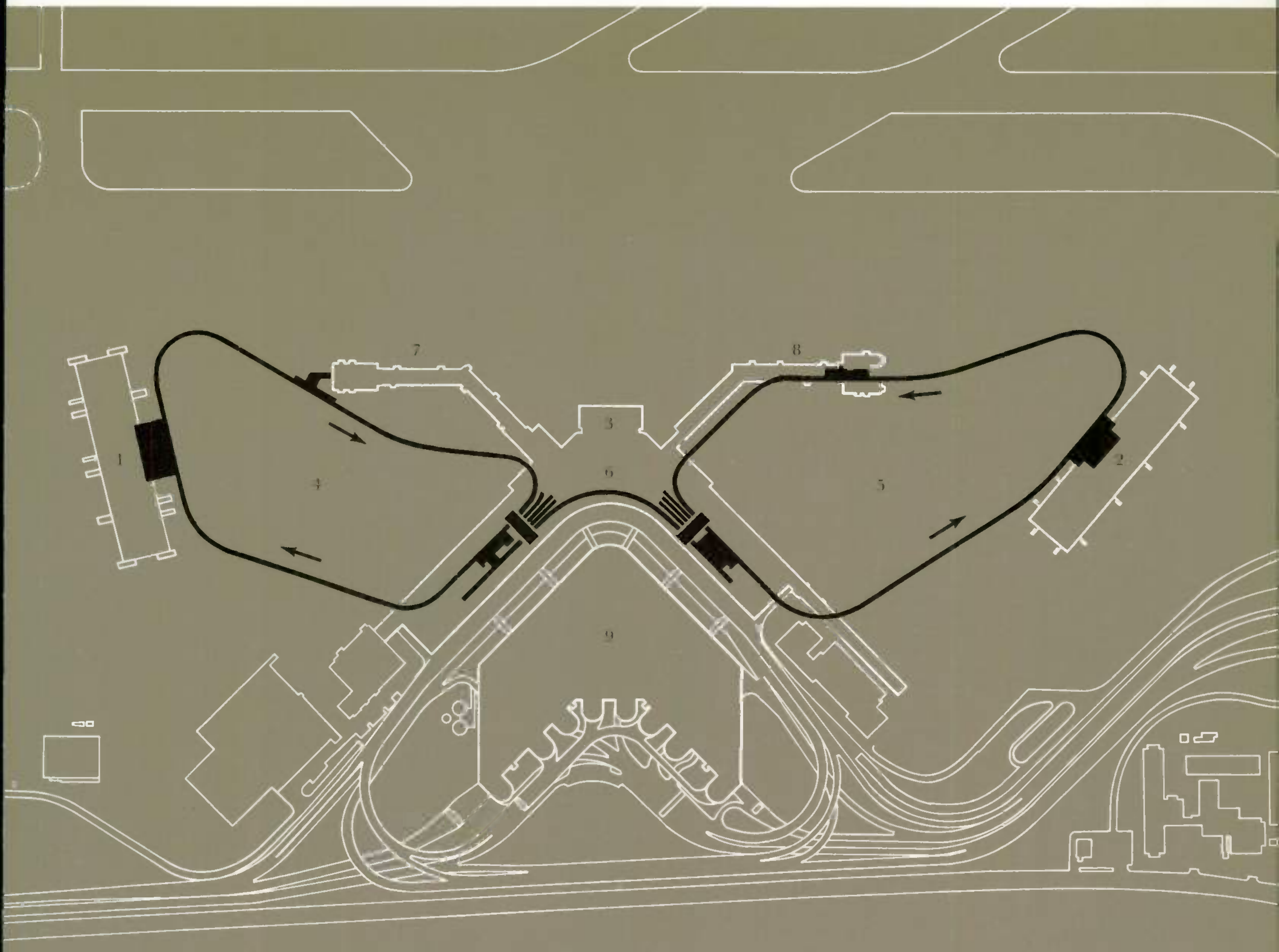
The System

The Satellite Transit system utilizes many features of the Transit Expressway, which is a rapid-transit system employing electrically powered rubber-tired vehicles moving on a roadway consisting of two concrete running surfaces.[1] The vehicles are guided by a steel beam located midway between the running surfaces. The flexibility of Transit Expressway allows economic application at grade, on elevated structures, or below ground. The Satellite Transit system also has drawn

Predicted Capacity Requirements of Satellite Transit, One Way per 5 Minutes

Year	*Loop Lines*	*Shuttle Line*
1971	400	60
1975	650	100
1980	1200	175

Ralph Mason is a project manager at the Transportation Division, Westinghouse Electric Corporation, Pittsburgh, Pennsylvania.



1—The Satellite Transit system at Seattle-Tacoma International Airport is so named because it will link two new satellite terminal buildings (south, *1*; north, *2*) with the main terminal building (*3*). It consists of the South Loop (*4*), North Loop (*5*), and Shuttle (*6*). The system is underground so that airplanes will be able to load and unload all around the satellite buildings as well as on both sides of the projecting concourses (*7* and *8*). A parking garage (*9*) is adjacent to the main terminal building. Automatic control of the passenger vehicles will minimize waiting and travel times. (Figs. 1 and 5 are used by permission of The Richardson Associates.)

on the technology applied in the passenger transfer system at Tampa International Airport.[2]

Satellite Transit tunnels measure approximately 14 feet 6 inches wide by 13 feet 10 inches high (in the straight sections) and are being constructed by the cut and cover method. The North Loop consists of about 4100 feet of tunnel, the South Loop 3700 feet, and the Shuttle 1100 feet. Every portion of the tunnel contains a walkway for maintenance and emergency purposes; if a train stops due to a power failure or malfunction, passengers can step from the vehicle to the walkway and walk out of the tunnel.

The trains are driverless, all movements being made under the control of fail-safe electronic equipment. As in Transit Expressway, each vehicle is locked to the roadway by pneumatic guide wheels backed up by steel discs that run close to the web and beneath the top flange of the I-section guidebeam, a feature that insures against derailment.

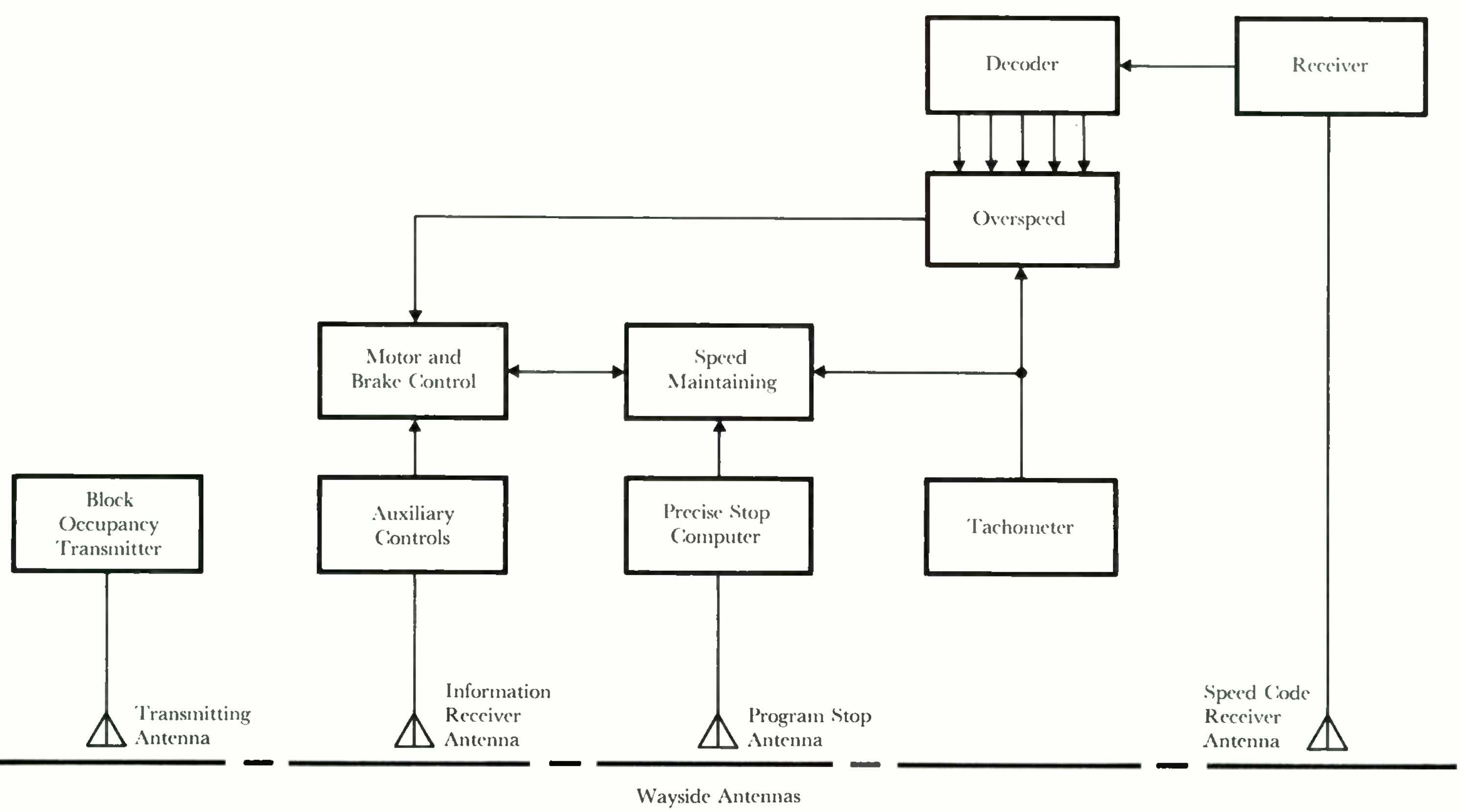
Power System—Three-phase ac power at a nominal 600 volts is supplied to the vehicles, for main propulsion and all auxiliary and control purposes, by power rails mounted on one side of and below the roadway running surface. There are six substations, three feeding the South Loop and three the North Loop; the Shuttle is also fed from one of the North-Loop substations. Each substation is supplied with 12.5-kV three-phase 60-Hz power from one of two main substations at the airport.

The power system is designed for a threefold increase in power requirements. Its feeder and distribution system will be installed to handle 3600 kVA, but the initial transformer capacity will be 1200 kVA. As airport traffic volumes expand and more vehicles are required, additional transformers will be installed to supply the necessary power to the system.

Power rails are sectionalized to allow portions to be safely taken out of service for routine maintenance. Power is collected on the vehicle by two current collectors mounted on one axle, this arrangement providing redundancy and therefore increased reliability. The vehicle also carries a grounding brush that contacts a continuous ground rail laid along the top of the guidebeam. The ground rail is connected to each span of the guidebeam which is, itself, grounded by connection to rods driven through the tunnel floor at regular intervals. The power rail system includes a protective cover, which, in the unlikely event of something falling on the rails, will minimize the possibility of short circuits.

Vehicles—Each vehicle is 37 feet long, 11 feet 3 inches high, and 9 feet 4 inches wide. Two 8-foot-wide doorways are located on the station side of the vehicle. On-board control equipment interacts with the wayside and central parts of the

2—The car-carried part of the control system receives information from wayside antennas and converts it into control and communication signals. It also transmits information to the wayside antennas.



Satellite Transit's automatic train control system (Fig. 2).

Movement of large numbers of passengers into and out of the vehicle (as many as 212 at the main-terminal stations) with a minimum of confusion and in the shortest time possible was a prime objective in the layout of the interior (Fig. 3). Windows in the ends and seats located on the opposite side from the doors provide natural inducements for entering passengers to move away from the doors, thus allowing room for other passengers behind them. Windows in the vehicle doors will add to the passengers' sense of motion and provide visual notice of the approach of stations.

To orient passengers, graphic display panels are located above head height on either side of the vehicle interior. The display panels incorporate a schematic map of the transit system, portions of which are sequentially illuminated to indicate the present location of the train and the next station at which it will stop. To supplement the visual information, recorded audio messages will announce the next station stop and the airport gates accessible from that station.

Interior furnishings include carpeted floor and walls, vinyl-covered seats, stainless-steel stanchions and handrails, and anodized-aluminum and Micarta trim. Bright nonglare lighting and a filtered and conditioned air supply assure passengers a comfortable atmosphere.

Guidance, propulsion, and braking systems are located beneath the floor. The car rides on eight pneumatic rubber tires (two dual wheels per axle), and it is guided around the tight curves of the loop tracks by eight pneumatic guidewheels that ride on the web of the central I-beam. (Minimum curve radius of 96 feet was dictated by the need to weave the system between the columns of an existing building.) The body suspension is an air-bag and leaf-spring type that provides lateral and longitudinal stability.

A full passenger load approximates 9 tons. To maintain the vehicle floor at a uniform height relative to station platforms, an automatic floor-leveling system controls pressure in the air bags in proportion to the passenger load.

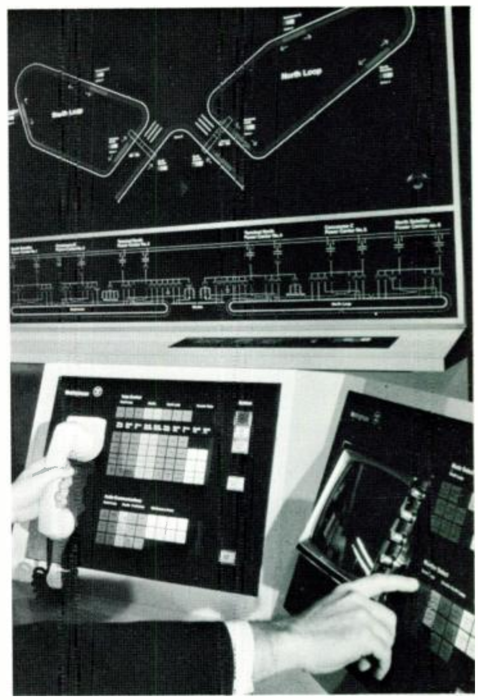
Electric power fed to each vehicle is conditioned by a transformer and a full-wave thyristor control on the vehicle. The control delivers an infinitely adjustable dc voltage to a single 100-hp series-wound traction motor and thus allows smooth acceleration and fast response to propulsion commands. As the train reaches a desired speed on varying grades, or is required to slow down for a curve or station stop, the propulsion control equipment adjusts and maintains motor torque and speed to the required level.

