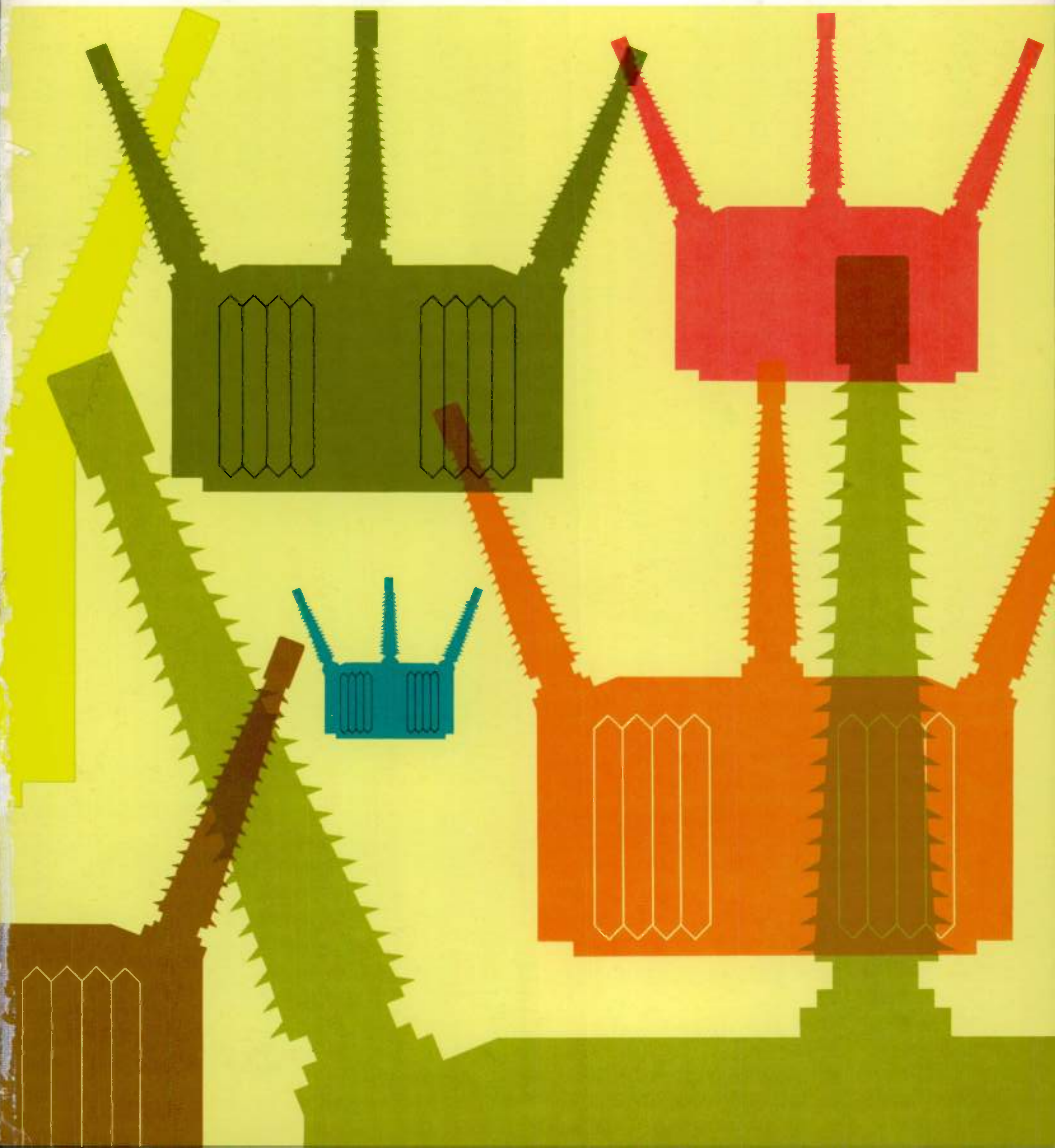
Westinghouse ENGINEER

March 1967



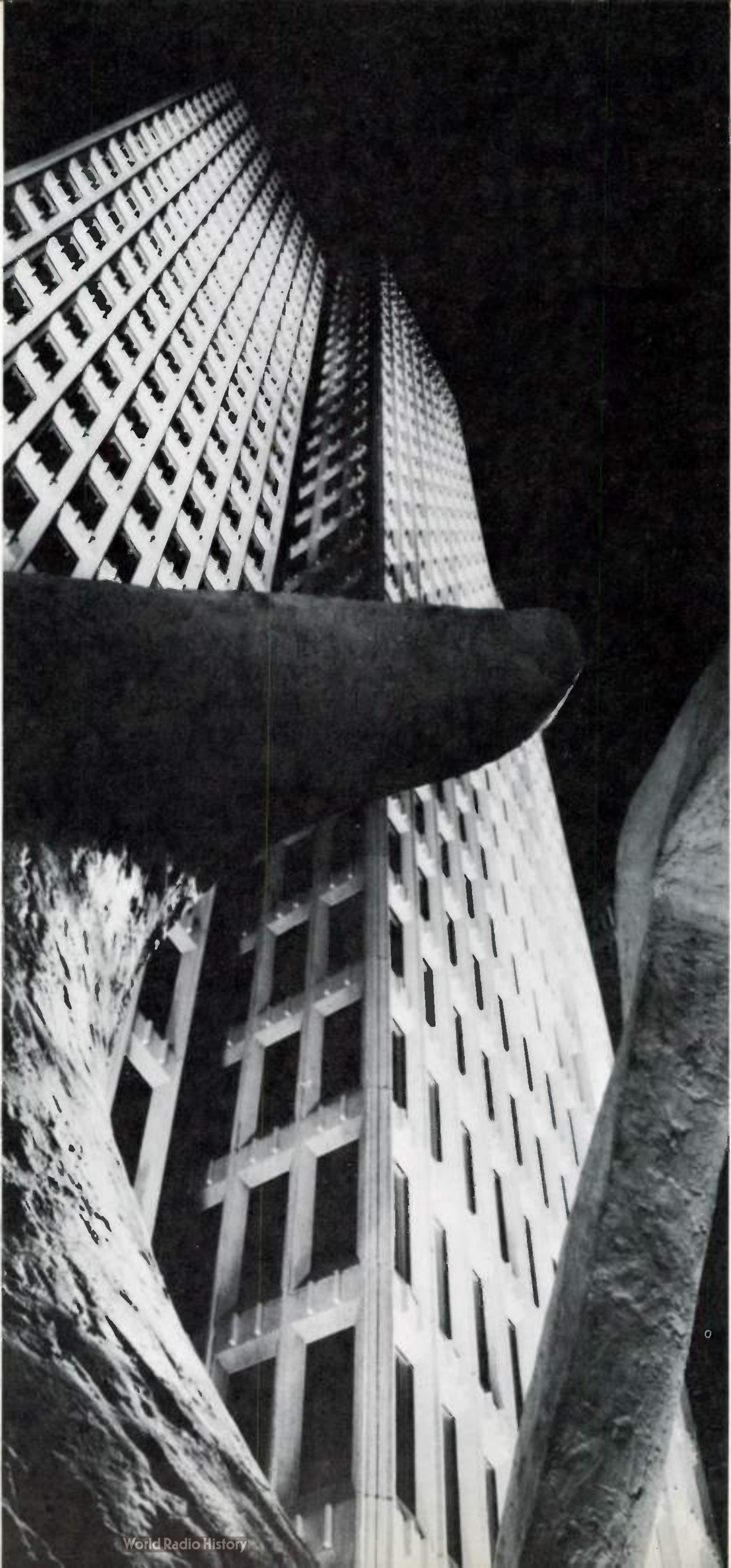
Peachtree Center Office Tower Becomes Atlanta Landmark at Night

Most office buildings sort of disappear into the night at sundown, to reappear the next morning. Exterior lighting, however, is being resorted to more and more to preserve a good structure's esthetic value by keeping it an integral part of the community night and day. An example is the new 30-story Peachtree Center Office Tower in downtown Atlanta, Georgia, the first step in the projected privately financed redevelopment project to be known as the Peachtree Center Complex.

To make the lighting uniform for best appearance and at the same time to make it emphasize the building's structural design, special searchlight units were selected to project overlapping beams from near the base up to the top of the building—344 feet. A lamp with the most compact filament possible was needed to enable the searchlight to project a narrow but intense beam while also providing enough spread to cover the lower areas. Moreover, the lamp would need sufficient burning life to last until all lamps were group-replaced at yearly intervals. Not surprisingly, no such lamp existed.

Lamp designers went to work on the problem and produced a globular lamp eight inches in diameter containing a special 80-volt 2000-watt filament. A collector grid traps the particles of tungsten as the filament vaporizes, to help prevent lamp blackening, and the hard glass used for the outer envelope withstands the high temperature produced.

This lamp produces at least 3,000,000 candlepower in its searchlight unit, and 102 of the units are installed in pits along the faces of the building. They are supplemented by a number of 500- and 300-watt lamps that help floodlight the lower stories and the center tower section, and by other units illuminating the plaza and its sculpture. The result is uniform illumination that makes the structure stand out at night without glare, in its true scale and detail.



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Cover design: The virtually unmistakable silhouette of a power transformer was used as the design element in this month's cover by artist Tom Ruddy. The subject was suggested by the article beginning on the following page, which describes some new design techniques being used in the development of power transformers.

New Techniques Improve Power Transformers

W. T. Duboc

Current emphasis on EHV transmission and higher unit kva ratings has spurred development in power transformers. Many new designs and techniques have resulted. Many of these also contribute to improved power transformers in lower ratings as well.

While much attention has been focused recently on EHV equipment because of the rapid and dramatic increases in voltages and ratings, actually the whole range of power transformers is being affected by major changes intended to achieve greater reliability and size reduction. Both of these characteristics assume greater importance as power system interconnections increase and kva ratings of individual units grow.

Traditionally, progress in power transformer design has been evolutionary, with many individual developments as contributing factors. A six-fold increase in the amount of kva that can be designed into a single package has been achieved during the last 40 years (Fig. 1).

In the present era the design and manufacturing effort has been intensified to keep pace with the rapid increase in operating voltage; and of equal significance, the techniques and materials applied to EHV transformers can be of benefit to most power transformers. This is especially important because 99 percent of all power transformers now being built, representing 88 percent of the mva, are still for voltages of 230 kv and below.

Thus, the developments now taking place in power transformers are still largely evolutionary, but they have been accelerated by the demands for EHV transformers. For example, the rise in operating voltages from 287 kv to 345 kv took about two decades; in contrast, the first commercial 500-kv lines were energized in 1964, the first 700-kv lines six months later, and development is now proceeding toward the possible use of 1000 kv. Capacity has been increased to the point where three-phase banks of 1200 mva are not unusual.

W. T. Duboc is Engineering Manager of the Power Transformer Division, Westinghouse Electric Corporation, Sharon, Pennsylvania.

Insulation Improvements

As can be noted from Fig. 1, many of the more significant improvements in reliability and size reduction have been brought about through developments in insulation, either in the nature of improved materials or better design, with the net result that it is now possible to use smaller clearances for the same operating voltage. This work is continuing at an accelerated pace because of present requirements and trends for higher voltages and larger capacity.

Increases in voltage have made necessary considerable skill in the design of insulation structures if the transformers are to be kept within reasonable size and, indeed, within shipping limitations. As a start, voltages must be determined between different parts of the windings and between windings and ground under both steady-state low-frequency and impulse conditions. The steady-state voltages can, of course, be precisely calculated from turns ratio. The initial distribution of impulse voltage, which depends on the characteristics of the capacitance network within the unit, can be calculated with fair accuracy by hand and with high accuracy by a digital computer program. Voltage differences that occur between points due to oscillations as the impulse voltage wave travels through the winding are another matter, however, and for this purpose, the precise answer lies in the use of one-quarter or one-fifth scale electromagnetic models (see photo at right).

Each model consists of a core and coils in which the individual coil inductances are exactly the same as in the full-scale transformer that it represents. Coil-to-coil, coil-to-ground, and other capacitances are made the same through the addition of external capacitors, some of which can be seen on top of the core structure in the photo. Leads are brought out from various critical points in the winding and oscillograms are taken of the voltages that occur at these points when an impulse wave from a laboratory surge generator is applied at the line terminals. By scaling photographs of these oscillograms, voltage differences at any point in time can be determined for use in designing the insulation structure.

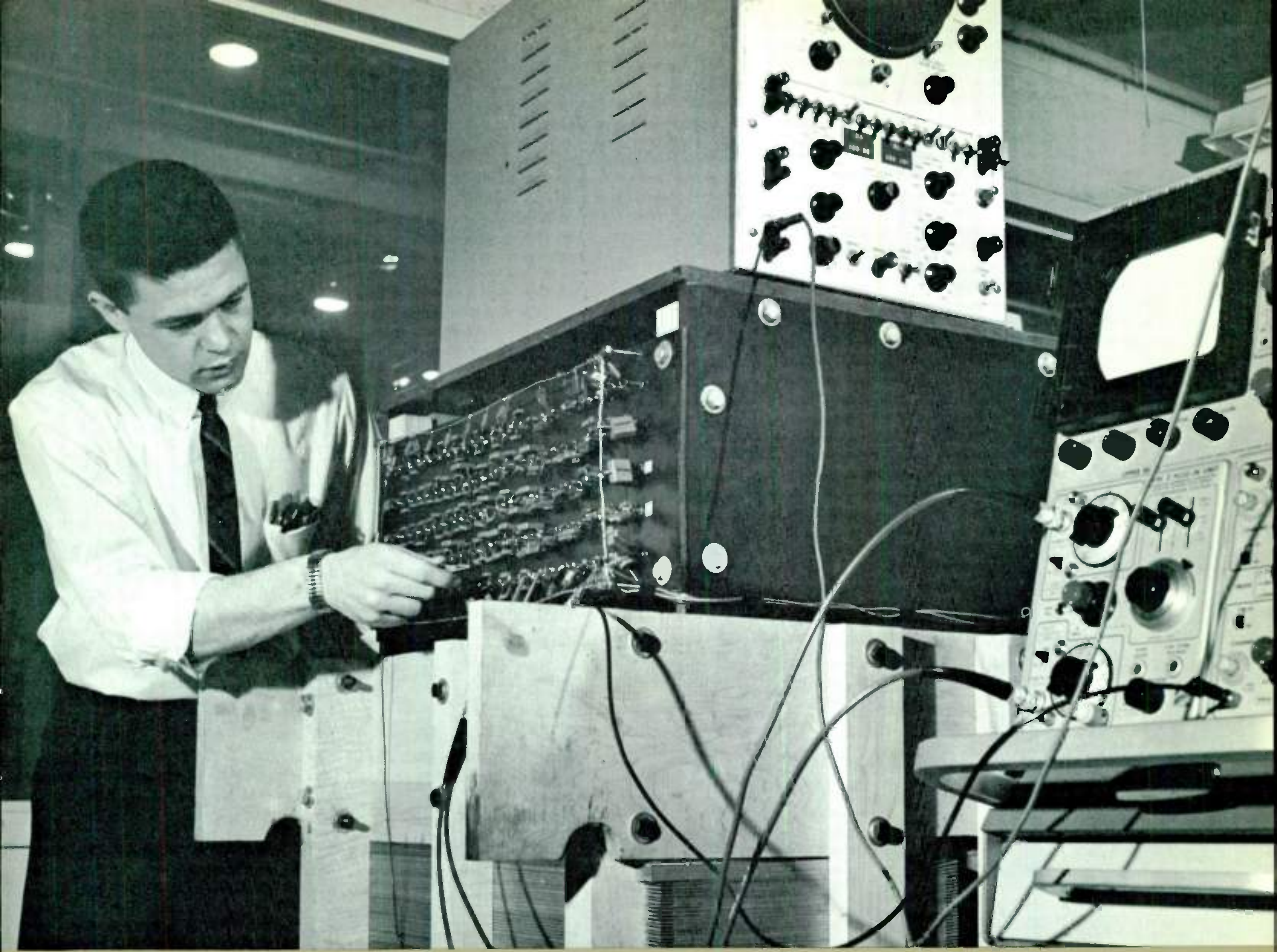
Once voltages are determined, it is still necessary to evaluate the voltage stress (volts per mil) that will occur at all points in space between the winding electrodes and ground or between various parts of the windings including static shields. For this purpose field maps are utilized; in these maps an analog is developed by using resistive paper on which copper foil is accurately located to represent the turns of the winding, and additional carbon paint is deposited in the areas where solid insulation is located. Thus a full-scale replica of the insulation structure itself is developed in which the resistivity of the paper at any point is proportional to the dielectric constant of the material, oil or pressboard, at that point in the full-scale unit. Direct-current voltages can be applied to any point in this analog, proportional to steady-state or impulse voltages as determined above, and equipotential points can then be determined throughout the structure by the use of null galvanometer. Separate equipotential lines can then be drawn on the map to illustrate the distribution of stress under impulse or steady-state voltage conditions, with the distance between lines of differing potential determining the actual stress at any location as well as the voltage across this distance.

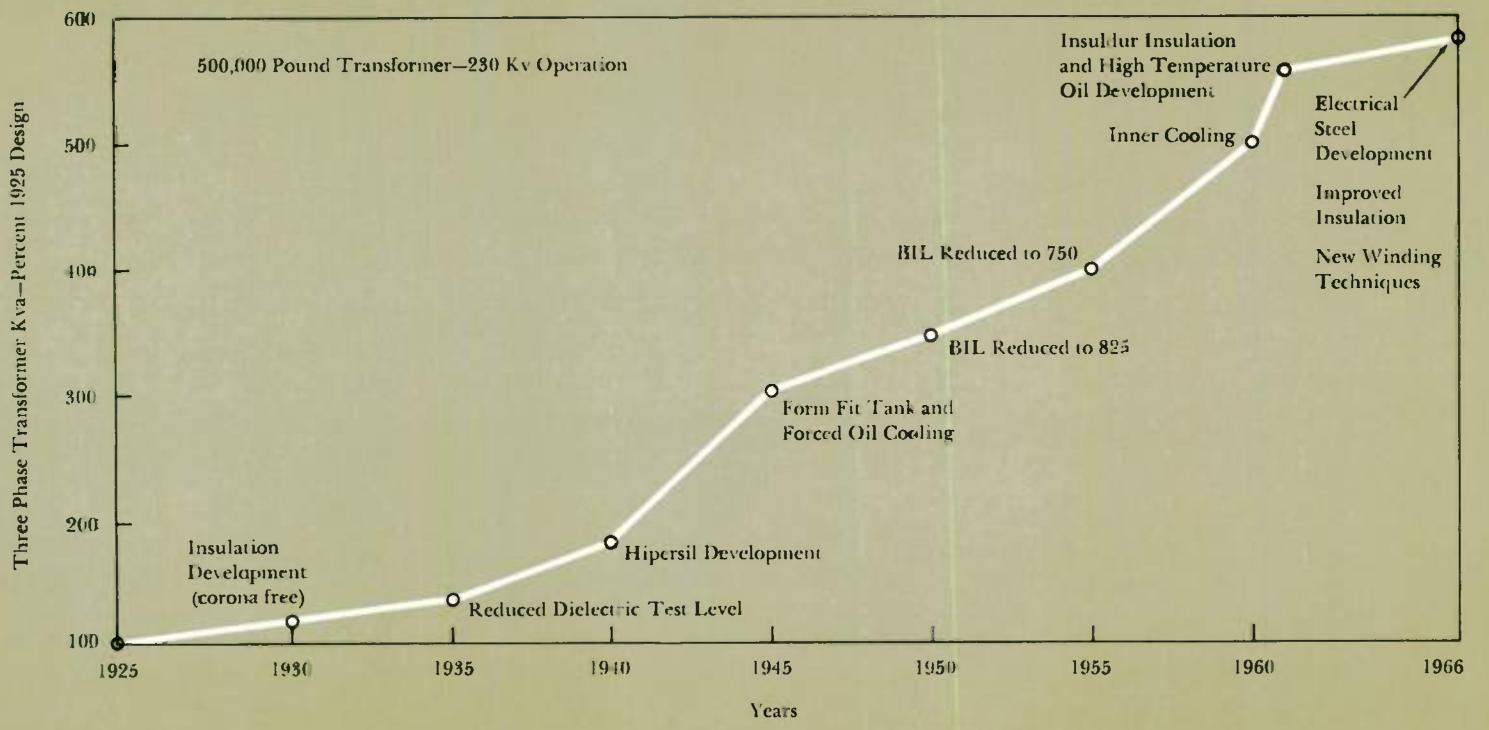
For greater precision in specific areas, such as those around a line coil or other high stress points, a digital computer has recently been programmed to print out voltage stress and direction of field at each point in a grid of any mesh and with any magnification. Lines can then be drawn through equipotential points and the coils, static plates, and other electrodes can be located; the result is a more accurate enlarged field map of a small area.

These electromagnetic models, field mapping techniques, and computer programs are powerful tools for the designer of large EHV transformers and reactors.

Photo—Scale models such as this are used to determine voltage differences between points in the transformer as an impulse voltage wave travels through the winding.

1—The trend of development in shell-form transformers is illustrated by this curve for one weight and kv rating.