The braking system consists of truck-type drum friction brakes operated by compressed air, with each pair of dual wheels equipped with a brake drum and two sets of brake shoes and actuators. Each axle has a separate braking system to provide redundancy and to improve brake-system performance. In addition, a fail-safe spring-applied back-up system is provided for emergencies.

The vehicles can operate at 25-percent passenger overload for 6 minutes of any one hour. At greater overload, an interlock prevents operation.

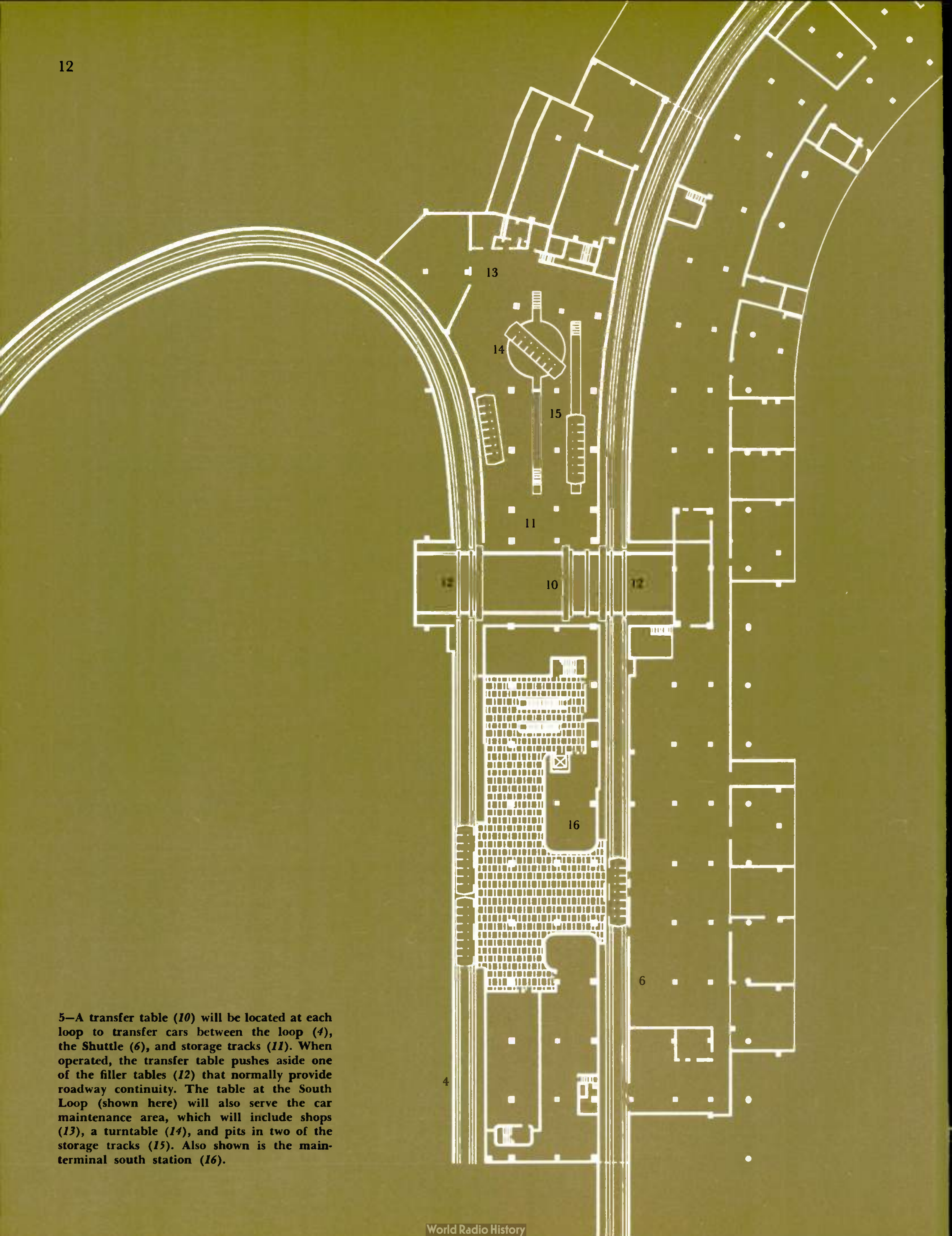
Automatic Train Control—The Satellite Transit is controlled by an automatic electronic communication and logic system, which employs a train protection system incorporating fixed geographic lengths of track known as "blocks." Trains may travel at speeds up to a certain fixed maximum within a given block, the maximum being determined from various factors including limitations due to curves and stopping distances. Separation of trains is achieved by transmitting different maximum-allowed speed commands to each block. Movement of a train automatically sets the allowed maximum speed of the block through which it last passed to zero. Thus, if a train stops in a block for some reason, the train traveling behind it in the same direction runs into the zero-speed-limit block and stops within it, thereby avoiding the possibility of collision with the train stopped ahead.

The automatic train control system that implements this principle is designed so that any failure of equipment results in a safe condition, thus assuring the safety of passengers. It has three major



3—Transit cars can be operated singly or in trains, depending on demand. This mockup of a car interior shows the overhead visual display that tells riders where they are and where the car will stop next. Because of the brevity of the ride, and to maximize carrying capacity, only a few seats are provided.

4—Central control consoles will permit operator inputs to the automatic transit control system. A display panel will show system status and car positions continuously.



5—A transfer table (*10*) will be located at each loop to transfer cars between the loop (*4*), the Shuttle (*6*), and storage tracks (*11*). When operated, the transfer table pushes aside one of the filler tables (*12*) that normally provide roadway continuity. The table at the South Loop (shown here) will also serve the car maintenance area, which will include shops (*13*), a turntable (*14*), and pits in two of the storage tracks (*15*). Also shown is the main-terminal south station (*16*).

subsystems: wayside control, central control, and car-carried control.

Wayside control consists of equipment mounted in cubicles close to each passenger station and connected to each block. Within each block is an antenna laid along the track and serving that block only; signals are transmitted and received between the station equipment and this antenna. Antennas aboard each vehicle pick up the signals in the wayside antenna and in this way receive information from the wayside. The vehicle-mounted antennas can also transmit information to the wayside antenna, and that information can then be fed back to the station equipment.

The wayside controls provide the correct speed-encoding signals to the trains around the system, and to all unoccupied blocks, through fail-safe circuits. Further, the equipment provides interlocking functions at the transfer tables (which move vehicles between service and storage tracks), provides signals for coupling and uncoupling cars on the loops, and controls station stopping, station and vehicle door operation, and the station dwell time.

A program-stop technique previously developed by Westinghouse provides precise stopping of trains at stations under all conditions of approach velocity, grade, and load. Train stopping is so accurate that doors will be used between the station area and the vehicles. The doors operate much like elevator doors. Separation of the building and the transit system has a number of advantages, including the ability to air-condition the station area, blocking out of any noise or draft caused by train movement, and the added safety afforded passengers by preventing access to the roadway. The station doors are controlled by the wayside equipment in unison with the vehicle doors.

The program stop technique employs a special transposed-cable station-stop antenna laid along the track at station approaches. The wayside equipment energizes this antenna with a continuous frequency signal that, through the regular transposition of the cable (and the phase shift thus induced), provides position intelligence to the car-carried control equipment. Additional wayside antennas mounted at the stations check that the train has stopped within the established position tolerance. If that and all other safety conditions are satisfied, the control sends an "open" command to the vehicle and station door equipment. After a preselected dwell time, the wayside control equipment sends a "close" command to the door systems.

The *central control* is connected to each set of station equipment. It is located on the fourth floor of a multistory parking facility adjacent to the main terminal building. System operation is controlled at consoles (Fig. 4). However, this control is limited to changing the mode of operation of the system, changing station dwell times, changing the number and size of trains, and stopping trains. Once established in a given operational mode, train movement is entirely automatic and does not require action on the part of central-control personnel.

System operational modes have been designed to accommodate varying traffic demands and to allow routine maintenance of the roadway and power system. For operating purposes, the system is broken down into the geographically separated North Loop, South Loop, and Shuttle, and a different mode of operation is possible on each section at any one time. Each loop can function in one of two "operating" modes and one of four "movement" modes; the Shuttle has the same two operating modes but only one movement mode (back-and-forth operation of its single vehicle).

The first operating mode consists of continuous train operation with a predetermined dwell time at each station. The second is the on-call mode, which is similar to elevator operation in that a passenger must push a button at any station to start the trains operating. In the second mode, an optical sensing device between the station and vehicle doors automatically sets the system section for one complete round trip every time the light beam is broken. This operating mode will normally be used at off-peak hours when passenger demand is fairly light. It assures a passenger of reaching his desired destination, but if there is no further passenger demand it holds the trains at the stations with doors closed.

The four movement modes on the loops are: clockwise looping on the South Loop and counterclockwise looping on the North Loop by one, two, or three trains; one train shuttling directly back and forth between any two adjacent stations; one train shuttling back and forth between any two stations and stopping at an intermediate third station; and two trains each shuttling between two adjacent stations, one of which is served by both trains, with each train moving in the same clockwise or counterclockwise direction at the same time.

The first movement mode is the normal one and will be used most of the operating day. The other three allow any section of track to be taken out of service for maintenance.

The complexity of system operation created by the possible combinations of modes for each of the three sections made the task of central control supervision a suitable application for a digital computer. In addition to initiating and supervising the operation of each section of the system, the computer will supervise and adjust station dwell times, initiate and supervise the coupling and uncoupling of vehicles, initiate and supervise transfer-table operations, check and verify the legality of certain input commands originating at the control consoles, control the starting sequence of trains to minimize simultaneous starts and thus smooth power demand, and perform certain other functions.

One group of pushbuttons on the central console is used to initiate operation of the transfer tables that add or remove vehicles to or from the system. Each of the two transfer tables is part of a subsystem that also includes two filler tables, which are normally positioned in the main roadway (Fig. 5).

When a car is to be added to a train, it is first checked out functionally by a maintenance man and then moved onto the transfer table, which is aligned with the storage track on which the vehicle is located. When the vehicle is correctly positioned on the transfer table, the automatic operations to add it to the system are initiated by pushing a button on the central control console to bring into operation a computer program. The next train to cross the filler table is stopped at the normal station position just down the roadway from the table, the transfer table and vehicle move into the main guideway, the added vehicle moves forward at low speed and automatically couples with the train, the computer verifies that all train-line circuits have been made, the transfer table moves out of and the filler table into the main guideway, and the train is allowed to leave the station. The operating sequence is fail-safe in that it is stopped by any failure of the computer or any lack of input regarding positioning and locking.

A similar fail-safe procedure is used to remove a car from a train. The train stops with its last car positioned on the transfer table (previously moved into the main roadway), the car is uncoupled, and the remainder of the train moves forward into the station. The transfer table and vehicle then move out of the main guideway, and the filler table moves in to provide track continuity.

Car-carried control aboard each vehicle includes interface equipment to receive the transmitted speed and information commands from the wayside and convert them into signals to the propulsion and braking controls, door controls, interior graphics, and communications (Fig. 2). It is divided into several subsystems, which are rack-mounted in separate cradles and thus easily removed for maintenance and rapid restoration of train service in the event of a malfunction. Each cradle has a number of printed-circuit boards composed of integrated circuits and other solid-state devices. Also included aboard each vehicle is the precise-stop computer that performs the calculations necessary and issues the required commands to stop the train accurately at the stations.

All vehicles have a plug receptacle for a manual control box carried by maintenance men. Once the box is plugged in, only its buttons and switches can control train movement. Maintenance personnel can thus move vehicles around the storage areas or operate trains in the event of an emergency that requires slow-speed operation or movement past an area in which maintenance work or construction is being carried out. A service vehicle that can be used to move a disabled passenger vehicle also has manual control.

Communications—To maximize passenger security, a radio-telephone will be installed in each vehicle so that any passenger will be able to converse directly with the central dispatcher in the control room. In addition, the central dispatcher will be able to make announcements to trains over the speakers in each vehicle, and he will also have access to a station speaker system for station announcements. The radio-telephone system will also be used by maintenance personnel when operating vehicles in manual mode; moreover, personnel will have a telephone system linking handsets at various tunnel, station, storage-area, and power-substation locations to the maintenance office and to the central control room.

The central dispatcher will have visual contact with the station platforms and transfer-table areas via closed-circuit television. Pictures from each of 18 cameras will be displayed in sequence on a monitor mounted in one of the central control consoles, and the dispatcher can hold any desired picture on the screen. The system will allow central control to monitor passenger demand and to take action if problems occur at the stations.

Maintenance Program

Because airport users must ride the Satellite Transit system, all the equipment and subsystems must have a very high degree of service availability. To achieve it, an extensive preventive maintenance program has been planned. Maintenance facilities are being built between the South-Loop and Shuttle tracks at the north end of the main-terminal south station (Fig. 5). Vehicle access to the maintenance shop is provided by the transfer table, which can be aligned with the Loop, the Shuttle, or any of (ultimately) three storage tracks. Pits provide access to the underside of the vehicles.

North-Loop vehicles needing service will be manually operated to the maintenance area via the Shuttle and the transfer tables. A turntable is provided so that vehicles that normally operate on the loops can be turned around for operation on the Shuttle.

Conclusion

If transportation within airports is to keep pace with the revolution in travel habits that has occurred over the past few years, systems of automated horizontal movement are clearly required to complement the escalator and elevator. Such a system at Seattle-Tacoma International Airport will soon afford the public (and airline and airport personnel) a fast, convenient, safe, and reliable means of horizontal transportation. Only through the imaginative application of such systems will airports provide an environment for pleasant and comfortable travel.

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[2]E. E. Hogwood and R. B. Maguire, "Passenger Transfer System Will Take the Long Walk Out of Air Travel," *Westinghouse ENGINEER*, Jan. 1969, pp. 9-15.

Integrated-Drive Generator for Aircraft Accelerates Trend Toward Less Weight and Longer Life

J. K. Taulbee

Generator and drive are close-coupled to minimize the size and weight of the package, and further reduction in size and weight is made by cooling the generator's heat-producing components with oil spray and mist. Improved cooling also greatly lengthens generator life.

As with all aircraft equipment, light weight and high reliability are prime design goals for the engine-mounted generators that supply ac power to the aircraft electrical system. A new line of aircraft generators has been developed with weight less than half (and life increased by a factor of 10) compared with the lightest generators available as recently as 1965.