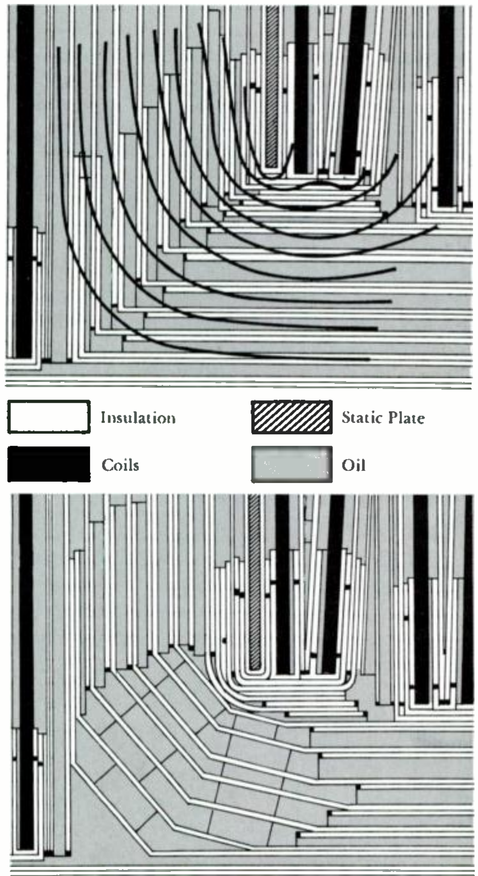




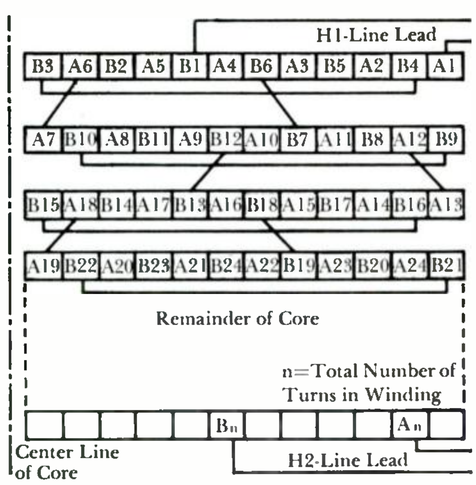
500,000 Pound Transformer—230 Kv Operation
Three Phase Transformer Kva—Percent 1925 Design
Years
100
200
300
400
500
600
1925
1930
1935
1940
1945
1950
1955
1960
1966
Insulation Development (corona free)
Reduced Dielectric Test Level
Hipersil Development
Form Fit Tank and Forced Oil Cooling
BIL Reduced to 825
BIL Reduced to 750
Inner Cooling
Insuldur Insulation and High Temperature Oil Development
Electrical Steel Development
Improved Insulation
New Winding Techniques

Many improvements, including optimum size and location of static plates (i.e., shields), the design of the static plates themselves, and specification of type and size of the insulation on outside turns and other vulnerable electrodes have resulted from such studies.

One of the more significant features to come out of this effort is "contoured" insulation. In a conventional insulation structure the equipotential lines cross the surface of many pieces of pressboard insulation structure, as shown in Fig. 2. This condition results in long paths of surface creepage on the insulation; thus the insulation is subjected to high voltage along these paths. Before the advent of 500-kv transformers this condition could be tolerated because the paths were inherently short enough or the stress low enough so that the critical limiting point in insulation design was still in the vicinity of highly stressed electrodes, such as static plates. A principal characteristic of creepage paths, however, is that the insulation strength per unit of distance (volts per mil) decreases markedly as the distance becomes longer (even more than strength in puncture); thus in 500 kv and higher voltage transformers there are occasions when the limiting design factor in a structure such as that shown in Fig. 2 is not in the vicinity of the electrode but in the area between electrodes. The solution to the problem, of course, is to design the insulation structure to eliminate long creepage paths with high stress, which means that the solid insulation items should be contoured to essentially follow the equipotential lines.



2—At top, a conventional insulation structure, with equipotential lines indicated; below is a contoured insulation design, showing how the insulation essentially follows the equipotential lines.



3—A mutually single interleaved two-conductor winding, shown in cross section.

Testing of New Designs

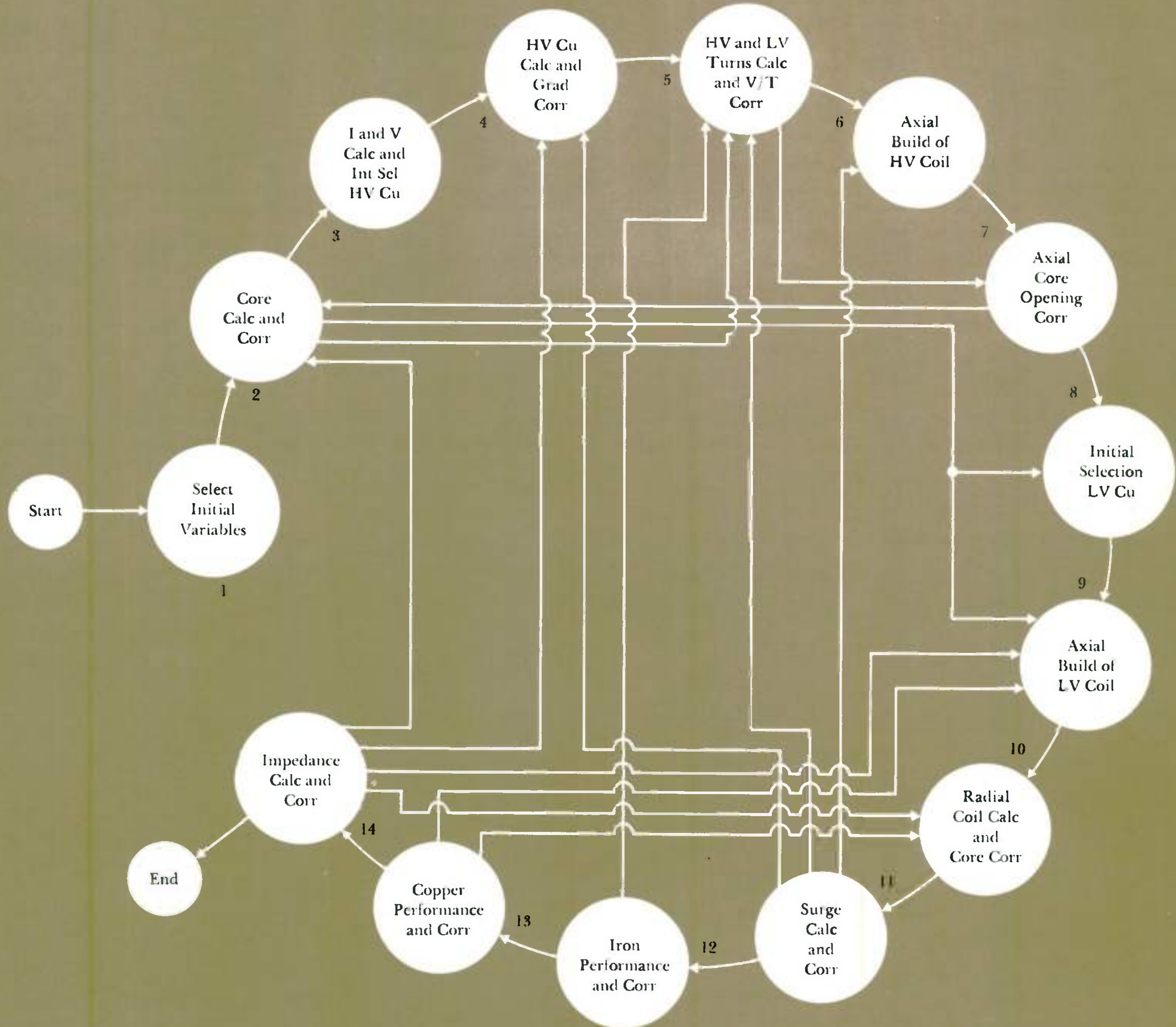
A comprehensive insulation development program includes analytical studies like the foregoing, but also involved is much detail work of designing and testing laboratory samples of new materials and insulation configurations. Even then an insulation system can only finally be proved in full-scale transformers. For this purpose two units of approximately 75 mva, single phase have been built—one for 230 kv and the other for 500 kv operating voltage. When a new concept of winding arrangement, insulation structure, or method of coil winding is developed, it is applied in one of these units and tested to destruction, after which the coil and insulation assembly is torn down, examined, and ultimately scrapped. The core and tank are retained for proving the next generation of insulation development. Only in this way can new concepts be proof tested, including proof of manufacturability, and unnecessary and undesirable risks inherent in premature application be avoided.

There are other things besides insulation development that can be counted upon to make the curve in Fig. 1 continue upward. Circulating currents and loss within parallel strands of the winding and stray loss in end frames and tank walls, which are both caused by magnetic leakage fields, result in increased size because of the additional cross sectional area required in the winding to reduce the losses in it and make the total meet a given performance limitation. New methods of shielding and new and more complete techniques for transposition of the strands that compose a single turn will reduce the stray losses to the point where the windings and the entire transformer can be smaller for a given mva capacity and loss performance.

Medium and Small Power Transformers

The foregoing has described some of the developments in the large EHV transformers of shell-form construction. Equally important innovations are occurring in the medium and small power field (up to 100 mva) in which the core-form construction is generally most favorable. In smaller ratings the inherent linearity of transient voltage distribution and mechanical strength of the shell-form construction do not represent the significant advantage that they do in the larger transformer sizes.

Windings—The initial distribution of an impulse voltage in a transformer winding is determined by the ratio of the ground capacitance to the series capacitance of the winding. While there is no direct proportionality involved, the higher the ratio, the more nonlinear the distribution—i.e., the greater the percent of



4—Early computer programs simulated the trial and error method of the design engineer, following a flow path like the one above. Circles 2 to 10 are the discrete design model. Circles 11 to 14 are performance calculations. The lines within the large circle are iteration paths.

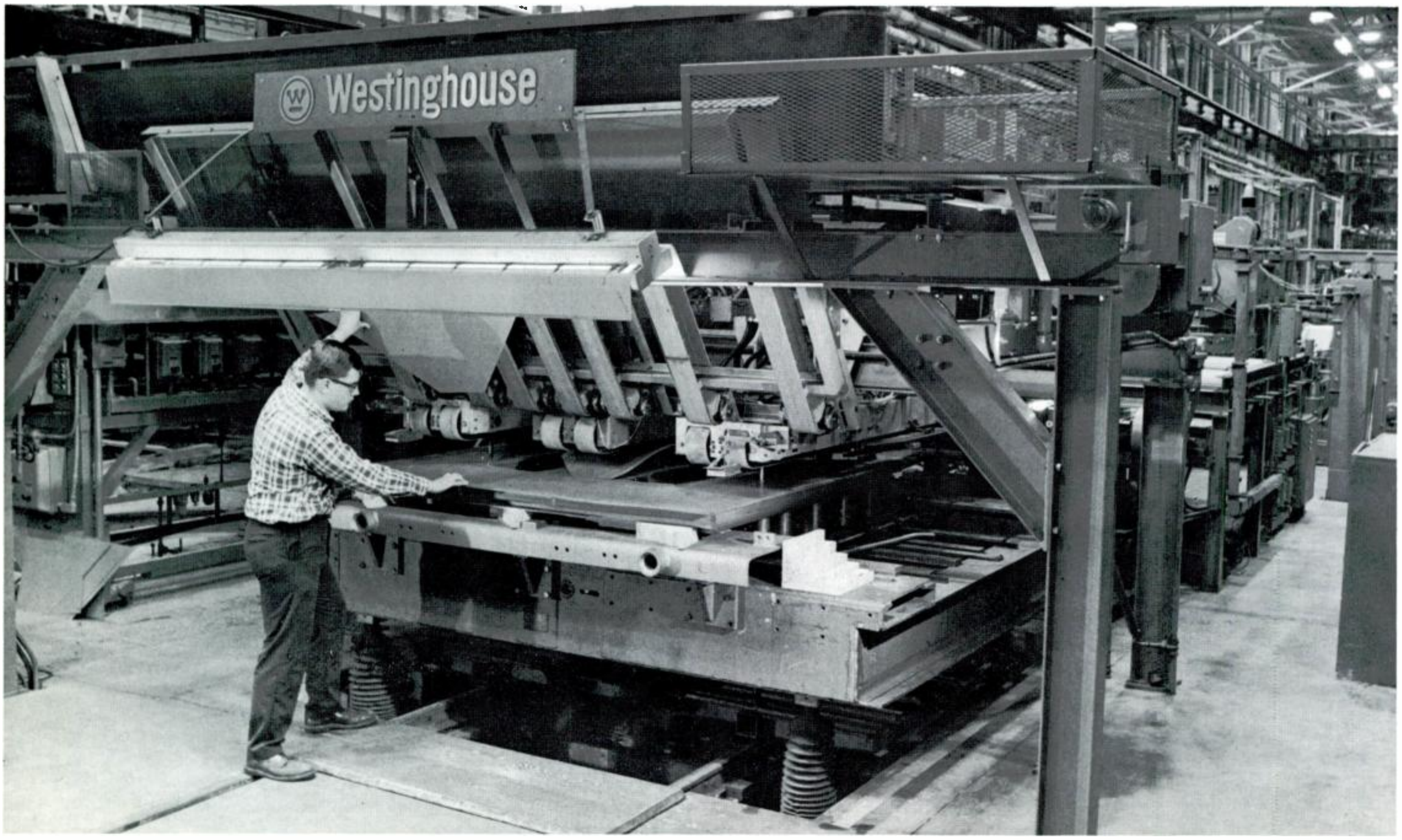
the applied voltage that appears across the turns or sections connected to the line lead. The poor transient voltage distribution of a core-form transformer arises from its relatively large number of turns and sections compared to a shell-form unit of the same size and, therefore, lower series capacitance and higher ground capacitance. There are ways to overcome some of this disadvantage, however, by interleaving the turns and thus greatly increasing the series capacitance, and about 20 years ago the first Hisercap (for *hi*gh *ser*ies *cap*acitance) was introduced for this purpose. Since then many improved variations have been developed.

For example, one of the most recent of these is the mutually single interleaved two-conductor winding, shown in Fig. 3, which permits the use of parallel conductors and higher current while at the same time achieving better interleaving under certain conditions and, therefore, higher series capacitance and better transient voltage distribution. Referring to Fig. 3, which shows in cross section the first four sections of a typical core form transformer winding, the interleaving is achieved by interposing turn number 4 of conductor B (one of the two in parallel), for example, between turns 1 and 2 of conductor A. In this case it requires four sections to complete the cycle; hence four sections constitute an interleaving group. In other cases, particularly with single conductors, an interleaving group consists of one or two sections.

As these windings have come to be applied in larger and larger coils, the problem of mathematical analysis has become even more complex. Successful application requires considerable experience and manufacturing know-how.

Computer Design—The design of transformers in this range of core-form construction is particularly adaptable to computer techniques, and because of this it has become possible to optimize designs with a degree of sophistication that would have been out of the question as recently as ten years ago.

The early computer programs for power transformers were automated to simulate the trial and error approach of the design engineer, using a flow diagram similar to that shown in Fig. 4. By iterating through the various sub-programs after starting with certain assumptions based on empirical data from previous designs (Circle 1, Fig. 4), convergence was obtained. An example of this iterative process would be the case where the surge voltage calculation of the design produced by the initial assumptions



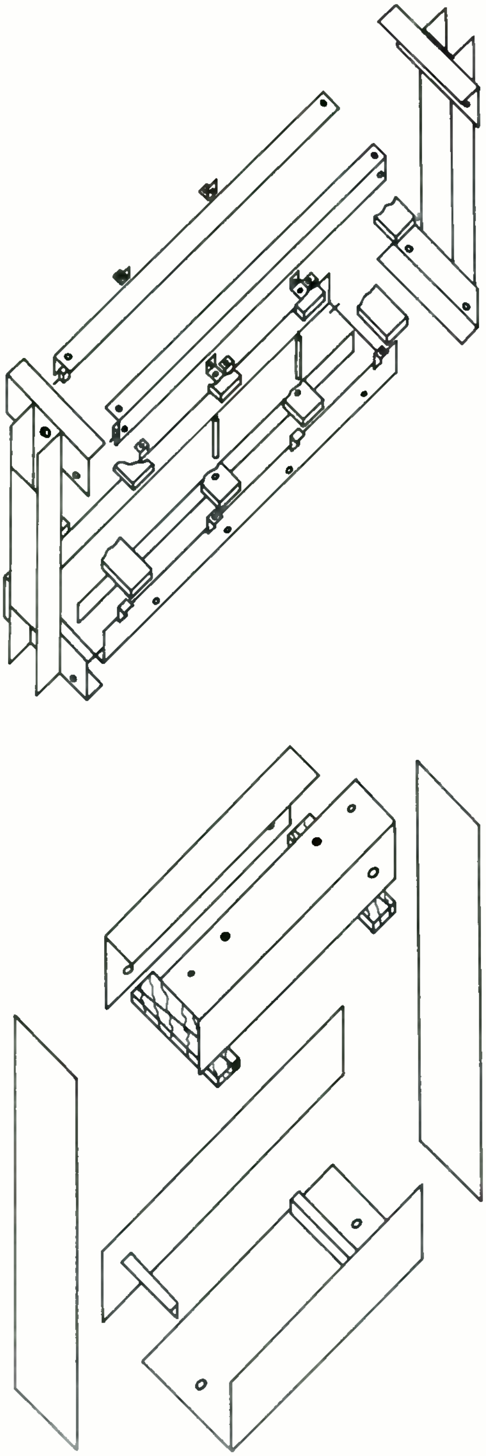
5—This automatic core stacking machine cuts and stacks the punchings for a three-phase core-form transformer.

(circle 11) did not meet requirements because of, say, insufficient conductor insulation. Adding insulation, however, affects the radial and axial build dimensions of the coil and other constants so after making this correction, the program must return to circle 6 and the calculations repeated from there on.

The first programs produced transformer designs comparable to those made by hand, but no attempt was made to optimize them. In recent years, however, through the use of heuristic techniques, ways have been found to logically approach the problem of optimizing cost, including evaluated losses if desired, size or other characteristics, with the result that transformers can be better proportioned and cost and weight improved. It is now possible to optimize almost every commercial order on a routine basis.

Aluminum Windings—Transformers of this size have been improved in many other ways. For example, developments in the joining fields have made it possible to build transformers with aluminum windings that are at least as reliable as those with copper. The stability of price and its ready availability have always made aluminum an attractive alternate, but until recently these advantages were offset by the difficulty in making reliable joints. The development of MIG and TIG inert gas welding as a substitute for brazing, together with new crimping techniques, have solved the joining problems to the degree that it is now at least as easy, and in some cases even more economical, to join aluminum than it is to join an equivalent amount of copper. One of the more interesting developments along this line is the resistance welding of copper braid to aluminum strap.

Manufacturing Techniques—Considerable headway has been made recently in the improvement of manufacturing practices to produce a more consistently uniform and, therefore, more consistently reliable product. A major development in this area is the automatic core stacking machine shown in Fig. 5. This machine automatically cuts the punchings for the three legs and top and bottom yokes of a three phase, core-form transformer and stacks the legs and bottom yokes. Only five operators are required, including two assemblers who perform set-up and final assembly of associated core parts. The top yoke punchings are set aside for manual yoking after the coils are loaded on the core.



6—Old (top) and new (bottom) designs for the parts required to hold together the core of a 2500-kva transformer. Number of parts was reduced from 53 to 14, and new design is smaller, more compact and reliable.

Reduction of Parts—Core-form transformers inherently have large numbers of parts required to hold them together and are thus especially adaptable to value engineering techniques. One of the more successful examples of the use of this approach was the reduction in the number of parts required to hold together the core of a 2500 kva transformer from 53 to 14 as shown in Fig. 6. Thus, the new design is smaller, more compact, yet more consistently reliable supporting structure.

Tighter Coils—The overriding requirement for power transformers is reliability, and for this reason any viable development program must include a major effort to improve or maintain this characteristic; in fact, it must be of first importance in considering any change for whatever purpose. For example, transformer coils must remain tight throughout the life of the unit if it is to survive repeated application of short-circuit currents, which are typical of system operation in the field and result in large vertical forces on the coils. Tight coils are difficult to maintain, however, because they contain one to three feet of cellulose material distributed throughout the height of the coil. Nevertheless, this problem has been solved over the past three years through the use of high-density pressboard, improved mechanical stabilization of the cellulosic insulation through special techniques including Insuldur treatment and, above all, by the mechanical prestressing of the coils (during the manufacturing process) to a force equal to that which they experience during short circuit. Through these means, and the use of adequate safety margins in the mechanical structure of the core and coil assembly, assurance is provided that the transformer of today is better able to survive rugged duty than any past design.

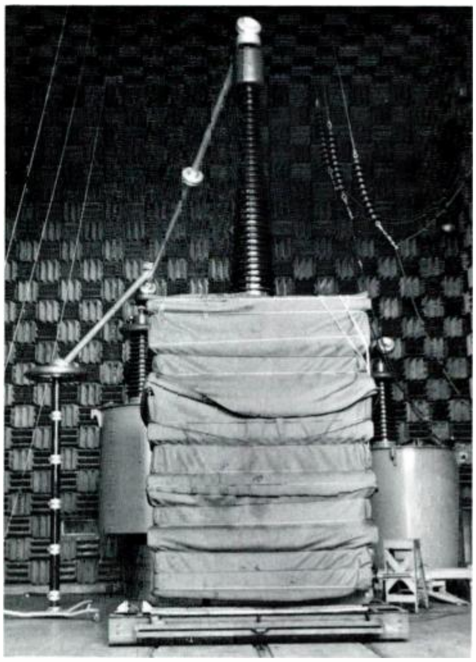
Still another recent example of a development program geared primarily to reliability is that which led to the introduction of WEMCO-CX oil, which has at least three times the oxidation stability of any other known insulating oil.

Bushings—A transformer is generally thought of as being simply a core surrounded by two or more windings and, indeed, the design of this much of any unit is perhaps the most critical. However, other portions of a particular transformer present equally difficult and challenging design opportunities for improvement. For example, the design of a 735-kv bushing such as that shown in Fig. 7 presents difficult problems in dielectric heating as well as voltage stress. The bushing in its test tank for thermal stability is 28 feet long and weighs 9600 pounds, yet will be dwarfed by the ones currently in design for service on transformers that will operate at line-to-line voltages of 1100 kv.

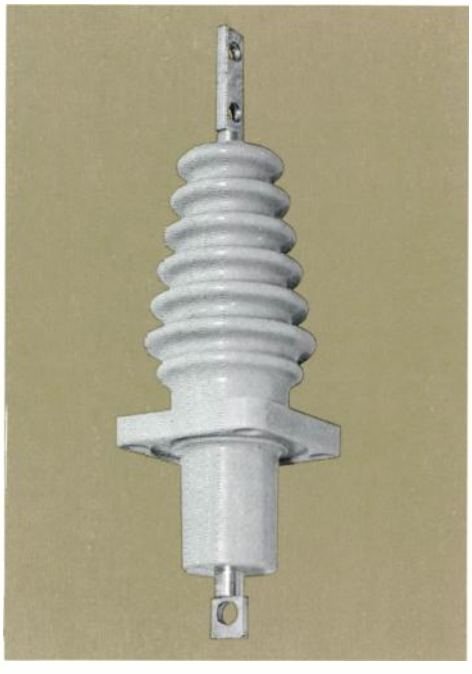
At the other end of the scale, the availability in recent years of suitable epoxy materials has started an accelerated conversion from the conventional porcelain bushing, with or without an internal condenser, to cast epoxy, particularly for indoor applications. A typical bushing is shown in Fig. 8. Performance of bushings similar to this is equal to or better than porcelain as indicated by track resistance tests, deflection under cantilever loads, thermal cycling and power arc tests. Similar materials are planned for use in outdoor service, with initial applications in the lower voltages such as 15 kv but gradually working up to higher voltages.

The epoxy materials have the advantage of flexibility. One of their earlier applications, for instance, was the molding of bus-bar bushings for furnace transformer applications, which permitted the first thoroughly effective and reliable gas-tight bushing in this type transformer and, therefore, made possible the use of an effective oil preservation system.

Tap Changers—The complex electric power systems of today require precise voltage regulation and this in turn means under load tap-changer equipment for transformers. Here again, the primary emphasis has been on reliability, which means simplicity and ruggedness. Recognizing this, new load tap changers have been developed with a 50 percent reduction in the total number of parts compared to their predecessors. In addition, the drive mechanisms have been simplified through the avoidance of critical switch positions, so that no brakes are required to stop the mechanism in a precise location and cams and other items are noncritical.



7—This 735-kv bushing is 28 feet long and weighs 9600 pounds, but is small in comparison to those now being designed for line-to-line voltages of 1100 kv.



8—A bushing of cast epoxy. Epoxy portion in this case is about 12 inches long.

For large, high-voltage applications, the interconnection of EHV systems has created a demand for voltage regulation at kilovolt levels well above those of even a few years ago and this in turn has created a need for the UTH 1175 tap changer; the designation indicates that it will withstand all 1175 BIL tests to ground. This tap changer represents a dramatic departure from past practice in the United States in that it is a resistance rather than a reactive tap changer. It is good for service at the line end of 335 kv windings with maximum reliability, and contact life greater than 500,000 operations in most applications.

This change in practice was dictated by the need for high speed switching and longer contact life at these high voltages and power, which are brought about by the interruption of in-phase voltages and currents. This aspect overrode the advantage of using half the number of winding taps that accrue to the reactive type of switching through the use of bridging positions, in which the reactor is "bridged" across two taps and power is taken from the midpoint on half the total tap changer positions.

As shown by the foregoing, the state of the art in power transformers is progressing at an accelerated pace with the advent of new materials, techniques, and concepts. An engineering development program must take advantage of all of the new art as it becomes available while intelligently applying known techniques in new ways. At the same time, judgment and experience must influence the application of the new ideas so that the net result is a prudent yet continuing evolution of smaller and more reliable transformers. It is especially fortunate when this experience encompasses all types of designs, so that each new technique can be applied in the most effective way.

Steam Turbines for Auxiliary Drives

Mario Pierpoline

As power plant ratings continue to grow, the applications for auxiliary drive turbines increase. Already widely accepted for boiler feed pump drives, the boiler fan drive is now a promising application. Turbine and control designs are being continually refined to handle these applications efficiently and reliably.

The auxiliary drive steam turbine has been a widely and rapidly accepted innovation in steam power plant design in recent years. The demonstrated reliability of this specialized turbine in handling the many demands on boiler feed pumps, along with the turbine's contribution to improved steam cycle heat rates, has often led to the decision to use a single or two half-size turbines for boiler feed pump drives.

The steadily increasing ratings of main units, combined with increased applications of pressurized, once-through, and cyclone furnace boilers, have raised boiler fan power requirements to the point where the auxiliary drive turbine is also becoming economically attractive for this application—in many cases because of the same factors that have already justified the boiler feed pump application.

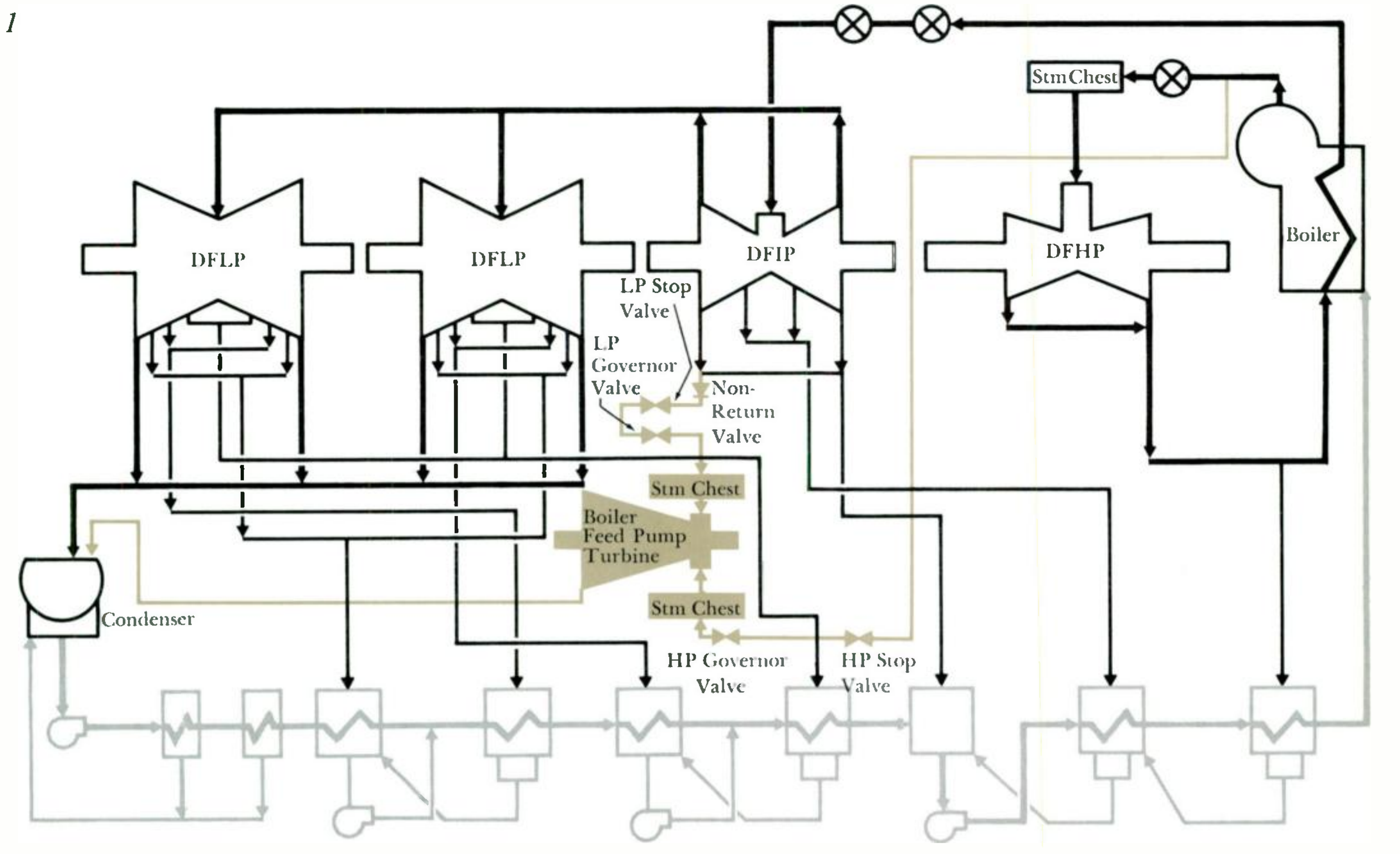
In nuclear power plants, moreover, steam turbines are being applied to drive the primary and secondary feed pumps. With the increased outputs planned for future nuclear plants, the auxiliary drive turbine should always be considered for this application.

To meet the need for efficient dependable auxiliary drive turbines, Westinghouse steam turbine designers are applying the same reliability criteria to the auxiliary turbine design that is applied to

Mario Pierpoline is a fellow engineer in the Small Steam and Gas Turbine Division, Westinghouse Electric Corporation, Lester, Pennsylvania.

1—Condensing boiler feed pump turbine is paralleled with low-pressure elements of the main unit. This arrangement effectively increases total exhaust area and reduces exhaust losses of the main unit.

1



main unit turbines. Continuous refinement of basic turbine and control designs has resulted in a comprehensive line of pre-engineered turbine drives for the complete range of boiler feed pump and boiler fan applications.

Condensing Turbines

For the past four years, the condensing high-speed turbine has dominated the field over the noncondensing unit. The performance advantage of high speed and the thermodynamic advantage and relative simplicity of condensing operation have made this combination an industry standard. The economic advantages of the condensing auxiliary turbine are further enhanced as the size of the main turbine-generator unit increases.

Boiler Feed Pump Drives—The condensing boiler feed pump turbine is integrated into the steam cycle as shown in Fig. 1.

By bleeding steam from the main unit at the crossover point, and exhausting directly into the main condenser, steam flow through the feed pump turbine is in parallel with the main unit. This effectively increases the total exhaust area, which reduces the exhaust losses of the main unit and produces a thermodynamic gain for the overall steam cycle.

To obtain the greatest benefit from diminishing the exhaust losses of the main turbine, steam for the boiler feed pump turbine should be extracted at as low a pressure as possible. Since low-pressure steam has relatively low energy content, high volumetric flows are required. At low or partial loads on the main unit, steam conditions from the crossover point are reduced so that the control valves on the auxiliary turbine must open to admit

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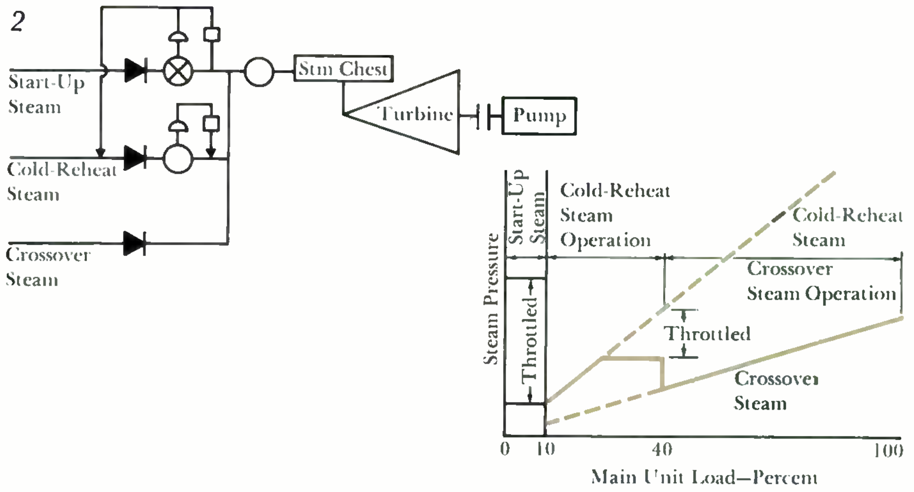

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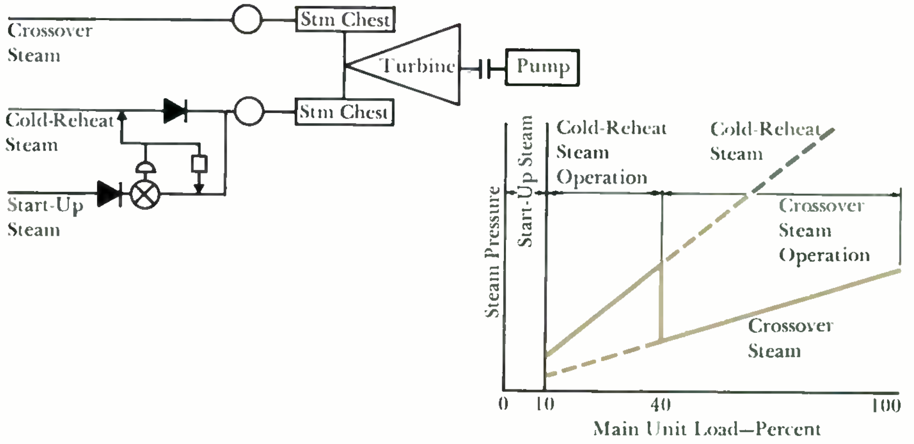

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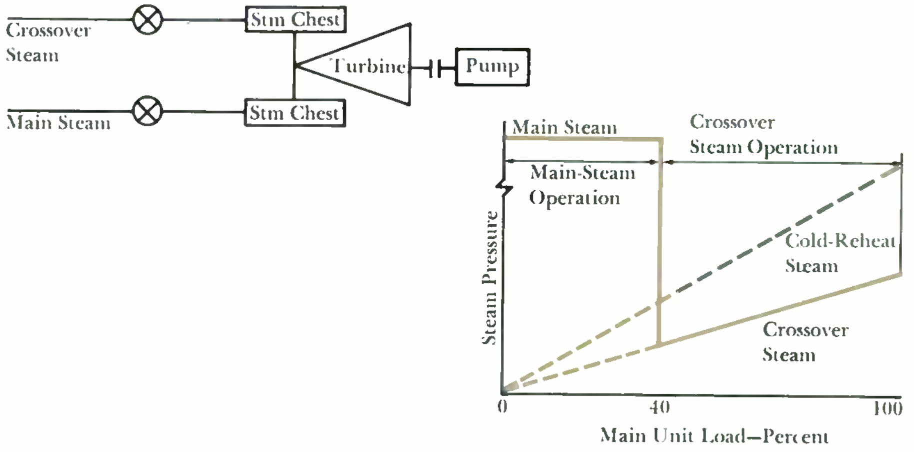


2—Single steam chest with multiple steam sources permits auxiliary turbine operation over entire load range of the main unit.

3—Two-steam-chest arrangement uses crossover steam for normal operation and cold-reheat steam for low-load operation.

4—In this arrangement, crossover steam is used for normal operation and main boiler steam is used for low-load operation. The integration of this arrangement into the steam cycle is shown in Fig. 1.

even larger volumetric flows.

The auxiliary drive turbine can operate from one source of steam from full main-unit load down to approximately 40 percent load before another source of steam is required. Actually, the efficiency of the auxiliary turbine increases as main-unit load drops from full load to low load, but, for all practical considerations, efficiency can be assumed to be constant over this range.

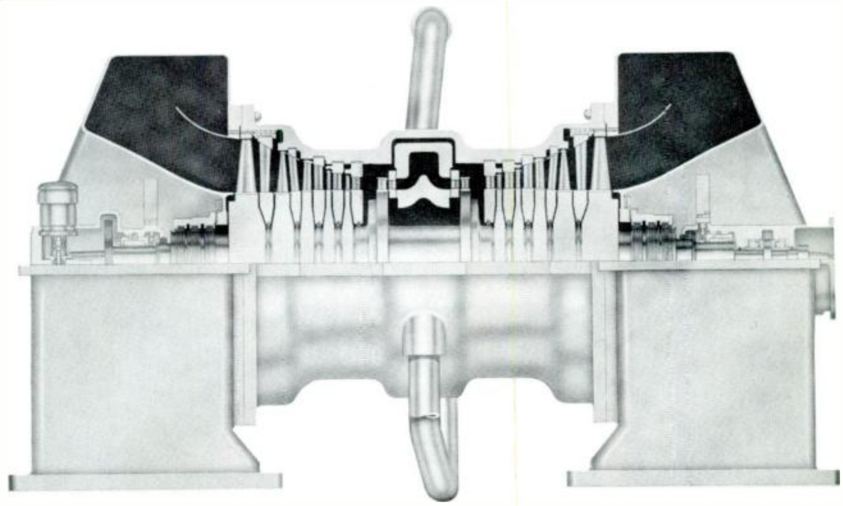
Some boiler feed pump turbines are built with a single steam chest and are operated over the entire load range with the steam source arrangement shown in Fig. 2. All steam sources are manifolded externally to the turbine, and the transfer from one steam source to another is done automatically.

Boiler feed pump turbines are also built with two separate steam chests. For example, the arrangement shown in Fig. 3 uses crossover steam for normal operation and cold-reheat steam for low-load operation. The cold-reheat steam chest is separately mounted.

In another arrangement, shown in Fig. 4, the boiler feed pump turbine operates from high-pressure main steam during low-load operation. In this case, the main boiler steam chest is located at the base of the turbine cylinder; the high-pressure stop and governor-valve assembly, which automatically selects the required steam source, is separately mounted at the side of the turbine. This arrangement is integrated into a typical steam cycle as illustrated in Fig. 1.

Several auxiliary-drive turbines have been built in the 40,000-hp range for inlet steam pressures below 100 psia. To meet the high-volume flow requirements of such an application, a high-speed turbine with a complete double-flow configuration has been developed (Fig. 5).

5



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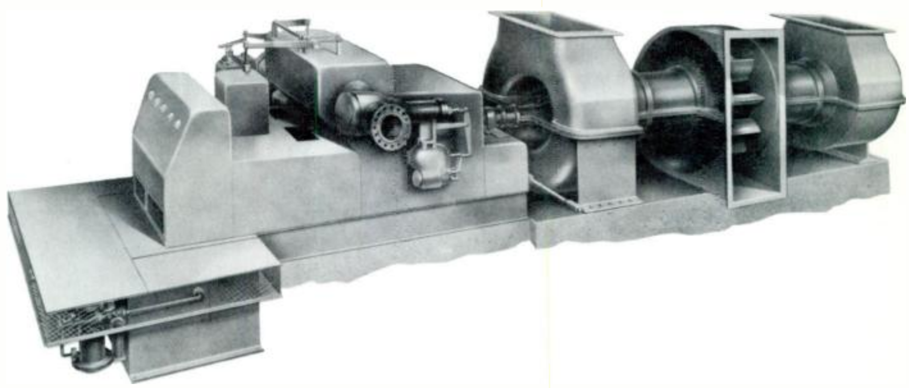

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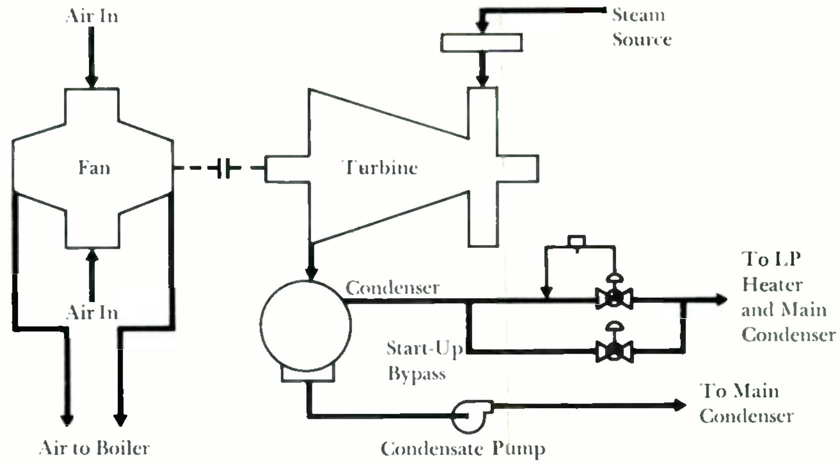

5—High-speed auxiliary turbine with complete double-flow configuration has been developed to handle high volume flow requirements for low inlet steam pressures.

6—The axial-flow fan can be direct-connected to high-speed steam turbine drive.

7—Typical arrangement for integrating boiler-fan turbine into main unit steam cycle.

This design incorporates the same advanced features that are used in main-unit designs, such as diffuser exhaust hoods, internal moisture separation, separately mounted steam chests, and individually inserted nozzle chambers with welded expansion sleeves. The design shown in Fig. 5 also has a double-ended drive, developed for those applications where it is desirable to drive a booster pump from the same turbine as the main feedpump.

Fan Drives—The motor-driven centrifugal fan has long been the standard for boiler fan application. However, the ever increasing demand for larger volumetric flows of air at elevated pressures for supercritical-pressure, once-through boilers makes these applications well suited to the axial-flow fan. Since the axial-flow fan is inherently a high-speed machine, it can be directly connected to a steam turbine. The speed control flexibility of the steam turbine makes the drive well suited to the application. A fan-drive configuration in which an axial-flow fan is direct connected to a steam turbine is shown in Fig. 6.

The thermodynamic integration of a turbine drive for boiler fans into the steam cycle differs from that of the boiler feed pump turbine. Fan power for a standard once-through boiler decreases more rapidly than boiler feed pump power for a similar main-unit load reduction, so that the operation of a turbine fan drive can be extended over a greater range without a secondary steam supply. Steam for the fan-drive turbine can be bled from the main cycle at the crossover point and exhausted to a separate condenser, or to an air heater. Several schemes have been advanced, where turbine exhaust pressure is varied, to provide exhaust steam for an air preheater for summer and winter operation.