These advantages are achieved primarily by a new cooling method. The generators are cooled by oil sprayed directly on the heat-generating components instead of by air, or by oil circulated through passages. They were developed for the new Integrated Drive Generator system (IDG), in which the generator is integrated into the constant-speed drive (Fig. 1). (The drive mechanically converts variable engine speed to constant generator speed and thus produces constant generator frequency.)

Generator Cooling Methods

Air cooling was the first method used, but it has severe limitations. Air has low specific heat and low density, and, therefore, a low heat transfer coefficient. Moreover, in supersonic aircraft, the ram effect (compression of air in the cooling-air intake) produces such high inlet air temperatures that air cooling is not at all practical.

These problems resulted in development of oil-cooled generators that used engine fuel as a heat sink and oil as the heat transfer medium. Because generator insulation materials available at that time would disintegrate and contaminate the oil, it was necessary to keep the oil separate from the generator windings; consequently, the cooling oil was circulated through closed passages around and near the heat-generating components. Oil is a much better coolant than air because its specific heat is twice as high and much greater mass flow rates can be obtained. However, since the oil was contained in passages, the thermal conductive path between heat-generating components and oil was through electrical insulation materials that are also thermal insulators. Thus, the total temperature differential was high, just as in air-cooled generators.

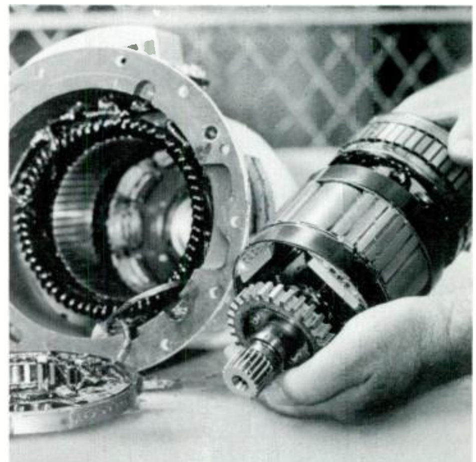
Development of generator insulation materials compatible with aircraft engine lubricating oils made the new spray-cooling concept possible. Spray cooling combines the best features of air cooling and conduction oil cooling: the coolant comes into direct contact with the sources of heat, but instead of air it is oil with its greater heat capacity and heat-transfer capability. The resulting low temperature rise between coolant and heat sources permits higher current densities and, thereby, reduces generator weight and size for a given rating. The dramatic decline in generator weight is illustrated in Fig. 2.

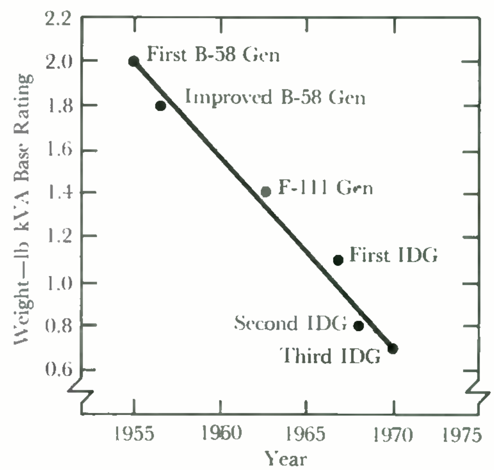
Three generations of spray-cooled development generators have been built, and they have been thoroughly ground-tested by Westinghouse, Sundstrand Aviation Corporation (the constant-speed drive manufacturer), and several airframe manufacturers. One has been flight-tested by the U.S. Air Force and is the first IDG to be proven airworthy.

The prototype generators were basically rated at 60 kVA, 120/208 volts, to provide 3-phase 400-hertz power. They had to be capable of delivering 300 percent rated current for 5 seconds and of withstanding overloads of 90 kVA for 5 minutes and 120 kVA for 5 seconds.

The first spray-cooled generator was essentially a test bed to develop calculation constants and determine the effectiveness of spray cooling.[1] It had provision for both conventional conduction oil cooling and spray cooling, and construction methods were essentially the same as had been used on previous generators. Current densities were also maintained at the same level as previous

J. K. Taulbee is a design engineer in the Power Systems Department, Aerospace Electrical Division, Westinghouse Electric Corporation, Lima, Ohio.





1—(*Top*) Compact and efficient, this brushless ac generator for aircraft has a base rating of 60 kVA and can operate continuously without insulation damage at 90 kVA. It weighs only 41 pounds, or 0.68 pound per kVA. The high ratio of power to weight was achieved mainly by cooling the heat-producing components with direct oil spray and mist; high speed (12,000 r/min), improved design, and advanced materials also helped. The generator is part of an Integrated Drive Generator system (IDG), so called because it is coupled closely with its constant-speed drive for additional space and weight saving.

2—(*Bottom*) Dramatic decline in weight per unit of rating is illustrated by comparing representative high-performance aircraft generators produced in the past 15 years. The first three generators listed were conduction oil-cooled; the three IDG's, spray oil cooled.

generators. This machine weighed 69 pounds. Testing indicated that oil spray cooling was so effective that the conduction cooling could be eliminated and winding current densities could be considerably increased.

Both changes were incorporated into a more advanced generator, which weighed 49 pounds. This second-generation machine was flight-tested on a C-135B aircraft in which one channel of the original generating equipment was removed and replaced with the Westinghouse-Sundstrand IDG package. It achieved the goal of 250 flight hours of operation, and the Air Force considers the flight test complete. Examination of the generator at the completion of the test showed it to be in excellent condition (Fig. 3). A complete report on its condition has been supplied to the Air Force.

Laboratory testing showed that stator spray nozzles were not required as adequate cooling was obtained with rotor spray nozzles only. That finding, and experiments on such variables as oil flow rates and nozzle openings, led to construction of the third-generation machine. It weighs only 41 pounds, less than half the 85-pound weight of a recent conduction oil-cooled generator of the same rating. The generator is cooled entirely from spray nozzles on the rotor. Besides that simplification, it contains many significant improvements in the spray cooling technique, in mechanical construction, and in electromagnetic design. (See table.)

The Aerospace Electrical Division also has built a similar generator rated at 40/50 kVA and weighing less than 33 pounds (Fig. 4). It has been thoroughly tested in the laboratory and has confirmed the design techniques developed for the 60-kVA generator.

Cooling is completely adequate in both generators, with winding temperatures well within the oil capability even up to loads of 90 kVA on the 60-kVA generator (Fig. 5). That machine has been selected for use in the Lockheed S3A antisubmarine aircraft.

Design Features

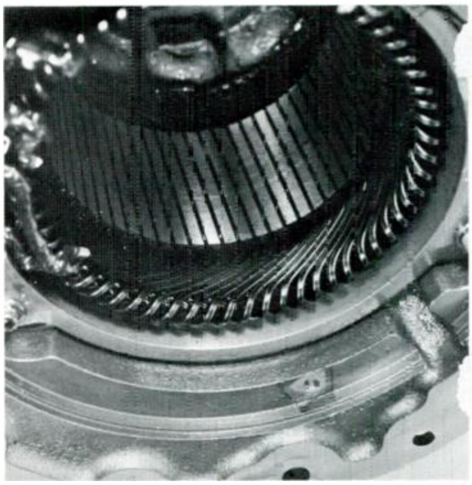
Construction—The generator is housed in a one-piece cast frame, and it couples intimately with the constant-speed drive for space and weight savings. It is driven through oil-lubricated splines (Fig. 6). Drive and generator share one bearing and have a common oil supply, sump, and heat exchanger. The design was developed mutually by Westinghouse and Sundstrand.

Oil enters through the mounting flange under pressure and flows through a passage to the antidrive end and to the shaft through a transfer tube. A small amount

Comparison of Recent Conduction Oil-Cooled Generator and IDG Generator

Main Features	*Conduction Oil-Cooled (F-111)*	*IDG (Third Generation)*
System Rating	60/68 kVA, 120/208 V, 3 phase, 400 Hz	60/90 kVA, 120/208 V, 3 phase, 400 Hz
Operating Speed	8000 r/min	12,000 r/min
Weight	85 lb	41 lb*
Maximum Continuous Rating (with 150-degree-C oil inlet temperature)	60 kVA	90 kVA
Insulation Design Life at Maximum Continuous Rating	1900 hr	12,000 hr
Electrical Performance Specification	MIL-G-21480	MIL-G-21480
Number of Rotating Seals	1	0
Time Between Overhauls	3000 hr	On condition**

*Weight reduction includes effect of higher speed.
**Generator contains no parts with predictable wearout.



3—(*Top*) After 250 hours of operation in the air, the flight-tested generator was in excellent condition with windings appearing as new. There was no evidence of oil deterioration, no spray nozzles were obstructed, and bearing and spline showed no wear.

4—(*Bottom*) Latest IDG built and tested is this smaller unit, rated at 40/50 kVA and weighing less than 33 pounds.

of oil is metered through the clearance seal between the tube and rotor to lubricate, cool, and flush the bearing. At each end of the rotating field, oil is ejected through calibrated spray nozzles against the rotor coil end extensions. The resultant oil mist cools the ac stator, the exciter stator and armature, the rotating diodes, and the permanent-magnet generator that provides excitation power. The remaining oil (a controlled amount) continues through the shaft to lubricate the drive parts, while that in the generator cavity is extracted by the drive sump pump assisted by pressurizing air.

Spray Nozzles—The spray nozzles on the rotor are the essential element in the cooling system. Although the cooling oil is filtered, additional steps have been taken to assure that the nozzles will not clog.

One step was to reduce the number of nozzles to the smallest number that would still direct the required amount of cooling oil to the heat-generating components; that results in each nozzle having a relatively large spray orifice for the required total flow at the applied oil pressure. Initial designs had 36 nozzles, but the present design has only 8. The result is that nozzle spray orifices have increased from 0.016-inch diameter in the original designs to 0.036 inch.

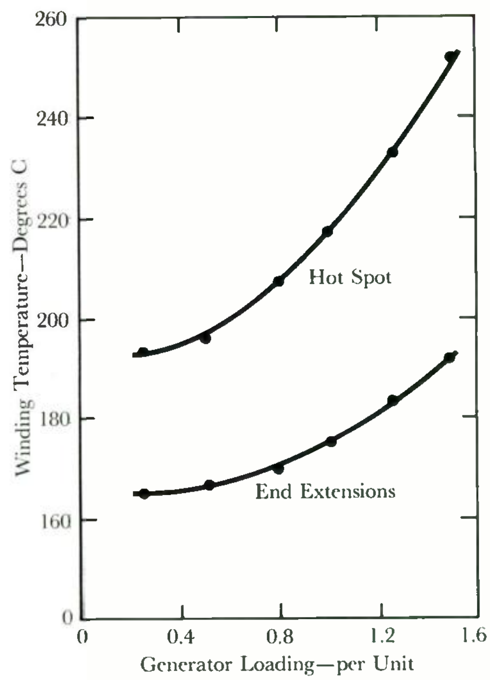
The second step was use of a new nozzle design that employs rotational forces to clean the openings centrifugally. The spray passage is not drilled straight through; instead, two holes are cross-drilled at the nozzle's inner end to intersect the spray passage and form four entrance ports (Fig. 7). The cross-drilled holes are made slightly smaller than the spray passage so that any clogging will occur only at an entrance port. The probability of all four entrance ports of a nozzle clogging is very small. Moreover, the nozzle is pressed into the shaft so that its entrance ports are approximately a fourth of an inch beyond the inside surface of the shaft; in operation, debris or sludge that might block the entrance ports is swept away by rotational forces normal to the ports.

Generator Ratings—Spray cooling is so effective that the nominal full-load rating of the new generator is not determined by heat dissipation ability but by the normally specified performance requirements such as short-circuit capacity, overloads, voltage transients, and the voltage unbalance permitted with unbalanced loading. In conduction oil-cooled generators, it was nearly always the ability to cool the windings at continuous rated load that determined the size of the copper conductors. In an IDG, the limiting design factor is the temperature at which the cooling oil would begin to deteriorate.

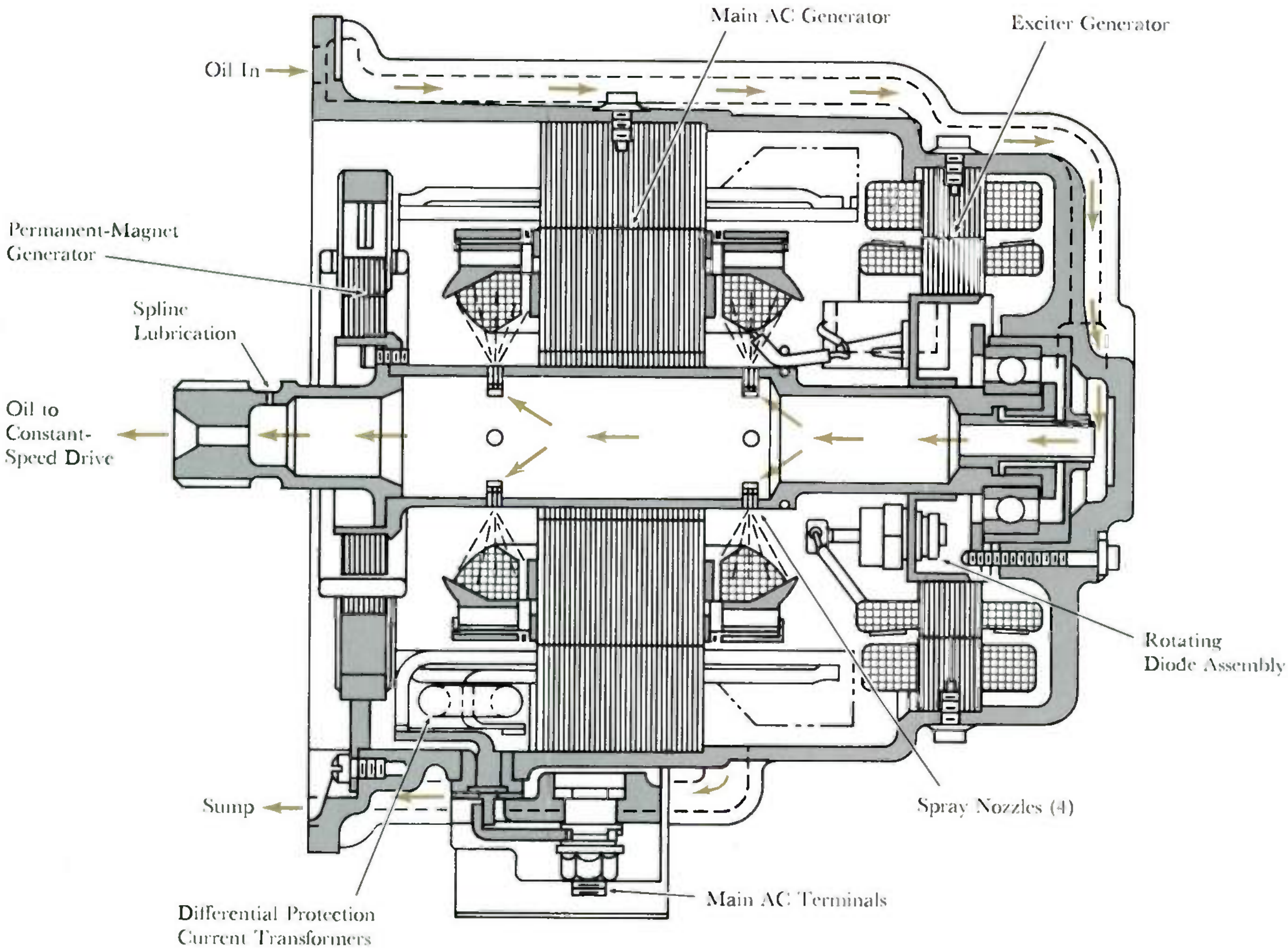
Present aircraft synthetic oils can tolerate 230 to 240 degrees C winding temperature continuously, so this temperature is the design limit for the continuous rating of the IDG. If restricting winding temperature to this limit were the only requirement, the copper current densities could be increased until the winding temperature limit were reached at rated (100-percent) load. Aircraft power systems, however, normally require a fault or short-circuit capacity of three times rated current for 5 seconds. During this short-time fault condition, the winding temperature can be permitted to exceed 240 degrees C; however, the winding must not fail. Time to failure during the fault is a function of the current density and the mass of the copper, since practically all of the heat generated must be stored in the copper; it thus becomes the more critical design limit and determines the copper size.