One typical cycle is shown in Fig. 7. Steam is bled from the main unit at the crossover point and exhausted to a separate condenser or a low-pressure heater. An excess of steam from the condenser may be bled to the low-pressure heater for summer operation.

The steam flow through the condensing turbine is in parallel with the main unit, which in effect increases the total exhaust area of the main unit. This effect, although smaller than that for a boiler feed pump turbine, will help reduce exhaust losses of the main unit and contribute to overall thermodynamic gain.

Electrohydraulic Governing System

The introduction of centralized speed control and the application of computers to oversee the main unit turbine have created additional burdens for the auxiliary drive turbine governing systems, and this has necessitated reevaluation of the design criteria for the auxiliary-drive turbine control. For example, as the sizes of the control system and its components have increased (due to larger steam volumes and flow rates for auxiliary drive turbines), so have the inertia of parts, friction, and system time delays, which in turn affect the performance and accuracy of the control.

To meet these new requirements, the electrohydraulic control system[1] originally developed for main-unit turbines has been modified for application to auxiliary drive turbines. This new auxiliary drive turbine control combines the advantages of solid-state electronics and high-pressure hydraulics and has provided major gains in flexibility and response.

The Basic System—With the electrohydraulic control system shown in Fig. 8, steam flow is controlled at the turbine inlets by conventional valve arrangements. During a normal start, the stop valves are wide open and the governor valves regulate steam flow in response to the wide-range speed control characteristic of the electrohydraulic system.

However, unlike previous turbine controls in which the low-pressure lubrication oil provided the hydraulic *motive fluid* to operate the steam valves, as directed by a speed governing system that was usually considered an integral part of the turbine, the position-control actuators for the steam valves are now of the electrohydraulic type, and are controlled by signals initiated by a solid-state electronic controller. The hydraulic supply system from the main unit delivers high-pressure fluid to the actuators. The fluid, acting on relatively small actuators, produces the valve-positioning force requirements. The electric control signals result from a comparison of auxiliary drive speed with reference signals provided by boiler controls, or from commands initiated at the operator's panel.

The electrohydraulic turbine control system (Fig. 8) consists of four major parts:

1) A high-pressure fluid, supplied by the main unit control system;

2) Steam-valve servo-actuator assemblies;

3) An emergency trip system; and

4) A solid-state electronic controller and operator's panel.

Fluid Supply System—The complete high-pressure fluid supply, lubrication, and emergency trip systems are shown in Fig. 9.

The high-pressure fluid supply system is provided by the main unit and is of the unloading type, completely separate from the lubricating-oil system. A dual-pump system is used, with one pump serving as a complete backup. The ac motor-driven positive-displacement pumps, mounted on a small reservoir containing the fire-resistant synthetic-base fluid, operate with a submerged suction. The high-pressure fluid is discharged through metal mesh filters and isolation check valves and stored in a bank of nitrogen-charged piston-type accumulators. Unloading valves on the pump discharge divert the fluid to the reservoir when fluid pressure increases to approximately 1800 psig. Shutoff and check valves are

8—Electrohydraulic control system for auxiliary turbine drive is a modified version of the main-unit control system.

9—The high-pressure fluid supply system (provided by main unit) is completely separate from the lubrication system. Emergency trip is initiated by loss of pressure in high-pressure fluid trip header, lubrication oil header, or over-speed or other emergency conditions of the boiler feed pump turbine.

[1]Noyes, E. G., and Birnbaum, M., "Electro-Hydraulic Control Improves Operation and Availability of Large Steam Turbine," *Westinghouse ENGINEER*, March 1966, pp 49-54.

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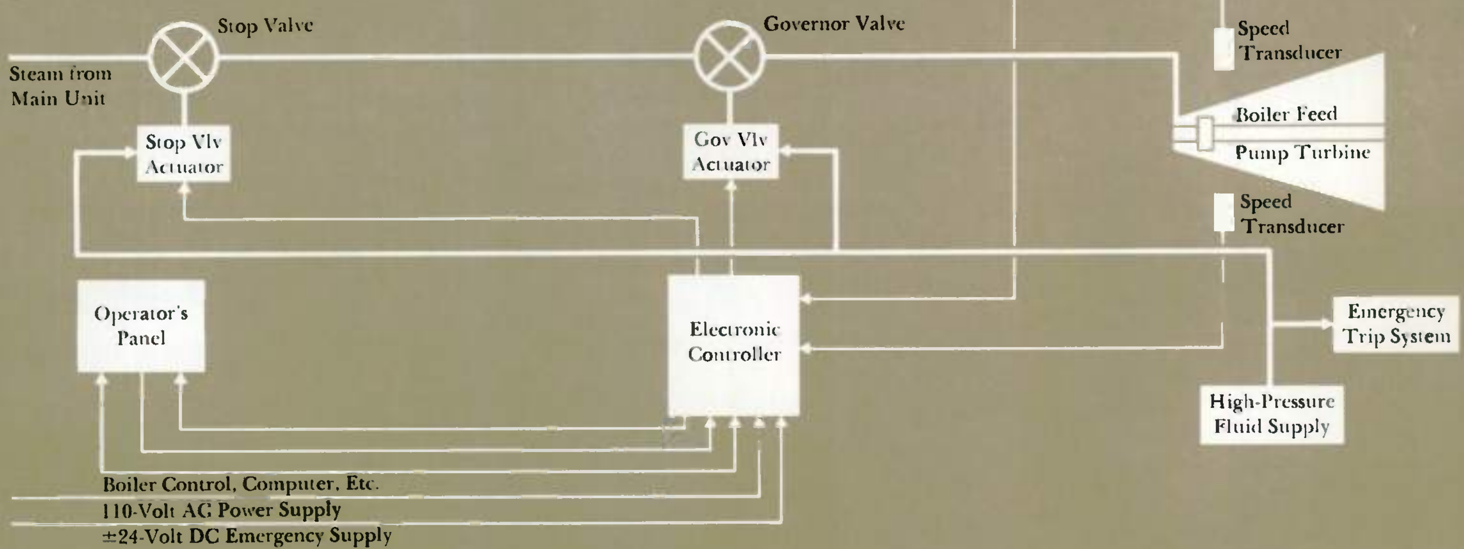
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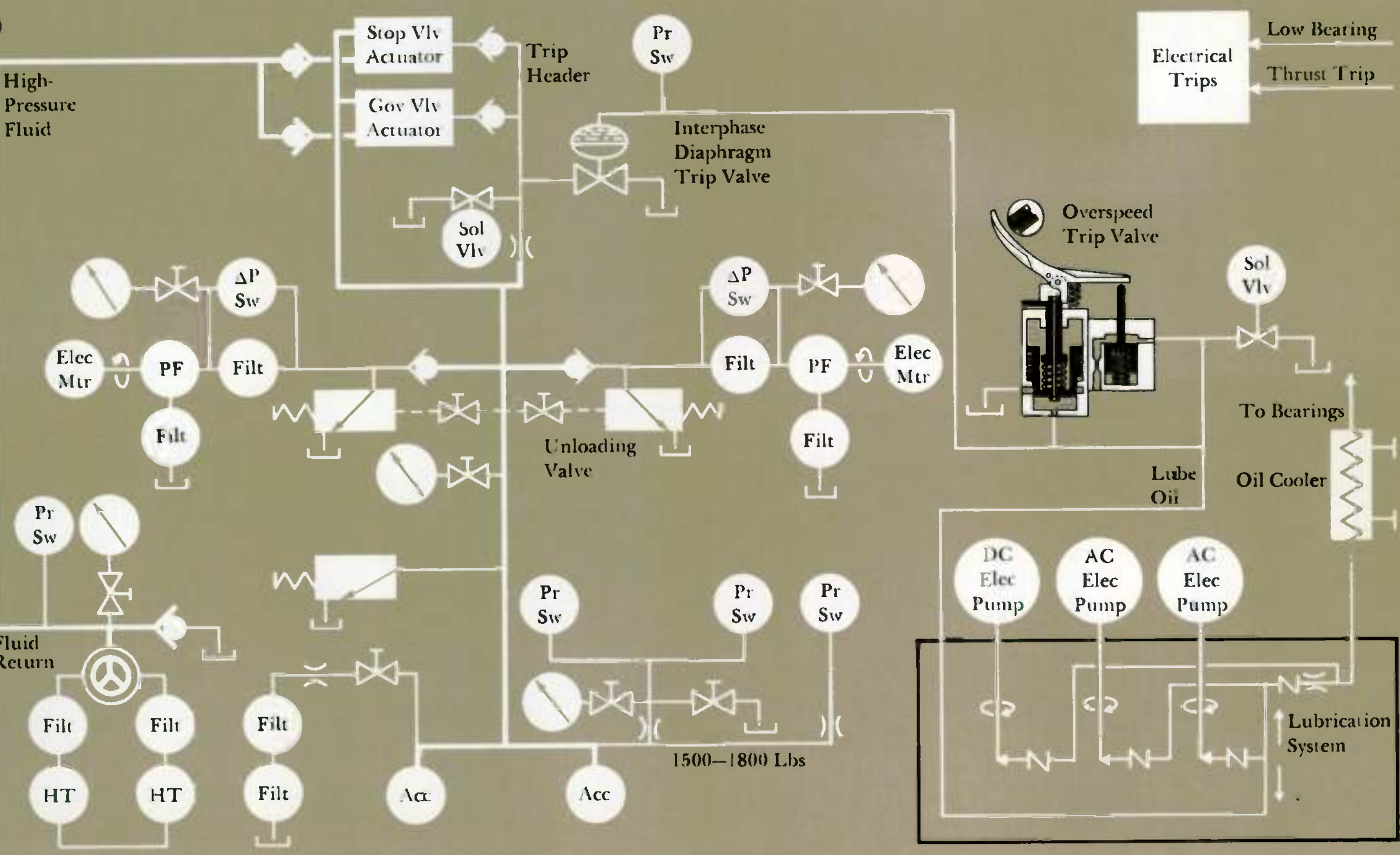
Governor Valve
Steam from Main Unit
Speed Transducer
Boiler Feed Pump Turbine
Stop Vlv Actuator
Gov Vlv Actuator
Speed Transducer
Operator's Panel
Electronic Controller
Emergency Trip System
High-Pressure Fluid Supply
Boiler Control, Computer, Etc.
110-Volt AC Power Supply
±24-Volt DC Emergency Supply

9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Gov Vlv Actuator
Trip Header
Pr Sw
Electrical Trips
Low Bearing
Thrust Trip
High-Pressure Fluid
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Overspeed Trip Valve
ΔP Sw
Elec Mtr
PF
Filt
Unloading Valve
To Bearings
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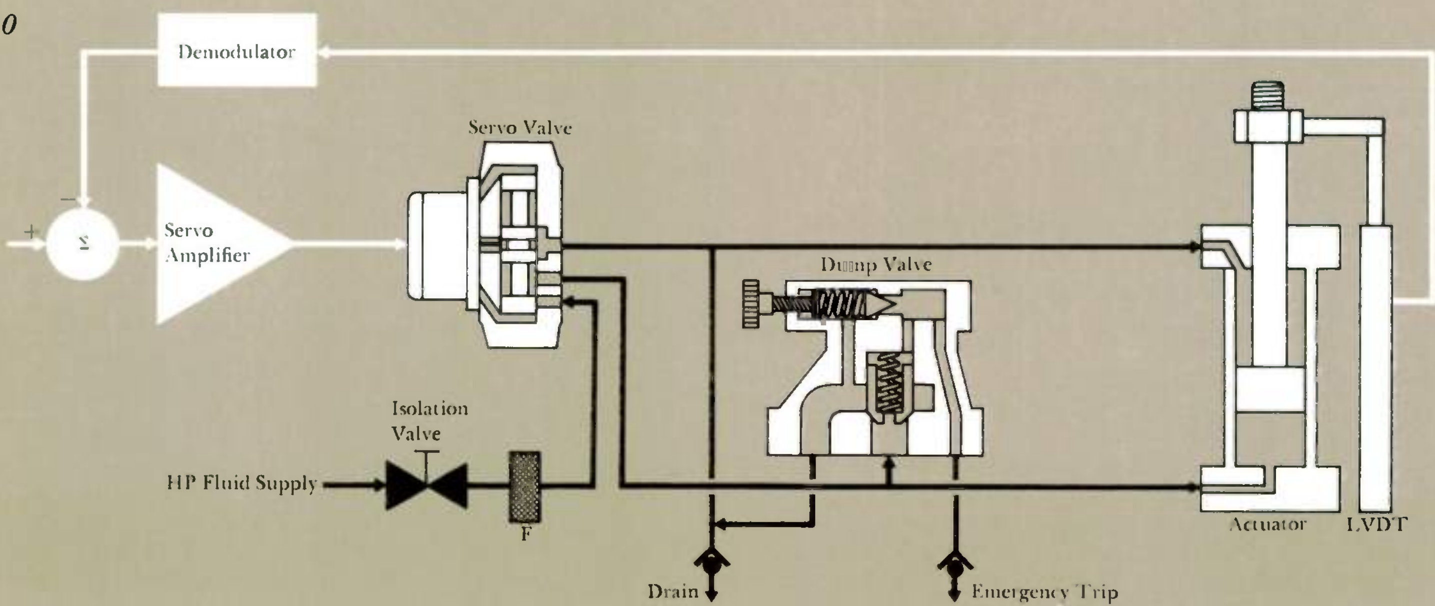
Acc
1500–1800 Lbs
Lubrication System

10


Demodulator
Servo Valve
+
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Servo Amplifier
Dump Valve
Isolation Valve
HP Fluid Supply
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Drain
Emergency Trip
Actuator
LVDT

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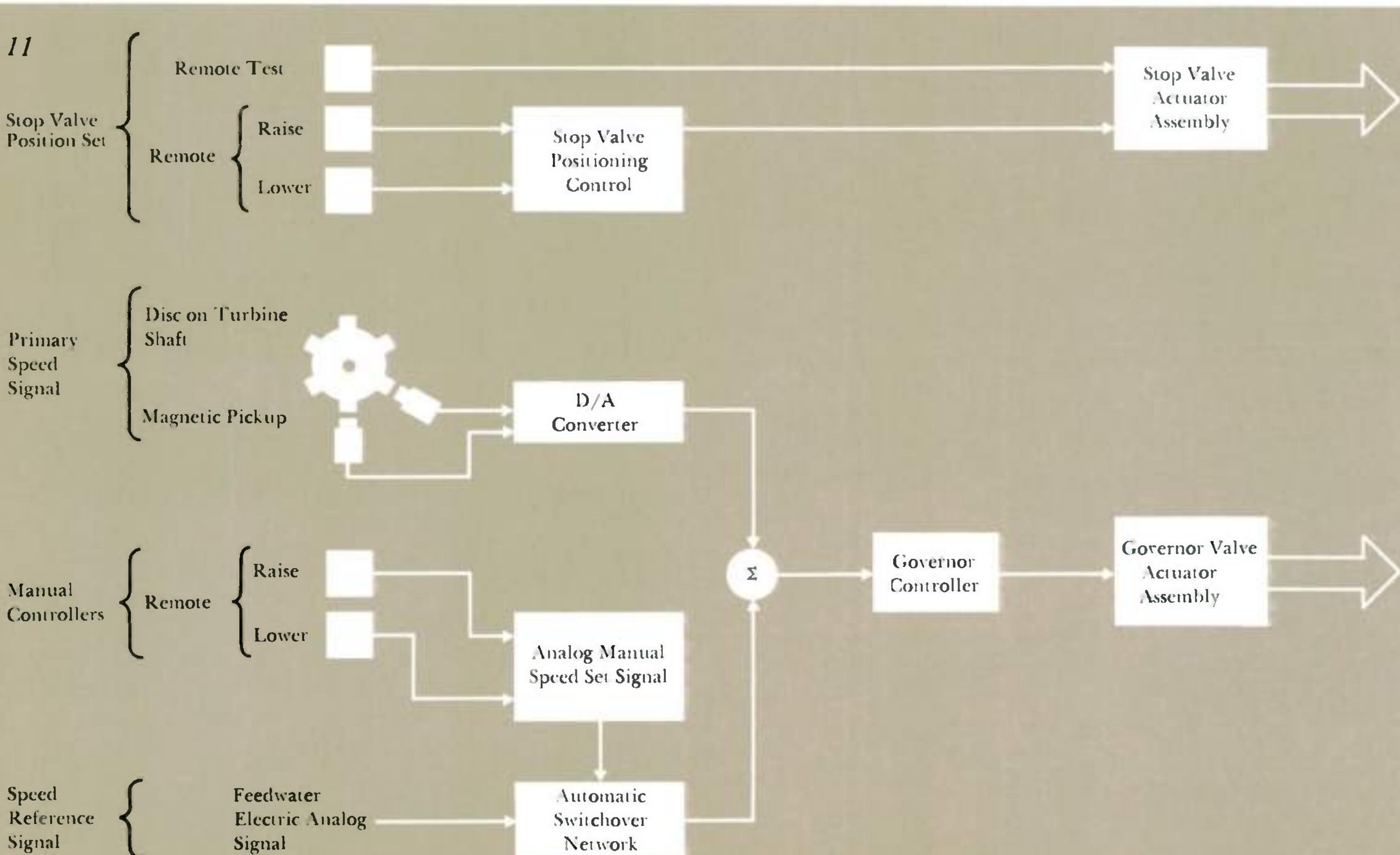
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Remote Test
Remote
Raise
Lower
Stop Valve Positioning Control
Stop Valve Actuator Assembly
Primary Speed Signal
Disc on Turbine Shaft
Magnetic Pickup
D/A Converter
Σ
Governor Controller
Governor Valve Actuator Assembly
Manual Controllers
Remote
Raise
Lower
Analog Manual Speed Set Signal
Speed Reference Signal
Feedwater Electric Analog Signal
Automatic Switchover Network

included in both pumping systems to provide isolation for on-line maintenance.

Emergency Trip System—The high-pressure fluid trip header, connected to the valve actuator assembly, is controlled by a diaphragm-operated trip valve and solenoid valve (Fig. 9).

The mechanical overspeed trip arrangement and the vacuum trip are retained from previous designs. When the trip valve is opened, either by overspeed or other emergency conditions of the boiler feed pump turbine, pressure in the header is released, initiating quick closing of all steam valve actuators. A solenoid valve actuated by a pressure switch on the lubrication oil trip header serves as a backup for the diaphragm valve.

Valve Position Actuators—Servo actuators used for the stop and governing valves require proportional position control (Fig. 10). The flow of high-pressure fluid through an isolation valve and a 10-micron metal mesh filter to the actuator is controlled by a servo valve. The position control signal and the feedback signal from the linear variable differential transformer (LVDT) are summed. In response to this analog signal, the servo amplifier modulates the servo valve to accurately position the actuator and steam valve. The servo valves are mechanically biased to assure fail-safe operation should the electrical signal be lost.

A dump valve with the pilot actuated by the emergency trip header provides quick closing independent of the electrical system. If trip header pressure is released, the operating fluid is diverted to drain, and the stop and control valves are closed quickly.

Special packaging techniques are used for these assemblies. The modular components are face-mounted on a stainless-steel block to form a complete actuator assembly. The isolation valve permits on-line maintenance of all components of the assembly, including the actuator. Adoption of this modular design technique and repeated use of standard components improves unit availability and maintenance procedures.

The servo position loop described is optimized to obtain a steady-state position accuracy of less than 0.005 inch and a valve-closing time for dump conditions of 0.3 to 0.4 second. This performance assures adequate overspeed protection and stable operation for changes in steam forces or fluid supply pressure.

Electronic Controller—This unit is basically an analog computer consisting of a number of solid-state dc operational amplifiers and signal input. The controller consists of five functional subsystems, as shown in Fig. 11:

1) Primary speed channel
2) Speed reference signal
3) Stop-valve positioning system
4) Governor-valve positioning system
5) Manual controllers.

The primary speed channel is similar to that used on the Westinghouse Digital Analog Control Apparatus (DACA), a wide-speed governor of precise control originally developed for the paper industry. A frequency proportional to speed is obtained from a reluctance pickup coupled magnetically to a notched wheel on the boiler feed pump turbine rotor. These pulses are amplified and converted to an analog signal proportional to turbine speed.

The electrohydraulic governor controls the turbine from approximately 500 rpm to maximum speed with a very high degree of accuracy.

The stop-valve system consists of a controller and position controls for the valve. The stop valve is designed to permit the exercising of the valve while the unit is under operation. A manual controller establishes the desired valve position.

The governing-valve system is similar to the stop-valve system. The input voltage to the servo amplifiers is derived from the automatic controller. The speed input to the governor-valve system provides wide-range speed control during starting.

The control system permits the transfer from automatic to manual and from manual to automatic without any abrupt change in speed. The transfer is gradual. The lowest signal, either automatic or manual, always controls the turbine.

The control functions are organized on individual plug-in printed-circuit cards and are cage-mounted in the main turbine electronic governor-controller cabinet. The rack-mounted modules with their associated test points facilitate trouble shooting and maintenance.

Electronic components were selected for their demonstrated reliability on prior equipment and are applied with considerable safety factors. Silicon planar type semiconductors are used extensively and are operated at no more than one-fifth their rated current or power. Pulse-width modulation and switching techniques are used wherever possible to minimize power dissipation and extend component life.

What Is Ahead in Turbine Drives?

As a general rule, boiler feed pump turbines should be used on all power plant applications where the main unit is over 400 mw and should be seriously considered for units above 300 mw. With the increase in main unit sizes, there will be a continuing increase in auxiliary drive turbine applications.