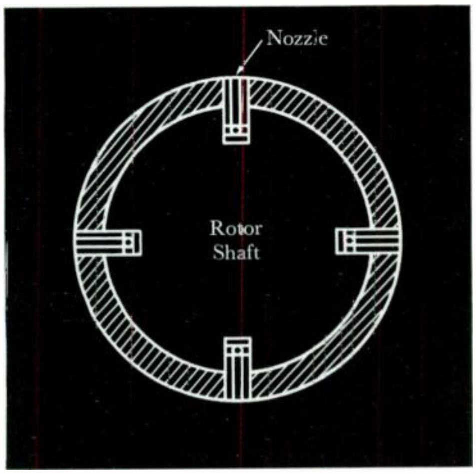
It follows that the generator can operate continuously at higher than 1.0 per-unit load (60 kVA) without exceeding the oil-deteriorating limiting temperature. Tests show that this maximum continuous load is approximately 1.5 per-unit load (90 kVA) when the copper is sized for 3 per-unit short-circuit current. The generator excitation system and electromagnetic design is limited to 2 per-unit load as required by aircraft electrical specifications.

System voltage transients and voltage unbalance with unbalanced loading are functions of the generator reactance. Generator reactance and weight are normally inversely related. The Westinghouse IDG, however, by use of a good



5—Generator winding temperatures are low because of the spray oil cooling—lower, in fact, at 1.5 per-unit load than at 1 per-unit load in recent conduction oil-cooled generators. The result is vastly increased insulation life. Winding temperatures are well within the tolerance of aircraft oils, which is presently 230 to 240 degrees C. (The hot-spot temperature occurs on conductors buried in the slots midway of the stack length and therefore not exposed directly to the oil.) One per unit in this graph is the 60-kVA base rating of the generator. Test conditions were 12,000 r/min speed, 0.75 power factor, 4 gal/min cooling oil flow, and 150 degrees C oil inlet temperature.


Main AC Generator
Exciter Generator
Oil In
Permanent-Magnet Generator
Spline Lubrication
Oil to Constant-Speed Drive
Rotating Diode Assembly
Sump
Spray Nozzles (4)
Main AC Terminals
Differential Protection Current Transformers



6—(*Left*) Section drawing shows how oil flows through the IDG to cool it and to lubricate its single bearing and its drive spline. Oil sprays from nozzles directly onto the end extensions of the rotor, and the resulting mist cools other heat-producing components.

7—(*Above*) The eight spray nozzles in the rotor shaft are designed to resist clogging: their spray orifices are made as large as feasible (and larger than their entrance ports), four entrance ports are provided, and the entrance ports are spaced in from the shaft wall so that rotational forces tend to sweep any debris or sludge away from the ports.

damper circuit and judicious selection of the stator slot combination, has relatively low reactance for its kVA output. The result is that the generator can meet normal specification requirements at a load higher than 1.0 per unit (60 kVA). It is usually approximately 1.25 per unit but, on some designs, can be as high as 1.5. Thus, a complete description of a generator's rating might be 60/75/90 kVA: 60 kVA defines the base for overloads and short circuits, 75 kVA defines the maximum rating at which all base performance requirements can be met, and 90 kVA is the maximum continuous rating without exceeding acceptable winding temperatures. Testing has shown that this particular generator can actually be rated 60/90/100 kVA.

Life and Reliability

The generators use high current densities in the winding copper to reduce size and weight. Even so, the winding temperature is much lower than in air-cooled or conduction oil-cooled generators that have lower current density because it must be held to 240 degrees C to prevent oil deterioration.

Winding temperature in a typical conduction oil-cooled generator, the F-111 generator, is 280 degrees C, which limits insulation life to about 1900 hours when operated continuously at rated load. Since the IDG's winding temperature is limited to 240 degrees C, its insulation life is much longer. At maximum continuous load, its insulation life would be more than 12,000 hours; at normal full load (the base rating), insulation life would be over 100,000 hours. This effective derating of the insulation not only extends the generator's life but also increases its reliability.

Service life and reliability are further enhanced by generous oil lubrication and flushing of the generator drive splines and bearings, which virtually eliminates wear on those parts. In conduction oil-cooled generators, a rubbing rotating seal was necessary to keep the constant-speed drive's oil out of the generator cavity because of limitations of generator insulation materials, and that seal was the primary factor in limiting time between overhauls to approximately 3000 hours. It also had the highest failure rate of all the generator's components. Now the need for the seal has been eliminated by integration of the generator and drive housings.

Taken together, these improvements enable a generator to be operated on the aircraft without a scheduled overhaul, i.e., "on condition." There simply are no parts requiring periodic replacement.

Continuing Development

Laboratory testing of the spray-cooling concept is being continued at the Aerospace Electrical Division to fully exploit its advantages. Under development are spray-cooled generators that will mount directly on gearboxes driven by gas turbines or internal-combustion engines without constant-speed drives. These generators are for use in aircraft auxiliary power units, ground power sets, and vehicular power systems.

Designs have been completed for a full line of spray-cooled generators with ratings from 30 to 200 kVA, and a 120/160-kVA unit is to be built and tested this year. While these designs were made primarily for aircraft use, only minor mechanical design changes are needed to suit them for the other applications.

REFERENCE:

[1] R. L. Gasperetti, "Aircraft Generator Weight Reduced by More Effective Cooling," *Westinghouse ENGINEER*, May 1969, pp. 71-5.

Cast Coils and Current-Limiting Bushings Improve Reliability of Distribution Transformers

Herbert W. Book
Rowe A. Ghirardini
Donald J. Ristuccia

As handling capacity is increased in distribution systems, the amount of available fault current is also increased. To provide the added reliability and protection needed for distribution transformers, Westinghouse has developed an epoxy resin cast coil and a bushing-mounted current-limiting fuse. The foil-wound cast coil offers such benefits as better space utilization, more efficient heat transfer, and greater short circuit strength; the current-limiting bushing rapidly interrupts fault currents that exceed the protective link's rating.

In the past, the safety of distribution transformers under high fault current conditions has not been a major problem because of high system impedance and low available fault current. However, times are changing. Increasing load densities have brought about a trend toward larger substations, shorter distribution feeders, and even higher distribution voltages. This trend allows more energy to be delivered to low-impedance faults and so has increased the possibility of transformer failure.

There are three main types of high-energy transformer failures: (1) A zero-impedance failure occurs when most or all of the fault current bypasses the impedance of the transformer winding, such as in a direct short circuit to ground from the high voltage lead of the transformer. (2) A more common type of failure is progressive breakdown of turn-to-turn insulation inside the winding, and it can be violent if the protective device is unable to clear the fault in time. (3) The most serious type of failure can result from overloading a transformer. For example, if a typical distribution transformer is 300 percent overloaded for several hours, its oil temperature may rise to over 150 degrees C. As the flash point of oil is 145 degrees, a small internal arc in the presence of oxygen can result in a violent explosion, i.e., a catastrophic failure.

Herbert W. Book is Product Development Section Manager, Rowe A. Ghirardini is the Area Sales Manager, and Donald J. Ristuccia is a development engineer at the Distribution Transformer Division, Westinghouse Electric Corporation, Athens, Georgia.

These failures can be limited or prevented from becoming catastrophic either by improving the transformer protective devices to limit the amount of energy they will pass, or by reducing the available system fault current.

To reduce the amount of available fault current, some utilities apply current-limiting reactors or high-impedance substation transformers. These measures help to reduce the current to about 6000 amperes but create new concerns such as voltage regulation and flicker, as well as adversely affecting the system reliability and economy.

Growing customer demand also makes it impractical to reduce available fault current. Duquesne Light Company recognized such problems in the early 60's when it began to convert 4.16-kV circuits to 13.2/23-kV. Realizing the inherent problems of reducing the system fault current, Duquesne undertook a 6-year study with Westinghouse to develop a fully coordinated protective device that would limit the current in high-energy distribution system faults. The resulting product was a current-limiting fuse mounted inside the high-voltage bushing of a completely self-protected (CSP) distribution transformer.

Although the current-limiting fuse can be purchased separately, maximum protection is afforded when it is combined with a foil-wound cast coil as in the CSP Foiltran (Fig. 1). That coil improves reliability by reducing many of the causes and effects of transformer failures.

Current-Limiting Fuse

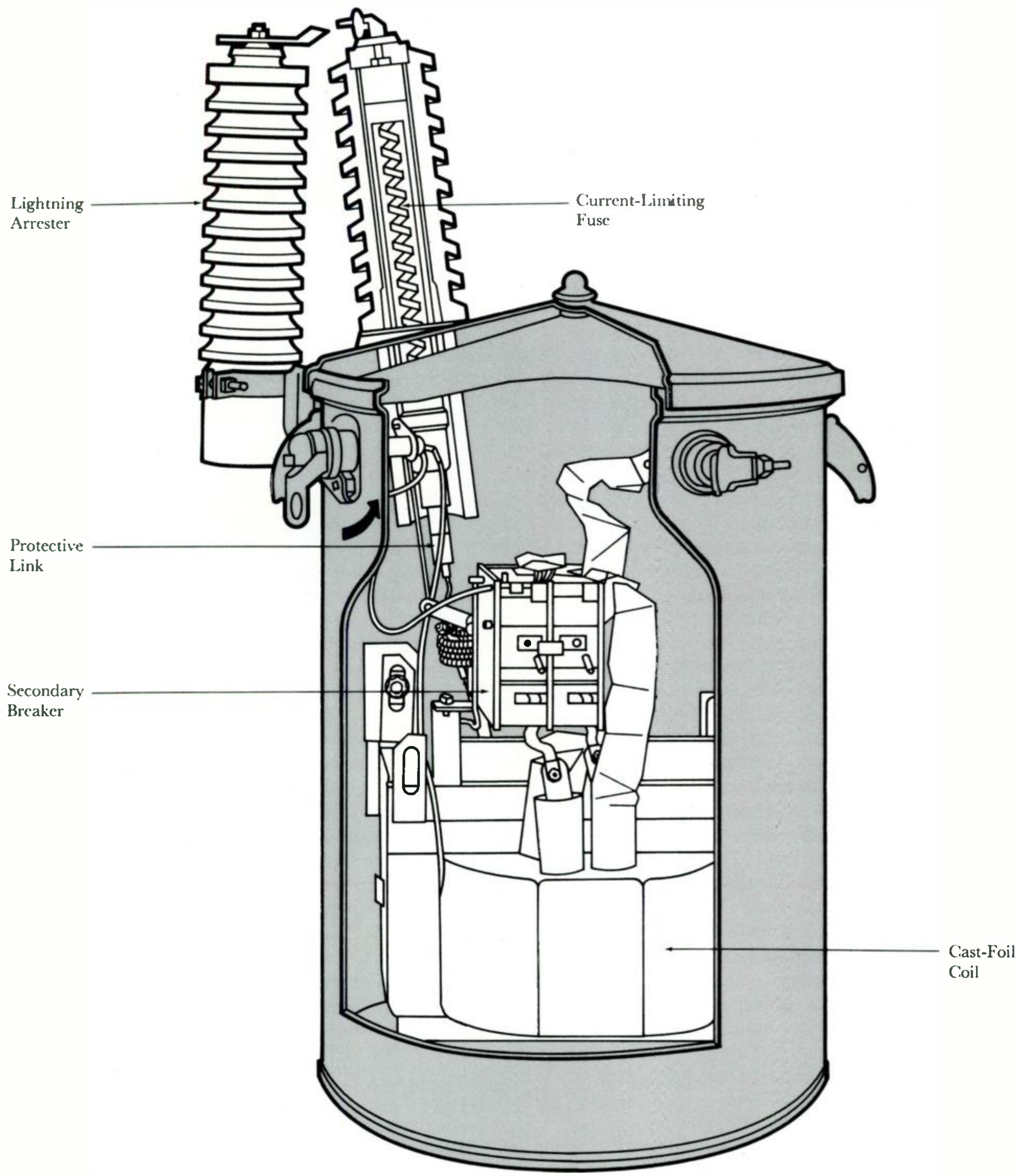
The high-voltage current-limiting fuse is designed to provide protection against extremely high fault currents that exceed the interrupting rating of the protective link. The link-type fuse is very effective within its own current rating, but since it is an expulsion type device like a cutout, at least one half cycle of unattenuated fault current passes before the link is able to isolate a faulted transformer from the distribution feeder. A current-limiting fuse is therefore connected in series with the link to obtain the rapid response needed for high-current fault protection. The fuse is basically composed of a silver ribbon wound in silica sand. When a high-current fault occurs, the silver element melts, interrupting current in about six percent of a cycle, while the arc energy is dissipated in the silica sand. The higher the fault current, the faster the operation of the silver element inside the fuse.

Fault protection in the Westinghouse CSP transformer is coordinated so that low-current faults are cleared by the link, high-current faults by the fuse, and load-side faults by the secondary breaker. The fuse combination developed for Duquesne provides fault protection from currents up to 25 kA symmetrical at 14.4 kV, and Westinghouse has since expanded its line to clear faults up to 40 kA symmetrical at 22 kV.

The current limiting fuse and protective link are both mounted inside the high-voltage bushing so that no extra space is required inside the transformer. This location protects the fuse from the weather and, more importantly, allows the fuse to be protected by the lightning arrester, thereby making it less subject to failure due to steep-front surges. The mounting arrangement also places the fuse as close as possible to the incoming high-voltage line, eliminates the possibility of an incorrect internal connection, and assures that any transformer fault is on the load side of the fuse.

The six year cooperative study with Duquesne Light Company has encompassed over 4000 distribution transformers equipped with current-limiting fuses. In 52 percent of all failures experienced by these units, the current-

1—The Foiltran is a CSP distribution transformer that has a bushing-mounted current-limiting fuse and a foil-wound cast coil to insure maximum safety and reliability. The current-limiting fuse affords protection from fault currents that exceed the rating of the lower-current protective link. It contains a silver-foil ribbon element packed in silica sand and is capable of interrupting fault currents as high as 40 kA symmetrical. The transformer coil is wound with enamel insulated aluminum foil and cast in epoxy resin to form a solid compact block.


Lightning
Arrester
Current-Limiting
Fuse
Protective
Link
Secondary
Breaker
Cast-Foil
Coil

limiting fuses had operated. Had the transformers not been so equipped, the protective links by themselves might not have cleared the faults, and violent failures could have resulted.

Foil-Wound Cast Coil

To appreciate the inherent benefits of the new coil design, it is helpful to first consider conventional coil construction and its limitations. Coils have been wound with copper wire and strap as conductors, insulated between turns with paper or enamel and between layers and coils with paper or similar materials such as pressboard. The entire paper structure is then vacuum-impregnated with mineral oil to develop the required high insulation strength. Although this type of construction has been the mainstay of high-voltage transformer coils for many years, it has some basic limitations: (1) It is difficult to produce a compact, high-space-factor coil from round or semi-round conductors and sheet insulation because of the wasted space between turns (Fig. 2a). (2) Coils wound in layers produce nonuniform stresses that require extra layer insulation to prevent tracking or creep, which further reduces the coil space factor. In addition, this layer insulation is used inefficiently, having very high voltage stresses at one edge and almost no stresses at the opposite edge. (3) The oil-impregnated insulation system must be carefully preserved in service as the entrance of air or moisture into the system results in eventual insulation breakdown and transformer failure. (4) The wire-wound coil is inherently susceptible to failure by mechanical deformation ("telescoping") as a result of short-circuit forces.

Foil Winding—The concept of foil winding (that is, a coil winding where the conductor is truly rectangular in shape, in the form of a thin enameled strip) eliminates the first two limitations of the conventional coil. First, foil or strip windings are efficiently compacted with almost no wasted space between conductors—just that required for turn insulation (Fig. 2b). Second, since a foil winding has only one turn per layer, insulation requirements are reduced.

Moreover, the basic simplicity of the foil winding lends itself to more efficient methods of manufacture as well as providing several important performance advantages. First, the improved "electrical balance" between turns of foil and the foil's inherent axial strength result in a coil with virtually unlimited short-circuit strength, eliminating the danger of coil telescoping. The usual thermal hot-spot found in conventional wire-wound coils is greatly reduced in the foil coil because heat generated within the coil is able to flow uniformly toward the coil surface without interference of layer insulation or insulation edge extensions. The high turn capacitance in the foil winding serves to distribute impulse voltage uniformly across the entire winding rather than concentrating it at the lead ends, thus eliminating the necessity for special shielding to assist in impulse distribution. Finally, reduction of layer stresses and elimination of cellulosic layer insulation within the foil coil greatly reduces the potential for failure due to insulation aging or contamination. The low electrical stresses also reduce the probability of corona failures.

Solid Insulation—The advantages of the foil-wound coil are maximized by making its major insulation (coil-to-coil and coil-to-ground) a solid cast epoxy resin. In the past, the fundamental problem of internal voids in areas of high electrical stress severely hampered the application of resin-casting technology to conventional wire and paper coils. Their intricate internal geometry made it difficult to obtain total coil impregnation, resulting in internal corona and eventual insulation failure.

In the foil coil, however, the resin is required only to provide the major external insulation, as the enamel film on the foil provides sufficient turn insulation at voltage stresses far below a detectable corona threshold. The result is a strong, compact, highly uniform structure with its windings virtually impervious to moisture and contaminants (Fig. 3). It is also less vulnerable to failure from creep and tracking since the solid epoxy casting eliminates the many insulation surfaces found in conventional coils. The inherent

Production of Cast-Coil Transformers

The first step in the maufacturing process is application of insulation to aluminum foil in a pressurized clean room. Bare aluminum foil is fed from rolls to machines where it receives multiple coats of insulating enamel on both sides (1). After the enamel has been cured, the foil is wound into supply reels and then slit to obtain the desired coil widths (2). The bare edges left by slitting are etched back beneath the enamel coating, and a later processing step restores edge insulation. Next, the coils are wound and inspected to insure consistent winding quality (3). The proper high- and low-voltage coils are assembled into casting molds and are tested and preheated (4), prior to epoxy encapsulation. Following this operation, the casting assemblies are placed inside vacuum chambers where, at elevated temperature and under high vacuum, filled epoxy resin is released to form a void-free encapsulation of the windings. The completed coil is then withdrawn from the chamber (5) and electrically reheated before being placed in ovens for the final gelling and curing. After removal from the casting mold, each coil is subjected to a 100-percent impulse proof-test (6). The coils are finally matched with the proper transformer parts for assembly (7). Completed transformers then enter a carrousel test area where the final series of standard commercial tests are conducted (8).

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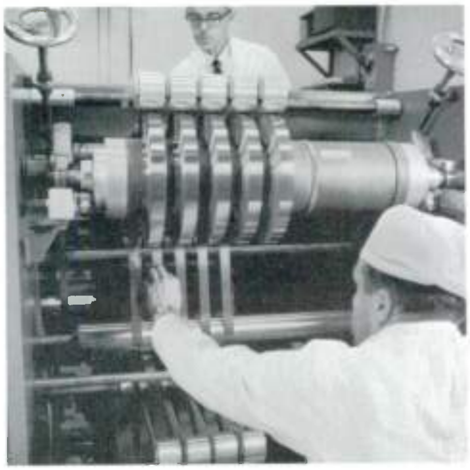

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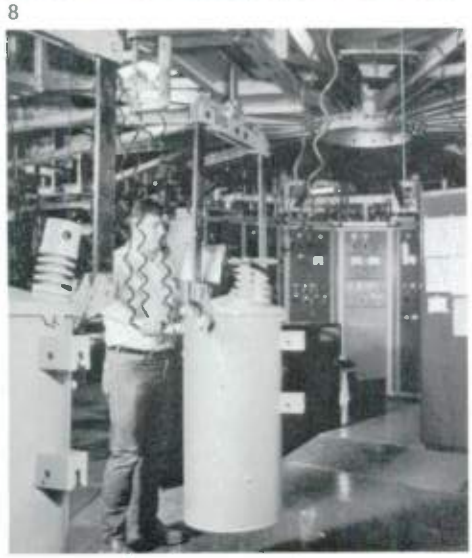
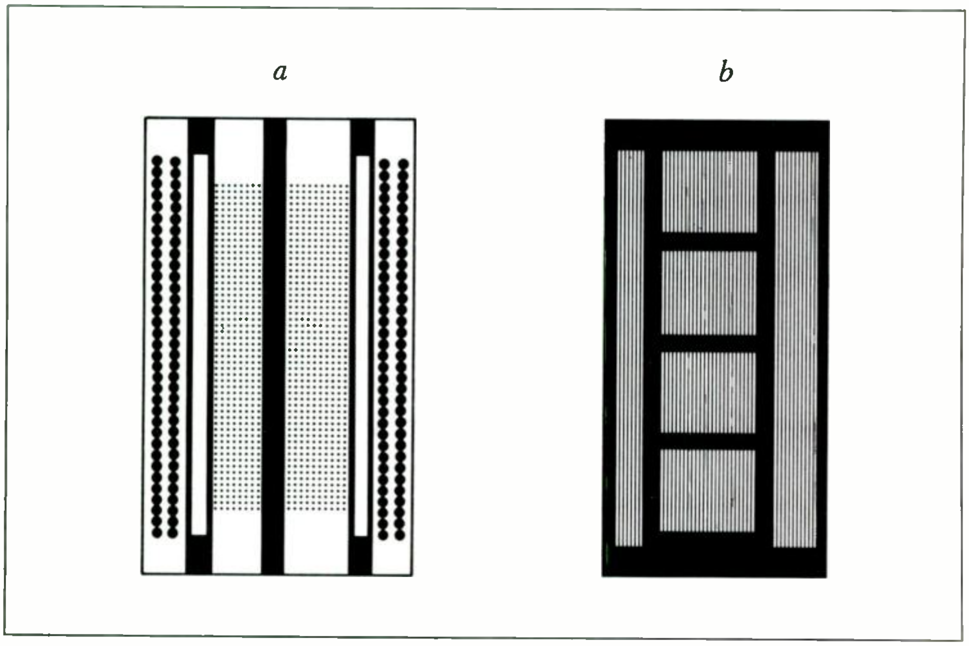
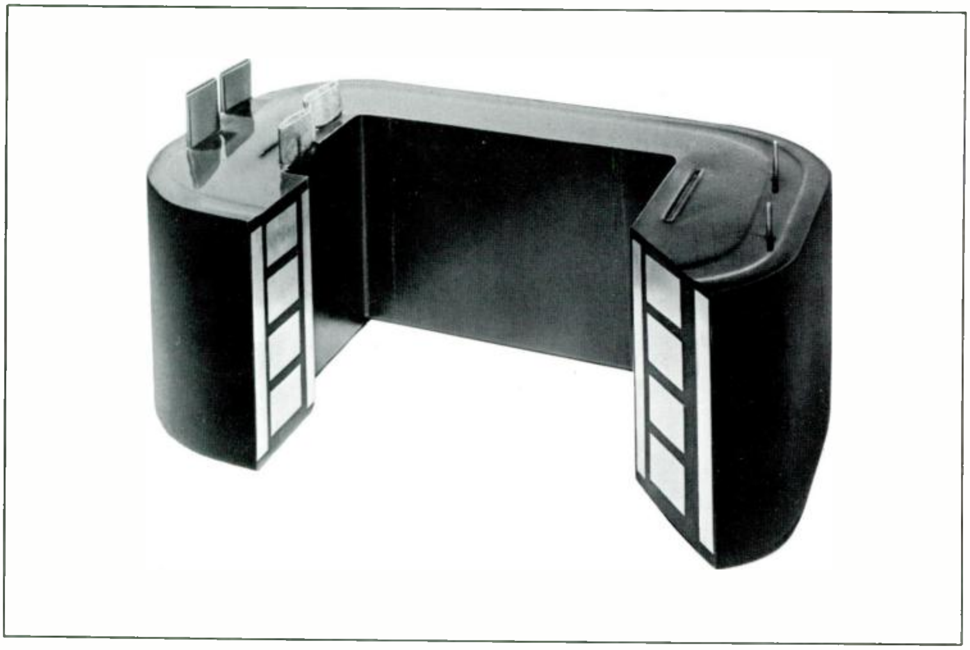






2—*(Top)* **A cross section of a conventional coil, *a*, illustrates how space is wasted when wire and strap conductors are used with paper and oil insulation. In the foil winding, *b*, the wire and strap conductors are replaced by flat thin strips of aluminum foil insulated with enamel coating. The windings are then encapsulated with an epoxy resin to produce a coil of compact size and total insulation.**

3—*(Bottom)* **A section of a typical cast coil is cut away to reveal its low-voltage windings (inner and outer coils) and high-voltage windings (center coils). This type of coil construction provides compact size and high short-circuit strength, prevents insulation contamination and aging, eliminates creep and tracking problems, and does not depend on oil for major insulation.**

ruggedness of this type of construction also improves its short-circuit strength; any coil failures that might occur would be confined within the solid block, thereby reducing further transformer damage.

Since cast resin provides the major insulation, the tank liquid can be chosen primarily for its cooling properties. Water, for example, offers much promise as a coolant. It has a high specific heat, low viscosity, and low cost. A cast-coil transformer rated 100-percent kVA in air would be rated 140 percent in oil and 230 percent in water. These features could result in large reductions in size and weight of transformers while providing a safe indoor unit with high overload capacity. Westinghouse is currently designing and life-testing water-cooled units, but more development work is needed to make the concept economically feasible.

Effort is also being expended to increase the range and application of totally dry-type cast-coil transformers. Presently available for the one-transformer-per-house concept is a 15-kV-class pad-mounted unit (House-Pak) in 10- and 20-kVA sizes. A dry-type pole-mounted distribution transformer is currently under development. It will offer such advantages as being smaller, lighter, and safer (contains no oil), it will have lower losses, and it will provide the same overload capacity as oil-cooled units. These advantages can mean substantial savings due to lower operating costs, fewer failures, simplified pole construction, easier handling and installation, longer life, greater short-time overload capacity, and greater short-circuit strength.

Conclusion

The bushing-mounted current-limiting fuse and foil-wound cast coil can help utilities assure safe reliable operation of distribution networks in times of increasing load densities. Although these products are available separately, the Foiltran CSP transformer combines them for maximum protection and reliability.

Phase-Control Ballast Circuit Operates All High-Pressure Arc Lamps

G. A. Kappenhagen

Each type of mercury, sodium, and metal-halide lamp has heretofore required its own type of ballast. A new circuit operates them all, sensing lamp operating conditions to automatically regulate power more accurately and efficiently than conventional ballasts can.

As new types of high-pressure arc lamps have been developed, the wide range in electrical characteristics of the various types has always necessitated development of a special ballasting circuit for each. Consequently, the availability of suitable ballasts for the various kinds of mercury, sodium, and metal-halide lamps has lagged behind lamp introduction. Now, however, a circuit has been developed that is versatile enough to operate all of the presently available high-pressure arc lamps, and incandescent lamps as well.