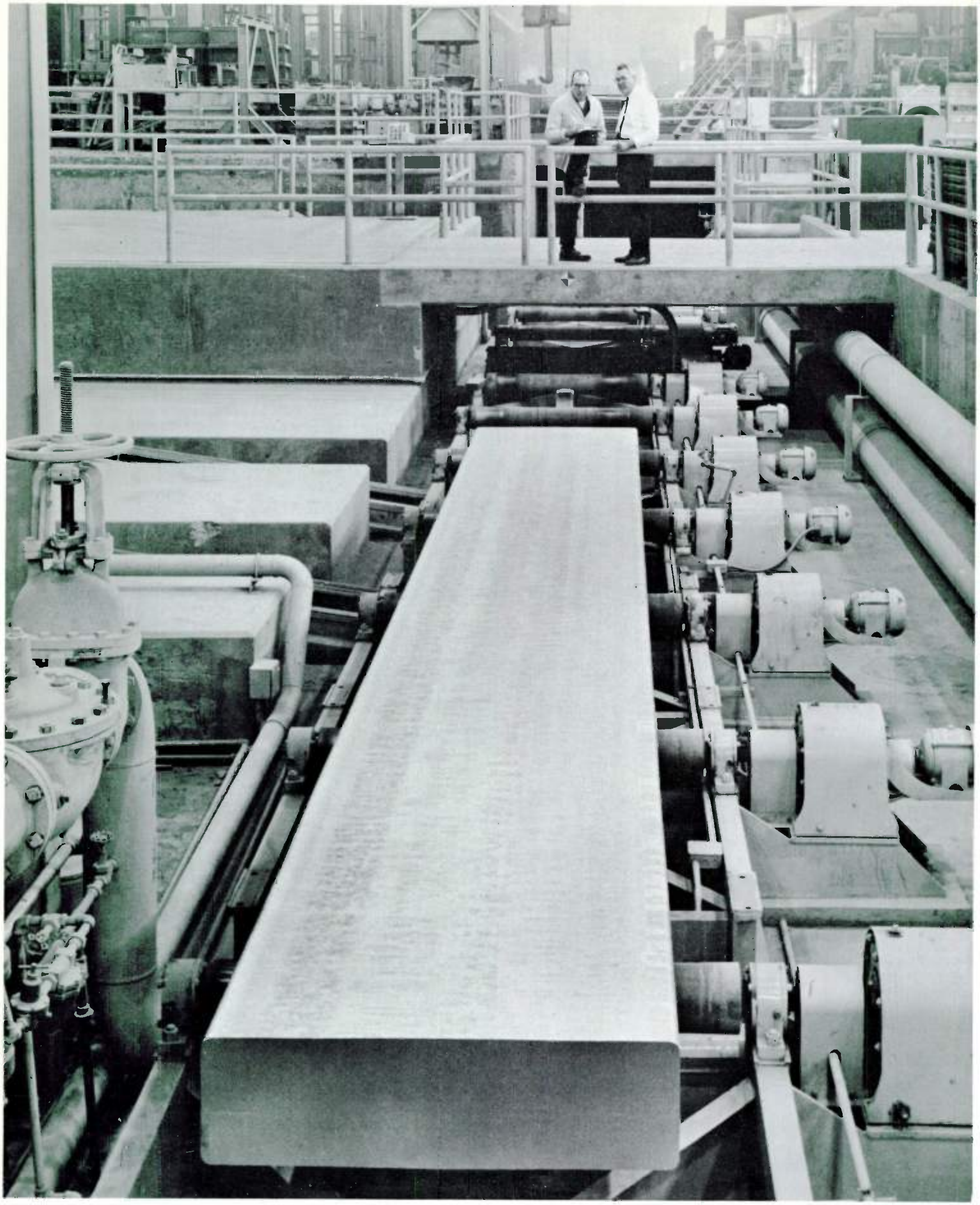
Boiler feed pump turbine capacity has grown from 500 hp for the first applications about ten years ago to the present large units of 40,000 hp for high-pressure, once-through boilers. Unit sizes in the area of 50,000 hp are becoming realistic, and turbine designs that can handle the required high volumetric flows are ready.

In nuclear stations, where relatively low horsepower feed pump drives are required because of the lower steam pressure in the secondary system, the high reliability and favorable economics of the steam turbine feed pump drive has proven attractive.

As main turbine generator units continue to increase in size, steam turbine fan drives integrated into the steam cycle also offer the possibility of improving the overall heat rate of the cycle.

10—Proportional position control system controls the servo actuators that operate the stop and governing valves.

11—The electronic controller, which provides the positioning signals to the stop and governor valve actuators, is basically an analog computer.



Massive aluminum-alloy ingots, often weighing more than 10 tons and up to 16 inches thick, are reduced to coils of sheet 0.008 to 0.016 inch thick in Alcoa's new rolling facility at its Warrick Operations near Evansville, Indiana. ***(Photos courtesy of Alcoa.)***

Aluminum Hot-Rolling Line Has All-Static Power Supplies

A. M. Curry
Warren Reid

Thyristor power systems supply adjustable-voltage dc power for all main and auxiliary drives in a large hot-rolling facility. These systems, and effective computer control, enhance operating capabilities and reduce costs.

The first aluminum hot-rolling line with static power supplies throughout has completed a year of operation at Alcoa's Warrick Operations near Evansville, Indiana. The line has more than 31,000 kw of thyristor power systems for supplying adjustable-voltage dc power to its main and auxiliary drive motors. These static power supplies completely replace the traditional m-g sets for converting ac line voltage to adjustable dc voltage for motor power and control.

Thyristor power systems were selected because of their potential advantages in lower installation costs and in lower operating costs due to higher productivity, higher efficiency, greater reliability, and less maintenance requirements. Operating experience to date is confirming the predicted advantages.

Another first is the high degree of automation in the hot-rolling line. A Prodac computer calculates rolling schedules and directs rolling operations.

The Warrick Operations include a smelting works, power plant, ingot-casting and soaking facilities, and a highly automated rolling-mill complex for producing thin-gauge aluminum-alloy sheet to close tolerances. The hot-rolling line includes a 66-inch hot reversing mill that can roll ingots 22 inches thick down to one-inch slabs, and the industry's first six-stand hot finishing mill which reduces the slabs to coils of sheet one-eighth inch thick. Two tandem cold mills produce the final coils of thin sheet. The facility is presently producing sheet at the rate of more than 20-million pounds a month.

This rolling-mill complex was installed in anticipation of the growing demand for thin-gauge aluminum sheet. The booming packaging industry is the largest market, with can manufacturers using the sheet in rigid containers for beer, soft drinks, foods, and other commodities. (Several million easy-open can ends are made from a single 10,000-pound coil of sheet.) Other applications are in construction products, such as siding, and in heat exchangers.

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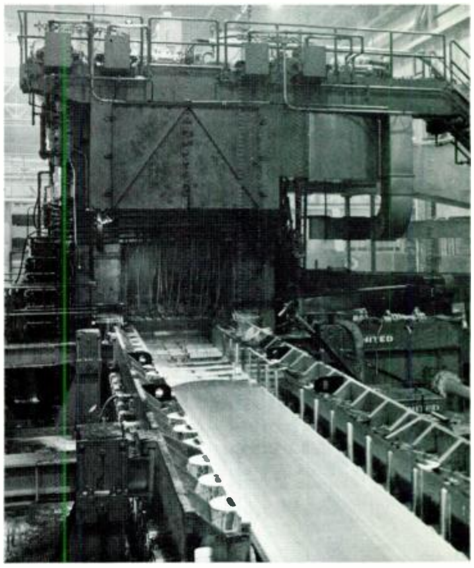
Thyristor Power Systems

The reversing mill of this hot-rolling line is powered by two 5000-horsepower 30/60-rpm motors, and the six-stand finishing mill has each stand driven by a 4000-horsepower motor. Aluminum ingots are first reduced in thickness in the reversing mill, sheared and trimmed, and then fed directly into the finishing mill. Two tension reels driven by 800-horsepower motors wind the delivered hot-rolled strip into coils.

Torque capacity of the twin-drive reversing-mill motors is as large as or larger than that in any other primary mill in the metals industry. Each of its motor armatures is supplied by a 4100-kw thyristor power system. Because of the operating manner of a reversing mill, these power systems have the capacity for frequently applied motoring and regenerative loads of 225 percent of rated full load in both directions.

Each of the six 4000-horsepower motors in the finishing mill is supplied by a thyristor power system rated at 3150 kw and with capacity for frequently applied loads of 175 percent of rated load. Ordinarily, there is no need for regenerative capacity in the dc supply for a stand while there is strip in the stand. However, when the tail end of one piece leaves a stand, stand speed may have to be reduced to accommodate a new piece entering the stand. In the traditional generator power supply, this speed reduction has been accomplished by reversing the armature-circuit current; the energy given up by the rotating mass is then absorbed by the ac system that supplies the m-g set drive motor.

A similar method could have been used with the thyristor power system, but it would have required dual converters (since the thyristor is a unidirectional device), and these are more expensive than single converters. Consequently, power is absorbed by a combination of voltage control and motor field reversal so that regeneration occurs without changing the direction of current in the armature circuit.



First reduction of an ingot is made by a 66-inch hot reversing mill, which rolls the ingot to a slab 1¼ inches thick.

Each reel motor is supplied by a thyristor power system rated 650 kw. These systems, too, have capacity for frequently applied loads of 175 percent of rated full load. Because of the need to adjust mill speed while rolling and to stop the reel quickly, both reel power supplies have full regenerative capacity.

Construction of the thyristor power systems is essentially identical for each motor regardless of the rating of the motor.* Each is an integrated system including a power supply and a feedback controller, and each is built from standard modules. The required power capacity for any drive is provided by assembling the necessary number of these modules. A module, the basic assembly, consists essentially of 12 thyristors grouped in a drawout case to form 6 standard controlled rectifying circuits.

*Stringer, L. F., and Tresino, L. R., "Thyristor-Power DC Drive Systems," *Westinghouse ENGINEER*, September 1966.

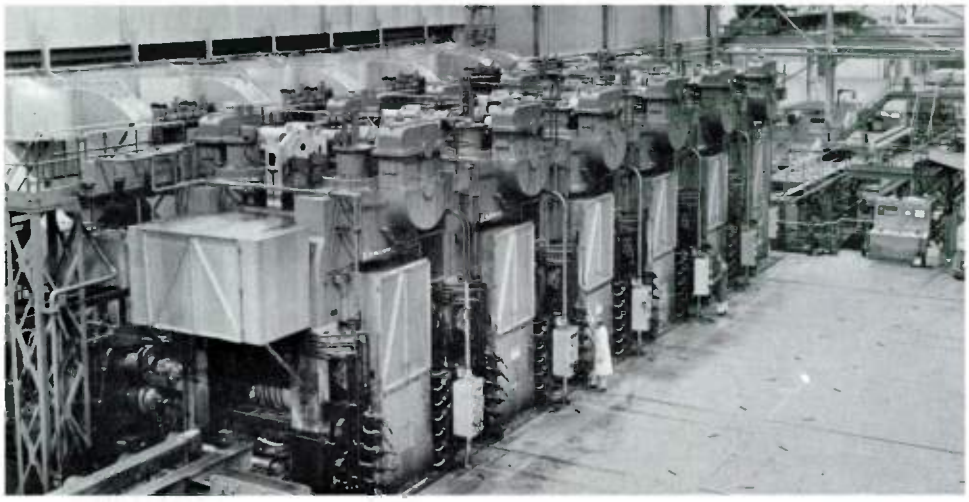
All of the many dc auxiliary drives are also supplied from individual thyristor power systems. They range from a 300-horsepower side-trimmer drive down to some requiring only five horsepower.

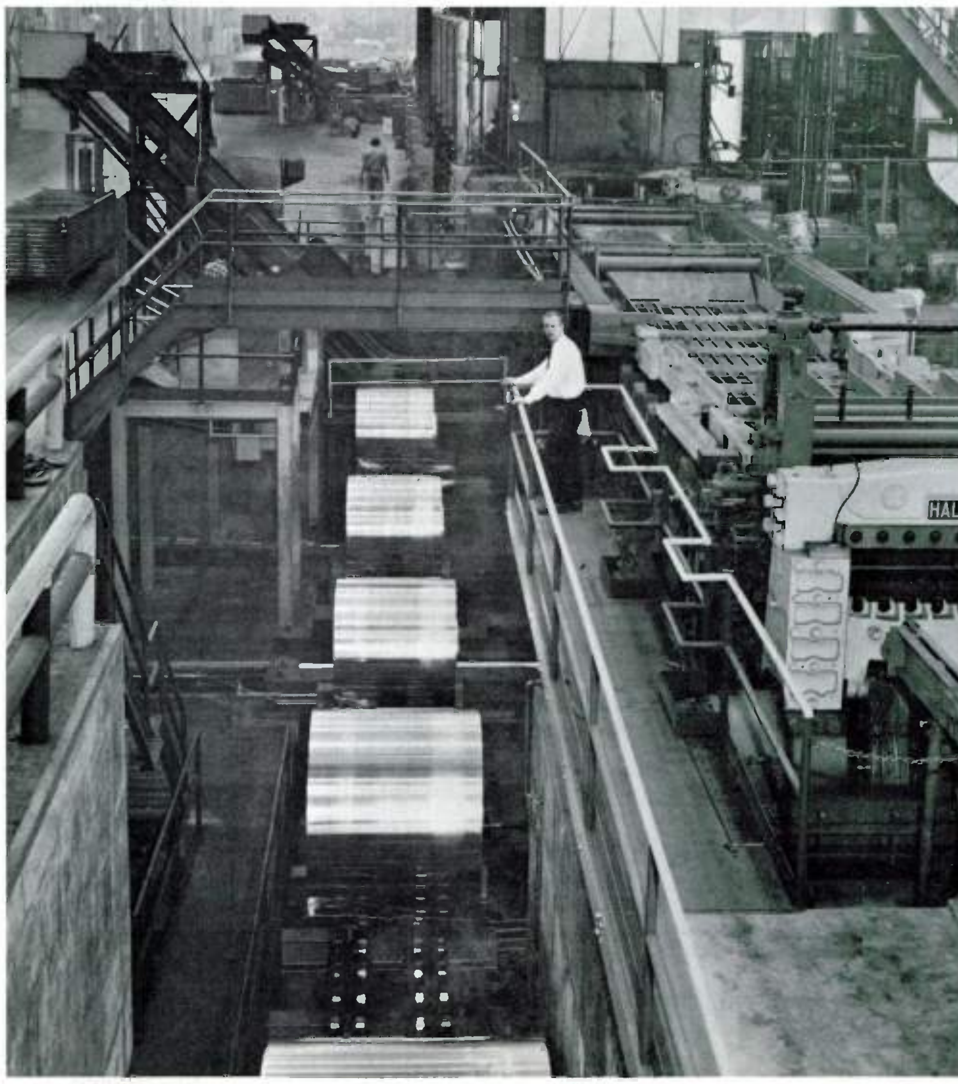
Advantages of Thyristor Power

The lower installation cost of the thyristor power systems results mainly from elimination of the critical mechanical alignment, heavy foundations, and complex air-duct systems needed with large m-g sets. Absence of m-g sets also greatly reduces noise and vibration in the plant.

The higher productivity achieved (after an initial shakedown period) stems mainly from the fewer maintenance requirements of the static equipment, resulting in less downtime, and from faster control response. Control response is essentially instantaneous because a thyristor power system converts signals from control devices and mill sensing devices into speed changes much faster than m-g sets can, since there is no generator field time constant. The screwdown drives, for example, are in current limit almost instantly after receiving a signal to start or to change speed. Thus, when a thyristor power system is used, the power supply itself is not a limiting factor in achieving maximum performance from a drive; only limitations in the mechanical equipment or drive motor can prevent full utilization of the essentially instantaneous response.

Fast response improves operation dramatically in the finishing mill. The thyristor power system makes possible such rapid changes in stand motor speeds that interstand tension is held much more uniformly than it would be with rotating power supplies, thus improving gauge control.





Above—Slab is further reduced by a six-stand 60-inch hot finishing mill, the first such mill in the industry. The mill rolls the slab to coils of sheet one-eighth inch thick. Both this mill and the reversing mill have thyristor power systems to supply adjustable-voltage dc power for their main drives and all their auxiliaries.

Below—Coils of sheet leave the hot finishing mill. After annealing, cold-rolling mills will reduce the sheet to the final thickness desired.

At the reversing mill, current-limiting protection is so fast that mistakes such as setting the screwdowns for too small an opening or attempting to roll a cold slab generally do not cause excessive overloads that trip the circuit breakers in the main-drive armature circuits, as they would in many mills. Rather, such errors cause current-limiting action or gate-pulse suppression, so less time is required to correct the operating error. Circuit breakers are used in the main-drive motor armature circuits, but they are only for final protection in the event of a malfunction of the other protective circuitry in the thyristor power system.

Full-load efficiency of the thyristor power systems is more than 98 percent, as compared with about 93 percent for m-g sets. This difference in efficiency is sufficient to provide considerable annual power savings.

Computer Control System

A Prodac computer calculates the rolling schedule for the reversing mill and directs the rolling operation. For the finishing mill, it calculates the rolling schedule and also provides direct references to the associated positioning equipment to set up the mill.

To be more specific, at the reversing mill the computer performs the following functions:

1) Controls the tables on the delivery side of the mill. The computer determines which table sections are required for the particular pass of the rolling schedule and then directs their speed and direction.

2) Controls the tables on the entry side of the mill. This control is similar to that for the delivery-side tables except that the computer calculates the lower entry operating speed as dictated by the percent reduction in the main mill rolls; that is, it provides automatic draft compensation.

3) Positions the screwdowns. Initial information supplied to the computer with a punched card includes the alloy designation, dimensions of the incoming piece, and desired dimensions of the piece after the last pass. The computer determines the number of passes required to produce the desired finished dimensions and supplies the references for automatically positioning the screwdown roll opening for each pass. The calculation takes into account the alloy, product dimensions, mill spring constant, electrical limitations, and special nonelectrical limitations. The roll force is measured on each pass; if there is an excessive difference between the measured and calculated value, the remaining passes are recalculated.

4) Determines maximum mill speed, taking into account the product dimensions and torque requirements.

5) Decelerates the mill so that the speed of the piece at exit will not cause excessive run-out on the tables.

6) Sequences the mill. Once the initial piece is positioned on the entry side of the mill and the automatic controls are initiated, the mill and tables accelerate, decelerate, and reverse, the screws position themselves after each pass, and the piece is rolled in the calculated number of passes—all without operator intervention.

At the six-stand finishing mill, the computer calculates the rolling schedule on the basis of the alloy characteristics and product dimensions. It also provides references for the speed of each stand motor, roll opening for each screwdown, interstand tensions, speed of tables preceding the first finishing stand, tension (current) for the reels, and automatic gauge-control equipment.

When the piece enters the first finishing stand, the measured and calculated roll forces are compared. If differences are excessive, the screw positions for the remaining stands are repositioned to compensate for the difference. After these corrections have been made, process control becomes the responsibility of the automatic gauge-control equipment. The computer monitors the results of the set-up it calculated, thus providing data to upgrade its program.

Alcoa and Westinghouse engineers worked together on the design and programming of the computer. Their respective knowledge of the rolling process and of computer applications were combined in such a manner that the resulting installation was successful from the first day of pilot operation. The computer calculated the rolling schedule and sequenced the mill for the third slab rolled in the reversing mill.

With the Warrick operators' long-established process knowledge and their newly acquired skill in programming, the computer program can be modified to suit special rolling problems. For some rolling schedules, it may prove advisable to program the reversing mill to roll the slab in the minimum number of passes. On other schedules, it could be advantageous to modify the program in such a way that the slab shear (located on the delivery side of the mill) would receive slabs of specified lengths so that the slab length, as rolled, would be shorter than the distance between the mill and the shear and the slab cross section would not tax the capacity of the shear.

The schedule calculation for the finishing mill proportions the load among the six stands, unless there are nonelectrical reasons for rolling with unbalanced loads. The computer output data from the last pass at the reversing mill becomes the computer input data for the finishing mill, unless there are major differences in measured and predicted temperature at the entry side of the finishing mill.

Conclusion

The results of the first year of operation of the hot rolling line have been favorable. A few problems did arise, but that is to be expected with such new and relatively untried equipment. The failure rate for the thyristor devices themselves has been less than one-fourth of one percent per year, and there is no reason to expect a great increase in this rate over the coming years. Even though the control circuits associated with the thyristor power supplies are more complex than those used with m-g sets, operating and maintenance personnel have accepted them quite readily.

The computer has proved to be a useful tool in obtaining a consistent high-quality product. Moreover, it protects both the electrical and mechanical equipment from the abuse that sometimes occurs on manually controlled mills.

System Provides Precise Uninterruptible AC Power for Critical Data-Handling Equipment

R. P. Bleikamp
G. K. Glover

An uninterruptible power system employing m-g sets converts 50- or 60-cycle poorly regulated power to precise 60-cycle power. It also maintains precise output limits during input power failures, drawing on battery emergency power or diesel standby power.

The vast majority of electric power users can accept occasional short-duration outages with little or no loss and can even accept the occasional prolonged outage without catastrophic loss. There are other applications, however, and their numbers are increasing, that can ill afford even the occasional momentary power interruptions caused by switching or automatic fault isolation, nor even significant degradation of voltage or frequency. Such applications may include aircraft flight control facilities, hospital operating rooms, spacecraft launching and tracking sites, defense warning systems, and Government communications facilities.

One especially critical area is digital data-handling, which utilizes high-speed computer switching. Even momentary power interruptions can cause error or loss of large amounts of critical data, and these interruptions are often accompanied by inability to recover in any reasonable length of time.

Such is the case in the Department of Defense worldwide digital data network called Autodin (Automatic Digital Network). The Autodin system, which is scheduled for completion by 1970, is designed for teletypewriter and data traffic. It will employ high-speed transmission, code and speed conversion to meet individual user requirements, multilevel precedence, and automatic error detection and correction. The system is fully automatic.

Overseas portions, especially, of the Autodin network may depend on electric power of inferior quality and reliability. This article describes the power system that insures continuity of precise power to these overseas sites.

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Uninterruptible Power System

The prototype 250-kw Westinghouse uninterruptible power system (WUPS) for Autodin has recently been placed into service following successful completion of performance, reliability, and maintainability tests. Several such systems will soon be in service overseas, insuring the continuity of Department of Defense communications.

The WUPS is a power-conditioning system. In its normal mode of operation, it derives power from the local commercial source and upgrades it in both voltage stability and frequency stability to precise power quality. The system also stores enough energy in storage batteries to permit full-load operation, 250-kw output, for 15 minutes following a loss of ac input power. This 15-minute period is sufficient to start up and transfer local diesel generation to the WUPS input if the utility outage is prolonged. Thus, the WUPS, by accepting input power from the local utility or from local diesel generation, and using battery-stored energy during the transition, is able to deliver precise power to the load on an uninterrupted basis.

"Precise power," as the term is used here, means power with tight limits on voltage and frequency excursions. The electrical load supplied by the WUPS is a complex assembly of communication equipment, digital computers, and specialized peripheral apparatus that require precise power for errorless operation. The WUPS has demonstrated the capability of maintaining voltage and frequency within ¼ percent of the nominal values of 120/208 volts and 60 cycles in steady-state operation, no load to full load. Under transient conditions, such as upon loss of utility power or with instantaneous load changes up to 25 percent of system load, voltage transients do not exceed ±5 percent and frequency transients do not exceed ±2 percent. Both voltage and frequency recover to steady-state limits within 500 milliseconds.

"Uninterruptible," as applied to WUPS, means that the precise output power limits remain effective for a large number of defined failures, both external and internal to the system. As previously explained, the system must furnish precise power throughout a failure of the ac supply system. The input power is considered unusuable if voltage departs more than ±10 percent from nominal or if frequency departs more than ±5 percent from nominal. The system is automatically switched to battery operation when the ac input goes outside these limits, other than momentarily. Internal failures which do not cause output disturbances beyond the transient limits of voltage and frequency will be detailed later; they include the loss of at least one component or subsystem of each major type.

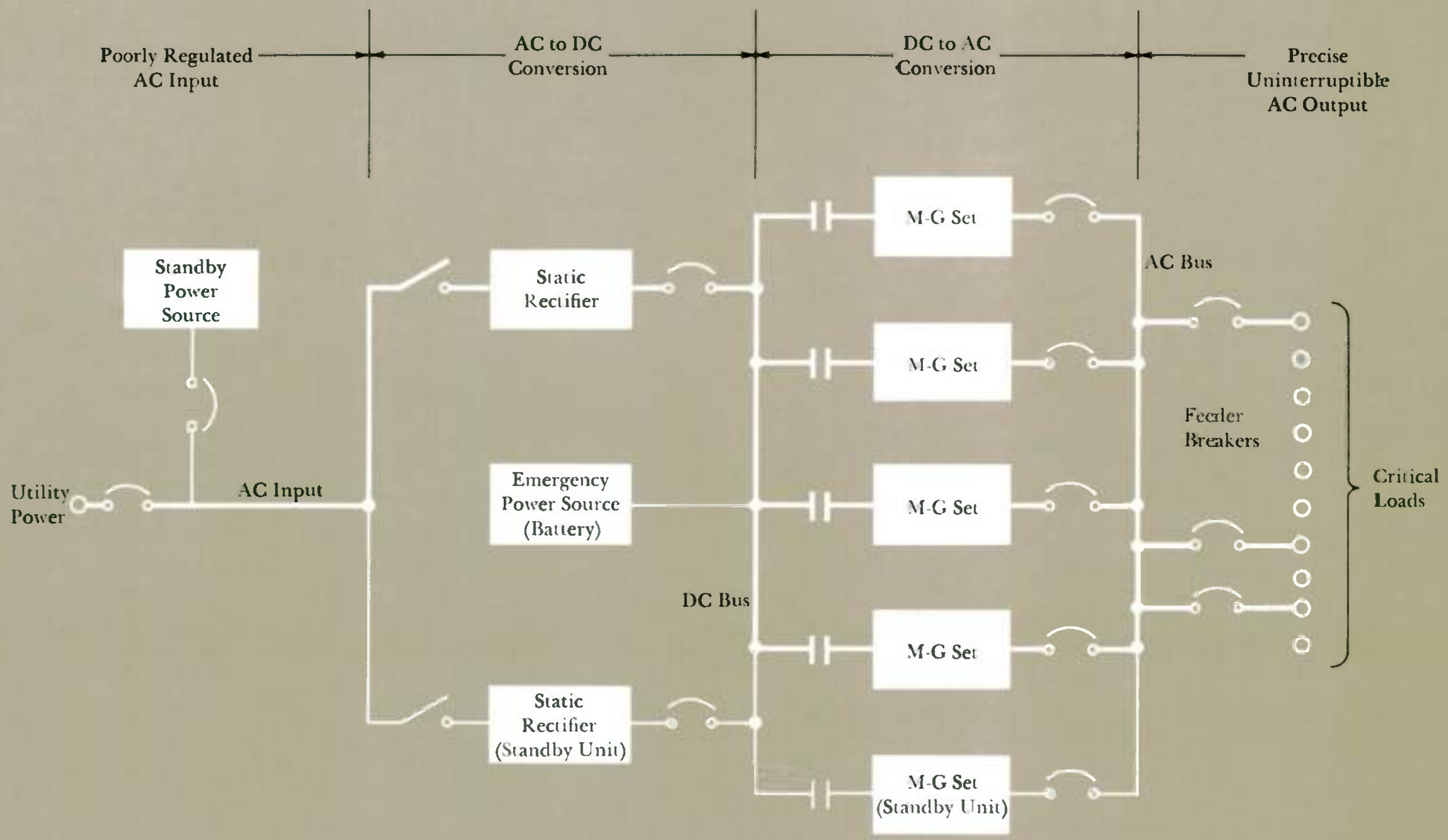
The achievement of greater reliability in a small complex power-conversion system than exists in an electric utility is difficult. Nevertheless, the prototype WUPS has operated more than 10 months with no chargeable instance of failure to provide precise power on the output bus, and it has kept the facility operating through three utility power outages associated with thunderstorms. In large measure, this demonstrated reliability results from the active introduction of reliability considerations into each design decision, starting with system configuration and extending to the most minute details of component selection and part location.

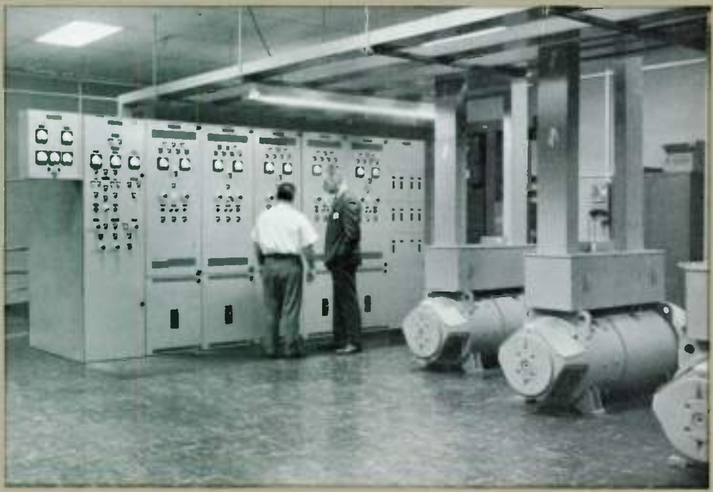
System Description

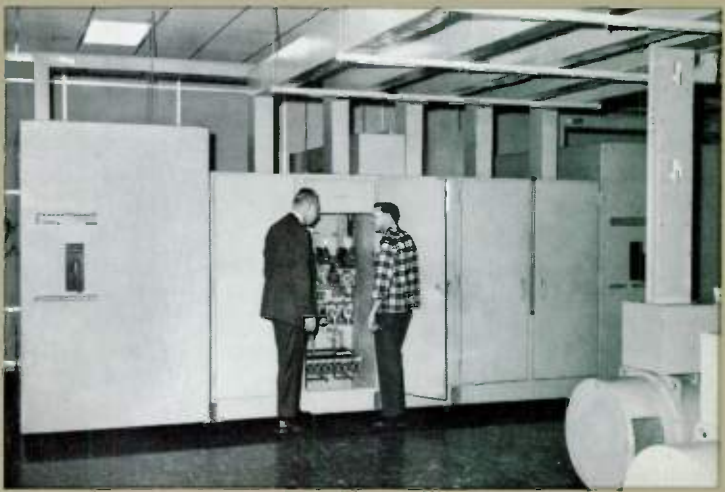
The WUPS make-up is diagrammed in Fig. 1. Ac power from the local utility or

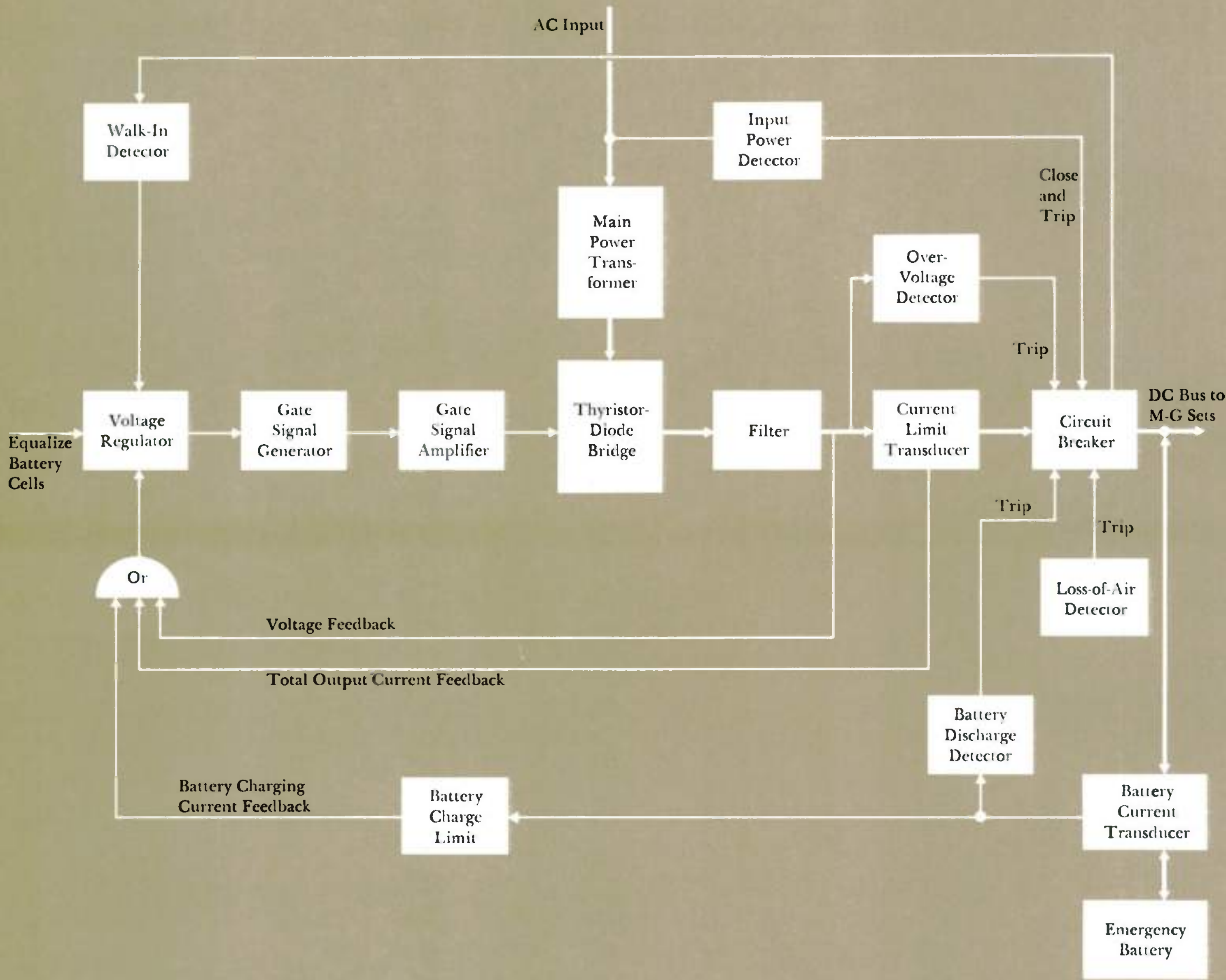
1—Uninterruptible power system in normal operation converts ac input power from a utility supply to dc power by means of a static rectifier, and then m-g sets invert the dc power to precise ac power for the critical system loads. One rectifier and one m-g set are normally on standby duty. A storage battery provides emergency power, and diesel generator sets provide standby power.

***Photos*—Low-voltage switchgear assembly *(left)* houses the m-g set controls; all operator control and indicating devices are on the doors. The m-g sets are staggered to minimize the amount of overhead bus duct required. Five dc magnetic timestarters *(right)* are located between the two rectifier cabinets.**


Poorly Regulated
AC Input
AC to DC
Conversion
DC to AC
Conversion
Precise
Uninterruptible
AC Output
Standby
Power
Source
Static
Rectifier
M-G Set
M-G Set
M-G Set
M-G Set
M-G Set
(Standby Unit)
AC Bus
Feeder
Breakers
Critical
Loads
Utility
Power
AC Input
Emergency
Power Source
(Battery)
DC Bus
Static
Rectifier
(Standby Unit)






AC Input
Walk-In Detector
Input Power Detector
Main Power Transformer
Close and Trip
Over-Voltage Detector
Trip
Equalize Battery Cells
Voltage Regulator
Gate Signal Generator
Gate Signal Amplifier
Thyristor-Diode Bridge
Filter
Current Limit Transducer
Circuit Breaker
DC Bus to M-G Sets
Trip
Trip
Loss-of-Air Detector
Or
Voltage Feedback
Total Output Current Feedback
Battery Discharge Detector
Battery Charging Current Feedback
Battery Charge Limit
Battery Current Transducer
Emergency Battery

from standby generation is converted to dc power by the ac-to-dc conversion subsystem. If ac power is temporarily not available, the battery supplies the dc power. The dc-to-ac conversion subsystem converts the dc power into precise ac power for the critical load.

AC-to-DC Subsystem—This consists of two identical voltage-regulated static rectifiers, one of which is normally in use with the other standing by to take over in the event of a failure in the on-line rectifier. Each rectifier is rated at 364 kw, 260 volts nominal, and includes six full-wave bridge circuits operating in parallel. Two benefits derive from using six paralleled bridges in each rectifier. First, several diode or thyristor failures can be tolerated without loss of output. Second, by proper phase-angle displacement, the ripple voltage in the output is minimized. Low ripple voltage contributes toward good commutation in the dc motors that operate from the dc bus.

Several regulating functions are provided in the rectifier (Fig. 2). During normal operation, the on-line rectifier regulates its output voltage (dc bus voltage) to 260 volts, which is the normal float voltage of the emergency battery. Approximately every three months, equalization of the battery cells is required. The operator initiates cell equalization, which causes the rectifier output voltage to increase to 280 volts for 12 hours. The voltage then returns automatically to the normal float value of 260 volts.

Two current-limit feedbacks can override the output-voltage feedback: battery charging current limit and rectifier output current limit. During recharge of the emergency battery, the output voltage of the rectifier is regulated to provide a constant battery charging current of 125 amperes up to a maximum voltage of 280 volts.

Using battery charging current limit has the advantage of minimizing the rating of the rectifier by limiting charging current, which is a load in addition to the m-g sets; moreover, it reduces the dc bus voltage at the start of the recharge cycle, which minimizes the frequency transients in the precise output power in the event of a rectifier failure during battery recharge. The emergency battery is completely recharged within 4 hours after a 15-minute discharge at full load. Output current limit of the rectifier protects the diodes and thyristors in the rectifier bridges by limiting the maximum output current of the rectifier to 1600 amperes.

2—Each rectifier in the power system has several regulating modes and automatic isolation features.

The rectifier also has a "walk-in" feature. The output voltage of the rectifier is 150 volts when its output circuit breaker is open. This voltage is below the dc bus voltage at the end of a 15-minute battery discharge. When the rectifier transfers to the dc bus, its output voltage gradually increases from 150 volts to 280 volts, based on an R-C time constant. The time to reach 280 volts is two minutes, provided the output voltage is not limited by the battery charge current limit.

This walk-in feature provides two advantages. First, the dc bus voltage changes slowly enough so that no frequency transient is discernable on the critical bus. Second, the input ac system is loaded slowly enough so that its regulation equipment has time to function properly, thus permitting the WUPS to be fed from relatively small weak systems.

The on-line rectifier monitors the input voltage and frequency continually, and it automatically disconnects from the dc bus if the input power goes out of limits—± 10 percent for voltage and ± 5 percent for frequency. In this event, the WUPS operates on the battery until input power (utility or diesel generated) is restored, whereupon the rectifier returns itself to the dc bus and starts to "walk in." During this operation, the standby rectifier is not called upon to transfer to the dc bus.

The on-line rectifier also monitors its output power and initiates tripping of its output circuit breaker if a fault develops. Conditions that can cause the on-line rectifier to isolate itself automatically are overvoltage, battery discharging, and loss of cooling air flow. When the on-line rectifier isolates itself from the dc bus, the standby rectifier automatically transfers to the bus. The battery supports the WUPS during this transition from one rectifier to the other.

The battery consists of 120 individual lead-acid cells, series connected, with an 8-hour rating of 1650 ampere-hours. The battery is always connected firmly to the dc bus and either charges, floats, or discharges as dc bus voltage and battery conditions dictate.

DC-to-AC Subsystem—This consists of five identical channels, each including a dc motor starter, a dc-to-ac m-g set, a frequency regulator, a static exciter and voltage regulator, a generator circuit breaker, and fault detection circuitry (Fig. 3). Any three of the five channels will support full system load continuously. Normal operation is with four channels on line and the fifth standing by to replace a failed channel.

The dc motor starter is a conventional three-point NEMA size 6 resistance starter with time-limit acceleration. Its main function is to accelerate an incoming m-g set to operating speed without creating undue transients on the dc bus.

The m-g set is a unit-frame two-bearing set with the dc motor armature, synchronous generator rotor, and flywheel all mounted on a single shaft. The motor, rated 148 horsepower at 260 volts, is conventional and includes design features to tolerate the ripple voltage in the rectifier supply. It has an appreciable shunt field range to permit constant-speed operation at 1800 rpm with armature voltages from 180 to 280 volts, which are the limits of battery voltage under all operating conditions.

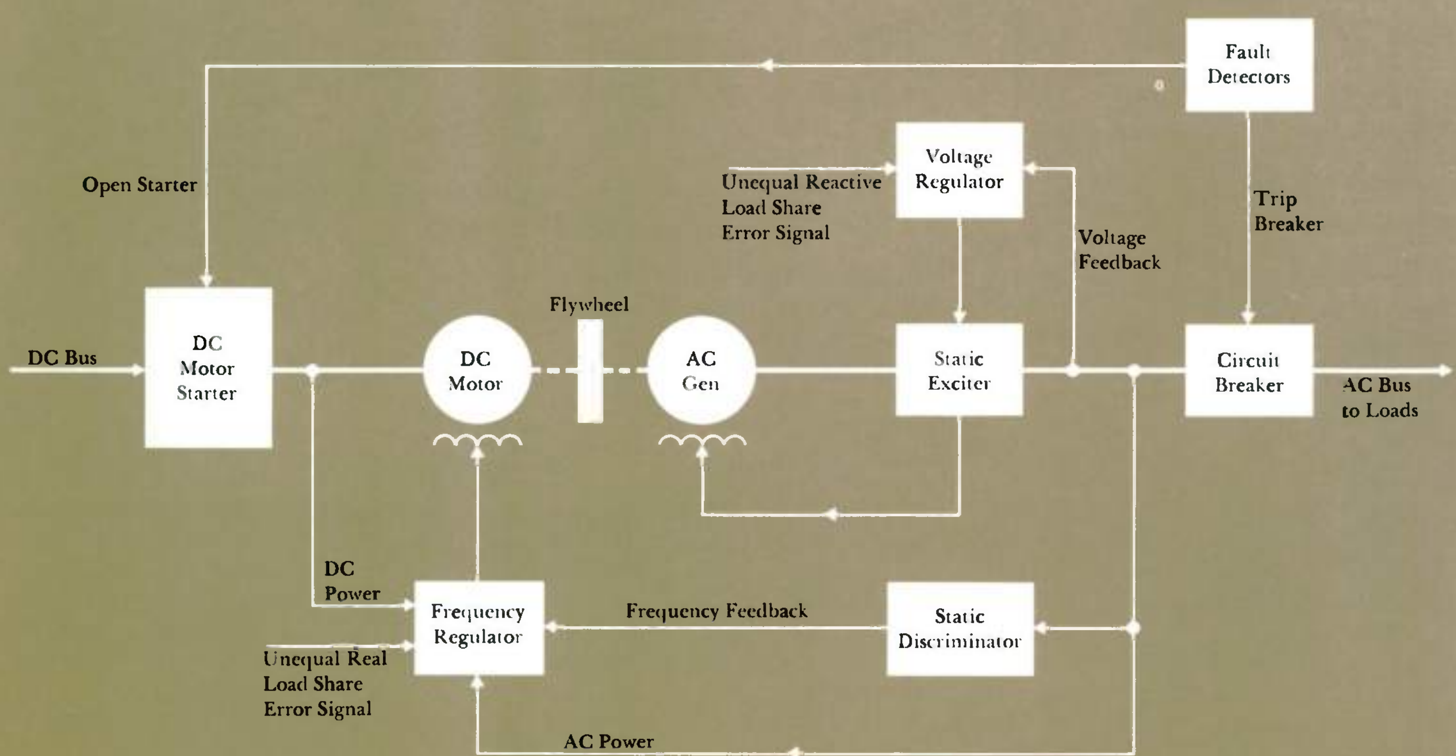
The salient-pole synchronous generator, rated 100 kw at 0.8 power factor, is conventional except that it has lower than normal subtransient and transient reactances to permit supplying the precise power under 25-percent step load changes.