A high-pressure arc is an electrical discharge taking place in a gas. In a lamp, the gas is a vaporized solid or liquid (such as sodium or mercury) plus a natural gas such as argon. The lamps have negative volt-ampere characteristics; that is, the lower the lamp voltage, the higher the lamp current. They have the typical nonlinear property of a gas discharge, which means that current to a great extent is independent of voltage. If, for example, a high-pressure arc lamp is accidentally energized in an incandescent lamp socket, the current increases without limit and the lamp is destroyed. Therefore, a high-pressure lamp needs a "ballast," which is a circuit that limits lamp current yet allows enough voltage to start the lamp and keep it operating properly.

Ballasting circuits can be made from all types of impedance elements, such as resistors, capacitors, and inductors, within various limitations. (Resistors, for example, are rarely used because they cause high power losses.) Two basic types of ballasting circuits are presently in general use: the simple series inductor type and a regulated-output type.

The simple inductor ballast consists of a coil of wire wound around a steel core. It is very efficient and corrects for the lamp's negative volt-ampere characteristics, but it provides no compensation for line voltage variation. Normally, the maximum allowable line variation for the inductor ballast is ± 5 percent, which corresponds to ± 10 percent variation in lamp wattage.

The regulated-output ballast was developed to compensate for both the negative volt-ampere lamp characteristic and line voltage changes. It includes a transformer with a portion of its magnetic circuit operating in the nearly flat region of saturation so that even large input changes cause only very small changes in output. A capacitor in series with the lamp is also an essential part of the regulated-output ballast, enabling the circuit to achieve a high power factor (90 percent or better).

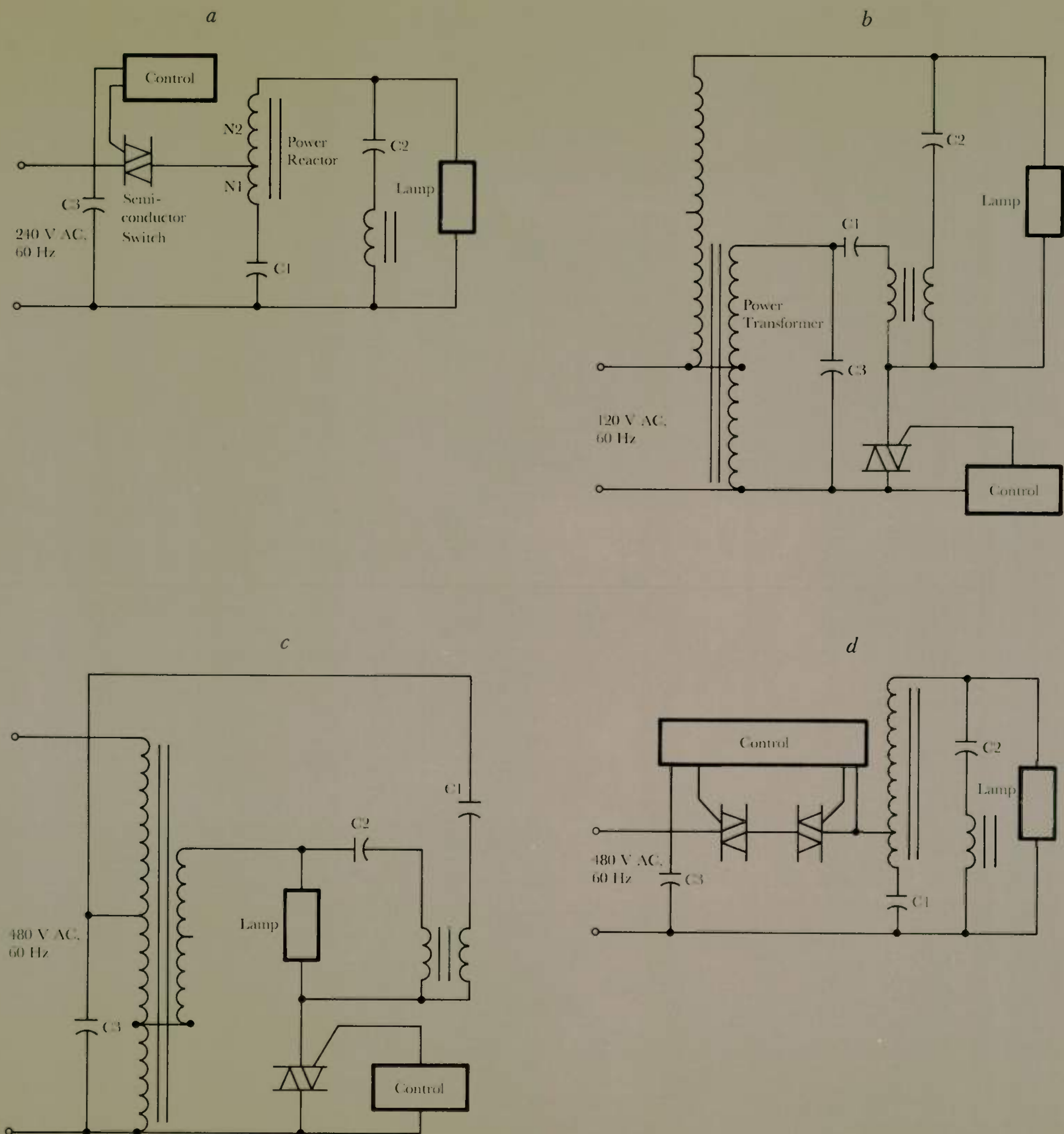
Even this ballast, however, does not completely meet the needs of modern lighting. It is not suited for sodium lamps, and, moreover, a ballasting circuit is needed that is not limited to a specific type of lamp.

For one ballast to be able to properly operate lamps filled with mercury, sodium, metal halides, tin, cadmium, zinc, or other metals and metal salts (singly or in combination with each other), it must be capable of maintaining control of lamp wattage for a wide range of lamp voltages. For example, lamps filled primarily with mercury have initial voltages randomly distributed between 115 and 150 volts, and voltage rises about 3 percent from the initial value during the life of the lamp. In contrast, lamps filled primarily with sodium have been observed with initial voltages from 70 to 100 volts, and the voltage during life may rise to as high as 170 or 180 volts. Also, the ballast must be able to produce a high voltage pulse to initially strike the arc in sodium lamps, and, for metal-halide lamps, it must produce sufficient reignition voltage each half cycle during warmup to prevent lamp dropout. (Dropout simply means the lamp going out when available voltage is not sufficient to keep it lit.)

The ballast described in this article is a solution to all of these design problems. It

Quad Master ballast circuit is built into the fixture it is used with. Here it is seen in the lower half of the housing of an OV-25 street-lighting luminaire.

G. A. Kappenhagen is a design engineer in the Outdoor Lighting Department, Westinghouse Electric Corporation, Cleveland, Ohio.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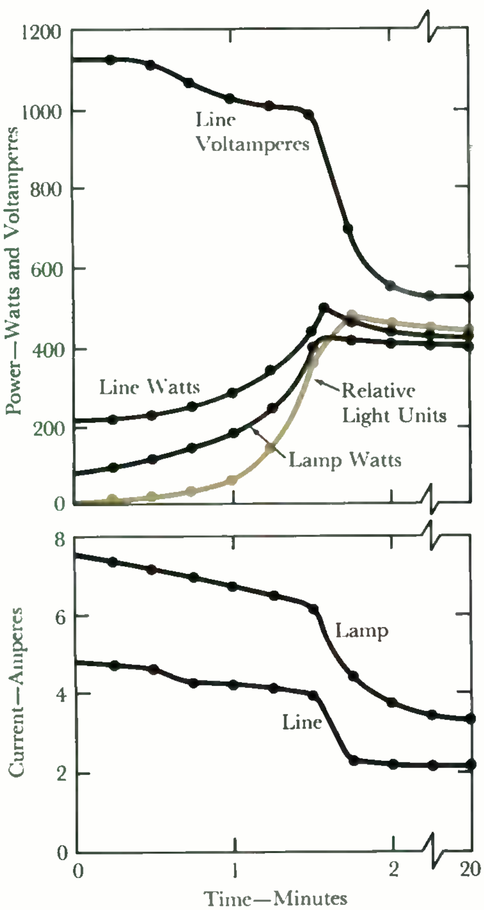


1—*(Left)* Quad Master phase-control ballast circuit consists essentially of a power segment and a control segment. The former varies somewhat with the voltage and wattage to be used, as indicated. (Schematic diagrams *a*, *b*, and *c* are basic 400-watt circuits, used also for lower ratings; *d* represents the basic 700- to 1000-watt circuit.) The control circuitry converts signals derived from lamp operating conditions into a control signal. This signal gates a semiconductor switch in the power circuit in such a way as to modulate input power as required for starting and operating any lamp at a preset power level.

2—*(Above)* Starting and warmup characteristics are illustrated for an H33 mercury-vapor lamp from turn-on (the zero time point) to stable hot operation. The new ballast circuit controls lamp power by regulating the point in each half cycle of input power at which the semiconductor switch closes, and the length of time it stays closed. (Line voltage in this example was 240 volts ac.)

is a hybrid, the result of combining modern solid-state technology and conventional ballast circuitry. To distinguish it from other hybrid possibilities, we call it "Quad Master."

The Quad Master can operate all the variety of lamps currently available. Moreover, its only requirements for the proper operation of any lamp over a wide range of lamp voltage, waveform, and starting-pulse requirements are a source of electrical power and insertion of any lamp of a wattage rating corresponding to the ballast setting. No physical changes are needed; if, for instance, the Quad Master is set at the factory to deliver 400 watts, any lamp put into the socket will run at 400 watts even if it isn't a 400-watt lamp. Connection points for multiple wattage settings are provided at the factory if ordered; the user then makes the desired setting by simply changing one or sometimes two electrical connections.

Power regulation is within ± 3 percent of the setpoint for any combination of lamp type, lamp voltage, and line variation within $\pm 12\frac{1}{2}$ percent of nominal. (Regulation of the mercury lamp, which is the most frequently used type of high-pressure arc lamp, is within $\pm 1\frac{1}{2}$ percent of the setpoint.) With most combinations of lamp type, lamp voltage, and line variation within ± 25 percent of nominal, the Quad Master gives power regulation within ± 10 percent of the setpoint.

Operation

The electrical circuitry can be divided into two segments—power and control. The power circuit varies slightly with the nominal supply voltage and wattage to be used (Fig. 1). Its major elements are a reactor or transformer, the lamp, and a bidirectional gate-controlled thyristor. The latter is a semiconductor switch, so it is simply called "the switch" in the rest of this article.

The control circuitry is a closed-loop system that converts signals from lamp voltage, lamp current, line voltage, frequency, and (if desired) ambient light level into a control signal. The control signal is coupled to the switch to cause it to close at exactly the right time in each half cycle so as to modulate the input power with respect to one or more of the parameters being sensed. This modulation regulates lamp power more accurately and efficiently than conventional ballasts can. Moreover, using the switch to automatically turn the lamp on or off in response to a signal derived from ambient light level eliminates the cost and complexity of a separate photoelectric control.

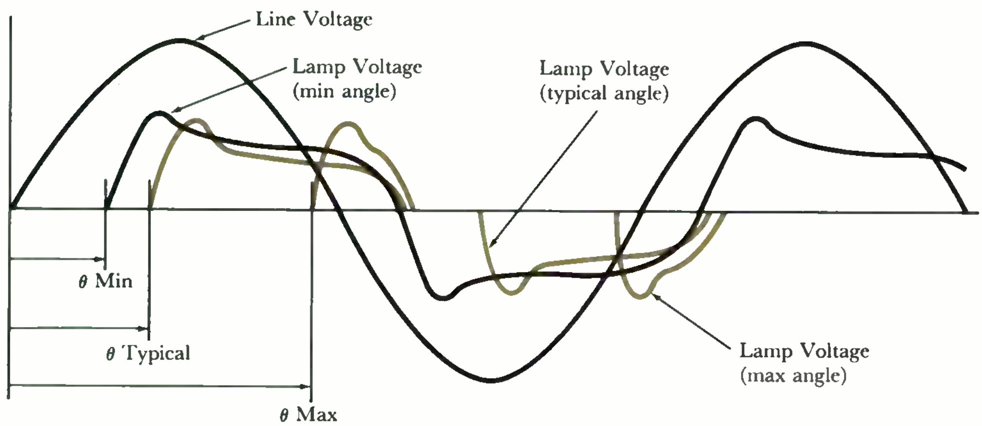
In operation, the circuit passes from an initially "off" condition through a warmup period to a stable hot-lamp condition (Fig. 2). Warmup time is needed because the arc medium initially is argon or other gas, which would permit destructive current levels; current has to be restricted by the ballast until enough metal halide in the lamp vaporizes to restrict the arc current.

Assume, for example, that the circuit of Fig. 1a is activated from the "off" condition by a signal derived from decreasing outdoor ambient light level in the evening. The signal causes the switch to close, and, since capacitor *C1* is initially in a discharged state, the full line voltage appears across the *N1* portion of the power reactor. The turns ratio of *N2* to *N1* is so chosen that a high voltage pulse (approximately 2500 volts) is generated and applied to the lamp for several millionths of a second. If an arc is not established in the lamp, the power reactor and capacitor *C2* form a relatively low-impedance series resonant circuit that establishes approximately 450 volts across the lamp terminals. If the arc discharge is initiated, capacitor *C2* discharges through the lamp with a high-energy current pulse. If, however, the lamp is not yet on, the sequence is repeated each half cycle with all pulses continuously being reformed until the lamp does begin to conduct.

After the lamp is turned on and until it comes up to power, warm-up current is controlled by the closed-loop control system, which allows the switch to close just long enough in each half cycle to maintain warmup current at the desired preset value. This feature is used to minimize warmup time without danger of exceeding lamp current capabilities.

3—*(Left)* **Switch closing angle (θ) can be varied over a wide range to achieve the desired lamp voltage, and thus the desired current. Angle θ_{min} is the most advanced closing angle the switch can have; in terms of circuit operation, it corresponds to the switch being always closed. Angle θ_{max} is the most retarded angle possible and corresponds to the condition just prior to the switch being always open.**

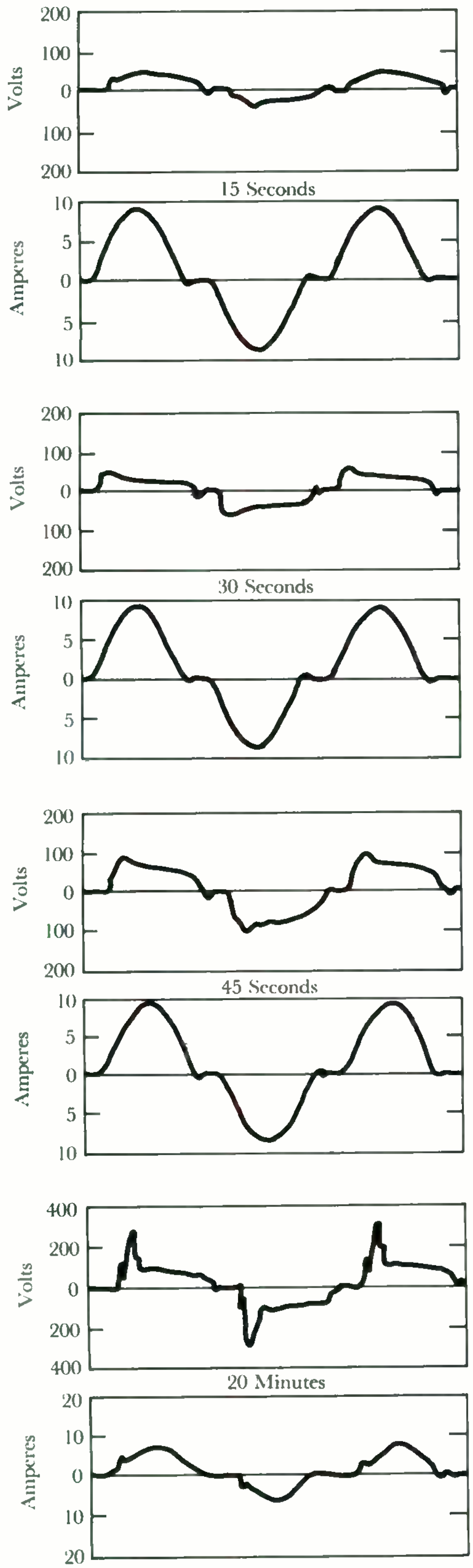
4—*(Right)* **Waveforms for a metal-halide lamp change radically as the lamp warms up, as shown by these typical curves for a 400-watt lamp. Even so, the Quad Master ballast retains control of wattage and current as required.**



*Lamp Operating Characteristics With 400-Watt Quad Master Ballast**

Lamp	*Warm-Up Time*	*Lamp Volts*	*Lamp Amperes*	*Lamp Watts*	*Line Voltage at which Lamp Drops Out*	*Lamp Voltamperes*
400-W Mercury	3½ min	111.5	5.10	400	164	568
400-W Mercury	2 min	127	3.51	391	172	446
400-W Metal Halide	1¼ min	114	3.68	394	158	419
400-W Metal Halide	1 min	124	3.63	393	167	450
400-W Metal Halide	1 min	147	3.71	391	148	530
400-W Sodium	22 min	85	6.4	436	Below control capability	543
400-W Sodium	3½ min	102	5.47	415	134	558
400-W Sodium	3 min	108	5.01	406	137	541
400-W Sodium	1 min	136	3.93	396	132	534
400-W Sodium	1 min	174	3.04	390	195	529
400-W Sodium	1 min	183	2.96	389	220	542
405-W Incandescent	2 sec	117	3.41	397	Below control capability	399
450-W Self Ballasted	2 sec	184		355		
275-W Sodium**	4¼ min	73		282	128	
250-W Mercury Short Arc**	6¼ min	53		247		

*Random lamps, 240-volt 60-hertz line.
**Ballast operated on 275- and 250-watt setpoints, respectively, instead of 400-watt.



Upon reaching rated lamp wattage, the control system changes the amount of time the switch is closed, thereby maintaining the lamp wattage and allowing the lamp current to decrease until it reaches its normal steady-state value and lamp operation is stabilized. The circuit continues in this mode of operation until a signal derived from increasing light level at daybreak causes the switch to remain open continuously. With the switch open, the lamp remains off until the cycle repeats the next evening.

A wide range of switch closing angles is possible (Fig. 3).

Test Results

The Quad Master ballast circuit has been tested extensively under various conditions such as different line voltages, different lamps, and during warmup of a metal-halide lamp.

Applied line voltage in service often varies from the nominal voltage of the system. The new ballast circuit, however, maintains lamp power at the desired setting by varying voltage and current waveforms slightly. Peak lamp current and voltage decrease slightly with low line voltage, but conduction time increases; the reverse occurs with high line voltage.

Different lamps have pronounced differences in voltage and current waveforms, even when operated at the same wattage. Among high-pressure arc lamps, these differences result from use of different materials in the arc and, with sodium lamps, from reduction of the amount of active sodium with use. The Quad Master ballast circuit accepts the nonuniformity of the lamps and still operates them at the preset wattage, an ability that makes this ballast unique.

A metal-halide lamp has waveforms that change radically as the lamp warms up (Fig. 4). Through all the changes, the Quad Master controls either lamp current or lamp wattage as required. The lamp also develops high reignition voltage spikes at some time during warmup due to the sudden vaporizations of the several compounds in it, but the ballast operates it without dropout through that region because the low-impedance series-resonant circuit applies more than adequate voltage to cause reignition. (The spikes are not shown in Fig. 4 because of their random occurrence.)

Ballast performance and lamp operating characteristics for various types of randomly chosen lamps are summarized in the accompanying table. Within each division, the lamps are arranged by their operating voltages. In the first four divisions, only the first two sodium lamps were outside the voltage range in which the ballast is designed to operate them with really close control of wattage; as a result, those two had operating wattages slightly off from the 400-watt setpoint of the ballast. The fifth division lists a self-ballasted lamp that cannot be forced to run at the 400-watt setpoint because it is already being ballasted internally; it is the only type lamp known to date that is not recommended for use with the Quad Master. (The lamp is mercury-vapor with an incandescent filament ballasting it and adding to the light output.) The last two divisions list lamps picked randomly to illustrate operation of a ballast provided with setpoints of 275 and 250 watts respectively in addition to 400 watts.

Conclusion

The new circuit for lamp ballasting combines the advantages of a simple inductive ballast with the flexibility of solid-state circuitry to form a unique hybrid type. It can operate all commercially available high-pressure arc lamps, it controls lamp current during warm-up, it regulates lamp power accurately and automatically, and it can have automatic dusk-and-dawn control built in.

Thorough Factory Testing Applied to Industrial Control Systems

To facilitate thorough testing of control systems, the Westinghouse Industrial Systems Division has been using a new automated test facility called RIFCA (Rapid Integrated Factory Circuit Analyzer).* It was first used to test printed-circuit cards, as many as 300 a day. Now its use has been extended to the testing of complete control systems right in the assembly area.

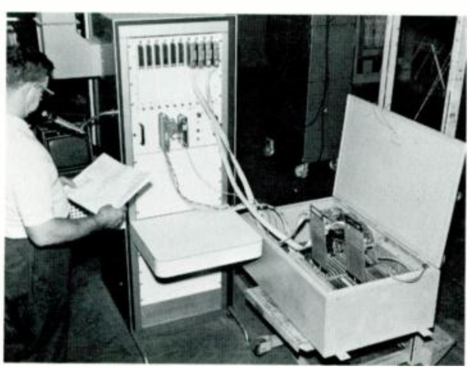
The first complete systems tested were for warehouse stacker cranes. The solid-state control systems will supervise positioning and sequencing of the cranes, positioning a crane to better than half-inch accuracy over a range of 500 or more feet and to as many as 31 levels—about 75 feet up. The cranes can stack two loads in each bin. Bin-location data and commands can be input to the control systems either by computer or by punched cards; both types of input and all modes of operation were simulated by RIFCA during the tests.

Twelve remote testing stations are linked to the central RIFCA station. Circuit cards, subassemblies, or completed systems are connected at a remote station and automatically tested by the central station, which compares the electrical values measured with standard information on tapes. After completing the required checks (as many as a thousand in two minutes for printed-circuit cards), the central station prints out any irregularities found and also the diagnostic information.

A self-programming mode generates new testing programs for RIFCA. In it, a circuit card or assembly that is known to be good is connected to a remote test station with instructions for the central station to scan it. The central station processes the operator instructions, adjusts the power supplied, makes the desired measurements (such as leakage, continuity, resistance, and voltage), sets tolerances, and directs the punching of a tape. The tape is then used to program the testing of subsequent units.

*Neville E. Jacobs, "Multistation Test System Allows Thorough Testing of a Wide Variety of Electronic Subassemblies," *Westinghouse ENGINEER*, Sept. 1970, pp. 154-7.

A control system for a stacker crane is being tested here by the RIFCA automated test facility. The tester on the shop floor has connected the system to a remote station, which is linked to the central station some 450 feet away. A microphone and television monitor keep him in touch with the central station and its operator.



Helicopter-Supported Radar Increases Detection Range

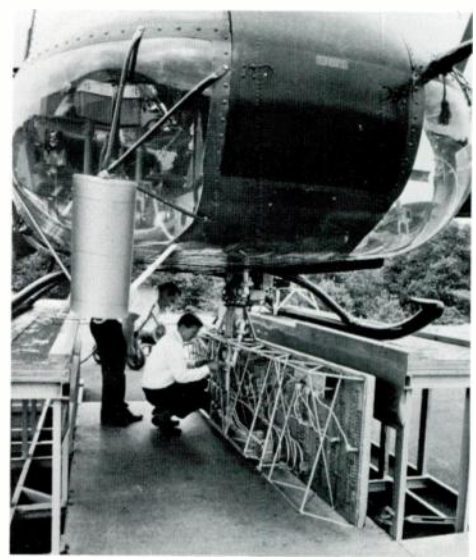
Because of the earth's curvature, a ground radar's detection range for an aircraft flying at tree-top level is about 10½ miles, provided there is no interference from terrain or foliage. However, if terrain or foliage cut just one degree from the angle of the radar's beam, the detection range is reduced to only half a mile. To overcome the difficulty, a developmental surveillance radar system uses a helicopter to elevate the antenna for better coverage. The engineering model was developed by the Westinghouse Aerospace and Electronic Systems Division for evaluation by the U.S. Air Force System Command's Rome Air Development Center.

In flight, the antenna rotates at 9 r/min beneath a UH-1 helicopter; for takeoff and landing, it folds into the space between the landing skids. It can be deployed or retracted in 30 seconds.

Since the radar looks down to the same extent that a ground radar looks up, the effect of ground clutter is greatly increased. (Ground clutter is noise in the system due to radar energy reflected in a variety of ways by everything on the ground.) The severe ground returns compete with the returns from targets, so the radar needs exceptional clutter compensating ability in its signal processing.

Two innovations that alleviate the ground-clutter problem are a digital moving-target indicator and coded-pulse anticlutter circuitry; they also lessen the effects of weather clutter. Moreover, some ability to detect ground targets has been observed. The digital features, combined

A helicopter supports a surveillance radar antenna aloft for better coverage. Elevating the antenna extends the radar's horizon by getting it above obstructions of terrain and foliage. The helicopter is on a special landing rack in the lower photo, allowing the antenna to be lowered for adjustment. The antenna folds into the space between the landing skids for normal takeoff and landing. In flight, it revolves below the landing skids.



with use of solid-state components for everything but the high-power transmitter and display tubes, make the system lighter, operable on less power, more reliable, and more stable than is possible with conventional techniques.

The radar is a two-dimensional system operating in the L frequency band. Its antenna is an array of stripline dipoles separated from a ground plane and mechanical support by a hard foam-plastic layer, a construction that eliminates the feed horn and the large heavy parabolic antenna that otherwise would have been necessary. The antenna has built-in provisions for reception and transmission of radar beacon signals.

A data link to send radar information to a ground display is part of the system. It provides two-way communication over a slant range of 10 miles. Two antennas are used on the helicopter for the data link, one in front and the other in back, so there is always one antenna in the line of sight to the ground antenna.

Heart-Assist Equipment Under Development

Cardiogenic shock, a condition that may follow a heart attack, occurs when the left ventricle of the patient's heart is unable to pump enough blood. To try to help such patients, an experimental intra-aortic balloon pumping system is being developed by the Westinghouse Research Laboratories in a team effort with Johns Hopkins University. The project is the first part of a program at the Laboratories, funded by the National Heart and Lung Institute, to develop systems for temporary heart assistance.

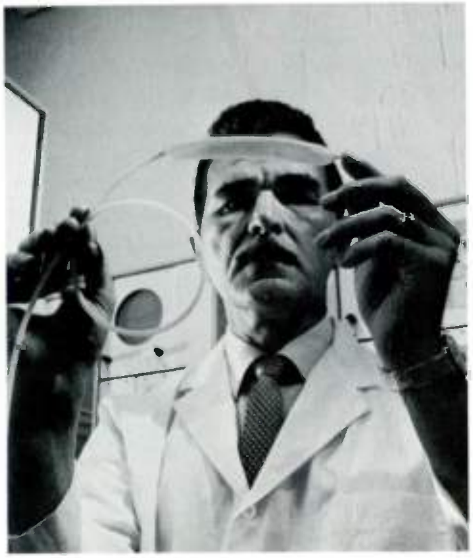
In use, a long slender balloon would be inserted into the aorta, the main artery leaving the left ventricle. The balloon would automatically inflate and deflate in rhythm with the patient's heartbeat. It would expand just after a beat to force blood before it into the circulatory system, including, most importantly, the vessels that supply the injured heart itself; it would collapse just before the next squeeze so that the heart would pump blood into a nearly empty aorta giving little back-pressure, thus relieving the heart of part of its work load. The procedure would be an emergency measure, used until the crisis is over.

The balloon is at the end of a long tube called a catheter, through which a gas is pumped to inflate and deflate it. It would be threaded up to the aorta through an incision in the groin, where a main artery (the femoral) is most accessible.

Pumping is controlled by electrical signals from the patient's own heart that are sensed by electrodes taped to his chest. Logic functions enable the device to interpret the signals and know when to act even during irregular heartbeat.

Prototype devices are now undergoing preclinical evaluation and refinement. A major goal of the project is development of components that will not fail in use. For example, project scientists devised a method to make polyurethane balloons without forming any seams, which could be weak points. In the remote event that a balloon develops a leak, pressure sensors detect the failure and immediately stop the pumping. The gas used to pump the balloon is carbon dioxide, which can be safely absorbed by the blood.