The flywheel is quite small, its function being to maintain speed during the short time it takes to establish power flow from the battery on failure of input ac power. This delay time is primarily a function of the dc machine field time constant and the degree of forcing employed in the

M-G Set Fault Detection Features

Fault	Function of Fault Detector	
	During Run-Up and Before Paralleling	*After Paralleling*
DC Motor Armature Overload	Shutdown and Alarm	Alarm Only
Loss of DC Motor Field Current	Shutdown and Alarm	—
Loss of Motor Field Current Fault Detector	Alarm Only	Alarm Only
Excessive M-G Set Vibration (Bearing Failure)	Alarm Only	Alarm Only
Unequal Real Load Sharing	—	Shutdown and Alarm
Unequal Reactive Load Sharing	—	Shutdown and Alarm
Generator Over Current (Circuit Breaker Trip Coils)	—	Shutdown and Alarm

Automatic removal of a failed channel initiates automatic start-up, synchronization, and paralleling of the standby channel. The type of fault is retained visually by indicating lights to assist in trouble-shooting and is also locally and remotely alarmed audibly.



frequency regulator. Flywheel inertia, dc machine field time constant, and regulator forcing voltage have been selected to maximize reliability while meeting the stringent transient frequency performance requirement.

An adjustable vibration detector on each m-g set gives visual and audible warning of impending mechanical malfunction. This device provides the best known method of detecting impending bearing failure and normally permits corrective maintenance before catastrophic failure occurs.

The frequency regulator works into the motor shunt field. Its function is to maintain 60-cycle output and also to insure equal real load division among paralleled m-g sets. Frequency sensing is from the ac generator output by means of a static discriminator. The real load share trimming signal is obtained from static circuitry that compares ac generator kilowatt output with system kilowatt output divided by the number of channels on line. The frequency regulator is a thyristor buck-boost type connected in series with the dc bus.

The combined static voltage regulator and exciter maintains correct ac voltage on the critical bus and insures equal reactive load division among m-g sets operating in parallel. The exciter is of the series boost type, completely static. It derives ac generator excitation current from the generator output circuit, using a combination of voltage transformers and current transformers. The two components of excitation are combined so that essentially the exact required value of field current results, regardless of load magnitude and power factors. The benefits are twofold: first, the system is extremely fast in responding to load changes; second, voltage regulator size is minimized because it merely acts to trim the exciter output.

The voltage regulator is also static, of the thyristor type. It uses three-phase average voltage sensing for its voltage feedback. Reactive load sharing is obtained by use of a signal proportioned to the difference between generator quadrature current and system quadrature current divided by the number of channels in use.

3—Each m-g set, with its associated controls, inverts dc power into precise 60-cycle ac power. An error signal of only 0.2 cycles in output frequency drives the system's frequency regulator into maximum forcing.

The generator circuit breaker is a DB-25 air magnetic breaker. Fail-safe automatic tripping is accomplished with the standard undervoltage trip attachment. The fault detectors have normally closed output contacts, and they interrupt voltage to the undervoltage trip coil for m-g set fault isolation. Fault-detection features and their functions for the individual dc-to-ac conversion channels are shown in the table at upper left.

Automatic synchronizing and paralleling of an incoming dc-to-ac channel is under control of a static automatic synchronizer. The stability and accuracy of the frequency and voltage regulators are sufficient so that the synchronizer is not required to adjust incoming machine frequency or voltage. Therefore, the synchronizer merely verifies that the incoming machine voltage and frequency match those of the critical bus, and then causes the incoming generator circuit breaker to close when the phase angles are correct. Limits for synchronizing for voltage, frequency, and phase angle are 3 percent, ⅓ of a percent, and 10 electrical degrees respectively.

Reliability

Continuity of precise power on the critical bus of the WUPS was the most important consideration throughout the program. Implementation included the establishing of an objective for MTBF (mean time before failure) for each major subsystem. Proposed designs were analyzed with established component failure rates to be certain that selected circuitry and components would, as a minimum, meet the MTBFs established.

All circuits and subsystems are fail-safe insofar as the precise output of the WUPS is concerned. Redundant components are used when required to insure that circuits fail safe for single-component failures. Periodic confidence checks are prescribed to detect and correct component failures that are not self-indicating.

Redundant circuits are used in critical areas common to the whole system so that the first circuit failure does not affect the precise output. Periodic confidence checks are also prescribed for these circuits.

Redundant subsystems are used in both ac-to-dc and dc-to-ac conversion to improve system reliability. Automatic fault detection and switching causes a failed subsystem to be replaced with the standby subsystem.

Reliability tests were conducted on the prototype system to demonstrate that the precise output remained in specification during and after induced and/or simulated failures of components, circuits, and redundant subsystems.

The system is hybrid in that static conversion is used for the ac-to-dc link and rotating conversion for the dc-to-ac link. The rotating link was selected in this instance because of considerations of overload capability, cost, demonstrated reliability, sinusoidal output waveform, and relative freedom from radio-frequency interference. However, all-static systems that provide the same overall function are being supplied for other applications.

Conclusion

In the United States and in other highly developed areas, the reliability of utility power approaches, but can never achieve, perfection. In less developed areas, utility power may be quite unreliable. In any event, there is always some probability that the electric supply to a given site will fail—perhaps completely or perhaps in voltage and frequency degradations beyond acceptable limits.

The operator of any critical facility must evaluate the economic or other loss that can be caused by an electric power failure and determine whether an alternate source of power should be provided to carry on when utility power or local generation fails. The uninterruptible power system described in this article has demonstrated ability to provide power of precise quality with great reliability regardless of what happens to the input power source.

Individual Engineering Leadership

Lee A. Kilgore

Personal qualities enter into leadership ability in engineering, just as they do in other professions. These qualities can be developed, to the benefit of the engineer.

Leadership is not a technique to be understood and practiced only by management. Every engineer can be a leader in some phase of his own field—can have his ideas respected and can guide those about him who need his technical knowledge. And every engineer *should* be a leader, for this is the only way for him to make the most of his technical ability

Individual engineering leadership requires, certainly, skill in the analytical techniques and knowledge of the science of one's own branch of engineering. However, there are also personal qualities that are essential to leadership. The key qualities are *ideas*, *judgment*, *convictions*, and *ability to gain the confidence and cooperation of others*.

These qualities are common to leadership in all professions, of course; if any one of them can be considered especially important to engineering leadership, it probably is judgment. An engineer's reputation depends greatly on his judgment, just as the research scientist's reputation is made by his ideas, and the general manager's success is measured by his ability to gain the confidence and cooperation of others. However, a good leader in any field must possess all of these qualities—and he must use them all diligently.

The author has been aided in his analysis of the factors that contribute to engineering leadership by years of objective listening to other engineers. Opportunities for additional observations and some new insights came while sponsoring two series of seminars that dealt with human relations and engineers[1] and with creative engineering.[2]

Ideas

Good ideas are an element in engineering leadership because engineers respect them. One of the best sources of ideas is in recognizing the *critical need* in a given situation—deliberately looking for the needs of clients, customers, and associates. The engineer must really *feel* a need to do something about it, because then he will be carrying the problem with him and the ideas will come. The engineers in the creative engineering seminars agreed generally that their best ideas had come to them at odd times, seemingly from the subconscious. But the subconscious mind works only on things that a person is keenly interested in.

Another source of ideas is in everyday *problems*, especially their unexplained or unfinished aspects. The philosophy of *problem = opportunity* can go a long way to

help an engineer feel the need strongly, and it can help him acquire the confidence necessary to inspire both himself and others.

This attitude was recently brought home to me in the difference in point of view expressed by two engineers. One described his knotty problem: even his competitors were in the same trouble. The other started his conversation (on the same subject) with, "We've got a terrific opportunity here." Knowing the enthusiasm this engineer generates by his positive manner and faith that a solution always exists, I am sure that he and his colleagues will find an answer.

Obstacles are a third source of ideas. If the engineer adopts a positive and confident approach, he can almost always find a way around. He needs to think: *obstacles = detour signs*. Obstacles are something to go around; if one approach doesn't lead anywhere, another may.

An incident in my own experience illustrates the value of a positive approach, even when faced with a particularly frustrating situation in which an idea cannot be used because there is not one but many unsolved problems. A few years ago, one of our marketing managers asked why thyristors connected in series could not be used in converters for high-voltage dc transmission. I started to list the unsolved problems, pointing out that all of the devices in series would have to be turned on in about one microsecond and that, until then, no one had commercially operated more than three in series, much less the 200 to 300 required for high voltage.

In the middle of this discussion I suddenly realized that I was certainly being negative; perhaps others as well as myself were being blocked by the frustration of facing so many unsolved problems at once. So I asked him to forget my negative comments, that I would think about it more, and later we would talk to the experts. Trying my own advice, I took the problems up one at a time with faith that each problem could be solved in turn. At least a plausible solution to each problem did present itself.

Then we had our session with the experts and they raised the same list of unsolved problems, but now I could hint that I had a possible answer. There is no surer way to release a man's inhibitions to finding solutions than to suggest that someone else has already found an answer. It must be that if he believes a solution does exist, this gives him added conviction that he, too, can find an answer. In this instance, in short order, we had not one answer but two for most of the problems, and we proceeded to test each of these solutions experimentally.

Judgment

Ideas and solutions are not enough in themselves. The engineer must evaluate the ideas, arrive at some convictions, and then act. Too often an engineer expects to hand his new-born idea to his superior

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or someone else, hoping that the worth of the idea will be instantly recognized. Rather, the engineer should first evaluate his own idea both technically and economically. This evaluation provides a firm basis for judgment and can be the means of arriving at a strong conviction about what action should be taken.

To evaluate an idea technically, the engineer should visualize how it is going to work out. He should not be satisfied by qualitative opinions; he should make a quantitative analysis, trying to put some numbers to each factor. With a good physical picture of the phenomena involved, the engineer can often get some quantitative data (even if empirical) and predict some results, using the simplest mathematics that can fit the case.

In new fields or difficult areas, where basic data is not available or cannot be calculated, key experiments are required to prove feasibility. Many times this can be done on a critical component that represents the unknown part. Some engineers rely only on calculation, others only on experiment. However, both techniques can usually be employed, and neither should ever be overlooked.

Economic evaluation involves determining the ultimate economic value, which usually can be measured by the total additional income or value that the idea will generate. Future income should be discounted because of the time delay, including time before it goes into use. Future income should also be discounted by multiplying by the chance of success.

The probable net gain can then be compared with the cost of development, including further verification, tooling, and new facilities. With a little help from accounting and manufacturing people, engineers are capable of making such evaluations. There usually are numerous alternate constructions, and the engineer must strive to avoid overlooking the best economic solution.

Convictions

With many engineers, a major block to reaching a final conviction and taking action is the desire to be absolutely certain before proceeding. (This search for certainty is also, sometimes, an excuse for procrastination!) However, in many technical evaluations, as in most business decisions, there is no such thing as absolute certainty. Therefore, one must rely on a conviction of adequate probability of success.

To determine adequate probability of success for a project or idea, the engineer must consider all key elements necessary for success and all alternate solutions to problems posed. Generally, he then arrives at a probability figure by judgment.

A more scientific approach consists of putting numbers to the probabilities of all the key elements and the alternate solutions. However, like a little knowledge, a few numbers can also be dangerous unless all possibilities are considered.

It is true that the probability of success is the product of the chances of success for each of the essential elements and, therefore, a smaller number than that for each element. But the chance of success of each element is one minus the chance of failure; thus, one should consider all alternate solutions, because the chance of failure of a key element is the product of the chance of failure of all alternates, again a smaller number than for each.

For example, if each of two key elements of a project has three alternate solutions having chances of failure of 20 percent, 50 percent, and 50 percent, the chance of failure of each element is $0.2 \times 0.5 \times 0.5$, or 5 percent; the chance of success of each element is $1 - 0.05$, or 95 percent; and the probability of success of the project is 0.95×0.95, or 90 percent. Note that we must still rely on judgment for the many probabilities. Thus, unless each probability is carefully and realistically developed, the final judgment may not have been improved by this scientific approach.

This type of reasoning is useful because it makes one consider all alternates before choosing a solution. It is often much more difficult or expensive to produce alternates later.

Another block to conviction is simply the fear of failure, often based on previous unfortunate experiences. However, if one thinks about a past failure objectively, the reason for failure can usually be determined, either in the idea itself or in the way it was presented. Thus, to gain confidence, the engineer should resolve to evaluate his ideas more fully and to communicate them better. To further motivate himself, he should contemplate and savor any past successes.

A less obvious block to conviction is the "they complex," the tendency to believe that someone else should act—that "they" should do something about it. But actually, the man with the facts and the conviction is the one to start some action.

If the engineer recognizes the need around him and takes a positive confident approach to his problems, he will get worthwhile ideas. If he uses good judgment in evaluating the ideas and reaches some convictions, he can then take action. This is exerting leadership.

Even when an engineer only evaluates another's idea, arrives at a conviction, and starts some action, he is exerting leadership. He should, of course, give credit to the one who originated the idea or, even better, invite him to go along in exploiting it.

Dealing with Others

Doing something with an idea eventually requires the cooperation of others, because very little in engineering can be completed all by oneself. Thus, a major requirement of leadership is the ability to gain the confidence of others and to win their cooperation.

A great deal can be learned by observation. Pick someone who is a natural leader—examine his personal characteristics and objectively review how others react toward him. In a similar exercise in the human-relations and creative-engineering seminars the participants enumerated many desirable personal characteristics of a leader, but a few were repeated regularly. For example, the natural leader was found to be a person with ideas and convictions. He was positive and enthusiastic, and his enthusiasm rubbed off on others.

The leader was also usually described as one who was interested in others and who recognized their abilities and worth. People always respond favorably to the person who shows interest in them. But any action involving others must also be carried out with sincerity, which may sometimes require a change in attitude. In dealing with someone whom we do not like personally or in whom we are not naturally interested, we must make the effort to at least understand him and his motivations; this helps in considering the problem from his point of view.

Also, strong leadership requires that we inspire others by appealing to their strongest motivations, and this requires *understanding* their basic motivations. The seminars on creative engineering led to some helpful insights here. Some of the most creative engineers were obviously highly motivated and, therefore, were asked what had driven them to come up with ideas. All agreed that it was a *desire for recognition*. Some wanted recognition from management, usually higher than their immediate supervisors. Others wanted the recognition of some technical leader they respected, and a few wanted recognition from their colleagues or peers.

This desire for recognition from someone we respect is universal, but different people respect different types. For example, research scientists most often respect the scientific leaders in their field whereas managers respect other managers up the line. So we must consider a person's associations and leanings in this matter if we are to understand him.

Every man carries with him a picture of how those he respects view him. The image has been built up by numerous personal experiences. For example, the most inventive engineer in the creative-engineering seminar told of his first "invention" as a small boy, which won him praise from family and neighbors and caused him to resolve to be an inventor. He worked his way through college, taught, and then became a leading development engineer. All the time he carried an image of himself as an inventor; before he died he had his name on more than 120 patents.

This self-image is a man's internal *status*, and he is strongly motivated when someone recognizes him for what he thinks he is and appeals to him in that light. If anyone, even unintentionally, implies he is something less than what he thinks he is, he is offended and certainly will not feel cooperative.

If we would really understand others, then, we must try to determine whose recognition they desire and what image they carry of themselves. A little introspection along these lines may even help us understand ourselves better. In analyzing others, there is one caution to observe: try to develop a real human interest in the person, because a purely analytical interest will not be appreciated.

Another specific problem in dealing with others is that of selling ideas. Engineers sometimes adopt the attitude that ideas and facts should sell themselves—but experience has proven that it does make a great deal of difference how an idea is presented. The seller must "talk the other fellow's language" in both speaking and writing. This means choosing both words and concepts that the listener can understand (and needs to understand). To avoid confusion and a negative reaction, many details of how the problem was solved should be omitted; these details are usually of real interest only to the originator of the idea.

Another good practice is to watch for the other person's reaction and use it as "feedback" to control our own output as we present the idea. This requires watching for the other person's response and listening when he tries to inject something into the conversation. Many engineers neglect this technique and rush ahead with their own ideas when the other person isn't even listening.

A great deal can be learned from observing how a good salesman organizes his thoughts in presenting something important. He knows that the other party must be in the right mood. If the listener is angry or worried about something, he lets him get it off his chest first. Next, the salesman gets the listener's attention on the subject, usually with the most positive statement that can be made of the potential gain *to the listener*. Then he presents the essential facts, remembering that the things that will move the listener most are those that affect him directly. It even helps to dramatize things a bit and appeal to the imagination, so long as it is not overdone.

Finally, don't forget the saleman's last and most important rule, "Ask for the order." In other words, if the other person hasn't jumped to the conclusion desired when you think you have sold your idea, ask him if he agrees a certain action should be taken. Leave with an understanding of what the next step should be and who is to take it. Through any such presentation, don't be impatient. If the idea is new, it may take the other man as long to grasp its significance as it did for you to originate it.

To Sum Up

Several key steps can be taken to develop the desirable qualities of leadership. First, look for real needs in every important situation, and recognize problems as opportunities. Take a positive approach, regarding obstacles as detour signs and looking for a way around. Evaluate ideas technically and economically to acquire judgment.

Reach convictions and resolve to act—don't wait for "they" to do something. Develop a real interest in others, consider their interests, try to understand their motivations, and don't forget to listen to them. And finally, sell your ideas effectively. The engineer who does these things well will be an even better engineering leader.

[1]Kilgore, L. A., and Baker, V. B., "Human Relations and Engineers," *Westinghouse ENGINEER*, July 1957, pp. 122-125.
[2]Kilgore, L. A., "Creative Engineering," *Westinghouse ENGINEER*, September 1960, pp. 136-139.

Old Mon River Cleaned with Flash Evaporator Plant

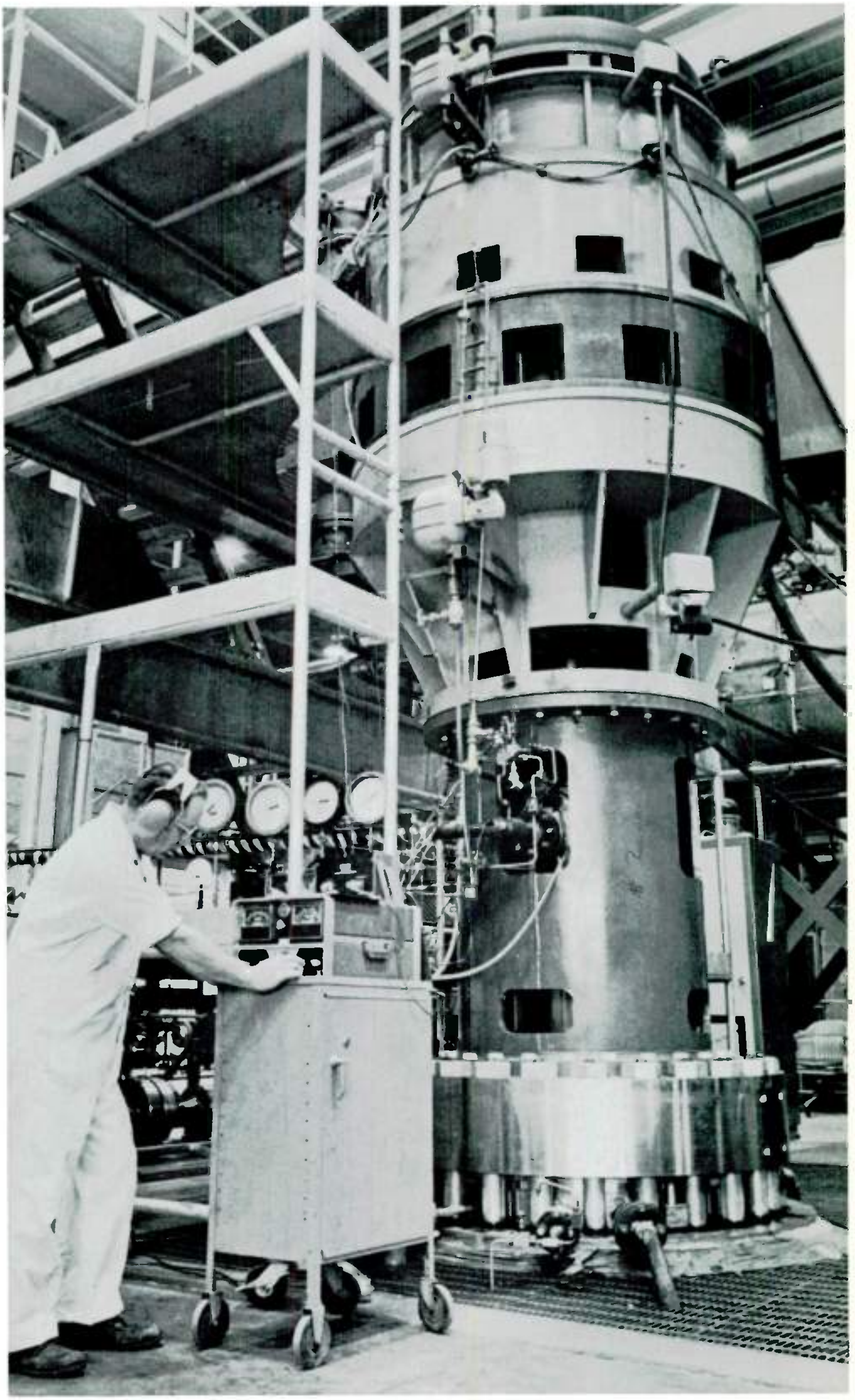
Large flash-evaporation plants have traditionally been associated with desalting seawater to provide fresh drinking water. However, flash evaporation is just as applicable to industrial situations where there is a need to purify water, and it often is less expensive than conventional sedimentation and chemical processes. It can be used with a wide variety of water sources, including rivers that contain large amounts of natural or industrial impurities.