A balloon is the active element in an experimental heart-assist device to aid victims of heart attacks. It would be inserted in the aorta and inflated and deflated, through a catheter, to pump blood between heartbeats.



Products for Industry

Functional testing unit checks the distance and overcurrent fault detectors and decision logic of installed solid-state relay systems. During a test, the relay system is isolated from the power system current and potential transformers to permit application of suitable ac test quantities to the fault-sensing relay inputs. The equipment consists of the type FTU functional test unit and the type SRU output relay. *Westinghouse Relay-Instrument Division, 95 Orange Street, Newark, New Jersey 07101.*

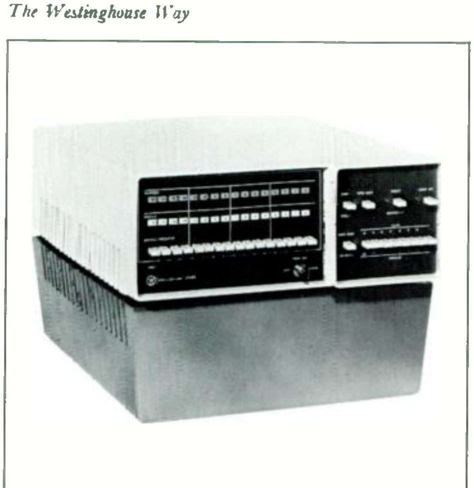
TV Pass/Pedestrian System tightens gate security by providing remote TV viewing of a face alongside a picture on an identification pass for comparison before admittance. It consists of two closed-circuit cameras in a weatherproof enclosure at the entry gate and twin monitors at the security desk. When a person inserts a pass in the gate unit, the cameras transmit pictures of the pass and the person's face to the monitors. *Westinghouse Security Systems Division, 7800 Susquehanna Street, Pittsburgh, Pennsylvania 15221.*

Life-Line T mill and chemical motors are ac squirrel-cage machines specially designed for dependable service under demanding conditions. They are available from stock because design features that once were extras are now standard. The motors are available in both explosion-proof and totally enclosed fan-cooled models. Standard features include overload capacity, corrosion-resistant paint, moisture-resistant insulation, and simplified hookup with three-lead single-voltage connections. The three-phase 460-volt motors are available in ratings from ¾ to 200 hp in NEMA frame sizes 143T to 447T. Additional voltage ratings are available. *Westinghouse Medium AC Motor and Gearing Division, 4454 Genesee Street, Box 225, Buffalo, New York 14240.*

Graphical Display for recording and presenting information accepts input data in digital form from a data logger, process control computer, or magnetic tape, or analog signals directly from sensors or

Graphical Display

The Westinghouse Way



Westinghouse 2500 Computer

measuring instruments. The data is converted to video signals for presentation in wave form on one or more standard black-and-white television monitors, providing a readout similar to that of a pen recorder. Four records on a moving time base can be set independently over a wide range; for example, the records on the screen could simultaneously cover seconds for one trace, minutes for another, hours for another, and several days for the last. A memory keeps each trace on the screen until it is erased or new data entered. Traces can be displayed in color by fitting a plastic mask over the tube face; the mask can be of a single color or composed of four different strips, one for each trace. *Canadian Westinghouse Company Ltd., Hamilton, Ontario, Canada. Marketed in the United States by Westinghouse Computer and Instrumentation Division, 200 Beta Drive, O'Hara Township, Pittsburgh, Pennsylvania 15238.*

The Westinghouse Way is an office environmental system that includes the components necessary to create a great variety of private or semiprivate offices without wasting valuable floor space. Assembled with pliers, screwdriver, and level, the system can be quickly erected and rearranged. The wall panels can rotate 360 degrees around a connector assembly, so they permit layout of either free-form or 90-degree office areas. Components come in a choice of 17 colors and include a variety of wall panel assemblies, storage units, shelf units, tack or chalk surfaces, acoustical panels, work surfaces, and accessories. The standard panel surface is Micarta. *Westinghouse Architectural Systems Division, 4300 36th Street, S.E., Grand Rapids, Michigan 49508.*

Westinghouse 2500 computer is the first of a new line of small computers with the speed of data-processing machines as well as the reliability and capability needed for process control. A general-purpose machine for industrial, communications, and scientific applications, it has 16-bit word length and memory speed of 850 nanoseconds. Modularity permits both hardware and software expansion in the field. Hardware multiply and divide plus double-precision add and subtract are standard features. Options include memory protection, up to 65,536 words of core memory, floating-point hardware, and a choice of several mass memories. The unit is available in table or rack-mounted models and has a full line of peripheral equipment. Its instruction repertoire has more than 500 basic machine operations derived from a set of 44 instruction codes. Software packages include several versions of real-time monitors, assemblers, FORTRAN IV compilers, BASIC compilers, linking loaders, and peripheral handlers. Also included are applications software, a simulator/assembler, a library of subroutines, and debugging and utility packages. *Computer Department, Westinghouse Computer and Instrumentation Division, 1200 West Colonial Drive, Orlando, Florida 32804.*

About the Authors

Philip N. Ross is Manager, Power Systems Planning. He joined Westinghouse in 1939 after graduating from Harvard University with a BSEE and an MSEE, and his first assignment was in the Central Station Engineering Section. He was on loan to the Navy Department in Washington, D.C., during the war years of 1941 to 1945 and then on loan to the Oak Ridge National Laboratory from 1946 to 1948.

Ross joined the Bettis Atomic Power Laboratory when it was formed in 1948 and served in a series of technical management positions until he was appointed General Manager in 1959. (The Bettis Laboratory developed the reactors for the *USS Nautilus* and the first commercial atomic power station at Shippingport, Pennsylvania.) He was named Manager of the Electric Utility Headquarters Department in 1966 and Manager of Power Systems Planning in 1969. He is responsible for systems engineering, marketing, business analysis, and planning for the Westinghouse Power Systems Company.

L. G. Hauser is Manager, Fuels and Energy Systems, Power Systems Planning. He graduated from Carnegie-Mellon University in 1942 with a BS degree in electrical engineering. After World War II service with the U.S. Army Signal Corps, he joined Westinghouse as a design engineer for the Welding Division. This was followed by assignments as district representative and subsequently as Manager of Application Engineering. Hauser transferred in 1954 to the newly formed Atomic Equipment Division, created to supply nuclear apparatus for the atomic power industry. As Manager of Marketing, he participated in the phenomenal evolution and growth of nuclear power. In 1967, he was appointed Generation Consultant to the Electric Utility Headquarters Department with responsibilities in special areas of power generation.

Hauser is now responsible for technical, economic, and environmental evaluations of fuels and complete energy systems for electric power generation. His recent publications include articles on the effect of escalation on utility fuel costs, the long-range effect of cooling water regulations, and an analysis of the industry generation capacity requirements for the next two decades. Hauser has done graduate work in marketing at Syracuse University and in business at the University of Pittsburgh. He was the founding chairman of the NEMA Atomic Applications Group and is currently a member of its Static Energy Conversion Section.

Ralph Mason combines his two main professional interests—the movement of people and the analysis of alternative investments—in his engineering evaluations of transportation alternatives. He is presently the Transportation Division's project manager for the Satellite Transit system being built at Seattle-Tacoma International Airport.

Mason attended the University of Birmingham, England, after serving a year at sea in the British merchant navy. He received his BSc degree in mechanical engineering, with honors, and then joined Westinghouse on the graduate student training program. He worked first in application engineering of transportation systems, especially Transit Expressway; in 1969, he was made project engineer for the Transit Expressway Revenue Line Feasibility and Preliminary Engineering Study, which defined major parameters of the planned Pittsburgh-South Hills system. Mason received an MBA degree from the University of Pittsburgh last year.

J. K. Taulbee graduated from Auburn University in 1958 with a BSEE degree, and he has since done graduate work in electrical engineering at the University of Pittsburgh and in business administration at Bowling Green University. He joined Westinghouse on the graduate student training program, and, since his main professional interests are in the design of rotating machinery, he went to work as a design engineer in the generator systems section of the Aerospace Electrical Division.

Taulbee has been the generator project engineer for the power systems of various aircraft, including the DC-9, F-28, T-38, and S3A. He has also had the electrical design responsibility for two major development programs: variable-speed constant-frequency generators and spray oil-cooled generators.

Herbert W. Book graduated from Pennsylvania State University in 1950 with a BSEE degree and joined Westinghouse on the graduate student training program the same year. In 1951, he became a design engineer at the Distribution Transformer Division in Sharon, Pennsylvania, and in 1963 he was made Supervisory Engineer. He became Project Manager of cast coil production in 1965 and is presently Section Manager of Product Development at the Overhead Transformer Department in Athens, Georgia. Besides helping pioneer the development of the cast coil, Book has made various contributions in distribution transformer protection and insulation systems.

Rowe A. Ghirardini attended Norwich University, earning a BSME in 1959 and joining Westinghouse on the graduate student program. His first position was in air conditioner manufacturing at the Major Appliance Division. He became a design engineer at that division in 1960. By 1961 he was an application engineer, first investigating air conditioner cooling properties and later doing application studies on panelboards and switchboards for commercial use. The following year he became an application engineer for the Bryant Electric Company, a Westinghouse subsidiary.

In 1963, Ghirardini transferred to the Newark Utility Field Sales Office as an assistant sales engineer. He has since held sales engineering positions at Washington, D.C., and New York City. He went to the Distribution Transformer Plant at Athens in 1966 to become a marketing representative, and he recently assumed his current position there as Area Sales Manager. He provides technical assistance to customers and engineering guidance on the application, coordination, and protection of transformers.

Donald J. Ristuccia earned a BEE degree from City College of New York in 1965. Later that year he joined Westinghouse via the graduate student program and accepted a development engineering position at the Distribution Transformer Division. He worked there on the design and production of transformers and auxiliary devices, and in 1969 he transferred to the Overhead Transformer Department at Athens in the same capacity. He specializes in transformer switching mechanisms, insulation systems, and protective devices such as the current-limiting fuse.

George A. Kappenhagen graduated from Cleveland State University in 1959 with a BEE degree and a BES in physics. He has since done graduate work at John Carroll University toward an MS degree in physics. He worked first at Park Ohio Industries in design of r-f generators and control circuits for induction heating.

Kappenhagen joined Westinghouse in 1966 in the Lighting Division, where his first assignment was in design of a 25-kW square-wave converter for operating fluorescent lamps. He is now in the ballast engineering section of the Outdoor Lighting Department, responsible for design of solid-state photocontrols, solid-state dc ballasts for high-pressure lamps, and both hybrid and full solid-state ac ballasts for high-pressure lamps.

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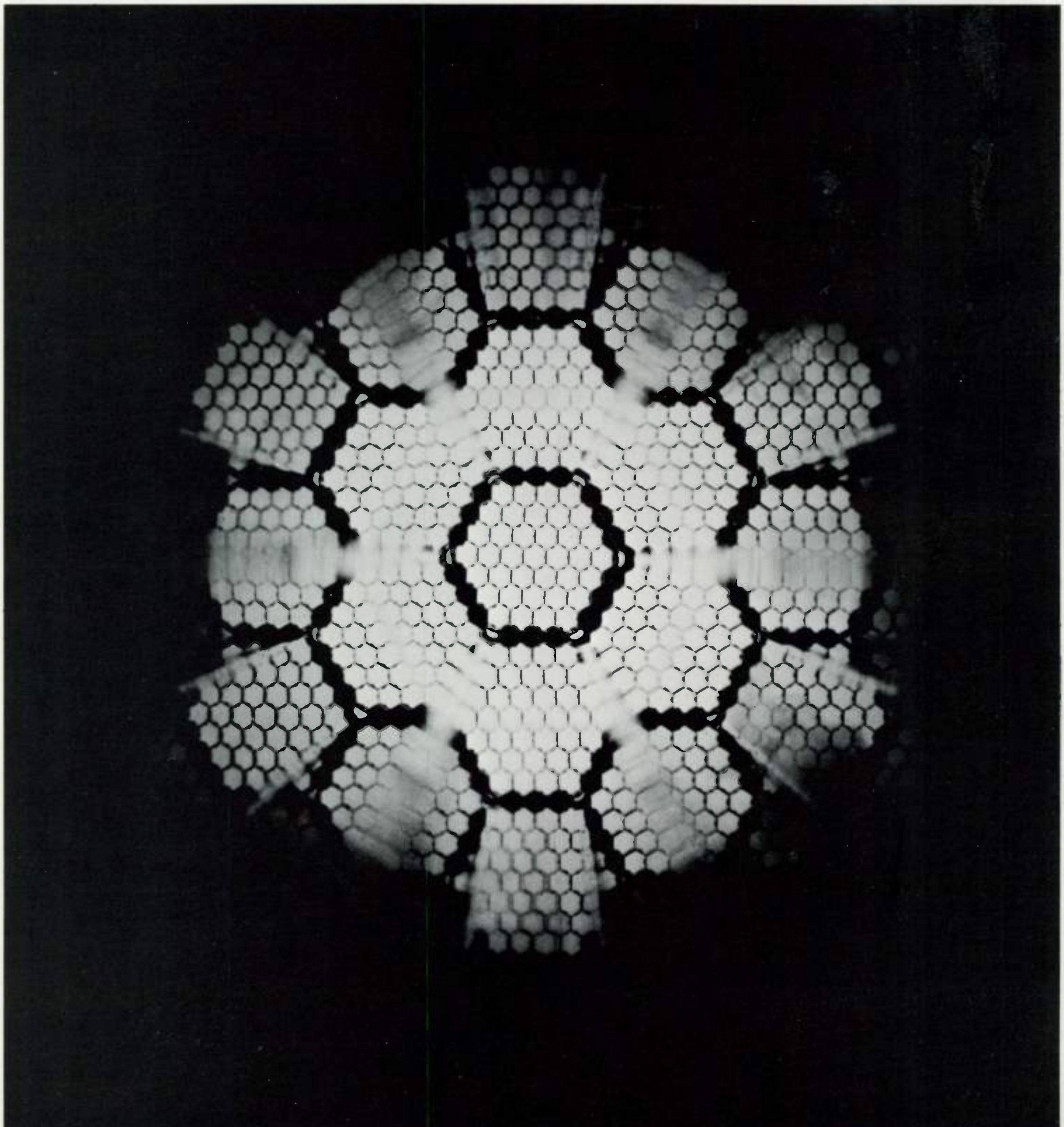

Fuel-rod support for fast breeder demonstration reactor.
(Information on contents page.)