For these reasons, a multistage flash-evaporator plant is being installed at the U.S. Steel Clairton Works near Pittsburgh, Pennsylvania. The unit will purify more than a million gallons of water a day from the Monongahela River for use in high-pressure steam boilers, where pure water is needed to prevent scale buildup and corrosion.

Reactor Coolant Pumps Grow with Plant Sizes

As pressurized-water nuclear reactors are increased in size to provide ever-larger power outputs, the capacity of their coolant pumps also increases. The pump in the photograph, for example, will circulate water through the primary (coolant) loop of a nuclear generating plant at 65,000 gallons a minute; when photographed on test, it was the largest of its kind yet completed.

Effective shaft sealing is a formidable problem with such pumps because of their large size and the high temperature and pressure at which they operate. (The one shown is designed for a coolant temperature of 650 degrees F and a pressure of 2500 psi.) A controlled-leakage seal system in this pump allows leakage of only two gallons a minute. This leakage is collected and returned to the reactor coolant system. Forty such pumps have been built or are being built; some of them will have



Nuclear reactor coolant pump in production test circulates 65,000 gallons of water a minute. Performance was checked at the design condition of 225 feet of hydraulic head.

a flow rating of 93,000 gallons a minute.

The unit shown here weighs more than 80 tons and stands 26 feet tall. Its pump casing is not visible because it is below floor level in the test loop. A 4000-hp motor at the top of the assembly drives the pump.

Portable Audio-Visual Center for More Effective Instruction

Audio-visual aids have come to be widely used by instructors because they tend to stimulate the learner's mind and improve retention. They can also make the learning process faster than it otherwise would be, especially where new or difficult concepts are involved. Such considerations have prompted development of an electronic audio-visual instruction center that brings together a number of teaching aids.

This WAVE system (for Westinghouse Audio-Visual Electronics) includes television equipment; projectors for slides, film, and opaque materials; an audio tape recorder; a sound system; and an AM/FM radio. The television equipment can be used with closed-circuit systems to disseminate lessons live, from tape, or from film, and it can also be used to pick up telecasts from outside. The system was designed by educators to be operated by just one person with little training; it allows an instructor to forget the technical aspects of the apparatus and concentrate on getting ideas to the student.

Two caster-mounted stands and a tripod-mounted vidicon camera make up the WAVE system. One stand houses a fixed vidicon camera for pickup of filmed material and opaque materials, two opaque pickup areas, operating controls, an overhead transparency stage, two television picture monitors, a digital clock, remote controls for projectors and tape recorder, lighting, and the audio system. The other stand has a 2-by-2 slide projector, space for a filmstrip projector and for an 8- or 16-mm motion-picture projector, the audio tape recorder, the AM/FM radio, a multiplexer that permits split-screen presentations, and provision for remote control of multiplexer and projectors.

80-Inch Hot Strip Mill Produces Both Quality and Quantity

A new hot strip mill at Inland Steel Company's Indiana Harbor mill, East Chicago, Indiana, produces high-quality strip with the aid of advanced electrical drive equipment and a computer control system. (See photos at right.) The 80-inch mill can produce steel strip at 3870 feet a minute. Slabs as large as 10 inches by 76 inches by 32 feet can be rolled through a five-stand roughing train, driven by ac motors, and a six-stand dc-motor finishing train.

The Prodac 580 computer system provides data-logging for the entire rolling mill—from slab depiler to strip coiler—and automatic control from the furnace slab extractor to the strip coiler. Because it monitors and controls strip production constantly and to close tolerances, it assures a product of higher quality and greater uniformity than would otherwise be possible.

For data-logging, the computer system logs both process and product data and transfers it to typewritten printouts. These printouts provide a record of product specifications, production performance, and other information needed for management control of work coordination, production planning, and inventory.

For control, the computer system interprets information entered on punched cards and other information fed back from the mill by sensing devices such as roll-force gauges, width gauges, and X-ray thickness gauges. It tracks and identifies slabs going through the furnaces, detects slab travel during processing, ascertains slab temperature at selected locations, calculates settings to be made on the mill and auxiliaries for each slab, and corrects preliminary calculations with information received by feedback.

Although the computer's basic input is by cards prepared in the office, card punching and preparation can also be done at the rolling mill itself. The operator can assume manual control at any point in the rolling cycle and then return the system to automatic operation.

The electrical drive for the finishing train includes six 9000-horsepower double-armature dc motors rated 750 volts, 125/312 rpm; six 7200-kw 750-volt-dc ignitron rectifiers (13.8 kv, three-phase ac); and 18,898 horsepower in dc motors and 12,500 horsepower in ac motors for auxiliary drives. All dc adjustable-voltage circuits and excitation subsystems have thyristor regulators.

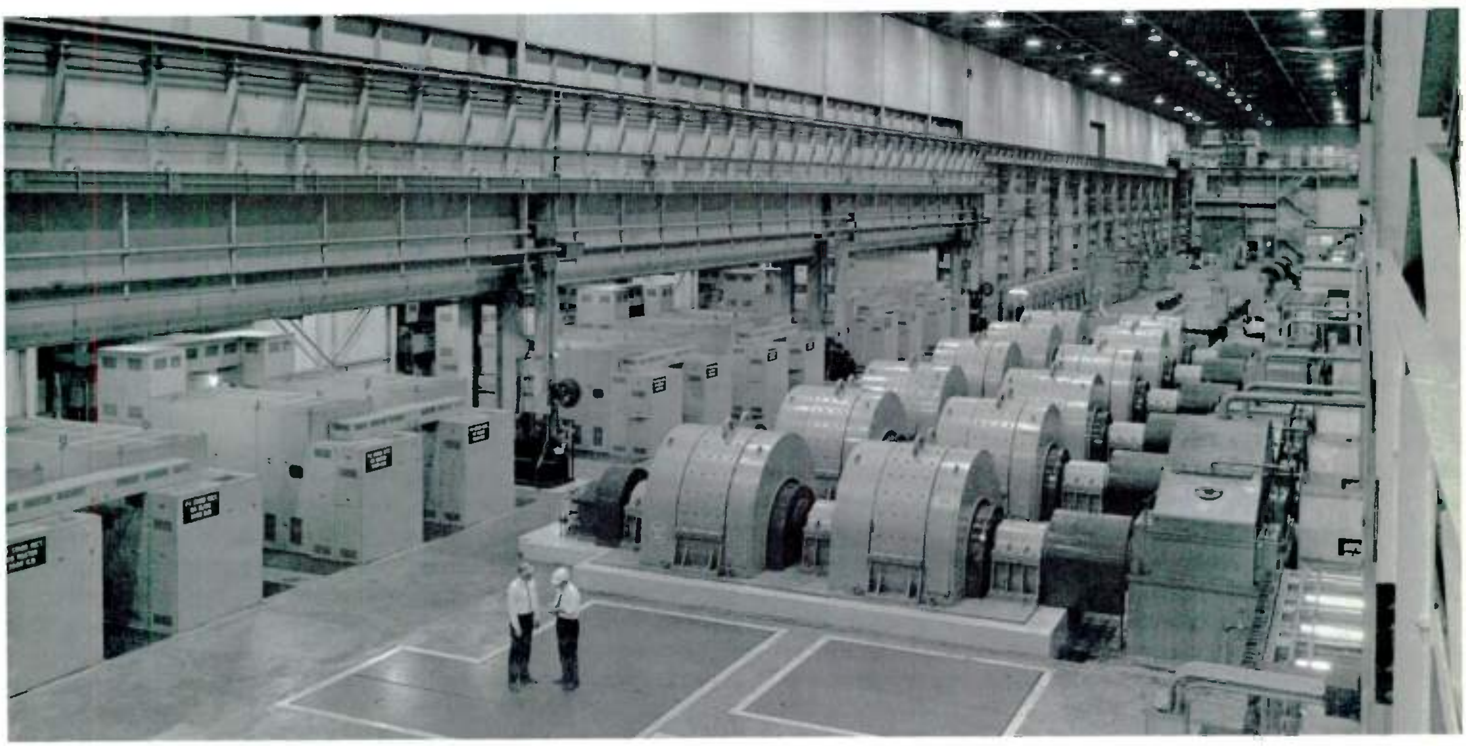
Each ignitron rectifier supplies dc power to each of the six finishing-stand motors. Acceleration is by field control. Fast motor speed changes are made through a thyristor-controlled firing circuit for the rectifiers; a slower motor field regulator allows armature voltage to be maintained at the correct values so the final motor speed equals the new speed reference.

Industrial Plant Power Problems Solved by Computer Simulation

Computer services have long been provided for the electric utility industry for simulation of many power generation, transmission, and distribution problems. The same computer programs are now being modified and used to solve the power problems of large industrial plants.

Modern dc rolling-mill drives, for example, often have large thyristor power supplies to furnish the motor armature voltage. Phase-angle firing of the thyristors produces a constant dc voltage that is independent of variations in the ac system voltage. When viewed from the line side of the power-supply transformer, the dc load appears as a constant-mva load with a varying power factor. This change in power factor with system voltage must be represented when performing load-flow analyses for the steel mill. A new computer routine, developed for use with the 1000-bus load flow program, uses the linear relationship between the small ac system voltage variations and the corresponding power factor of the dc power supply to make an accurate representation of the system.

Other computer programs are used to accurately represent large synchronous generators, synchronous motors, and induction motors. Impact loading of synchronous motors, for example, is simulated by applying a shaft torque to the



(Top) Inland Steel Company's 80-inch hot strip mill stretches for more than 2500 feet at the Indiana Harbor works. A slab is shown being reduced in thickness in the mill's roughing train, which consists of both vertical and horizontal scale breakers and five roughing stands. The slab then continues on to the finishing train to be rolled into light-gage hot-rolled strip. *(Bottom)* Six double-armature dc motors, which are rated 9000 horsepower each, drive the new mill's finishing train. The ignitron rectifiers on the left supply adjustable-voltage power for these motors. A computer system logs data and performs automatic control for the entire rolling mill.

motor base load. This torque can be delayed by a specific time if necessary, and it can be in the form of a unit step, ramp, or third-order polynomial, depending on load characteristics. Impacting can be done on one stand, simultaneously on several stands, or on separate stands at varying time intervals.

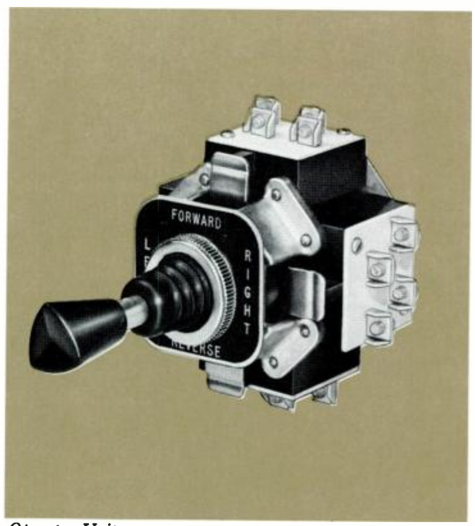
The same computer program provides sufficient detail to simulate other types of industrial loads by treating them as a constant impedance, current, power, or combination thereof. The program can also simulate the power factor regulation controls for synchronous motors by treating them as nonlinear functions.

Products for Industry

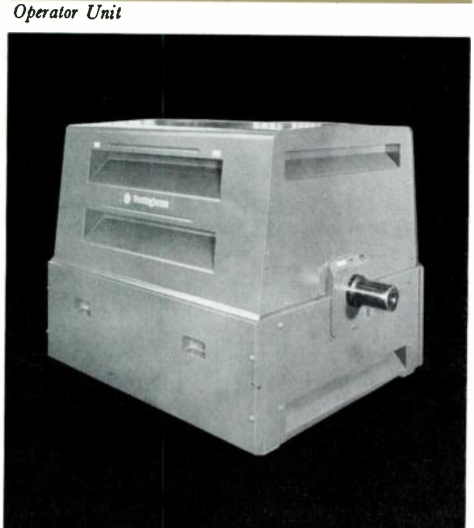
Type AP totally enclosed transformers provide stepped-down voltages to machine-tool control devices with a much lower sound level than that of open core and coil units. The dry-type transformers are particularly applicable where space is at a premium and where liquid-filled units are prohibited. Since they are insulated and cooled by air, they cannot explode, no toxic gases can be released, and fire hazards are negligible. Ratings are 5, 7½, and 10 kva single phase at 240/480 to 120/240 volts, 60 cycles. *Westinghouse Specialty Transformer Division, Box 231, Greenville, Pennsylvania 16125.*

Operator unit provides "joy-stick" operation of four contact blocks. It can consolidate the operations of four push-buttons, for example, in a single four-way toggle switch in which handle position can relate to function initiated. Automatic interlocking of functions is provided because only one contact block can be operated at a time. The unit has a 10-ampere noninductive rating in continuous service. Applications include machine tools, chemical process equipment, traveling cranes, and control pulpits such as those for metal rolling mills. Any or all operator positions can be either maintained or momentary, and the unit can be converted from one to the other in the field. *Westinghouse Standard Control Division, Beaver, Pennsylvania 15009.*

Two-speed PAM motors (pole amplitude modulation) operate on the principle of modulating the stator flux field of an ac squirrel-cage machine. For example, if a six-pole field is modulated by a two-pole field, the result is a four-pole field and an eight-pole field. Such modulation is accomplished by reversing all the coils in half the periphery of the motor. If only a remaining eight-pole field is desired, the four-pole field can be eliminated by proper spacing of the starting point of each phase winding. Such a motor runs at six-pole speed when connected normally and at eight-pole speed when half the coils are reversed. Speed changing is accomplished through six leads. Speeds can be any combination, as close as 1200/900 rpm or as far apart as 1800/360 rpm, all with a single winding. PAM motors are smaller than equivalent two-winding units and about 10 percent lighter. The entire winding is used for both high-speed and low-speed operation, resulting in greater thermal capacity and higher efficiency. Construction in general is that of other F/A (fully accessible) motors, including use of permanently aligned bearings and Thermalastic epoxy insulation. Motors are available in variable torque, constant torque, or constant horsepower. Applications include ventilating fans, forced- and induced-draft fans for boilers, centrifugal pumps, machine-tool drives, compressors, conveyors, and cooling-tower fans. *Westinghouse Large Rotating Apparatus Division, 700 Braddock Avenue, East Pittsburgh, Pennsylvania 15112.*



Operator Unit


Two-Speed AC Motor

New Literature: *Diving Submersible, Deepstar-2000*, is a booklet describing the second in the family of *Deepstar* submersibles, a utility workboat able to operate at 2000-foot depth for about eight hours. The booklet lists operating parameters and describes the vehicle's configuration, its safety features, and its equipment. Diagrams show plan and side sectional views. Copies available from Underseas Division, Westinghouse Defense and Space Center, Box 3061, Baltimore, Maryland 21203.

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About the Authors

W. T. Duboc's career has gone in a complete circle since he first joined Westinghouse in 1946. His first assignment was at the Transformer Division, where he worked in design and development. In 1956 he transferred to the Westinghouse Defense Center in Baltimore, where he held a number of technical and administrative management positions involving defense equipment. One of his assignments was as manager of the field support department.

He completed the circle in early 1965, returning to the Transformer Divisions to become engineering manager of the Power Transformer Division. There he has responsibility for product development and design of all Division products manufactured at Sharon, Pennsylvania, and Muncie, Indiana.

Duboc is a graduate of Cornell University, where he earned his BSEE in 1944. After taking miscellaneous extension courses in the Graduate School of the University of Pittsburgh, he went on to Harvard University, where he was awarded an MBA degree in 1956.

During his career, Duboc's activities have spanned a wide variety of electrical engineering activities. One of the most notable is his role in the development of the first computer program for the design of power transformers, a subject he discusses briefly in this issue.

Mario F. Pierpoline graduated from Cornell University in 1945 with a B. of M.E. He earned his way through college almost completely by competitive examination, winning four different scholarships (one from New York State and three through the Board of Trustees of Cornell).

From college, he came directly to Westinghouse on the graduate student course and accepted a permanent assignment at the Steam Division. Pierpoline has had a variety of engineering design assignments, starting with the mechanical design section, then the thermodynamic section, the condenser engineering section, and now the small steam and gas turbine engineering department. In this last assignment, which started in 1957, he has worked on boiler feed pump turbines, natural gas turbines, and other small turbine designs. He presently is taking the lead in the design of boiler feed pump turbines, the subject of his article in this issue.

A. M. Curry and **Warren Reid** bring the points of view of electrical equipment user and supplier to their article on a new hot-rolling line for aluminum sheet products.

Curry joined the Aluminum Company of America in 1938 as a cooperative student while at the University of Tennessee. He received his BS in electrical engineering in 1940, and from then until 1947 he worked on the design, application, and maintenance of mercury-arc rectifiers for electro-chemical applications. Since then Curry's work has been primarily concerned with rolling-mill applications.

In his present position of Senior Electrical Engineer, he has been responsible for many mill projects employing thyristor power supplies such as those used for the line described in the article in this issue.

Reid graduated from Vanderbilt University in 1943 with a BS in electrical engineering. He joined Westinghouse on the graduate student course and was assigned first to condenser bushing design at the Switchgear Division. After a tour of duty in the U.S. Navy, Reid joined the Industry Engineering Department, one of the predecessors of his present organization (Industrial Systems Division). His work throughout that time has been in the application of electrical equipment to rolling mills. He is now a Fellow Engineer, responsible for negotiation and application of electrical equipment for rolling mills in both the ferrous and nonferrous metals industries.

Reid is a member of the Association of Iron and Steel Engineers and has written three technical articles for that association.

R. P. Bleikamp and **G. K. Glover** collaborate in this issue of the *ENGINEER* to describe an uninterruptible power system, as they did to design the system.

Bleikamp is Manager, Quality Assurance, Motor and Gearing Division. He joined Westinghouse in 1950 on the graduate student course and worked first in design engineering in the former Industry Engineering Department.

He moved to the Motor and Gearing Division's engineering department in 1960, and in 1963 he was made manager of defense operations. This later became the drive and power systems group, an organization responsible for the sale, engineering, and administration of commercial and defense systems projects. Bleikamp assumed his present position early this year.

Bleikamp earned his BSEE at Washington University in St. Louis in 1950 and his MSEE at the University of Pittsburgh in 1956. He also holds a Certificate in Business Administration from Pitt.

Glover graduated from the Engineering Division of the University of Missouri at Rolla in 1962 with a BSEE degree and joined Westinghouse on the graduate student course. His first permanent assignment was to defense operations at the Motor and Gearing Division. He was responsible for the design of the uninterruptible power system. He has also been responsible for the design of diesel-generator power systems for satellite tracking stations and has contributed to the design of the drive system for the Titan III mobile service tower at Cape Kennedy.

The essential qualities of engineering leadership suggested by **Lee A. Kilgore** are ideas, judgment, convictions, and ability to gain the confidence and cooperation of others. These qualities have characterized Kilgore himself throughout his career.

Kilgore came to Westinghouse in 1927 from the University of Nebraska, where he had earned his BSEE. He was assigned from the graduate student course to the turbine-generator division at East Pittsburgh to work with big equipment—large motors, generators, electric couplings, and rectifiers. He progressed from engineering supervisory to management positions, along the way adding an MS from the University of Pittsburgh in 1929, and an EE degree from the University of Nebraska in 1934. In 1956, Nebraska awarded him the honorary degree of Doctor of Engineering. He also attended the Harvard advanced management course in 1950.

Kilgore was made assistant manager of the ac generator engineering department in 1946, and in 1954 he became Director of Engineering for the East Pittsburgh Divisions. He assumed his present position of Consulting Engineer for the East Pittsburgh Divisions in 1964.

Besides being a designer and inventor with some 30 patents to his credit, Kilgore is also an educator. He taught in the Westinghouse Design School from 1928 to 1931, and he taught a course in advanced machine design at the University of Pittsburgh graduate school from 1936 to 1949 and has continued to act as a thesis advisor there. He has aided and guided young engineers in other ways also; his work in organizing and conducting seminars, for example, has been described in previous articles in the *ENGINEER* and formed part of the basis of the present article.

Advanced drive and control systems help this hot strip mill produce high-quality steel strip, at Inland Steel Company's Indiana Harbor location, at 3870 feet a minute. A Prodac 580 computer system provides automatic control for the mill, but operators can assume manual control at any time and then return the system to automatic operation. The mill has five main control pulpits—this finishing-train pulpit and one each for the slab-depiling, furnace-charging, roughing-train, and downcoiler areas. For more information, see the article on page 62.